

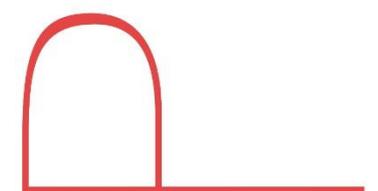
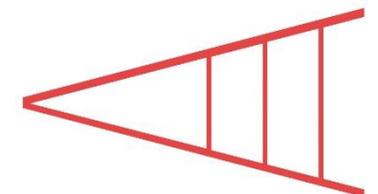
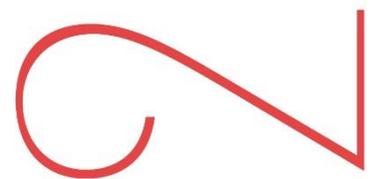
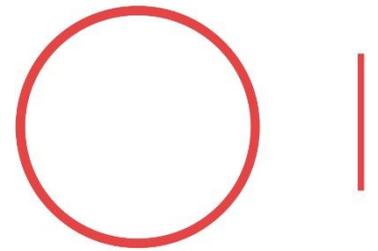
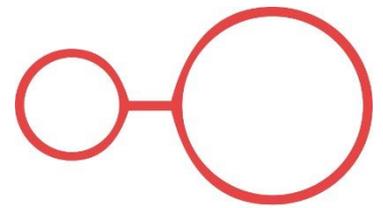
# VOLUME 3

34<sup>th</sup> International Conference on  
Passive and Low Energy Architecture

Smart and Healthy  
Within the Two-Degree Limit

Edited by:

Edward Ng, Square Fong, Chao Ren



**PLEA 2018:**

**Smart and Healthy Within the Two-Degree Limit**

Proceedings of the 34<sup>th</sup> International Conference on  
Passive and Low Energy Architecture;

Dec 10-12, 2018

Hong Kong, China

Organised by:



香港中文大學  
The Chinese University of Hong Kong



香港中文大學環境、  
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Electronic version as:

ISBN: 978-962-8272-36-5

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# PLEA 2018

PLEA stands for Passive and Low Energy Architecture. It is an organisation engaged in a worldwide discourse on sustainable architecture and urban design through its annual international conference, workshops and publications. It commits to the development, documentation and diffusion of the principles of bioclimatic design and the application of natural and innovative techniques for sustainable architecture and urban design.

PLEA is an autonomous, non-profit association of individuals sharing the art, science, planning and design of the built environment. PLEA pursues its objectives through international conferences and workshops; expert group meetings and consultancies; scientific and technical publications; and architectural competitions and exhibitions. Since 1982, PLEA has organised conferences and events across the globe. The annual conference of PLEA is regarded, attracting academics and practicing architects in equal numbers. Past conferences have taken place in United States, Europe, South America, Asia, Africa and Australia.

It is the first time that the PLEA conference comes to Hong Kong in 2018. The juxtaposition of Hong Kong's compact and high-density living and scenic countryside makes it an intriguing case of urban sustainability and climate resilience. The urban and built environment represents both challenges and opportunities amid climate change. As the world approaches the 2-degree limit, living smart and healthy has become a priority in urban development. Smart cities are driven by science and technology but are meaningless without consideration for the people and community. Design and practice are essential in implementation, while education and training stimulate innovation and empower professionals and laymen alike.

With the theme "**Smart and Healthy within the 2-degree Limit**", the conference strives to address the different facets of smart and healthy living and aims to bring together designers, academics, researchers, students, and professionals in the building industry in the pursuit of a better and more sustainable urban and built environment.

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Short Paper

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## **SCIENCE AND TECHNOLOGY**

Science and Technology has a central role in innovation for better urban living. This track explores the latest scientific and technological research that improves our understanding of the environment and brings changes to future urban development, for example:

- low energy building performance and simulation technology
- renewable energies and energy technology
- material technology and zero waste construction
- the sciences of urban heat island, urban design and adaptation to climate change

## A Load-Bearing Wall Construction House: Analyses of Heat Problems and Resolutions

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**ABSTRACT:** Thermal conditions of spaces in a load-bearing wall house were investigated. The key finding results are 1) steel reinforced concrete structure is needed to be reduced due to its high capability of heat accumulation 2) measured data showed that peak temperatures occurred in late afternoon due to the material's heat inertia. A new wall system that use the same material was developed. The new wall has the less mass and the air inside the block's cavities could be ventilated by stack effect in order to reduce heat build-up in the wall and lower peak temperatures of the spaces.  
**KEYWORDS:** Energy, Load-Bearing Wall, Heat Problems, House, Stack Effect Ventilation

### 1. INTRODUCTION

This article presents an on-going research project: The Efficiency Improvement of Thermal Resistance of Concrete as a Building Material for Reduction of Heat in Building. A housing project was initiated with a concept of cool living by using the company's building material—standard concrete masonry unit (CMU) for walls. The load-bearing wall structure system is used as the house's structure instead of the common reinforced concrete post and beam structure. The company experienced problems of heat accumulation and unpleasant thermal conditions in interior spaces. Therefore, an investigation of the thermal condition problems is needed to conduct to solve the problems.

### 2. RESEARCH HYPOTHESIS AND METHODOLOGY

This research aims to investigate related factors that cause accumulation of heat and raising of indoor air temperature. With a research hypothesis that heat is absorbed, transferred, and confined by the building envelope (exterior walls and roof), research's objective is to develop an exterior wall system, based on the company's CMU, that has less heat absorption in its body and less heat transferring to the interior spaces.

The research methods include: 1) Studying of the house's planning and construction through surveying and construction drawing, 2) Analysis of steady-state heat conduction [1, 2] of the CMU, 3) Analysis of building envelopes 4) Measurement of indoor thermal conditions in spaces 5) Analysis of thermal comfort [3] and 5) Design and experiment of a new CMU wall system.

### 3. RESULTS

#### 3.1 Analysis of Thermal Properties of CMU

The insulated CMU (Fig.1) was examined and its thermal resistance (R-value) was weighted-calculated using the material's actual thickness and standard conductivity (k) value [1]. The Insulated CMU's  $R_T$  is 1.635

$m^2 \text{ } ^\circ\text{C} / \text{W}$ . Comparisons of the R-values show that the insulated CMU has higher thermal resistance 4.5 times ( $0.364 \text{ m}^2 \text{ } ^\circ\text{C}/\text{W}$ ) and 2.7 times ( $0.613 \text{ m}^2 \text{ } ^\circ\text{C}/\text{W}$ ) than common brick and light-weight concrete block respectively.

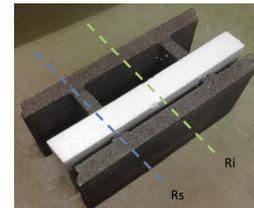


Figure 1: The insulated concrete masonry unit. The dashes lines indicate two-difference construction of the material.

#### 3.2 Investigation of Heat Accumulation in Spaces

Steel reinforced concrete was required for stiffness and stability. Fig. 2 shows an elevation of the house that illustrates the area of the walls that the CMU's hollow cores are filled-in with steel reinforced concrete (dotted rendering area). The wall areas were identified into 3 categories; reinforced concrete filled-in block, insulated CMU, and Opening. The result shows that the reinforced concrete filled-in block area and the insulated CMU area are in almost equal proportions in the total wall area (39.64 % and 40.66 % respectively). The rest of the wall area (19.70 %) is the opening, which is the glazing area. The proportion of structural wall is very substantial to the



Figure 2: Front view of the house (Left) and front elevation drawing with rendering of structural area of the walls. Insulated CMUs are showed as white rectangular blocks. (Right)

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proportion of the insulated wall area; the more area of structure, the lesser area of insulated wall. Therefore, the extensive area of the structure is needed to be reconsidered, because it is substantial to the heat problem.

### 3.3 Measurement of Thermal Conditions in Spaces

The measurements of thermal conditions of spaces were conducted in hot season (Fig.3). The air temperatures of the bedroom and the stairway hall were higher than those of living room (1<sup>st</sup> Floor) about 2°C and 3°C respectively.

The thermal conditions of the spaces (Fig.3) were changed according to outdoor temperatures, but the temperatures in those spaces swung in narrower ranges (about 2°C). These were the effect of thermal inertia of the CMU walls. The plotted data showed that the peak temperatures in the spaces occurred in late afternoon (16:30 – 18:00).

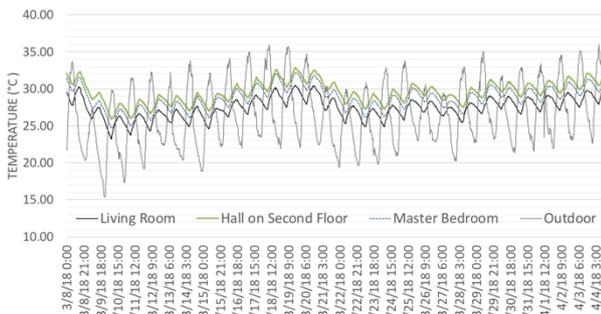


Figure 3: Comparisons of Temperatures in Living rm., Bedroom Versus Outdoor Temperatures from March 7<sup>th</sup> to April 4<sup>th</sup> 2018.

### 3.4 Analysis of Thermal Comfort

Thermal conditions in the spaces were analysed in psychrometric charts as presented in Fig. 4. The thermal conditions in both spaces were scattered in relatively wide range of temperatures and humidity. This wide oscillation of the outdoor air temperatures caused the spreading of temperature ranges. Due to lack of rainfall, the humidities were also spread out in low and mid relative humidity levels. Some night time thermal conditions were in the thermal comfort. This would be satisfied by occupants. However, the building has not been occupied, so thermal comfort could not be evaluated in this time.

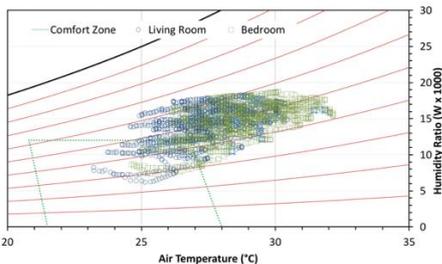


Figure 4: Thermal conditions of the living room and master bedroom from March 7<sup>th</sup> to April 4<sup>th</sup> 2018.

### 3.5 Design of the New CMU Wall System

A new wall construction system (Fig.5) has been developed to solve the problem of heat storing in the exterior wall. High strength mortar is used to construct the wall instead of steel reinforced concrete fill-in the hollow cores. This new construction has significantly less mass of wall material and it utilizes vertical hollow cores inside the wall to ventilate heat of the wall using stack effect by air-buoyancy. The heat could be drawn by the flowing wind through the roof (Bernoulli Effect).



Figure 5: 3D Model (Left) and Experimental Building (Right)

## 4. CONCLUSION

The exterior walls were examined and found that the proportion of structural area to the total wall area is very high resulting in a large amount of the heat storing in the area. The thermal inertia effect of the walls caused peak temperatures of spaces occurred in late afternoon. This is the period of time that building users usually arrive home on the workday, so peak temperatures needed to be reduced and shifted to earlier time.

The new CMU wall system was designed using new technique that allow less heat storing in the material, while heat could be flow naturally by stack effect ventilation in the vertical cavities of the blocks. Results of the experiment building are expected to reduce heat accumulation in the wall, and the peak temperatures would be reduced and shifted to earlier time.

## ACKNOWLEDGEMENTS

This research has been co-funded by Office of the Higher Education Commission and National Science Technology and Innovation Policy Office, Thailand.

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# Whole-Life Carbon in Office Building Design: Lessons from Built Precedents and Design Application

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**ABSTRACT:** CO<sub>2</sub> emissions of buildings are progressively shifting from operation to other lifecycle stages. Despite the increasing importance of embodied carbon, it remains unregulated, without defined standards or industry benchmarks. This paper presents research findings from the analysis of five exemplary built precedents, comparing both operational and embodied CO<sub>2</sub> emissions with benchmarks. Designed with a holistic approach, the whole-life carbon emissions from these buildings are shown to have been reduced by some 50%. Design guidelines resulting from study of these built precedents have been synthesized into a design application for central London, with estimated a 75% reduction in carbon emissions when compared to standard buildings.

**KEYWORDS:** whole-life carbon, office design, operational, embodied

## 1. INTRODUCTION

The increasing strictness of national energy standards combined with the gradual integration of renewable energy generation are effectively lowering CO<sub>2</sub> emissions from buildings. However, as buildings become more energy efficient, the embodied carbon accounts for an increasing proportion of their whole-life CO<sub>2</sub> liability. Yet, this is not regulated, there are no benchmarks, and no standard assessment methodology has been agreed [1-2].

## 2. METHODOLOGY

The paper draws from the results of a comparative study of five high-performance office buildings that were designed to minimise CO<sub>2</sub> emissions over their entire lifecycle [3]. The buildings' carbon emissions were calculated over 60 years with CO<sub>2</sub> intensity factors for space heating and cooling of 0.194 and 0.55 kgCO<sub>2</sub>/kWh respectively disregarding grid decarbonisation. Embodied carbon analysis includes lifecycle stages from cradle to gate, defined as A1-A3 by CEN/TC350. Results

were extracted from technical reports produced by the design teams or calculated by the author based on project drawings and embodied carbon coefficients [3].

## 3. CASE STUDIES

Each of the five buildings selected for this comparative study manifests visionary concepts aiming at a new paradigm for sustainable architecture. Driven by challenging design briefs, the buildings tackle operational carbon through passive design while also addressing the CO<sub>2</sub> emissions associated with manufacture and construction.

The study has shown that internal heat gains drive the operational CO<sub>2</sub> whilst embodied carbon is subject to the built form and materiality of the buildings. Figure 1 shows operational CO<sub>2</sub> savings of some 60% compared to current Building Regulations [4-5]. Moreover, embodied CO<sub>2</sub> was reduced by 40-60% from reference values [6-9]. Absolute savings in embodied carbon are comparable to the reduction in operational CO<sub>2</sub>.

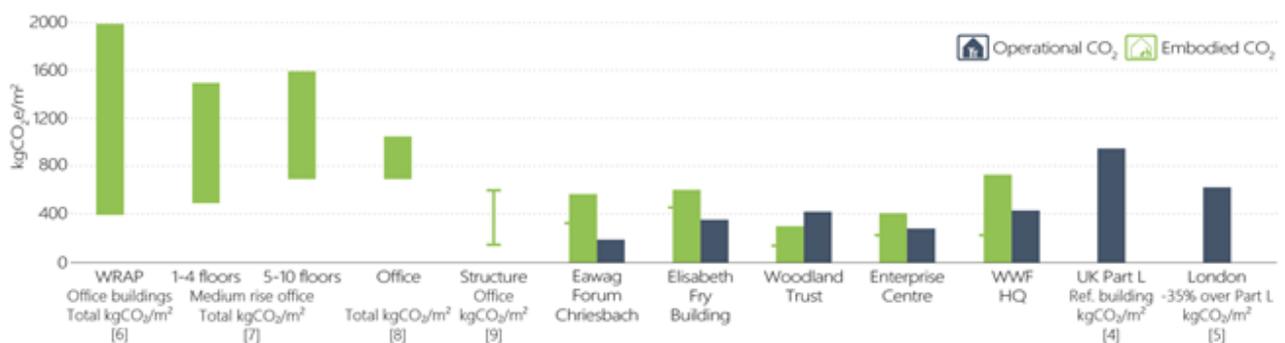


Figure 1: Benchmarks for embodied and operational carbon [4-9]

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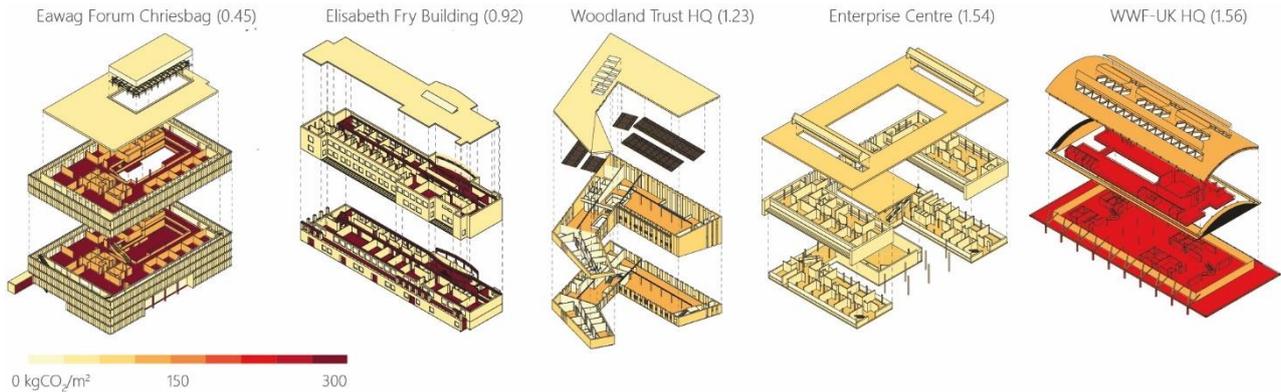


Figure 2: Embodied CO<sub>2</sub> by floor area and compactness ratio

Embodied carbon results are summarised in Figure 2. In the case of Eawag and Elisabeth Fry buildings the CO<sub>2</sub> intensive components are balanced by the buildings' compact shapes, with an envelope to floor area ratio of 0.45 and 0.92 respectively. For Woodland Trust HQ and Enterprise Centre the result is influenced by their use of natural materials. WWF-UK HQ is subject to high exposure owing to strict site requirements.

#### 4. DESIGN PROPOSAL

The comparative study was followed by a design exercise that synthesises the research findings. The design proposal is for a real site in Central London and thus responds fully to constraining site conditions as well as applying the design strategies extracted from the built precedents. The built form is designed to maximize daylight and winter solar access while maintaining a compact shape (Fig.3). The volume is perforated by two atria that help organise the plan as well as enhancing natural ventilation during summer.

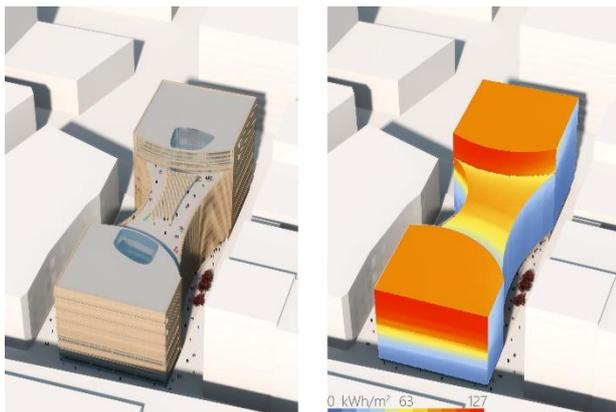


Figure 3: Design application in central London – aerial view and winter solar radiation analysis

Construction is of a CLT structure and acetylated timber envelope aimed at low embodied CO<sub>2</sub>, whereas lateral stability and thermal inertia are provided by two concrete cores. The aforementioned design strategies reduce the whole-life CO<sub>2</sub> emissions of the project by 75% compared to a standard office building [3].

Operational emissions were calculated over 60 years using future weather files. CO<sub>2</sub> intensity factors are 0.194 kgCO<sub>2</sub>/kWh for heating and 0.49 kgCO<sub>2</sub>/kWh decreasing to 0.08 kgCO<sub>2</sub>/kWh in 2032 for cooling. Embodied carbon analysis includes life cycle stages A1 to A3.

#### 5. CONCLUSION

Tackling the increasing importance of embodied CO<sub>2</sub> in buildings is fundamental to reduce their whole-life footprint. The effective manipulation of building shapes and materials is essential to lower both operational and embodied emissions. Design teams may be able to achieve reductions of 50-75% in whole-life carbon emissions by careful application of environmental design strategies from the inception of the project.

#### ACKNOWLEDGEMENTS

This research would not have been possible without the support of the projects' design teams, specially Binta Anderegg, Simon Sturgis, Quian Li, Zachary Gill, Hester Brought and Kayleigh Szekeres. Also, Rafael Alonso Candau appreciates the bursary awarded by the Architectural Association to carry out this research.

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# Calculation Methods for the Ventilation with Solar Chimneys: Comparison of Analytical Models, Simulations and Measurements

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**ABSTRACT:** The use of solar chimneys for natural ventilation could contribute to a reduction of the energy consumption of buildings. For the design process of solar chimneys, it is necessary to be able to predict the ventilation effectiveness precisely. In this paper, different analytical equations are compared to results from computational fluid dynamic simulations and experimental measurements. It was found that the investigated analytical methods neglect the occurrence of backflows which leads to an overestimation of the air flow for chimneys with a large depth. For an accurate result, detailed calculations with an adapted discharge coefficient are required to account for this effect.

**KEYWORDS:** Solar chimney, natural ventilation, calculation methods, CFD

## 1. INTRODUCTION

The largest potential for a significant reduction of greenhouse gas emissions can be achieved in the building sector [1]. The energy consumption can be reduced by 30 to 80 % of both existing and new buildings, using proven and commercially available technologies [1]. Considerable energy saving could be achieved by using natural ventilation instead of mechanical ventilation systems. An established natural ventilation concept is the solar chimney, which has been used for hundreds of years in the Middle East. An absorber placed inside the chimney collects solar irradiation, which enters the solar chimney through a transparent cover and heats up the absorber surface. This arising temperature difference results in a buoyancy effect and air is drawn out of the building. A schematic of a solar chimney can be seen in Fig. 1.

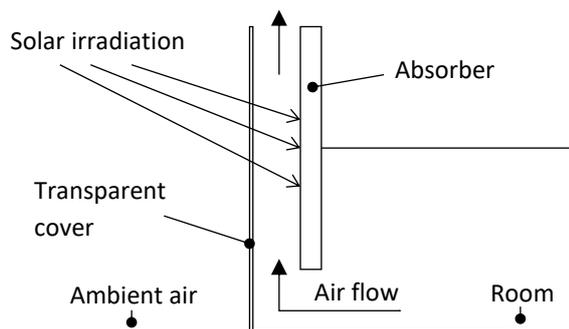


Figure 1: Schematic of a solar chimney.

For the design process of solar chimney projects, it is essential to be able to predict its ventilation effectiveness. In this paper, four analytical models are evaluated in comparison to simulated and measured results for different depths of a solar chimney.

## 2. METHODOLOGY

Based on a literature review, analytical equations for the air flow will be presented in the first part of this paper. In a next step, the analytical results will be compared to results from computational fluid dynamic simulations (CFD) of a 2.75 m high solar chimney with three different depths of 0.1, 0.3 and 0.5 m. The simulated results are validated with experimental data from a test facility with the same boundary conditions.

## 3. LITERATURE REVIEW OF CALCULATION METHODS

One of the first equations to calculate the air volume flow provided by a solar chimney was formulated by Bansal, Mathur and Bhandari in 1993 [2]. Their calculation is based on the temperature difference between the solar chimney and the ambient air. The volume flow is calculated with Equation (1):

$$\dot{V} = C_D \cdot A \cdot \sqrt{g \cdot h \cdot \frac{T_{SC} - T_{\infty}}{T_{SC}}} \quad (1)$$

where  $\dot{V}$  - air volume flow (m<sup>3</sup>/h);  
 $C_D$  - coefficient of discharge (-);  
 $A$  - Area (m<sup>2</sup>);  
 $g$  - gravitational acceleration (m/s<sup>2</sup>);  
 $h$  - height (m);  
 $T_{SC}$  - air temperature in the solar chimney (K);  
 $T_{\infty}$  - ambient air temperature (K).

Two other calculation methods were presented by Li in 2000 [3]. The solar chimney is divided into two separate parts (with the height  $h_1$  and  $h_2$  and the temperatures  $T_{SC1}$  and  $T_{SC2}$ , respectively) to consider the temperature increase inside the chimney. His first version can be seen in Equation (2):

$$\dot{V} = C_D \cdot A \cdot \sqrt{g \cdot \left( h_1 \cdot \frac{T_{SC1} - T_{\infty}}{T_{\infty}} + h_2 \cdot \frac{T_{SC2} - T_{\infty}}{T_{\infty}} \right)} \quad (2)$$

In his second version, Equation (3), the temperature increase is considered to be linear:

$$\dot{V} = C_D \cdot A \cdot \sqrt{\frac{1}{2} \cdot g \cdot \left( h_1 \cdot \frac{T_{SC1} - T_{\infty}}{T_{\infty}} + h_2 \cdot \frac{T_{SC2} - T_{\infty}}{T_{\infty}} \right)} \quad (3)$$

Another calculation method (see Equation 4) was presented by Sandberg in 1999 [4]. Sandberg considered the heat flux in the wall more specifically instead of temperature differences and introduced a new factor for flow losses.

$$\dot{V} = A \cdot \sqrt[3]{\frac{\alpha \cdot B}{\psi}} \quad (4)$$

where  $\alpha$  - factor for location of heat input (-)  
 $B$  - specific buoyancy flux ( $m^4/s^3$ )  
 $\psi$  - factor for flow losses (m)

#### 4. COMPARISON WITH SIMULATED AND MEASURED RESULTS

The geometry of the chimney is, except for the cross section area, unconsidered in equations (1), (2) and (3). Effects of the fluid flow are neglected in all previous equations. This results in an air volume flow that is too high for large chimney depths. Fig. 2 shows a comparison of the calculation methods together with simulated (CFD) and measured (Exp) results. For the analytical calculation methods, a constant coefficient of discharge of 0.57 was considered, as it is recommended in the literature [5]. The height of the solar chimney is 2.75 m.

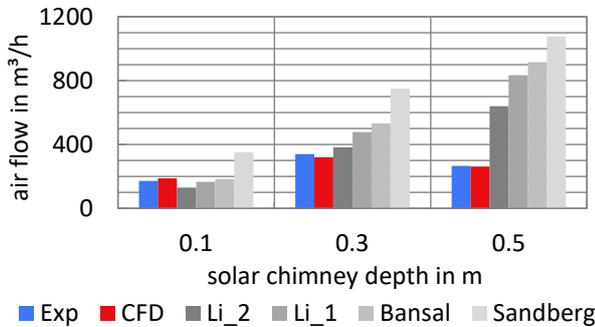


Figure 2: Comparison of calculation methods with simulated and measured results for different solar chimney depths.

The second calculation method of Li (Equation (3)) achieves the most accurate results. However, the calculated air flow is increasing with the chimney depth for all four equations, whereas the experimental and simulated results show a maximum volume flow for a chimney depth of 0.3 m. It can be seen, that for solar chimneys with a depth of 0.5 m, backflows occur and reduce the air volume flow. This phenomenon can be visualised with smoke tests at the experimental test facility and can be seen in the results of the CFD simulations. The backflows are illustrated in Fig. 3c, which shows the velocity vectors for a chimney depth of

0.5 m. For smaller chimney depth, the velocity is more equally distributed along the chimney depth, as it can be seen in Fig. 3a and Fig. 3b.

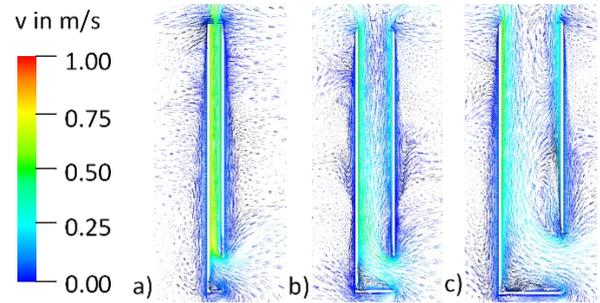


Figure 3: Velocity vectors for different solar chimney depths: a) 0.1 m; b) 0.3 m; c) 0.5 m.

The higher drop in pressure due to the backflows can be considered with the  $C_D$ -value in all equations. However, therefore the impact needs to be quantified with experiments or CFD simulations. The calculated  $C_D$ -values are listed exemplarily for Equation (3) for all three chimney depths in Table 1.

Table 1: Calculated  $C_D$ -values fitted to the experimental results for the second equation of Li (Equation (3)).

Depth	0.1 m	0.3 m	0.5 m
$C_D$	0.75	0.51	0.24

#### 5. CONCLUSION

This paper showed that a maximum air flow can be determined for a chimney depth of 0.3 m. Present analytical calculation methods cannot provide accurate results compared to CFD simulations and experiments for large chimney depth due to unconsidered backflows. To be able to predict precise ventilation rates, the discharge coefficient needs to be adapted as a function of the depth of the solar chimney according to results of CFD simulations or needs to be calculated with CFD completely. The most accurate analytical calculation can be carried out with a method of Li.

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# Designing Naturally-Conditioned Dwellings for Chile

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*ABSTRACT: The techniques applied in this paper were planned to minimise the additional energy and capital costs required for achieving occupant thermal comfort in Chilean residential buildings. Extensive analytical work is reviewed here to assess the influence of building design and operable envelope controls on auxiliary space-conditioning energy. Results of dynamic thermal simulations indicate that indoor comfort temperatures can be achieved all year long at low extra capital and without recourse to traditional space-heating and cooling. The methods applied for this analysis outline guiding principles for designing naturally conditioned dwellings across the country's main inhabited region.*

*KEYWORDS: Fuel Poverty, Low Energy Dwellings, Passive Building Design, Operable Controls*

## 1. INTRODUCTION

It is estimated that more than 16% of households in Chile are living in fuel poverty –an inability to afford adequate warmth and energy services in the home [1]. Besides the burden of space-conditioning costs on household income residential space-heating is responsible for [2]: one third of national domestic energy use; excess toxic levels of gaseous combustion pollutants and in combination with extremes of low and high indoor temperatures in dwellings a cause of seasonal morbidity and mortality [3].

This paper reviews the findings of a doctoral thesis on improving the design of new standard dwellings in Chile [2]. The objective of the study was to achieve all-year indoor comfort temperatures at low extra capital costs and without recourse to traditional space heating and cooling. The planned outcome was the design of a prototype that can be adapted to be built and operated to suit different locations with minimal use of conventional fuels [2].

## 2. METHODS AND TOOLS

The strategy for improving dwelling design draws on the performance of a base-case that meets minimum national statutory regulations and standard parametric features (Fig. 1). The analysis in this paper focuses on design strategies applied to a base-case for Santiago, located in central-interior Chile, and characterized with a cool semi-arid Mediterranean climate: cool winters (May-September), warm-dry summers (December-March) and an average annual temperature of 14°C [3]. During typical winter and summer days, outdoor temperature peaks range between 0–15°C and 15–30°C, with global solar radiation peaking at 0.4 and 1.1 kWh/m<sup>2</sup> respectively (Fig. 3).

The effect of different design measures on occupant thermal comfort was assessed over a year period using a computational simulation tool [4]. Indoor comfort

temperatures, building performance, and occupancy characteristics were based on data from field studies [2]. Also in conforming to the adaptive model of thermal comfort [5], upper and lower comfort temperature limits of 17–24°C and 20–27°C were considered in the analysis for typical winter and summer days. Simulations were performed for a multi-zone dwelling model assuming a fixed air exchange of 1.0 ach; internal heat loads of 5.0 W/m<sup>2</sup> per person and 5.0 W/m<sup>2</sup> for appliances; and occupation by a typical household of four: one adult at home, two children at school and one adult out at work most of the day.

Fig. 3 shows the performance of the base-case (red lines). As shown for the winter day (Fig. 3a), room temperatures reach the comfort zone only over few daytime hours falling below 15°C during morning and evening hours (over the whole winter temperatures below this limit occur over 60% of all waking hours, from 7am-11pm). For the summer (Fig. 3b), room temperatures exceed the upper comfort limit during the afternoon and evening with values rising above 30°C (with temperatures above this limit occurring by 20% of all summer hours).

## 3. BUILDING ENVELOPE DESIGN

To assess possible improvements, design variations were applied on a cumulative order as described below:

### 3.1 Thermal capacity

The timber-frame structure of the base-case was replaced by a solid-clay brick construction with light concrete partitions and a heavyweight plaster finish on interior surfaces (Fig. 2). This aided to moderate large diurnal temperature fluctuations by reducing the difference between the lowest and highest peaks by as much as 5–7K on each day and all throughout the year.

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## 3.2 Thermal insulation

An additional insulation layer of 100 mm was applied on exposed walls (Fig. 2) –to comply with regulatory standards the roof of the base-case was already insulated. By adding external wall insulation winter room temperatures were raised to comfort reaching a daily average value of 17°C. During summer days additional insulation caused no penalties to comfort lowering mean room daytime temperatures by 1.5K.

## 3.3 Glazing-to-floor areas

Glazing-to-floor areas were increased in rooms from 10 to 18 % (Fig. 2), offering the additional solar heat gains to achieve better temperatures of 15–22°C in winter and 21–26°C in summer. However, when no further measures are taken additional heat losses and gains may cause discomfort over other periods of the year. To prevent this, operable envelope elements were provided.

## 3.4 Operable elements

Operable elements comprise internal insulated shutters, trickle-vents, external sliding louvers (shading factor: 0.4) and window openings (Fig. 2). These allow occupants further adjustments of ±4K if required in addition to other adaptive actions [5] which can be performed to achieve comfort over each season and all over the year.

Fig. 3 shows the performance of the improved dwelling (blue lines), by applying the strategies proposed. The results show that it is possible to achieve comfort ranges of 17–24°C in winter and 20–27°C in summer without other energy than the passive heat gains from occupancy and solar gains. By day-by-day use of operable elements occupants can maintain temperatures within comfort all year-round [2]. For users requiring stringent provisions, auxiliary space-heating and cooling can be provided economically using electric heaters, extractors and/or fans.

## 4. AUXILIARY ENERGY AND BUILDING COSTS

The methods applied had also relevant effects in saving energy, capital costs and emissions. Assuming a 16-hours thermostat of 17°C for the living area and all bedrooms from May to September (7am-11pm) the annual space-heating energy demand of 25 kWh/m<sup>2</sup> estimated for the base-case decreases by 96.4% with the improved dwelling which reaches 0.9 kWh/m<sup>2</sup> – equivalent annual savings of 20 kg/m<sup>2</sup> in carbon dioxide emissions. With an extra building capital of 36 USD/m<sup>2</sup>, 8.8% of that incurred initially for the base-case savings in running space heating energy were valued at 440 USD year which over the peak month of July translate into as much as over 60% of the monthly capital income of households [2].

## 5. CONCLUSIONS

The results of analysis for Santiago in Central Chile indicate that there is promising scope for alleviating fuel poverty in dwellings by designing buildings that can be heated and cooled naturally. Further research in pursuing this aim could be performed to validate the designs pro-posed through their application in occupied dwellings.

Fig. 1 Base-case dwelling

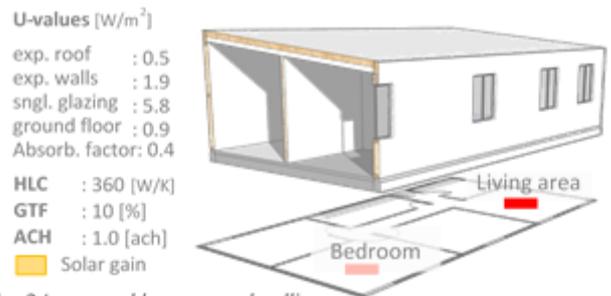
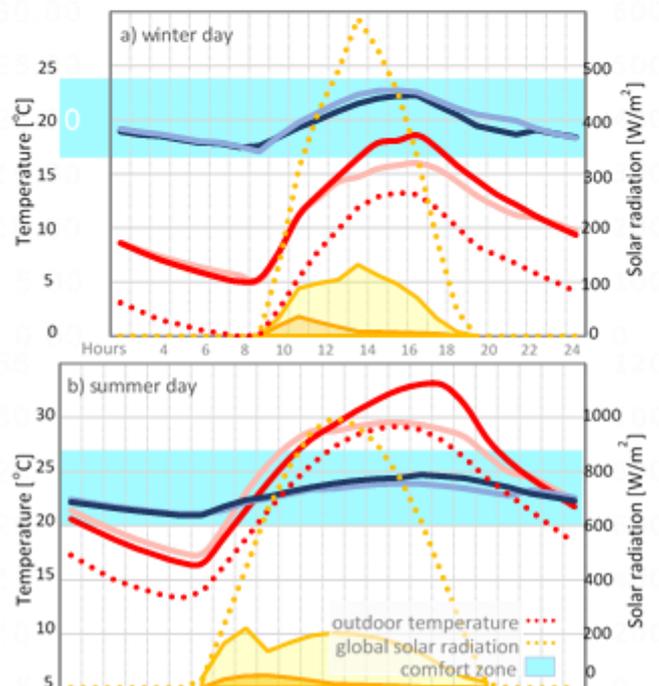


Fig. 2 Improved base-case dwelling



Fig. 3 Results of dynamic thermal simulations



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# The Potential for BIPV Installation in Dense Urban Areas: An Open-source Model for Analysis of Urban Form

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**ABSTRACT:** The successful deployment of distributed photovoltaic (PV) systems requires assessment of the potential of possible installations for electricity generation. Exposure to solar radiation in dense urban locations must account for shading by adjacent structures, at high spatial and temporal resolution. 3D modelling of the shadows cast by buildings is carried out with a new R package that can simulate the shadows cast on vertical surfaces (typically walls) or horizontal ones (typically roofs), given a database of obstacles representing buildings in the form of extruded polygons, and the sun's position at any desired time interval. The methodology is demonstrated for a case-study neighbourhood in Rishon-LeZion, Israel, with diverse building typologies, but is suitable for any location, using the open-source code developed. The simulation shows which building typologies offer the greatest solar potential, calculated per dwelling, building plot area or for the entire neighbourhood. Although roofs are preferable to vertical surfaces, some facades can still make a substantial contribution to the overall solar potential of urban buildings.

**KEYWORDS:** solar energy, density, urban form, open source code, shadowing

## 1. INTRODUCTION

Distributed PV has the potential for generating a significant proportion of the electricity needs of city buildings. However, the number of installations in dense urban locations is still negligible. Unlike detached single-family homes in low-density neighbourhoods, where installation is relatively straight-forward and solar access is generally unobstructed, dense urban areas pose special challenges. Although there are several research or commercial tools for assessing how building configurations affect insolation and PV installation potential on building envelopes (roofs and facades) in complex, irregular urban environments<sup>[1]</sup>, none are currently available as a free, open-source tool.

## 2. METHODOLOGY

The study comprises several stages performed in sequence:

First, a method for temporal and spatial simulation of shadow patterns in the urban environment was developed. The 'shadow' model<sup>[2]</sup> was developed in R<sup>[3]</sup>, an open-source language for statistical analysis, and is available on CRAN<sup>[4]</sup>. The model's inputs are the azimuth and elevation of the sun, and the outline and height of all objects, such as buildings, obtained from a GIS database.

The method was then demonstrated on a dataset representing a large residential neighbourhood in Rishon-LeZion, Israel, which includes several contrasting building types, listed in Table 1.

Finally, the solar potential of different urban forms was analysed by integrating model results over time (a TMY) for different building configurations.

Table 1: Building types within the study area

Building Type	No. of floors	Built fraction [% of site]	Dwelling density **
Tower	10-13	15.5	15.9
High-rise	8-10	17.8	14.5
Medium-rise	5-9	25.2	15.5
Courtyard block	5-7	25.1	13.7
Low-rise building	3-6	20.8	8.3
Apartment block	4-5	19.6	7.7
Terraces	3-5	22.5	6.8
Row houses	1-3	49.3	11.0

\*\* No. of apartments per 1000<sup>2</sup> of site area

## 3. RESULTS

### 3.1 Solar potential of building envelopes

The annual direct solar radiation on each point of the 1 m<sup>2</sup> grid was mapped and analyzed in ArcScene GIS 3D software, forming a visual summary of the annual solar direct irradiation (Figs. 1 and 2). The images show fairly uniform insolation levels on roofs, but substantially lower and more varied insolation levels on building facades, due to shading by adjacent buildings and the effect of orientation. The annual direct insolation on the south facades, as much as 600 kWh/m<sup>2</sup>/yr, is much higher than on the other facades.

### 3.2 Suitability for BIPV installation

The optimal location for a PV module is on the roof, facing the equator with a tilt angle approximately equal to the local latitude. However, where the roof area alone is insufficient, a visual display of the relative potential of additional building surfaces may be useful.

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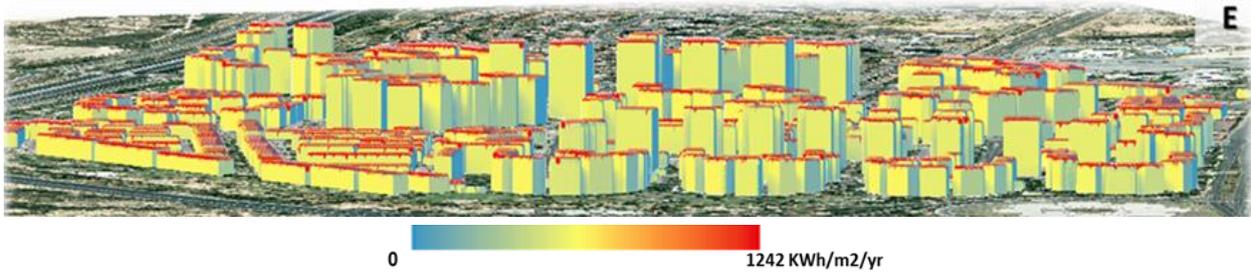


Figure 1: Total direct annual insolation on building exteriors in the area under study, viewed from four the east



Figure 2: Total annual insolation on building exteriors in the area under study: detail of the model (colour scale as in Fig.1)

Because PV installation might not be economically viable on areas that are exposed to insufficient direct solar radiation, a cost analysis will determine a threshold value below which installation is not recommended. This value will vary according to the solar resource in a given location. The application of such a threshold as a decision support guideline is demonstrated in Fig. 3 for an arbitrary threshold of 40% of the insolation on a flat rooftop (horizontal plane).

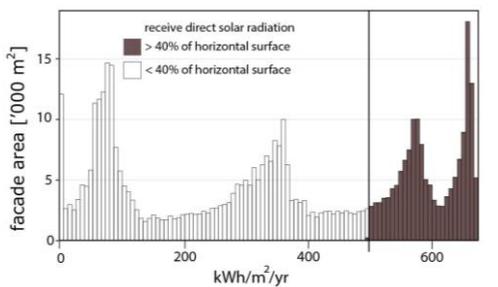


Figure 3: Distribution of annual direct radiation on building facades in case study neighbourhood. Column heights indicate surface area of each façade.

### 3.3 The solar potential of different urban typologies

The potential for BIPV depends on how large the building envelope is. Buildings with large roofs and/or facades, such as row houses and apartment blocks, therefore had high average insolation scores. However, as energy consumption in residential buildings is typically evaluated on a per capita basis or per household, it may be useful to compare the offsetting production of electricity provided by PV systems in these terms.

The low-rise high-density typologies, such as row houses, apartment blocks and terraces, had the greatest solar potential per dwelling. Apartments in row houses

had a total solar potential of about 70,000 kWh per year in a realistic scenario, and apartments in terrace houses nearly 60,000 kWh, compared to less than 30,000 kWh per year for typical apartments in tower blocks.

Where land prices are high and new urban construction is geared towards high density, the solar potential of each building type may be a key indicator of sustainability. Our method can be used to estimate solar potential given different construction densities in the different parts of the neighbourhood. In our case, the building type with the largest solar potential per site area is, again, the row houses, which have a solar potential of over 750,000 MWh/km<sup>2</sup> annually.

### 4. CONCLUSIONS

Row buildings, characterized by large rooftops, are most likely to be favourable for building-integrated PV installation, if siting limits shadowing effects by adjacent buildings and guarantees solar rights. However, although roofs typically receive more sunlight than exposed walls and are less affected by mutual shading than vertical facades, the solar potential of some facades (mainly south) may be substantial due to their often very large areas, especially in the case of high-rise buildings. The methodology presented here, which is developed as an open-source resource, can be applied in the development of urban BIPV installation, solar dissemination policies and urban planning.

### ACKNOWLEDGEMENTS

The study was funded by the Israel Ministry of National Infrastructures, Energy and Water Resources under research grant no. 021-11-215.

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# Thermal Comfort in Micro-Apartments In The Subtropics – Winter Season

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*ABSTRACT: This paper aims to discuss about the thermal performance during the winter season of the recent production of open plan micro-apartments in São Paulo. The field research was conducted during 20 days, in the cold weather period, and consisted in the measurement and analysis of five units that are representatives of this dwelling typology.*

*KEYWORDS: Residential, micro-apartment, thermal comfort, subtropical climate*

## 1. INTRODUCTION

This paper presents a research about thermal performance of the recent production of open plan micro-apartments in São Paulo, during winter. This season was specially considered in this research since in the dwellings the night period is crucial in terms of comfort, and São Paulo subtropical climate presents cold winter nights. The object of this research are open plan micro-apartments smaller than 45 square meters built between 2011 and 2015. This typology increased from 7.9% in 2011 to 35.9% of the total apartments smaller than 45 square meters launched in 2015 in São Paulo [5]. The high representativeness of the micro-apartments in the current real estate market emphasizes the social and cultural transformations, and the occupation of land in the accelerated process of verticalization in the city, therefore highlighting the importance of studies focused on these new dwelling models.

## 2. METHOD

The method followed is the experimental inductive for the field research of thermal variables (air temperature, mean radiant temperature, relative humid, and air speed). The field research was conducted during 20 days in August (from the 11<sup>th</sup> to the 31<sup>st</sup>), a cold weather period, and consisted in the measurement and analysis of five units that are representatives of this dwelling typology.

The Adaptive comfort model was followed to evaluate thermal performance in this research since it considers naturally conditioned buildings and the occupant as an active individual for comfort definition, similar conditions as of the case studies. The adaptive comfort model index used is the recommended in the ASHRAE 55-2013, based on the work of de Dear and Brager (2002). This standard uses the relationship between the indoor comfort temperature and the outdoor temperature to delineate acceptable zones for indoor temperature in naturally conditioned buildings [6].

## 2.1 The case studies

The units selected as the case studies have an approximate area of 45m<sup>2</sup>, without occupants and with one veranda, which constitutes a large part of the total indoor area. The five micro-apartments patterns analysed in this research were: (a) a unit with thermal insulation in the west façade; (b) a unit with a glass-sealed veranda; (c) a unit with large uncovered veranda, almost 65% of the total indoor area; (d) a duplex (unit with two floors); and (e) a unit with double-height (5,6m).

All of them are exposed to low direct solar radiation, since they are facing between Southwest and Southeast. In this case, the indoor heat penetration is diminished because the main access to ventilation and solar radiation occurs through the veranda opening.

In addition, more than 90% of the micro-apartment launched between 2011 and 2015 in São Paulo, including the case studies, has a simple glass sliding door between the veranda and indoor, regardless the orientation. This building standard has repercussions in the performance and the quality of the dwellings, since only one component is responsible for several complex functions.

## 3. DISCUSSION AND RESULTS

In residential buildings, comfort strategies oriented to night-time are more relevant because the occupation rate is higher during this period. Since the study was performed during winter, with cold nights, the capacity to retain heat gained during the day is determinant to achieve thermal comfort.

As all the units were uninhabited (without indoor heat loads) and without active conditioning system, their thermal performances are guided on the passives solutions adopted. Therefore, the combined effects of the inertia, the openings and the solar shades are determinant to the thermal comfort.

The first analyses of the results demonstrated the high indoor daily temperature amplitudes, as shown on Fig. 1 below, indicating high heat exchange capacity.

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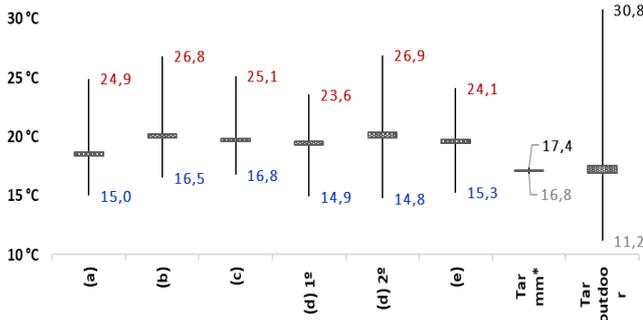


Figure 1: Box plot of indoor operative temperatures in each unit, outdoor air temperature (Tar outdoor) and mean monthly outdoor air temperature (Tar mm\*). The error bars show the mean values considering a 90% confidence interval.

The extent of such issue can be verified by plotting each unit operative temperature against Adaptive model ranges of comfort. The 90% and 80% acceptability limits are presented in Fig. 2 as a function of the mean monthly outdoor air temperature measured for each day. The results demonstrated (Table 1) that all the solutions adopted concerning thermal performance are more than 45% of the time below 80% acceptability range of adaptive mode.

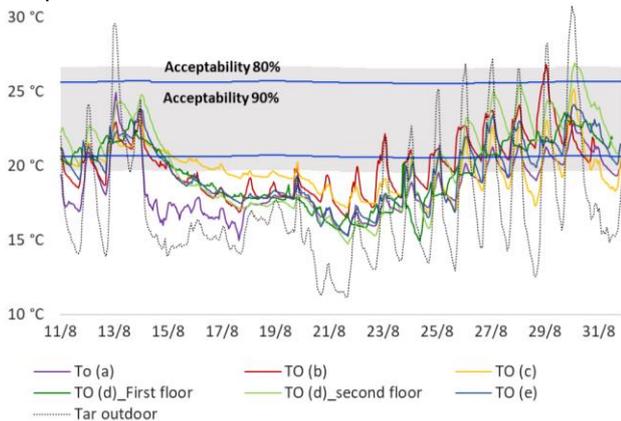


Figure 2: Daily indoor operative temperature for each unit, outdoor air temperature and ranges of 90% and 80% acceptability limits

Table 1: Ratio of time that each study case evaluated stayed outside (below or above) 90% and 80% acceptability limits of adaptive model.

	Outside accep. 80%		Outside accep. 90%	
	Below	Above	Below	Above
(a)	70,7%	-	83,6%	-
(b)	46,5%	0,8%	63,1%	0,2%
(c)	50,9%	-	74,3%	-
(d)	47,1%	2,4%	52,5%	0,4%
(e)	50,5%	-	65,3%	-

The situation is compounded when it observes, singly, a winter typical day, as it occurs on 19<sup>th</sup> August. In this day none of the units were in the 80% acceptability range of adaptive mode. This probably occurs due to the thermal mass and the low penetration of the radiation solar.

The thermal mass plays an essential role in setting comfort as it contributes to conserve heat gain. In micro-apartments due the smaller indoor air volume and the higher envelope contribution, the thermal mass effect tends to be amplified. However, in the units evaluated this effect is affected by the wide glass area of the veranda doors and the thin walls, with the low inertia of the materials employed. The large variation of the indoor operative temperatures strengthens the low capacity of these units in retaining heat gained during the day to warm the indoor during the night.

Furthermore, in the case studies, except for the unit (e) – loft, the access to ventilation, sun and sky is limited to only one opening. This element must perform a variety of roles and, therefore, should present more sophisticated methods of control for ventilation and daylighting to avoid compromising the occupant's comfort.

Nevertheless, what was observed were openings standardization and frames sealing deficiency, both leading to poor thermal insulation by allowing air infiltration and heat leakage. This issue was confirmed by the high indoor air speed data registered with the doors and windows closed (around 1.0 m/s).

## 4. CONCLUSION

This research assessed the thermal performance of current micro-apartment through the evaluation of five case studies. The results demonstrated a deficient thermal performance, driving to the dependency on air conditioning to promote thermal comfort and resulting in higher energetic consumption. This reality is not only environmentally unsustainable, but also impacts negatively the health and well-being of the occupant.

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# Numerical Sensitivity Analysis of Human-body Exergy Balance Under an Unsteady-state Thermal Environment. Physiological Adaptation Induced by the Difference in Thermal Environment in Summer

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*ABSTRACT: Using numerical analysis, I investigated the human body exergy balance under an unsteady-state thermal environment surrounding the human body in the course of individuals moving indoors after having been outside for a while in summer. The mechanisms of thermal physiological adaptation such as sweat secretion were clarified from the exergetic perspective to some extent. Human body exergy consumption rate in the conditions that indoor absolute humidity is equal to outdoor is smaller than that in the conditions in which indoor absolute humidity is lower than outdoors. It suggests that extracting indoor moisture by ventilation is preferred compared to the dehumidification.*

*KEYWORDS: Thermal Comfort, Thermal Adaptation, Human Body, Exergy, Dynamic comfort*

## 1. INTRODUCTION

### 1.1 Thermal adaptation

It is as important to strive for comfort and energy saving with regard to a resident's thermal adaptation as it is to optimize the environmental system of a building because energy use by the building equipment is considerably influenced by the turning on/off of the air-conditioning/cooling units [1].

### 1.2 Cyclic process from sensation to behavior

Thermal adaptation is a cyclic process from "sensations" via "perception" and "cognition" to "behavior" [1]. At the final stage of a single cycle of this process, a specific behavior emerges for changing the state of the physical environment in order to renew the sensation, the examples of which include opening or closing a window and switching a mechanical cooling unit on or off [1].

### 1.3 Spiral process by continuous cycle

The sequence of these cyclic processes becomes a spiral process. There are two probable types of spiral processes: a spiral process corresponding to high exergy consumption and the other corresponding to low exergy consumption. Even though a resident of a building performs a wasteful or appropriate action, human body physiology (homeostasis) acts to decrease the exergy consumption within a human body. Furthermore, the cerebral paleocortex of the human brain tends to seek a "pleasant" thermal environment. This drives the emergence of a spiral process under the unsteady-state environment. Therefore, the consideration of the pattern of the unsteady-state human-body exergy balance could help in designing the environmental

systems of buildings in order to provide both thermal comfort and desirable adaptations that will decrease the consumption of fossil fuels. The consideration of this pattern can also clarify the mechanisms of physiological adaptation.

### 1.4 Purpose of research

Herein, a sensitivity analysis focusing on the relationships between thermal adaptations and the pattern of the human body exergy balance has been performed. Using numerical analysis, this study investigated the human-body exergy balance under an unsteady-state thermal environment surrounding the human body for individuals moving indoors after being outside for a while in summer.

## 2. EXERGY EVALUATION

### 2.1 Architectural environmental system

For the evaluating the functioning of an architectural environmental system, it is important to refer to the concept of exergy because doing this can explicitly evaluate the diffusing capacity of energy and matter [1].

### 2.2 Human body system

The diffusion of energy and matter occurs randomly in an architectural environmental space, and in the human body, it must be anticipated that thermal sensations such as "hot" and "cold" correspond to the human-body exergy balance.

### 2.3 Thermal adaptation

The comfort temperature in an adaptive model is predicted based on the outside air temperature [2]. Since exergy is calculated considering the outside air

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temperature as the environmental temperature [1], it could be surmised that a certain relationship exists between adaptation and exergy.

## 2.4 Unsteady-state valuation

Thermal adaptation is influenced by both the long- and short-term history of the exposed thermal environment [1], and thus, both the adaptive comfort temperature and the exergy value are also influenced by such an unsteady-state thermal environment.

## 3. NUMERICAL ANALYSIS

### 3.1 Human body system and exergy balance equation

The human-body exergy balance equation is derived by combining three elements: the human-body energy balance equation, the human-body entropy balance equation, and the environmental temperature (outdoor air temperature) [1]. The equation can be set up in a general form as follows (For details, see reference [1]):

$$[\text{Exergy input}] - [\text{Exergy consumed}] = [\text{Exergy stored}] + [\text{Exergy output}] \quad (1)$$

### 3.2 Calculation method

The two-node thermal “energy” balance equations for the calculation of the human-body core, skin-layer, and clothing surface temperatures are numerically solved using the explicit finite-difference method (using forward differences). Herein, the calculation interval is set to 1 min to stabilize the calculation. The detailed procedure is described in reference [3].

### 3.3 Fixed conditions

The fixed conditions are summarized in Table 1. The calculation considered a period of 240 min, assuming a transition of 0–120 min in the outdoor environment and a period of 120–240 min within the indoor space. The metabolic rate and the amount of clothing were set to reflect the outdoor transitional period and the indoor period.

Table 1: Fixed conditions and comparative conditions.

				Indoor			
				Case 1	Case 2	Case 3	Case 4
Environment	Air Temperature	Outdoor	32 °C	32 °C	29 °C	32 °C	26 °C
	MRT	Outdoor	42 °C	32 °C	29 °C	32 °C	26 °C
	Humidity	Relative	60 %	60 %	71 %	35 %	50 %
		Absolute	18.0 g/kg'		10.4 g/kg'		
	Air Velocity	1.0 m/s	0.1 m/s				
Human Body	Metabolic Rate	2 met	1 met				
	Clothing Resistance	0.43 clo					

### 3.4 Comparative conditions

For comparison, the calculation conditions for four cases are summarized in Table 1. In Cases 1 and 2, it was assumed that the absolute humidity outdoors and

indoors were identical. In Case 1, it was assumed that indoor air temperature and MRT were equal to the outdoor temperature. This temperature is achieved when the air change rate is 15 times/h or higher. Case 2 assumed that the indoor air temperature and MRT of 29 °C were lower than the outdoor temperature of 3 °C. This temperature is achieved when a building envelope cool storage is considered in Case 1. In Cases 3 and 4, it was assumed that the indoor absolute humidity was lower than the outdoor absolute humidity. Case 3 assumed that the indoor air temperature and MRT were equal to the outdoor air temperature. This temperature is achieved when an air-conditioner drying operation is performed. Case 4 assumed that the indoor air temperature and MRT were 26 °C. This temperature is achieved when an air-conditioner cooling operation is performed.

## 4. RESULTS

The human-body exergy consumption rate is shown in Fig. 1. Immediately after the entrance into a room, in Cases 3 and 4, the human-body exergy consumption rate rapidly rises to a large value, whereas no rise is observed in Cases 1 and 2. For a period of 180 min or more after entering a room, where a stable value is observed, the consumption rate values are in order of Case 3 > Case 4 > Case 1 > Case 2. In addition to superfluous cooling, superfluous dryness may be a significant factor of either a cooling disorder or a feeling of fatigue. It is suggested that the discharge of dampness is more desirable for a human body than it is for dehumidification.

In Cases 1 and 2, the consumption rate showed the same rise and attenuation pattern as those previously observed for the blood flow volume and the amount of sweating. For the case wherein human-body thermal stress is small, aligning the human-body exergy consumption rate with the blood flow volume and the amount of sweating may be desirable.

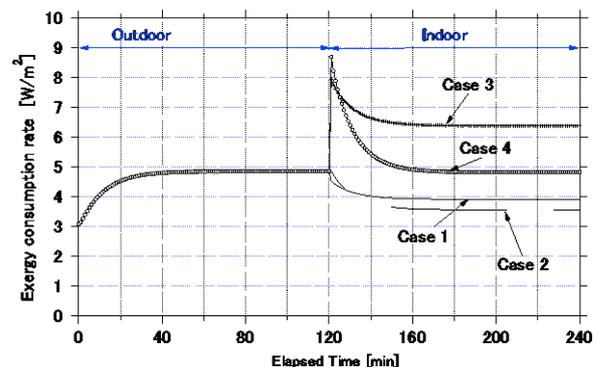


Figure 1: Human-body exergy consumption rate [W/m<sup>2</sup>].

## 4. CONCLUSION

The mechanisms of thermal physiological adaptation such as sweat secretion were clarified from the exergetic perspective to some extent.

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Human body exergy consumption rate in the conditions that indoor absolute humidity is equal to outdoor is smaller than that in the conditions in which indoor absolute humidity is lower than outdoor.

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## Passive Downdraft Cooling Towers Outlet Conditions Prediction: Regression Analysis on Data Collected from Built Prototypes

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**ABSTRACT:** This research proposes a new set of equations that predict conditions at the outlet of a single stage passive downdraft evaporative cooling tower (PDECT) as well as a multi-stage passive and hybrid downdraft cooling tower (PHDCT), namely temperature drop ( $\Delta T$ ) and air velocity ( $V$ ). Equations were developed through multiple linear regression using data collected from experimental evaluation conducted during Summer, 2017 in Tempe, Arizona on built prototypes of these towers. Regression analysis indicated a strong correlation between measured and predicted data with an adjusted coefficient of determination ranging between 0.80 and 0.95.

**KEYWORDS:** Passive Downdraft cooling, Passive Downdraft Evaporative Cooling Tower, Passive and Hybrid Downdraft Cooling Tower, Regression Analysis

### 1. INTRODUCTION

Several equations have been developed in the past that predict outlet conditions for passive downdraft evaporative cooling towers (PDECT) using data collected from experimental evaluations [1-4]. This study differs from the former in three ways. The first is that the same experiment setup was exposed to different climate classifications, specifically hot dry and hot humid. The second is that the outlet conditions of the towers were measured under a wider range of ambient conditions, from a low DBT of 73.0°F with 82.9% coincident RH, to a high DBT of 123.4°F with 7.8% coincident RH. Finally, this study proposes equations for a hybrid tower in contrast with all the former studies which solely focused on developing equations for single stage towers.

### 2. EXPERIMENT SETUP



Figure 1: Photo of final experiment setup from southeast corner. Left: hybrid tower, right: single stage tower.

The experiment setup (Figure 1) was built at the Design School Solar Lab at Arizona State University Tempe campus. The geometry of all components of the single stage tower (right in Figure 1) and the hybrid tower (left in Figure 1) were identical except for the towers inlets. The former had a cube shape inlet with diagonal baffles, whereas the latter had an all-aluminium bar and plate heat exchanger covered by a shading device to protect it from direct solar radiation. The evaporative cooling system was identical in both towers, each with four misting nozzles sitting directly below the towers inlets.

### 3. DATA ACQUISITION

A customized system completely supplied from Onset Computer Corporation was assembled. 30 second logging intervals were used when recording data to better understand the cooling processes. Every 10 recordings were converted to five-minute observations. Data was collected over a span of 42 days between June 8, 2017, and July 20, 2017. Different operational modes were tested in each tower by changing the water flow rates through sensible and evaporative cooling systems as well as using fans to understand the effect of forced ventilation on outlet conditions. All data processing and analysis were performed using Microsoft Excel.

### 4. REGRESSION ANALYSIS

Linear regression analysis was used since several studies found in the literature consider it to be the most acceptable [2, 4]. The independent variables taken from measurement equipment were ambient air dry-bulb temperature ( $T_{DBT, IN}$ ), ambient air wet-bulb depression ( $T_{WBD}$ ) and wind speed ( $WS$ ). The independent variables recoded into dummy variables were as follows:

1.  $F_1$  - Fan operation.  $F_1 = 1$  when on;  $F_1 = 0$  when off.

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2. M<sub>1</sub> - One mister operation (0.7 gal/h). M<sub>1</sub> = 1 when one mister on; M<sub>1</sub> = 0 when a different number of misters or no misters on.
3. M<sub>2</sub> - Two misters operation (1.4 gal/h). M<sub>2</sub> = 1 when two misters on; M<sub>2</sub> = 0 when a different number of misters or no misters on.
4. M<sub>3</sub> - Three misters operation (2.1 gal/h). M<sub>3</sub> = 1 when three misters on; M<sub>3</sub> = 0 when a different number of misters or no misters on.
5. HE<sub>1</sub> - Hybrid tower heat exchanger operation. HE<sub>1</sub> = 1 when on; HE<sub>1</sub> = 0 when off. Note: multiple water flow rates were tested. However, this had no impact on outlet conditions; thus, treated as on/off.

## 4.1 Single stage tower regression analysis

The data recorded from the single stage tower used in this analysis was equivalent to 221 hours of operation, or 2651 observations, collected over 29 days. This included 24 days of tower operation during daytime under hot dry conditions (1967 observations), 2 days of no tower operation under hot dry conditions (252 observations), and 3 days of tower operation overnight under hot humid conditions (432 observations). Less observations were used to develop the velocity equation (2363) because velocity patterns observed under hot dry and hot humid days were similar; thus, 2 hot humid days were excluded from the regression. Results in Table 1 below indicated that the adjusted coefficient of determination was high at 0.87 for ΔT and 0.80 for V. All independent variables were significant and should be part of the regression since R<sup>2</sup> and adjusted R<sup>2</sup> were in line with each other. All independent variables slope coefficients were significant as well, with probability values equal to zero when calculated at 99% confidence level. Refer to Equations (1) and (2) below.

Table 1: Regression statistics for single stage tower

Statistic	ΔT	V
Multiple R	0.9319	0.8972
R <sup>2</sup>	0.8684	0.8050
Adjusted R <sup>2</sup>	0.8681	0.8046
Standard Error	3.6024	22.0563
Observations	2651	2363

$$\Delta T_{PDECT} (^{\circ}F) = -25.1018 - 0.7727 \times F_1 + 19.9265 \times M_1 + 25.3981 \times M_2 + 28.6186 \times M_3 - 0.0101 \times WS + 0.4893 \times T_{WBD} + 0.1162 \times T_{DBT,IN} \quad (1)$$

$$V_{PDECT,OUT} (fpm) = 91.8632 + 37.1160 \times F_1 + 36.8460 \times M_1 + 40.2457 \times M_2 + 40.4213 \times M_3 + 0.1267 \times WS \quad (2)$$

## 4.2 Hybrid tower regression analysis

The data recorded from the hybrid tower used in this analysis was equivalent to 232 hours of operation or 2789 observations collected over 31 days. This included 26 days of tower operation during daytime under hot dry

conditions (2141 observations), 2 days of no operation under hot dry conditions (252 observations), and 3 days of tower operation overnight under hot humid conditions (396 observations). Results in Table 2 below indicated that adjusted coefficient of determination was high at 0.95 for ΔT and 0.83 for V. All independent variables were significant and should be part of the regressions since R<sup>2</sup> and adjusted R<sup>2</sup> were in line with each other. All independent variables slope coefficients were significant as well, with probability values equal to zero when calculated at 99% confidence level, except for wind speed in the velocity regression, which had a value of 0.0002. Refer to Equations (3) and (4) below.

Table 2: Regression statistics for hybrid tower

Statistic	ΔT	V
Multiple R	0.9751	0.9116
R <sup>2</sup>	0.9508	0.8311
Adjusted R <sup>2</sup>	0.9507	0.8307
Standard Error	3.3084	14.8099
Observations	2789	2789

$$\Delta T_{PHDCT} (^{\circ}F) = 13.9159 + 22.8738 \times M_1 + 30.2403 \times M_2 + 35.6508 \times M_3 - 1.2290 \times F_1 + 10.6377 \times HE_1 - 0.0078 \times WS + 0.2256 \times T_{WBD} - 0.1651 \times T_{DBT,IN} \quad (3)$$

$$V_{PHDCT,OUT} (fpm) = 122.0507 + 26.0527 \times M_1 + 25.1486 \times M_2 + 30.4002 \times M_3 + 55.4202 \times F_1 + 6.4487 \times HE_1 - 0.0044 \times WS - 1.0520 \times T_{WBD} \quad (4)$$

## 5. CONCLUSIONS AND FUTURE RESEARCH

The strong correlation between measured values and values predicted using the proposed equations suggests that these equations could be used in software applications for sizing downdraft cooling towers. Future research will focus on understanding the impact of the tower height and cross section area on the outlet conditions through experimental evaluation on built prototypes of towers with different dimensions. These variables will then be added to the equations above.

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# Shading Effect and Heat Reflection of the Green Façade: Measurements of an External Corridor Building in Munich, Germany

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**ABSTRACT:** Risks of urban heat island (UHI) on the outdoor comfort and human health are rising in the trends of high-density urbanism. Green façade (GF) is one of the technologies which interested by researchers and architects because of the effects of the diminution on UHI, urban acoustic, and air pollution. This paper focuses on the shading effect of the GFs on the semi-outdoor thermal environment. A student dormitory with GFs is invited to investigate on a summer day in Munich, Germany. Through the measurements comparing the shaded and exposed area, results show that the Ave. and the Max. air temperatures (Temps) are decreased by 0.7 °C (W) and 2.1 °C (W), the Ave. surface Temp of the glazing is reduced by 1.2 °C (E), and which of the aluminium is reduced by 3.5 °C (W) in the shaded area. Results confirm the shading effect of the GFs and reveal the potential of the decreasing heat reflection on building façade to the surrounding environment.

**KEYWORDS:** Green facade, Shading effect, thermal environment, heat reflection

## 1. INTRODUCTION

High-density urbanism is one of the trends in the developing counties and areas, which reducing a large amount of green land and aggravating of the problem of urban heat island (UHI) [1]. As a response, vertical greenery system (VGS) applying in building design is more and more regarded as one of the technologies of the UHI decreasing [2]. Recent researchers have also pointed out that the VGSs have good effects on building thermal environment improvement [3] and energy saving [4].

The green façade (GF) is one of the VGS technologies, supporting the climber plants to grow on the building façade [5]. The GFs were widely used as the shading devices in recent years. However, the shading effect and the influences of heat reflection on the environment are still needed to study through measurements in situ.

This research took measurements on a summer day. The object was a student dormitory in Munich, Germany. which was installed an entire GF was installed on the edge of the external corridors. The workflow of this research is showed in Figure 1.

A. Purpose	<ul style="list-style-type: none"> <li>● Shading effects</li> <li>● Heat reflection performance</li> </ul>
B. Measurements	<ul style="list-style-type: none"> <li>● Air temperature (Temp), relative humidity (RH), wind velocity (Va)</li> <li>● Foliage coverage ratio (FCR) of the GF</li> <li>● Surface Temp of GF, glazing, aluminium plate</li> </ul>
C. Analysis	<ul style="list-style-type: none"> <li>● Comparison</li> <li>● Correlation Analysis</li> </ul>

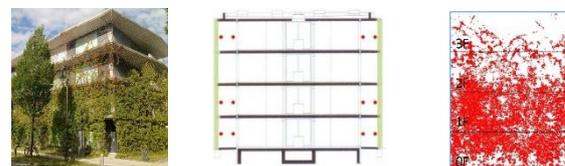
Figure 1: Workflow of the research.

## 2. MEASUREMENT METHODOLOGY

The student dormitory lies in the open location where is on the edge of the town in northern Munich (humid

continental climate, Köppen classification: Dfb). The long side of the building faces to east-west paralleling to the road. The wine plants of the GFs have grown up for 12 years since the building has been finished in 2005. The plants were planted in soil on the ground floor (0F). The FCRs of the GFs were different on the different height as the plants grew naturally.

This research set the test points on the corridors on east and west side of 0F, 1F, and 3F in order to compare the differences of the data (Figure 2). On the other side, one point of the environment was also set on an open space without shading of the buildings. Air data were recorded by the hand-held weather instruments and the surface Temp data were recorded by the non-contact thermal-meters. FCRs of the GFs were recorded by the camera and analysed with imaging processing software.



(a) photo of the dormitory. (b) building section with test points. (c) FCR analysis of the GF.  
Figure 2: Photo, section and FCR analysis of the test building.

## 3. RESULTS AND DISCUSSION

### 3.1 Results of the shading area

Results show that the Ave. Temps in the corridors are lower than the outdoor environment. The Ave. Temps of the 0F and 1F, whose FCRs are higher, are lower than which of the 3F by 0.7°C (W) and 0.1°C (E). The Max. difference between 0F and 3F is 2.1 °C (W) and 1.3°C (E). The Temp difference is lower on the east side because of

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the influence of the higher Va. The Ave. Va is higher on the 3F than the 0F and 1F, especially on the east side. The reason is that main wind direction of the test date was east-north. On the other side, the contrast of the RH of different test points is not obvious (Figure 2).

In this measurement, the difference of the Temp on the west façade could give a better comparison because of the lower influence of the high Va of the environment. Correlation analysis is invited to analyse the relationship between the Temp and the FCR. Results show that the correlation index (CI) is higher when the Temp increases. The Ave. CI is 0.54 and the Max. CI is 0.92 (Figure 3).

Results confirm the shading effect of the GF, and difference of the Ave. Temp is 0.7°C, and which of the Max. Temp is up to 2.1°C. The correlation analysis also reveals that the shading effect is much more obvious when the Temp is higher in the afternoon.

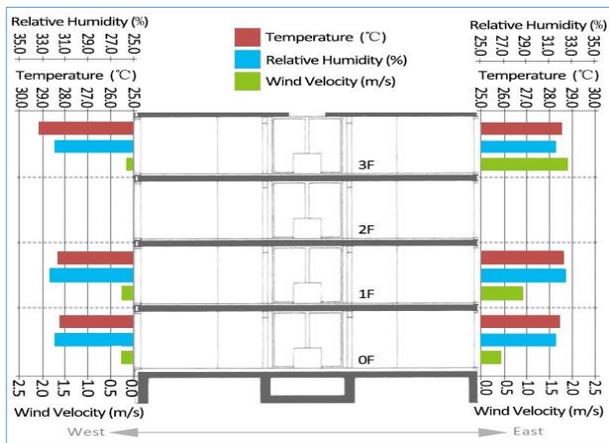


Figure 1: Ave. Temp, RH and Va data showing in the building section.

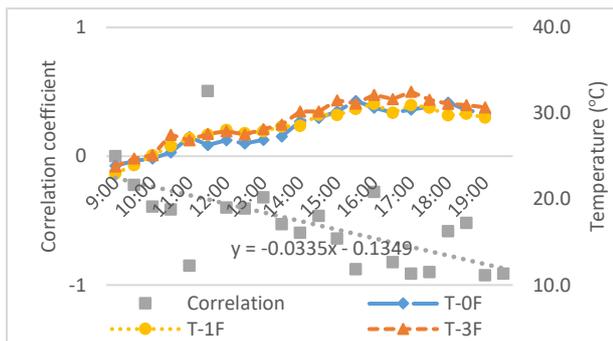


Figure 2: Temp variation, combing with the correlation index of the FCR and the Temp.

### 3.2 Results of the surface Temp

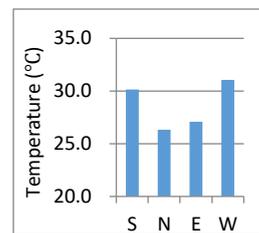
Three groups of the surface Temp of the GF and the material of the building wall were measured and compared.

The Ave. surface Temp of the leaves shows that the west and the south side of the GF have the higher Temp. Combing with the air Temp data of the corridor, it shows

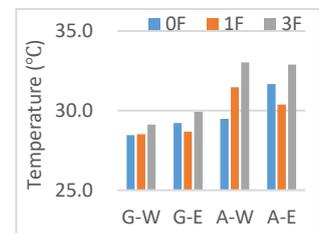
that the shading effect is better on the west side than the east side.

The glazing and the aluminium plate are on the inner side of the corridor. Comparison of the Ave. surface Temp of the glazing and the aluminium plate shows that the Temp is higher on the 3F than the 0F and 1F. Results are similar to the air Temp of the shading area. The Ave. Temp difference of the glazing is up to 0.6°C (W) and 1.2°C (E), which of the aluminium is up to 3.5°C (W) and 2.5°C (E) (Figure 4).

Results of the surface Temp also confirm the shading effect of the GF. Furthermore, the decrease of the surface Temp reveals the potential of the decreasing heat reflection to the surrounding environment.



(a) Ave. surface Temp comparison of the GFs.



(b) Ave. surface Temp comparison of the glazing (G) and the aluminium plate (A).

Figure 3: Ave. Temp comparison of the GFs, the glazing, and the aluminium plate.

### 4. CONCLUSION

This paper evaluated and confirmed the GFs' effect of shading and the diminution of façade heat reflection. The Ave. and the Max. air Temps are decreased by 0.7°C (W) and 2.1 °C (W), the Ave. surface Temp of the glazing is reduced by 1.2°C (E), and which of the aluminium is reduced by 3.5°C (W) in the shaded area. In the further research, the solar gain, human comfort, and the environmental thermal changes would be studied.

### ACKNOWLEDGEMENTS

This research is supported by the State Scholarship Fund of China, the National Natural Science Foundation of China (No.B5141490), and the Science and Technology Planning Project of Guangzhou, China (No.B3160760).

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# Evaluation of Microclimatic Conditions and Thermal Comfort of the City's Public Space: Example of the Old Marketplace in Lodz (Poland)

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*ABSTRACT: The records of the strategic documents for Lodz pay special attention to the need to undertake work in the historical parts of the city. One of the strategic objectives of the Municipal Revitalization Program for the city of Lodz 2026+ has become the "revival of the area of residence" through the transformation of residential objects with the environment related to them functionally, i.e. public and semi-public spaces.*

*One of the ways to improve the urban tissue standard is to ensure the correct microclimatic conditions prevailing in the areas of public spaces. In the paper, the microclimatic parameters and thermal comfort in the area of one of the oldest public spaces in Lodz - the Old Marketplace were estimated by the usage of the CFD program. Two types of input data have been applied, i. e. from direct field measurements and meteorological station database. It turned out that simulations based on data from direct field measurements were characterized by greater precision of obtained results. Existing thermal conditions were uncomfortable, which results in the necessity of redesigning public space.*

*KEYWORDS: Microclimatic Conditions, Thermal Comfort, Public Space, Urban Area, Climate Adaptation*

## 1. INTRODUCTION

Thermal comfort is a parameter that enables evaluation of perceived microclimate conditions, particularly in strongly urbanized areas [1]. It depends on the spatial management method of the area resulting from the existing urban forms, geometry and degree of development intensity, vegetation, water resources and surface types [2]. In the city centers, wind speed slows down, temperature increases and relative air humidity decreases. The quality of air in downtown areas deteriorates. In addition, there are negative phenomena in a form of urban heat island. In order to guarantee the residents of high quality of urban life, it is necessary to estimate thermal comfort at the planning stage of urban structures.

An aim of the study was to assess the correctness of microclimatic conditions simulation and to determine one of parameters of the thermal comfort in external environment, i.e. PMV index. It takes into account the modified equation of Fanger's thermal balance developed by Jendritzky and Nübler [3]. Currently it is used in the research on microclimate in urban areas to estimate thermal comfort within structures with high intensity of the building development, public spheres – traffic routes and green areas [4].

## 2. CASE STUDY – OLD MARKETPLACE IN LODZ

Field studies have been carried out in the Old Marketplace, which is the oldest public space located in Lodz (Poland). Currently, this area was covered by the program of "Urban Revitalization of the Centre of Lodz". Its main objective is to improve the living conditions of

people in the urban area. This can be achieved by ensuring proper microclimatic conditions within the public spaces.

## 3. RESEARCH METHODOLOGY

Two methods of data acquisition were used to determine microclimate parameters. In the first case, they were obtained from direct field measurements (2 m height). The air temperature value was determined by electric hytherograph. The relative humidity was appointed using multifunction meter. Research was conducted in six characteristic points, i.e. by corners of buildings (points: 1,6), on the main plate (points: 2,3) and along the frontage of market square (points: 4,5). Additionally, it was necessary to specify the other input parameters of the model, i.e. speed, air flow direction and atmospheric pressure. Information was obtained from the nearest Lodz-Lublinek meteorological station. Its location did not correspond fully to conditions in the city center, i.e. place of the measurement campaign. Therefore, it was necessary to convert the wind speed at a height of 10 m for the city centre area on the basis of dependence proposed by Simiu [5].

In the second case, information on the value of microclimate parameters was obtained from widely available digital databases of the measuring station. Data format (.xlsx) enabled fast adaptation of received information to requirements of CFD program in the input data of simulation.

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## 4. ANALYSIS OF RESULTS

Measurements of meteorological parameters should be carried out under conditions of cloudless weather [6]. Therefore, measurements were conducted on 29.07 and 04.08.2017.

Analysis of results showed that the highest degree of compliance with actual values was characterized by a study based on the direct field measurements carried out within the second position (Fig. 1). Its location on the main surface of market square in considerable distance from buildings eliminated the influence of aerodynamic effects on the results of studies. The daily mean absolute percentage error for air temperature was 2.71% – 0.62°C (29/07), 0.71% – 0.19°C (04/08), whereas for relative humidity fluctuated within the limits of 1.66% (29/07) and 2.03% (04/08).

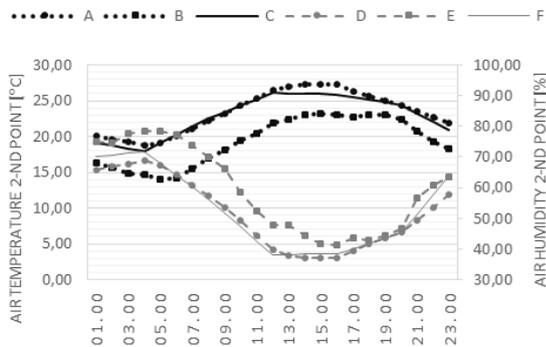


Figure 1: Values of meteorological parameters (the main surface of the public square – 2-nd point, 29/07 2017; simulation values: A,D – based on field measurements, B,E – based on meteorological station, C,F – reference values).

Results obtained in the fourth point located along the eastern frontage of the market square were characterized by the greatest discrepancies. It resulted from tall trees in the neighborhood, which modified the amount of solar radiation. The daily mean absolute percentage error for air temperature was 6.26% – 1.43°C (29/07), 4.27% – 1.11°C (04/08), and for relative humidity fluctuated within the limits of 3.46% (29/07) and 4.02% (04/08).

Studies based on data obtained from Lodz-Lublinek station were affected by greater measurement error of 3.72% (29/07), 2.91% (04/08) for temperature and 4.66% (29/07), 5.18% for relative air humidity.

PMV was appointed on the basis of obtained simulation values of meteorological parameters. Studies based on direct field measurements were characterized by higher average daily PMV values, i.e. 1.69 (29/07), 1.91 (04/08). The maxima were observed at 10am – 4pm. They were 3.56 (29/07) and 4.32 (04/08). The average daily PMV value estimated based on data from meteorological station fluctuated within the limits of 1.46 (29/07), 1.64 (04/08). In this case, the maximum values of indicator were also observed at 10am – 4pm, i.e. 2.38 (29/07) and 3.50 (04/08).

## 5. RESULTS OF THE STUDY

The usage of CFD program enabled to obtain information on basic microclimate parameters in a relatively short time. The simulations based on direct field measurements are characterized by almost three times greater precision of obtained results.

Studies have shown that in the area of Old Marketplace appear conditions determined as “slightly warm” and “warm”. Discomfort can be felt at 10am – 4pm. In order to provide comfortable conditions in the external environment it is necessary to redesign public space. It is possible by limitation of the use of artificial materials (such as concrete, asphalt which constitute 60% of analyzed space), introduction of additional plantings and addition of water elements. Application of cooling strategies can significantly contribute to the improvement of microclimatic conditions and as a consequence to provide thermal comfort.

## 6. CONCLUSION

In the era of climate changes city planners need reliable information to undertake comprehensive actions in urban areas. Data on microclimatic conditions and thermal comfort can be used as the starting point in revitalization processes. They can be used in the analytical and design part of urban studies – planning space that will provide comfortable thermal conditions for diverse users (for sitting, performing physical activity as well as passing-by users). Furthermore, these details can enable the placement of entities, infrastructure elements in regard to their functions.

## ACKNOWLEDGEMENTS

This research has been supported by the Young Scientists’ Fund at the Faculty of Civil Engineering, Architecture and Environmental Engineering, Lodz University of Technology, Lodz.

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# The Roof Impact on the Heat Balance of Low Height Buildings at Low Latitudes

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**ABSTRACT:** The central scope of this work is the architecture element roof, analysed through its close relationship with two conditions of low latitude regions. First, its relationship with climate conditions, in reference with the high amount of solar radiation it is exposed to, and second, the roof importance, in terms of area, in the middle of a disperse urban tissue. Thus, this study addresses the roof impact on residential buildings interior conditions, in these regions. This investigation has been handled with the use of simulation software. The input data and results were based and validated with a measurements campaign carried out in a seaside city of Ecuador. The results highlight the roof as the principal source of heat gains on the interior heat balance, even higher than direct solar gains through windows.

**KEYWORDS:** Roof, heat balance, low latitudes.

## 1. INTRODUCTION

In low latitude regions, the roof is the part of the envelope most exposed to solar radiation. The flux through opaque surfaces is often considered as a thermal loss. However, in these regions, the influence of solar radiation and other heat exchanges with the exterior reduce significantly these thermal losses or even turn it into gains [1]. The importance of this element on the interior conditions depends on the urban context and the building morphology [2][3]. In low latitude cities, which have adopted an urban sprawl model, low height buildings are the most extended urban typology [4]. Therefore, in these regions the roof gains play a determinant role on the building energy balance.

The specific objective of this research is to determine the roof impact on the heat balance of low height buildings, in low latitude regions.

## 2. METHODOLOGY

It has been used dynamic simulations with Design Builder interface and Energy Plus calculation engine, to evaluate the heat balance of a residential building. This work uses data from previous experimental work to validate the simulation results. The experimental study was carried out in a seaside city of Ecuador at 3°27' S (Santa Rosa), where the 75% of residential buildings are one floor high, as well as other cities in this country [5]. It evaluated the roof thermal behaviour of a dwelling, using the climatological factors of this region as: solar radiation (SR), sky thermal behaviour, etc [6]. The roof parameters and the climatological factors were used as input data for the present investigation. Furthermore, the results obtained from simulations were validated with the measured results.

A model of a residential dwelling has been elaborated. The geometric characteristics and materials of this model are based on the most used typologies in

this region, (Table 1). Thus, the model is a one-floor residence of 9m x 9m x 3.1m height, attached to equal buildings by its North and South sides. It has a 20% glazed area on its East and West façades (Fig. 1), which complies with the maximum allowed window area according to the climatic zone and its orientation [7].

Table 1 Simulation parameters

Roof	
Solar Reflectance	0,25
Emissivity	0,95
Thermal mass	70,51 KJ/m <sup>2</sup> .K
Thermal transmittance	2,68 W/m <sup>2</sup> .K
Walls - thermal transmittance	3,2 W/m <sup>2</sup> .K
Window - thermal transmittance	5,4 W/m <sup>2</sup> .K
Solar transmittance of glass	70%
Floor - thermal transmittance	1,96 W/m <sup>2</sup> .K
Occupancy	Const 0,04 people/m <sup>2</sup>
Infiltrations	Const 0,7ac/h
Ground temperature	25,8°C

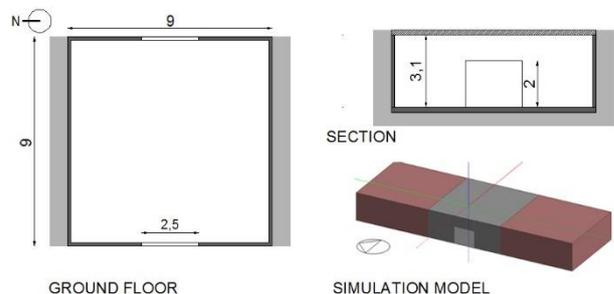


Figure 1: Simulation model.

The climatological data used corresponds to a day with the following characteristics: solar radiation 4,6 kWh/m<sup>2</sup>, sky cover 83%, sky temperature 15°C and outdoor air temperature 25,5°C. Every heat flux has been

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evaluated in terms of its total average in the day in relation to the total volume of the model ( $W/m^3$ ).

### 3. RESULTS

The computation shows that the exterior roof surface temperature remains higher than the air temperature during the day. This is in agreement with energy gains to the interior (positive flux), with minimal energy losses (negative flux) in the morning (Fig. 2).

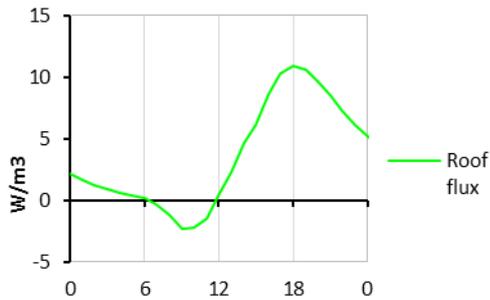


Figure 2: Hourly interior heat flux from the roof.

In order to analyse the thermal behaviour of the roof, it has been obtained the daily average of the whole heat interchanges to which it is exposed. The determination of these fluxes was based on the calculations models used by the software [8]. The results show that from the 100% of SR received by the roof, 25% is reflected ( $Q_{ref}$ ) and 75% is absorbed ( $Q_{abs}$ ), 52% is emitted by radiation ( $Q_{rad}$ ) and 18% is dissipated by convection ( $Q_{conv}$ ). The remaining 5% of SR (equivalent to  $3.9 W/m^3$ ) is transmitted to the interior by the roof (Fig.3).

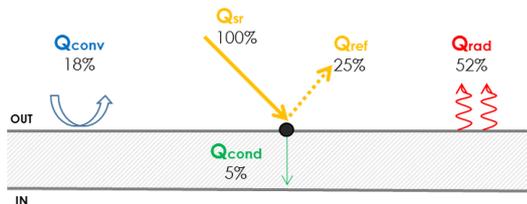


Figure 3: Percentage of the roof energy exchanges, in reference to the solar radiation received.

The interior heat balance results (Fig. 4) reveal that the positive flux from the roof ( $3.9W/m^3$ ), represents the 56% of the total energy gains of the building. Hence, the gains through the roof are higher than direct solar gains through windows. The negative flux through the roof represents only the 5% ( $-0.45W/m^3$ ) of the total losses, despite being a large part of the envelope. Then, the ground is the main heat dissipating element in this model while the roof has a minimal dissipation.

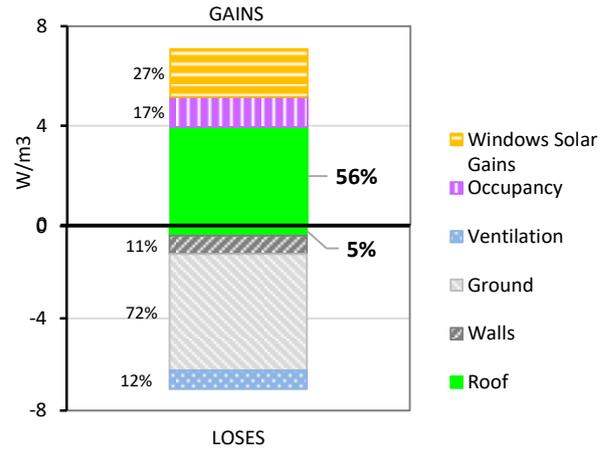


Figure 4: Average heat gains and losses of the residence interior.

### 4. CONCLUSION

This study supports the importance of the roof as the principal source of heat gains in one-floor residence from low latitude places and highlights its low capacity as a heat dissipater. The strategies to fight off overheating should better focus on reducing the heat gains through the roof. Future works will address the relevance of high reflectivity/emissivity materials, to control gains and encourage heat dissipation to the sky.

### ACKNOWLEDGEMENTS

Work supported by Spanish Ministry of Economy, project code: BIA2016-77675-R. JTQ acknowledges scholarship AR6C9307 from the government of Ecuador.

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# Matching Visual Impact, Solar Energy Production Potential and Energy System Optimization for an Enhanced Solar Integration: An Experience with a Novel Pre-Design Tool

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**ABSTRACT:** This study focuses on developing a BIPV pre-design computational platform combining visual impact assessment, building simulation and energy system optimization. The outdoor exposed surface of a pavilion court building block is evaluated through a physiologically reliable indicator of visibility that determines three scenarios of PV coverage ratio. Solar PV generation and demand for heating and electricity are simulated on hourly basis. Hourly PV energy that does not match electricity needs is used to fit a multi energy hub featuring PV panels, a battery bank and an internal combustion generator. A Pareto optimization is conducted considering levelized cost of energy and grid integration level, without showing a dominant solution: this outcome encourages the development of a Multi Criteria Decision Making (MCDM) tool.

**KEYWORDS:** BIPV, Multi Criteria Decision Making (MCDM), visual impact, building simulation, grid integration

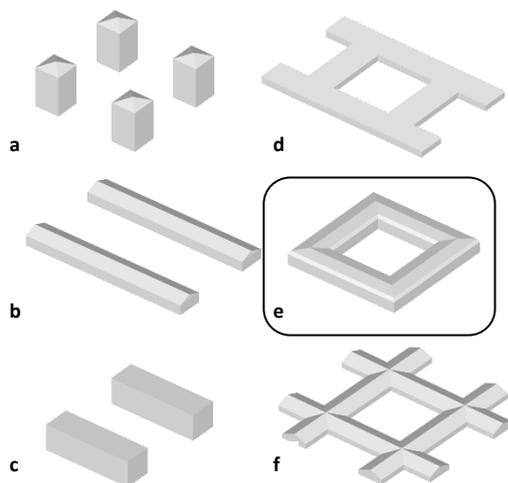


Figure 1: Building archetypes and analysed archetype

## 1. INTRODUCTION

It is foreseen that more than half of the global PV capacity from now to 2050 will be installed on buildings, producing a little less than half the total PV electricity needed [1]. The continuous cost reduction of solar technologies enhances the diffusion of new technical solutions [2]. However, it is still a challenge to integrate PV both in coherence with the architectural context [3] and within the energy system configuration [4]. Most of recent studies neglect the influence of PV on visual [5] and thermal perception [6] in urban contexts. It is interesting to experience a new design process centred on human perception to customize the PV arrangement at the building scale and assess the impacts on the energy systems at the urban scale. This makes it important to develop a pre-design tool bringing together

experts from multiple disciplines such as architects, building physicist, energy engineers and urban planners.

## 2. OBJECTIVE

This study focuses on developing a BIPV pre-design computational platform combining visual impact assessment, building simulation and energy system optimization. A Multi Criteria Decision Making (MCDM) technique based on Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) will accompany the computational platform to support urban planners in identifying a coherent integration of PV panels, by considering conflicting criterions.

## 3. METHODOLOGY

The proposed methodology is subdivided into the following parts: i) buildings typology, ii) visual impact assessment, iii) energy demand and BiPV production and iv) energy systems optimization.

A modular and repeatable urban form has been adopted for the current analysis, from consolidated environmental research [7] (Fig. 1). The typological set includes six LOD2 archetypes. For an effective comparison, heated floor area is kept constant for all typologies. A different roof type is assigned to every typological unit, to create a palette of possible urban configurations. The current paper focuses on a specific building typology: the pavilion court with mansard roof (Fig. 1e), a recurrent scheme in late 19th century developments. The building block is arranged around a square courtyard with a 35 m long side. Each wing is 15 m wide and covered with a two slopes mansard roof (60 and 10 degrees' tilt). The buildings are located in the city of Lausanne (Switzerland).

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As a second step, the visual impact of each outdoor exposed surface is evaluated into detail through a physiologically reliable indicator. Thirdly, three scenarios with variable PV sizes are defined, based on the available surface and its visibility. The building block is simulated on hourly basis in order to quantify solar radiation on each envelope surface, solar PV generation and demand for heating and electricity.

The hourly energy demand and PV production is then exported into the energy hub model, in order to optimize the energy system.

## 4. RESULTS

### 4.1 Visual impact assessment of the building envelope

Visual impact is here intended as the visibility of the building envelope from the public space: viewpoints are sampled on a sidewalk around the block at an average observer's eye level (1.5 m). The envelope surface is split in 2.5 m sized mesh faces that constitute the analysis grid. To perform visibility analysis, visibility rays are cast from the viewpoints to the mesh faces. Visual stimulus is calculated as the average solid angle, produced by a target feature (mesh face) on the spherical visual field of each observer (viewpoint) and related to the smallest perceived stimulus (threshold). The outcome, called "visual amplitude", represents a physiologically robust visibility index (Fig. 2). At this point, the envelope surface can be classified in three bins: low, medium and high visible surface according to the minimum visual acuity needed to detect a unitary mesh face.

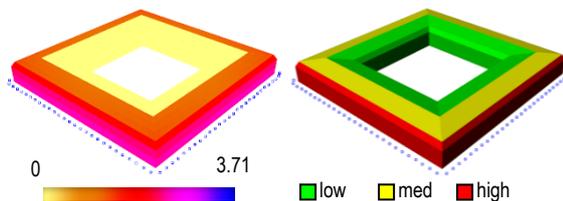


Figure 2: Visual amplitude index and its classification.

### 4.2 Load match and grid optimization

Energy demand of buildings, as well as BiPV production is assessed via the CitySim tool, in hourly values. BiPV sizing is based on the visibility map, which determines three scenarios of surface coverage ratios: i) 70% on low visibility, ii) 45% on medium visibility and iii) 20% on high visibility portion. For a 143 Wp/m<sup>2</sup> system, the annual average production amounts to 85 kWh per m<sup>2</sup> on the low visibility envelope portion, and to 75 kWhm<sup>-2</sup> on medium and high visibility surface. Finally, hourly PV energy that does not match electricity needs (for appliances and space heating via air-source heat pump) is used to fit a multi energy hub featuring PV panels, a battery bank and an internal combustion generator. A Pareto optimization is conducted for each of the three visibility levels, considering leveled cost of

energy and grid integration level (Fig. 3). Each Pareto solution gives a unique energy system configuration.

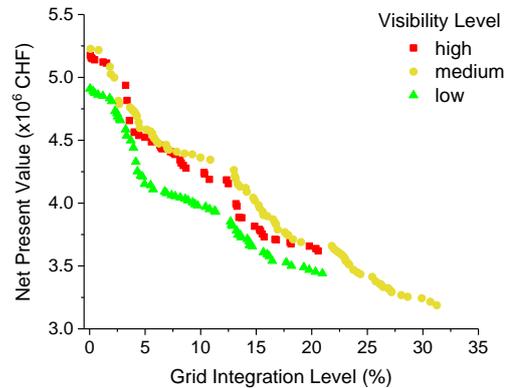


Figure 3: Pareto front of the three visibility scenarios

## 5. CONCLUSION

The absence of a dominant solution after optimization demonstrates the need of a MCDM tool, to handle BiPV visibility, energy demand of buildings and optimization of energy systems simultaneously at the urban scale. This paper represents a first step in this direction, proposing a new methodology for sustainable urban planning that focuses both on energy optimisation and on pedestrian's perception.

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## Exploring the Potential of WUDAPT Local Climate Zone Maps to Detect Vegetation Loss

A Study for São Paulo Metropolitan Region from 2002 to 2017

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*ABSTRACT: This paper investigates the potential of Local Climate Zones (LCZ) maps to identify vegetation loss in the São Paulo Metropolitan Region. LCZ maps from 2002 and 2017 were produced according to the World Urban and Database Portal Tool methodology for acquiring Level 0 data. A change detection analysis was performed to compare the two maps. The identification of vegetation loss through changes in LCZ types showed promising results as a free tool to monitor vegetation dynamics due to urban development, with great suitability for local government use.*

*KEYWORDS: Vegetation Loss, Local Climate Zones, WUDAPT.*

### 1. INTRODUCTION

Vegetation loss is a common consequence of different urbanization processes around the world. Vegetation replacement by impervious, hard and artificial construction materials change the surface properties, altering the energy balance of the pre-urban site and leading to more sensible than latent heat flux [4, 6, 7, 8].

The increase of urban vegetation cover is seen as a powerful strategy to cooling cities and save energy [1, 2, 3, 10]. In São Paulo Metropolitan Region (SPMR), located between latitudes 24°3'S and 23°10'S and longitudes 47°12'W and 45°41'W with a subtropical climate, the planning of new green areas faces the systematic loss of the existing vegetation cover, composed of Atlantic Forest and Shrublands. Deforestation has occurred since the early stages of urban development due to illegal and legal allotments, however no updated official monitoring is available. The lack of information about the vegetation dynamics in SPMR can be related both with technical restrictions and with suspicious political and economic interests [5]. In this context, monitoring vegetation loss due to urban development and its impacts on urban microclimate is an important strategy to inform civil society and urban planners.

Changes in vegetation cover can be monitored by changes in vegetation indexes or changes in land cover characteristics, which can be obtained by different methodologies. Local Climate Zones (LCZ) were conceived by Stewart and Oke [12] as a method to standardize the classification of urban sites for urban heat island studies in different cities. However, a wider range of applications have been tested in recent years [9, 13].

Therefore, this paper aims to investigate the potential of LCZ maps to identify the vegetation loss over the years in the SPMR.

### 2. METHODOLOGY

LCZ maps from 2002 and 2017 were produced according to the World Urban and Database Portal Tool (WUDAPT) methodology for acquiring Level 0 data. Training areas from 2002 were select from Google Historic Imagery in Google Earth when available. For non-imaged areas, IKONOS satellite images were used. Landsat 7-ETM+ and Landsat-8-OLI were used to generate the LCZ Maps. The year of 2002 was chosen due to the availability of Landsat 7 images, prior to the Scan Line Corrector (SLC) fail and due to the free availability of IKONOS images provided by the São Paulo State Government [11]. A change detection (CD) map was produced to identify the areas that lost vegetation due to urban development.

### 3. RESULTS AND DISCUSSION

In this study vegetation loss was considered as the conversion of LCZ A (Dense trees), LCZ B (Scattered trees), LCZ C (Bush, scrub) or LCZ D (Low plants) into any built LCZ types (LCZ 1 to 10), LCZ E (Bare rock or paved) or LCZ F (Bare soil or sand).

Areas with vegetation gain and areas with no changes in vegetation cover over the study period were also mapped to be compared with vegetation loss. Vegetation gain was considered as the conversion of any built LCZ type, paved surface or bare soil into LCZ A or B. Vegetation maintenance was considered as the maintenance of any vegetation LCZ type and also the conversion of LCZ A to B and vice versa.

The grouping of vegetated and non-vegetated LCZ types minimized individual maps inaccuracies and allowed the detection of changes not identified by visually comparing 2002 and 2017 maps. CD analysis was done in QGIS 2.18.

Figure 1 shows the vegetation loss, gain and maintenance from 2002 to 2017. It is possible to identify

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large areas with intense deforestation and several small areas where vegetation loss occurred less extensively.

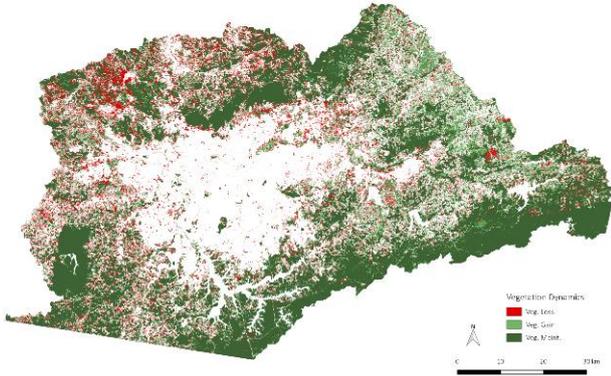


Figure 1: Vegetation loss, gain and maintenance between 2002 and 2017.

Figure 2a shows the vegetation loss due to a road construction and some irregular residential areas in the southeast of SPMR. Figures 2b and 2c show the same area in 2002 and 2017, respectively.

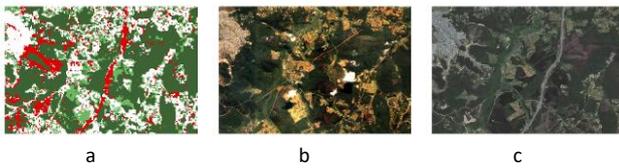


Figure 2: Vegetation loss due to a road construction and irregular residential areas. (a) CD map 2002-2017 (b) IKONOS image from 2002 (c) Google Earth image from 2017.

Figure 3a shows the vegetation loss due to a new industrial development in the northwest of SPMR. Figures 3b and 3c show the same area in 2002 and 2017, respectively.

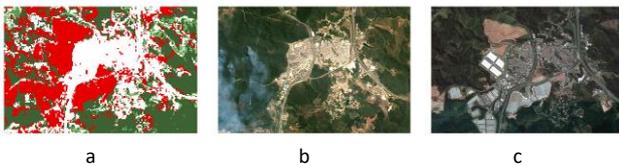


Figure 3: Vegetation loss due to a new industrial development. (a) CD map 2002-2017 (b) IKONOS image from 2002 (c) Google Earth image from 2017

## 4. CONCLUSION

The identification of vegetation loss through changes in LCZ types showed promising results as a free tool to monitor vegetation dynamics due to urban development, with great suitability for local government use, since the maps are georeferenced and vegetation loss can be quantified by pixel area. One possible application could be as an input to the Integrated Development Plan for the Metropolitan Region of São Paulo, which is under development by the São Paulo

Metropolitan Planning Company, EMLASA (<https://www.pdui.sp.gov.br/rmsp/>).

This method also permits the identification of the different urban forms responsible for deforestation, which can be subject for future work, along with the improvement of LCZ maps accuracy.

## ACKNOWLEDGEMENTS

This research was supported by the São Paulo Research Foundation – FAPESP (Grants #2015/17360-5 and #2016/02825-5) and by the National Council for Scientific and Technological Development – CNPq (Productivity Grant 309669/2015-4).

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# Energy Intensity of Materials and Equivalent Greenhouse Gases Emissions: Brief Analysis of Brazilian Case

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*ABSTRACT: This paper presents a brief analysis of the substitution of the main materials traditionally used in civil construction by less energy-intensive materials, their contribution to Energy Efficiency - EE and to the reduction of GHG emissions. For the analysis, the calculation method developed by Cruz (2018) was used considering three eco-indicators: energy - (kWh/m<sup>2</sup>), environmental - (tCO<sub>2</sub>/m<sup>2</sup>), and socioeconomic - relation between minimum wage and construction cost. The study does not intend to present the life cycle analysis of the construction industry or materials, considering that its focus is to perform an objective analysis through a direct method of evaluating the substantial energy of the materials and their equivalent GHG emissions. The final results present a representative case in the construction of Brazilian cities: Minha Casa Minha Vida Program, selected by the strong Brazilian housing demand, scope and volume of public investment.*

*KEYWORDS: Architecture, Energy Efficiency, Greenhouse Gases, Sustainability*

## 1. INTRODUCTION

Assessing sustainable development is an essential prerequisite for promoting a sustainable society and is important for policy-making and decision-making (World Resources Institute - WRI, 1998). To meet this need, since the 1990s, there has been a growing concern for the development of sustainability indicators in a diversity of areas related to the development of our societies.

Environmental indicators, or those developed to report on eco-efficiency, are also known as eco-indicators.

According to Nordheim and Barrasso (2007) the selection of eco-indicators suitable for a process is one of the most important steps in the assessment of sustainable development in industry. Pereira and others (2014) also consider that this can be a viable approach when one wishes to start implantation in an industrial unit where there is no quantitative monitoring.

On the other hand, it is important to emphasize that the Life Cycle Analysis (LCA) was not considered in this analysis given that many authors (FAY, 1999; TAVARES and LAMBERTS, 2008 ; CRUZ, 2018) consider the need to promote a more objective analysis related to energy and GHG emissions in construction, which facilitates the prior assessment of impacts at the project stage due to the significant participation of fossil energy sources in the production processes contributing to until 40% of the global CO<sub>2eq</sub> emission (CRUZ, 2018).

In this sense, the present research adopts a set of three indicators for the analysis of energy,

environmental and socioeconomic characteristics in the construction of cities. It is important to emphasize that the study delimits the study of the energy intensity represented by energy consumption used specifically in the main materials present in the construction of cities, the consequent emission of GHG represented by the quantification of CO<sub>2eq</sub>, and the relationship between the minimum wage and cost of the build.

## 2. INDICATORS USED IN THE RESEARCH

The Built Environment has a production and reproduction process that is not adequate for the current sustainability criteria. Thus, the energy, environmental and socioeconomic indicators were defined for the development of a tool, having as a parameter: energy - represented by energy intensity (kWh/m<sup>2</sup>); (tCO<sub>2</sub>/m<sup>2</sup>) and socioeconomic - the relationship between the minimum wage and cost per square meter (salary/CUB), according method developed by Cruz (2018).

The values used for the energy calculation of all building materials were acquired from the National Energy Balance (BEN, 2014), taking into consideration the energy inputs used in the production process of individual materials, whilst for the calculation of the environmental indicators (Intergovernmental Panel on Climate Change, 2002-2014), updated according to the Methodological Guide for the Conduct of Inventories of Greenhouse Gas Emissions (ABNT-BID, 2013). The socioeconomic indicator was based on data from the cost of civil construction - CUB practiced in 2013, obtained

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from SINDUSCON-RJ (2014) and the average value of the Brazilian minimum wage in 2013.

Furthermore, the identification of the most active materials in production was based on the selection of the most significant segments and sub sectors for the construction of buildings within Brazilian cities: Cement, Steel, Ceramics and Aggregates, analysed according to the energy sources used in their respective energy consumption, according to data provided by the Brazilian Energy Balance - BEN (EPE, 2014).

### 3. ANALYSIS

The study presents a tool that allows the objective analysis of the energy consumed in the production phase of the material used in the construction of most Brazilian cities in comparison to possible substitutes with low environmental impact.

*Table 1: Energy Efficiency Analysis*

Convent. Material	Energy Substantial (tEP/m <sup>2</sup> )	Eco material	Energy Substantial (tEP/m <sup>2</sup> )	Reduction (%)
Masonry	3.05E-02	Ecomasonry	1.30E-02	-57.41%
Steel	1.17E-03	Bamboo	0.00E+00	-100%
Roof tiles	4.31E-03	Eco roof	4.38E+05	-98.98%

From the analysis of the energy intensity of the material, that is, of substantial energy (Table 1), the amount of energy is converted into GHG (Table 2) according to the rules established by the Intergovernmental Panel on Climate Change (IPCC, 1996). Thus, it is possible to obtain the equivalent amount of greenhouse gases represented in CO<sub>2eq</sub>.

*Table 2: GEE Emissions Analysis*

Convent. Material	Emissions (CO <sub>2eq</sub> /m <sup>2</sup> )	Ecomaterial	Emissions (CO <sub>2eq</sub> /m <sup>2</sup> )	Reduction (%)
Brick	2.95E-02	Ecobrick	3.66E-02	-24.11%
Cement	5.98E-02	Ecocement	1.21E-02	-79.71%
Steel	4.76E-03	Bamboo	0.00E+00	-100%
Roof tiles	1.67E-02	Eco roof	8.89E-06	-99.95%
Aggreg.	1.46E-02	Ecoaggreg.	4.90E-05	-99.66%

*Table 3: Socioeconomic Analysis*

minimum wage 2014	R\$724,00 (DIEESE 2014)
total area	46m <sup>2</sup>
traditional construction	CUB/m <sup>2</sup> r\$ 1.145,42
sustainable construction	CUB/m <sup>2</sup> r\$ 1.183,00
mw/CUB* t.c.	0,62 m <sup>2</sup> per month
mw/CUB* s.c.	0,61 m <sup>2</sup> per month

\*CUB = basic unitary cost of construction

The socio-economic analysis was the minimum wage as the basis considering its breadth across the country and their representation and international economic index. Table 3 shows the purchasing power of the minimum wage on the CUB in relation to traditional construction. For each minimum wage received by the

Brazilian worker it is possible to purchase approximately 62 cm<sup>2</sup> of a normal standard housing construction and 61 cm<sup>2</sup> of a sustainable construction, which represents a negligible impact on the cost to society.

### 4. CONCLUSION

The results obtained from this research indicate that a standard house (46m<sup>2</sup>) built by environmentally compatible materials would produce energy savings of about 12,560 kWh compared to conventional materials, enough to provide electricity to about forty apartments for a month. Still, considering a standard house built with environmentally friendly materials, carbon dioxide (CO<sub>2</sub>) emissions can be reduced by about 3.7 tons, representing a notable financial stake in sales within the International Carbon Credit Market.

Thus, the analyses presented indicate that for the Minha Casa Minha Vida Program in Brazil, with approximately 250 million m<sup>2</sup> constructed, the total avoided GHG emissions could reach a reduction of more than 20 million tCO<sub>2</sub>, avoiding the consumption of approximately 47 TWh of energy, with the replacement of conventional materials by eco materials. Such gains could be highly representative for Brazilian cities in local scale, and for society in global scale.

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# A Microclimate Study of a Free-Running Historic Building through Computational Fluid Dynamics

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**ABSTRACT:** The conservation of archive buildings is particularly important due to the generally sensitive material that they are intended to preserve. A detailed understanding of the heat, air, and moisture transport within these buildings is important to ensure that informed decisions may be taken in their design. A case study of the Notarial Archives in Malta is presented here; a historic building composed of thick walls and high ceilings with no damproofing; augmenting the problems of rising damp and indoor air quality. Therefore, the study provides a number of challenges to the conservation of such archives. A Computational Fluid Dynamics (CFD) model was used to simulate such conditions, with the key focus on the validation of the model. Validation included the comparison of simulated data to data obtained during a monitoring cycle. The results highlight the effects of the boundary conditions on the space as well as other unsteady phenomena. The CFD model provided a more complete picture of the microclimate within such spaces that can aid a holistic conservation approach of such archives and their preservation for future generations.

**KEYWORDS:** computational fluid dynamics, micro-climate, building physics, heat air and moisture transport

## 1. INTRODUCTION

The conservation of historic buildings such as archives is crucial for the preservation of valued paper manuscripts. To this day, certain archives are not maintained as they should be for various reasons. Environmental conditions that cause severe deterioration are still poorly understood and not well documented, leading to various decisions being taken without adequate scientific evidence. Of particular interest are the temperature and humidity distributions within the environment. In this regard, Computational Fluid Dynamics (CFD) becomes an indispensable tool. Nonetheless, the use of appropriate boundary conditions that are to be used within such approaches remains an open question. The aims of this work are to (i) characterise the indoor microclimate within such buildings which are not environmentally controlled, (ii) provide guidance for the choice of boundary condition within CFD modelling applications.

## 2. ENVIRONMENTAL QUALITY

The environmental quality within historic buildings should be assessed to ensure the conservation of both the building and contained artefacts [1]. The key parameters for environmental quality include: air quality, temperature and humidity; each contributes to a set of deterioration processes. Unfortunately, their complexity makes it extremely difficult to implement design solutions that achieve the optimal conditions needed to ensure the conservation of historic archives; this highlights the importance of simulation tools to predict alternative solutions.

## 3. METHODOLOGY

A CFD model was used to simulate conditions of a case building located in Malta, with the key focus on the validation of the simulated data. In order to validate data obtained from the CFD model, physical data was obtained from a study carried out by Cassar [2], which was carried out to identify the environmental phenomena occurring within the space. Further on-site measurements were taken, including the overall layout, as well as an average air velocity from the original purposely-designed floor grating.

Following the modelling of a three-dimensional representation of the space, a fine tetrahedral mesh was created and a steady state simulation was considered throughout the study.

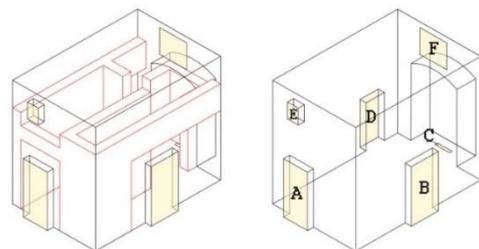


Figure 1: An isometric view of space being studied with all inlets and outlets labelled, and bookshelf layout.

Walls were assumed to maintain stable temperatures due to their thermal inertia (around 1.0m thick monolithic globigerina limestone); with the temperature value for such walls set to that measured. Bookshelves were modelled as solid masses that did not interact with the internal environmental phenomena. Moisture values measured at boundary conditions were not

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inputted as these were considered to be inaccurate and incomplete.

Due to a lack of air velocity data, Inlet F (Fig.1) was set to two distinct air speeds: 0m/s and 0.6m/s respectively; while Inlet C (Fig.1) was assumed to have a constant air speed. Air temperature and %RH values at the Inlet F were assumed to be equal to the external conditions measured, while Inlet C was assumed to contain similar values to those measured. The remaining outlets (A, B, D & E) were assumed to have thermal and humidity properties equal to those measured within the adjoining rooms.

For the purpose of this initial study, the standard k-ε model was deemed sufficient due to the simple nature of the case study. Nonetheless, the RNG k-ε and SST k-ω models will be used for follow-up studies due to their known improvement on accuracy when simulating real-life physical conditions [3-4].

## 4. RESULTS

A number of monitors were set within the model and the resulting velocity magnitude was plotted against each iteration in order to determine simulation convergence. Two types of convergence were obtained: linear convergence and oscillatory convergence; with the latter a result of a transient scenario being force simulated as a steady solution. Once verification was achieved, validation of the simulated data was carried out by comparing both RH% and air temperature datasets collected were compared to the simulated data obtained. The discrepancy between both data sets was minimal, with a maximum discrepancy of 3.3°C and 4.77% RH, for air temperature and humidity respectively. Following validation, the data obtained during simulations was converted to vector data, allowing the visualisation and understanding of the environmental phenomena occurring within all scenarios. This allowed for a comparative insight into the microclimate within the space at different points in time.

When the air velocity at Inlet F was set to 0m/s, the overall environment within the space was stable, with few flow patterns being established (Fig.2). Both temperature and humidity values varied slightly within different sections of the room (Fig.3 & 4); with surfaces experiencing slightly lower temperatures. A humid pocket within the centre of the space was also observed (Fig.3). The bookshelf above Inlet C was directly exposed to an airflow pattern that would introduce differing temperature and RH% values to those present within the space. When Inlet F was set to 0.6m/s, two jets are visible (Fig.2). Within this scenario, both air temperature and %RH are evenly distributed and are equal to external conditions. This highlights the profound effect Inlet F has on the internal environmental conditions. The bookshelf above Inlet C is exposed to an airflow, however, this was

deemed insignificant when compared to the impact from Inlet F.

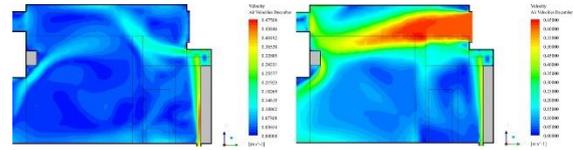


Figure 2: Air Flow Distribution – Inlet F set to 0m/s and 0.6m/s.

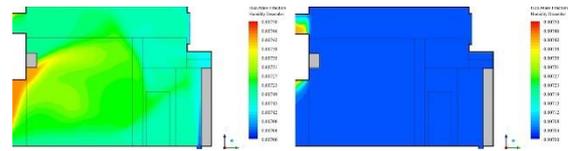


Figure 3: RH% Distribution – Inlet F set to 0m/s and 0.6m/s. (Min.: 70%, Max.: 75%)

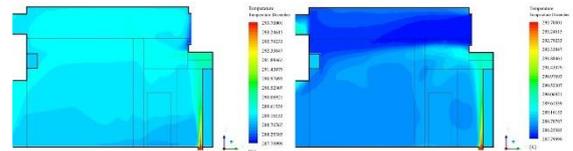


Figure 4: Temp. Distribution – Inlet F set to 0m/s and 0.6m/s (Min.: 287.80K, Max.: 293.70K)

## 5. CONCLUSION

The results obtained have helped to identify the key issues facing the archives and could easily validate any building refurbishment decision taken for the conservation of the archives. The CFD model was validated using the measurements available and thus confirming the adequate use of appropriate boundary conditions, as well as adequately characterising the internal conditions within the space studied. Inlet F was confirmed as a key contributor to the introduction of external conditions and pollutants and their spread within the archives. The closing of this inlet is justified as the effects of external factors were limited; particularly the ingress of pollutants and biological agents. Closing additional openings within adjacent rooms results in stagnant conditions that would also limit the spread of infection. Unfortunately, due to the porosity and lack of damp-proofing, such stagnation would result in the increase of RH% (Fig.3) due to a lack of ventilation needed to disperse rising damp.

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# Reading Diversity of Urban Districts through Environmental Performance Indicators

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**ABSTRACT:** *The diversity of the built environment corresponds to the variability of environmental conditions. In other words, vibrant urban environments are the consequence of comfortable urban spaces. In this context, comfort is mainly considered as thermal comfort in relation to the micro climatic conditions. The hypothesized dependency was modeled on the cases of two same sized cropped areas, extracted from two districts in Munich (Haidhausen and Neuperlach) that show evident differences in their morphological and environmental characteristics.*

*The study integrates urban data with field measurements to highlight a systematic relation between attractiveness and environmental qualities.*

**KEYWORDS:** *thermal outdoor comfort, urban morphology, diversity, environmental data*

## 1. INTRODUCTION

Quality of urban spaces has widely being discussed by researchers on urban planning and policy making over the recent decades. This topic can be investigated from multiple perspectives and standpoints; however one of the vital characteristics to achieve livable cities is described by concept of diversity. Jane Jacobs, in her most famous book entitled “The death and life of great American Cities” highlights the element of diversity as an effective indicator to characterize urban vitality. She argues that:

*“People gathered in concentrations of city size and density can be considered a positive good, in the faith that they are desirable because they are the source of immense vitality, and because they do represent, in a small geographic compass, a great and exuberant richness of differences and possibilities, many of these differences unique and unpredictable—and all the more valuable because they are.” [1]*

Defining diversity in terms of urban density, both in terms of population and built environment, can introduce additional layers of complexity. Anyhow, this complexity is appreciated because of its potential to propose a variety of opportunities for dwellers.

Following the outlined overview on the demand for diversity, the research hypothesis serves the argument that: the diversity of the built environment corresponds to diversity of environmental conditions. In other words, vibrant urban environments are the desirable consequence of comfortable environmental conditions. In this context, comfort is mainly considered as thermal comfort in relation to the macro climatic conditions.

## 2. APPLICATION

Following the mentioned hypothesis, a comparative method has been applied on the cases of two same sized cropped areas, extracted from two districts in Munich

(Germany) that show evident differences in their built structures (Fig. 1). The first case, *Haidhausen*, a historical district that was widely developed around 1900, with one of the highest population densities of the entire city. Originally a workers’ neighborhood, due to the increasing gentrification it became one of Munich’s most attractive places for living: it has an orthogonal urban grid, with closed block buildings with a homogeneous height. The second case, *Neuperlach* is a neighborhood development conceived as a satellite city for 80.000 people started 1967 in Munich’s southeast border. It is characterized by a main high-rise development dedicated exclusive to residential units. In a later phase, a shopping mall and administrative buildings were added. Due to its octagonal shape, the development is highly recognizable in Munich’s city plan.

The comparative study of the two cases aims to provide a deeper investigation on the effects of urban form in terms of diversity and environmental quality.



Figure 1: Building heights comparison.

## 3. MAPPING DIVERSITY

### 3.1 Demographics

The concept of diversity mapping included different layers and level; in the first phase, we have mapped social media, housing prices, functional mix, demographics, and accessibility in order to characterize the socio-economic diversity of both clusters. As an

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example, Figure 2 illustrates the functional mix distribution.

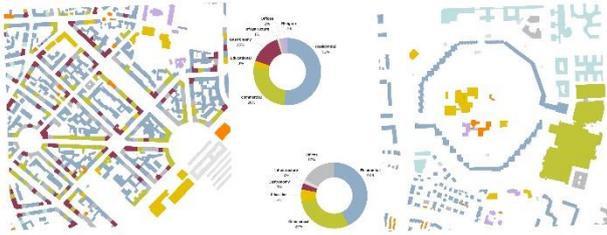


Figure 2: Functional mix comparison.

## 3.2 Climate walks

The second criterion used to measure environmental diversity is a field experiment conducted on November 21<sup>st</sup> and December 19<sup>th</sup> 2018 with the aim of measuring outdoor comfort in two diverse districts in city of Munich. The duration of the experiment was of 8 hours from 10 a.m. to 6 p.m. over the experiment the participants walked through varying environmental conditions from compact and dense settlements (Haidhausen) to open and expanded neighborhoods (Neuperlach).

Over the path, they carried a mobile meteorological station customized for microclimate measurements recording air temperature, humidity, wind speed, globe temperature, solar radiation and GPS signals [2]. The collected data was processed and mapped using the Universal Thermal Climate Index (UTCI) [3] to get better visual understanding of environmental diversity in the specified locations.

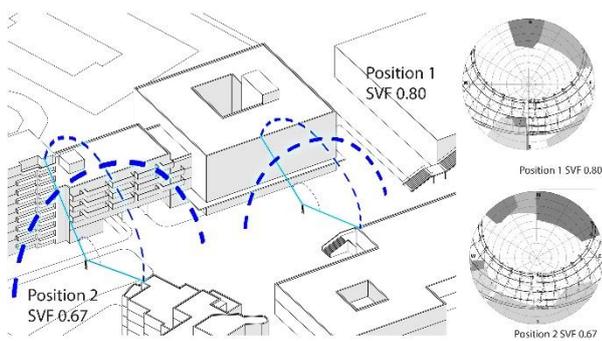


Figure 3: Sky view factor mapping for Neuperlach.

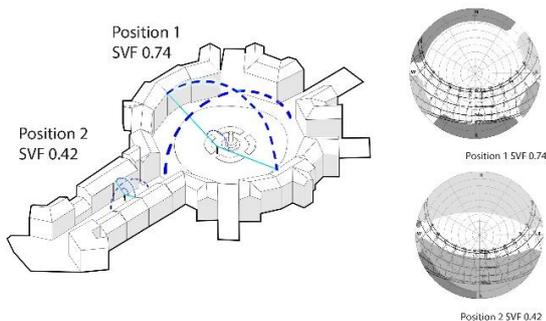


Figure 4: Sky view factor mapping for Haidhausen.

As a complementary metric, the Sky View Factor (SVF) was modeled with computational tools to correlate it with the field measurements (Fig.3, 4). Integrating urban data with field measurements aims at finding a systematic relation between attractiveness and environmental quality. The data was correlated highlighting similarities and differences (Fig.5).

## 4. OUTLOOK

The attention for immaterial qualities and for the processes that inform the transformation of the built environment can shape an alternative vision of the livable city. Together, these approaches will affect multiple aspects of human life including health and wellness, infrastructure and quality of life in cities. Furthermore, the study will provide additional knowledge for developing an integrated understanding of dependencies with the final aim of increasing quality through design to create more vibrant and healthier urban environments.

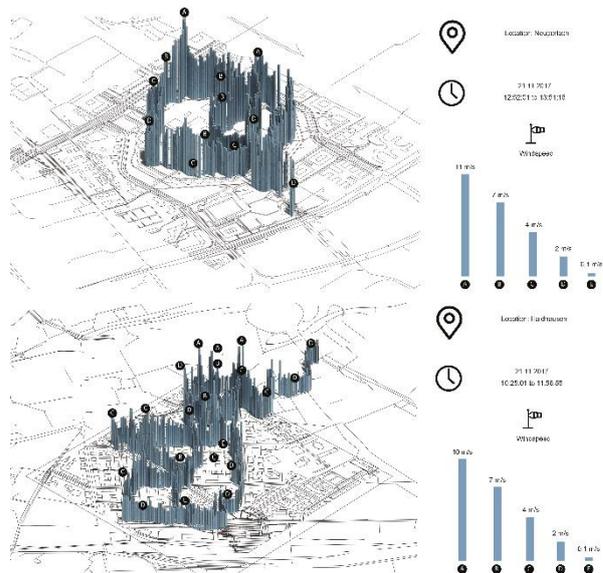


Figure 5: recorded air temperature comparison.

## ACKNOWLEDGEMENTS

The authors would like to mention the participants of the Design Studio “The Munich Factor” at the Chair of Building Technology and Climate Responsive Design for their supportive contributions during the winter term 2017/18.

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# Contribution to the Evaluation of Algiers Kasbah Microclimatic Comfort: Study of the Urban Models since the Algero-Ottoman Period until Today

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**ABSTRACT:** This paper presents the global methodology proposed for studying the microclimatic comfort of Algiers Kasbah. Three complementary approaches are used: (1) objective evaluation, (2) subjective survey, and (3) numerical simulation. Moreover, four typologies characterizing the Algiers Kasbah, since the algero-ottoman period until today, are considered to characterize the urban ambiances. This research aims to define the qualities and defects of different urban forms in order to outline a new framework for the future developments. The final objective is to learn from the past to produce urban spaces that respect the challenges of the sustainable development.

**KEYWORDS :** microclimatic comfort, Algiers Kasbah, evaluation

## 1. MICROCLIMATIC COMFORT IN ALGIERS

Many studies on microclimatic comfort were carried out [1, 2]. Most of these studies focused on evaluating characteristics of the European urban ambiances. These researches characterized the northern Mediterranean side climate and cultural context. Concerning the southern side, few studies have been published [3, 4]. Furthermore, very few studies explored the urban ambiances for the north of Algeria, characterized by its Mediterranean climate. The lack of local studies results from the fact that most of the cities in the north of Algeria imported European models. This produces a phenomenon of standardization of the Algiers urban image and a common representation of the microclimatic comfort. Therefore, the study of climatic conditions in Algiers public spaces seems essential to identify the users' needs and then to design comfortable and healthy urban spaces. This research aims to verify the conformity between these imported models and both climatic and sociocultural contexts of Algiers town. Thus, we hereunder propose to evaluate the microclimatic comfort of various urban typologies of Algiers Kasbah, since the Algero-Ottoman period until today. The present paper deals with identifying the ecological values of the local vernacular architecture in terms of thermal and visual comfort. It also intends to extract the architectural and urban lessons from Algiers old city to fill the current insufficiencies.

## 2. METHODOLOGICAL DESCRIPTION

This work seeks to develop an appropriate methodology for public spaces planers. For that, we choose Algiers Kasbah, which collects various urban typologies developed during the history: Local-fabric, mixed fabric, Colonial fabric and post-Colonial fabric.



Figure 1: Local fabric district in Algiers' Historic Centre. Sources: Plan extracted from Algiers Kasbah PPSMVSS [5], pictures by Assia TALHI, 2017.

The local typology is an organic fabric characterized by high urban density, narrow streets and local building materials. Specific urban morphologies exist like covered spaces and public fountains (fig.1).

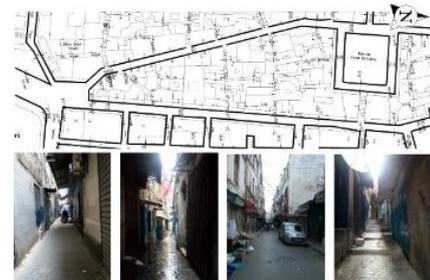


Figure 2: Mixed fabric district in Algiers' Historic Centre. Sources: Plan extracted from Algiers Kasbah PPSMVSS [5], pictures by Assia TALHI, 2017.

In mixed fabric, the local typology combines with the urban fabric resulting from the colonial period (fig.2). Therefore, this combined design has affected the facades and the streets width. Large windows and balconies have

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appeared in this typology which has preserved the organic fabric and local materials.

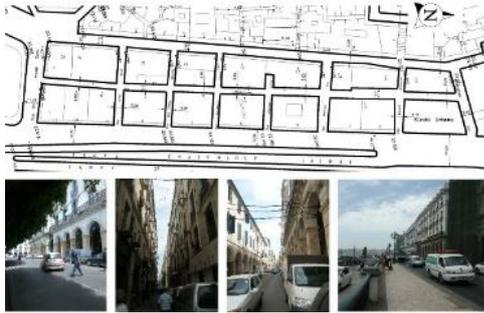


Figure 3: Haussmann fabric district in Algiers' Historic Centre. Sources: Plan extracted from Algiers Kasbah PPSMVSS [5], pictures by Assia TALHI, 2017.

The colonial fabric is characterized by Haussmann design, with a grid street plan (fig.3). New urban forms and materials of construction characterize this typology.



Figure 4: Postcolonial fabric district in Algiers' Historic Centre. Sources: Plan extracted from Algiers Kasbah PPSMVSS [5], pictures by Assia TALHI, 2017.

The last typology results from the postcolonial period, with large urban blocks surrounded by broad avenues and boulevards.

The methodology combines and compares the results of three complementary approaches developed in different research [6, 7]: an objective evaluation based on measurements, a subjective survey, and digital modeling. The measurements serve to characterize urban forms according to various physical parameters (air temperature, globe temperature, humidity, wind speed). The subjective approach allows quantifying the users' satisfaction level and their expectations, by using a questionnaire. An in-situ observation aims to examine users' behavior in different urban areas. Finally, the digital model is used to simulate climatic and typomorphological data [8]. This methodology is applied to each Algiers Kasbah's fabrics to identify the more comfortable places.

### 3. CONCLUSION

A first field campaign was conducted during 2017-2018 winter. This experimentation allowed us to

structure the methodology. Thus, we have defined the most relevant urban configurations for the study of microclimatic comfort. We tested commented thermal walk method (walk time, choice of the sample... etc.). Consequently, we defined the route in Algiers Kasbah. We also identified important physical and psychological parameters for users to assess effectively summer comfort. Therefore, a large majority of the interrogated population find that solar radiation is very important for their well-being in the city. Accordingly, the choice of the simulation of solar radiation appears totally justified. A part of the study was conducted using the tool Solar Analysis (Autodesk Insight 360® - Autodesk Revit® 2017). The results of this first simulation will be validated by the summer 2018 measurements campaign.

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# Testing a Procedure of Using Transepidermal Water Loss to Measure the Effect of Dry Air on Occupant'S Skin Condition and Hygrothermal Comfort in the Real Living

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*ABSTRACT: As a part of three years project, this study was the test of a research procedure that will be applied on older occupants in care homes in the future research. It aims to investigate the feasibility of using Transepidermal Water Loss (TEWL) to measure the effect of dry air on occupant's skin condition and hygrothermal comfort in a real living environment. 9 young adults participated in the 4-week study. Domestic humidifiers were used in each room to alter room humidity under a sequence of interventions. Data was collected under the circumstance of no interferences to occupants' daily life. The collected data includes room temperature, relative humidity (RH) and TEWL on front arm. Results show that the measured TEWL was not significantly correlated to room RH due to inappropriate research procedure. Room humidity was effectively altered to 40% RH through the domestic humidifier used.*

*KEYWORDS: Indoor humidity, Skin condition, Transepidermal Water Loss (TEWL), Real living environment.*

## 1. INTRODUCTION

Dry indoor air has become a common phenomenon due to inappropriate indoor heating and the lack of humidity conditioning measures in winter, which has led to 59-85% old occupants suffering dry air issues and affected their wellbeing in their living environment [1,2]. In our previous study [3], we measured indoor temperature and RH for 2016-2017 winter season in a care home in Edinburgh, UK. Results show that 53% of the recorded room temperature were higher than 24°C, the upper band of the recommended thermal comfort zone [4]. Only 3% of the recorded room humidity were within the recommended humidity comfort zone for older occupants (45-70% RH [5]). The dry air environment combined with overheating was serious in the tested care home. Beyond the environment issue, we also noticed some participants were suffering skin issues caused by dry indoor air. Although some studies have investigated the effect of humidity on skin condition in theory [6] and in experimental environment [7,8], there was no study that investigated the effect in a real living environment. In response to the problems identified in our previous study, a future study to test the feasibility of using an indicator of skin condition (TEWL), to measure the effects of indoor dry air on older occupants' skin condition and hygrothermal comfort is proposed.

This study is a preliminary study and aims to test the procedure that measures TEWL under a sequence of interventions to alter room humidity through domestic humidifiers in student dormitories. TEWL is comprised of insensible perspiration which is based on the diffusion of body water through stratum corneum and is clinically

relevant to skin condition. By measuring the TEWL, the effect of dry air on occupants can be assessed. Besides, indoor temperature and RH were recorded to evaluate the effectiveness of using domestic humidifier to alter room RH to the target levels.

## 2. METHODOLOGY

### 2.1 Participants and tested rooms

9 participants aging from 20 to 31 years old participated in the study in February 2018 in Edinburgh, UK. All participants were living in single student dormitories. Participants were required to follow their daily routines and habits without any interference.

Measurements were conducted in real living environment under a sequence of humidity interventions. 3 out of 9 participants were living in the rooms with a water basin while the rest participants were living in the rooms with an individual bathroom.

### 2.2 Research procedure

The 4-week study consisted of four stages. In the first and third stage, room humidity was not intervened. In the second and fourth stage, humidifiers in each room were turned on at the target setpoint of 40% and 60% RH respectively. Participants were required to keep the humidifier always on no matter their room was occupied or not.

During the four stages, indoor temperature and RH were hourly recorded through data loggers which were installed at about 1.5m height near the study desk where participants spent most of their time in their room. TEWL on participant's front arm was measured through

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everyday visits. Participants were required to stay in their rooms at least 2 hours for humidity adaptation before the TEWL measurement.

### 3. Result and discussion

#### 3.1 TEWL measurement

Because a two-hour humidity adaption time was required to reflect the effect of humidity change on skin condition [7,8], the measured TEWL was compared with the average RH in two hours before the measurement. The measured TEWL on all participants did not correlate with room RH. TEWL remained almost the same when average RH increased.

Theoretically, TEWL is comprised of insensible perspiration and evaporation through stratum corneum and will be affected by room humidity [6]. Moreover, laboratory studies have found a marked decrease in TEWL when RH increased from 10% to 50% [7,8]. The possible explanations to the uncorrelated result are: firstly, the intensity of RH intervention in the tested rooms was not able to significantly affect TEWL and, therefore, made TEWL change unmeasurable; secondly, the measurement site (front upper arm) did not entirely expose to the environment for enough time due to participants' wearing; thirdly, indoor air movement could lead to serious errors [6], making TEWL difficult to be accurately measured in real living environment.

#### 3.2 Humidity intervention

Fig. 1 shows the frequency of occurrence in different RH ranges in non-humidified and humidified stages in the tested rooms. In the non-humidified stage, room RH was lower than 40% in all tested rooms most of the time. When rooms were humidified to 40% RH, room RH was significantly increased and reached the target level most of the time in two tested rooms. However, in other tested rooms, RH seldomly increased. As RH in two rooms were successfully humidified to the target level, this result was probably due to the non-cooperative behaviours of participants (did not follow research instruction to keep the humidifier always on and refill the water tank when it was empty). When rooms were humidified to 60% RH, room RH increased but did not reach the 60% RH target level, which means humidification ability of the humidifier is not enough to make room RH reach that high humidity level.

### 4. CONCLUSION

This study tested a procedure of using TEWL to measure the effect of indoor dry air on occupant's hygrothermal comfort and skin condition in a real living environment. As it is a preliminary study to test the procedure that will be applied in a care home study, it exposes some problems and weaknesses in the research procedure.

Results show no significant correlation between the TEWL and RH, unlike the results from laboratory tests. The reasons for the indifference are insufficient intensity of humidity interventions, inappropriate measurement site and objective measurement errors caused by measurement environment.

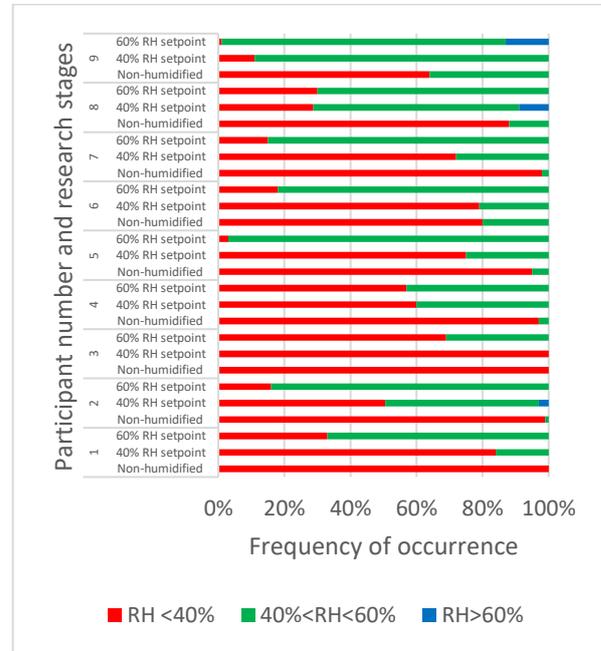


Fig. 1: Frequency of occurrence at different humidity ranges in each tested room.

Domestic humidifier used in this study effectively intervened room RH. A target humidity level of 40% RH can be reached under the circumstances of humidifier works all the time and its water tank is regularly refilled. A target humidity level of 60% RH was too high to be achieved by this type of humidifier used. Therefore, a lower RH setpoint in the second intervention period will be considered in the care home study.

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# Adaptation Measures of the Existing Residential Buildings in Hanoi to Counteract the Effects of Future Urban Warming

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**ABSTRACT:** This paper discusses how the existing urban houses in a hot humid climate of Southeast Asia can adapt to the future increase in urban temperature in the near future through building modifications. TRNSYS simulations were employed to investigate the indoor thermal environment under naturally ventilated conditions as well as to assess the effects of passive design techniques on the thermal comfort and cooling load under the current and future weather conditions in a typical row house in Hanoi, Vietnam. The results show that the passive design techniques perform well to lower the operative temperature but they are not able to satisfy the thermal comfort in the future weather condition. Further, the cooling load is predicted to increase by up to 23% in the future.

**KEYWORDS:** Urban warming, Adaptation, Row house, Passive design, TRNSYS

## 1. INTRODUCTION

Growing cities in Southeast Asia are expected to experience further urban warming, which is attributed to urban heat islands (UHIs) and global warming (GW). In Hanoi, Vietnam, the air temperature in existing urban areas is projected to increase by up to 2.1 °C in the 2030s, of which up to 1.5 and 0.6 °C are attributable to the GW and the land use change from the master plan, respectively [1]. The increased urban temperature will lead to deterioration of thermal comfort in buildings, thus increases energy consumption for space cooling.

This paper discusses how the existing urban houses in the growing cities such as Hanoi can adapt to the future increase in urban temperature through building modifications using passive design strategies. Similar studies were conducted in other regions such as Europe and the detailed review results are shown in [1].

## 2. METHODOLOGY

The case study house is an actual four-story row house which was constructed with RC structure and brick wall with the total floor area of 240 m<sup>2</sup> (Fig.1). The row house type accounts for 60% of the housing stocks in Vietnam. The study house was determined to represent a typical row house in terms of the number of storey, total floor area, building materials, etc., based on the analysis of more than 400 drawings in Vietnam.

Table 1 shows the detailed parameters of six passive design techniques assessed in this study. The selected techniques reflect the recommendation of Vietnam Green Building Council (VGBC) [2]. As shown, each technique has two levels of intensity. Level 2 applied the material specifications from [2], while level 1 was employed as the mid-point between baseline (without

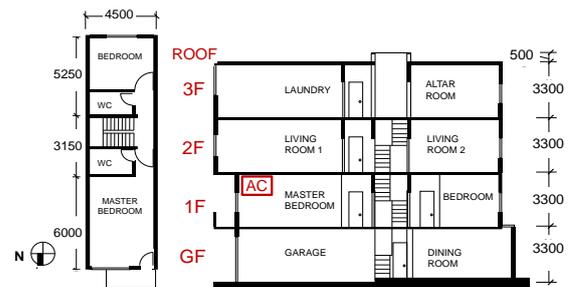


Figure 1: Floor plan and cross section of the case study house.

Table 1: Proposed passive design techniques.

Techniques	Parameter	Base	Level 1	Level 2
1. Reflective roof	Albedo	0.3	0.5	0.7
	Thickness (mm)	-	20	40
2. Roof insulation	U-value (W/m <sup>2</sup> K)	2	0.94	0.62
	Thickness (mm)	-	20	40
3. Insulation (exterior)	U-value (W/m <sup>2</sup> K)	2.05	0.88	0.57
	Thickness (mm)	-	20	40
4. Insulation (interior)	Thickness	-	20	40
	- Wall U-value (W/m <sup>2</sup> K)	2.05	0.88	0.57
	- Ceiling U-value (W/m <sup>2</sup> K)	2.25	0.96	0.61
5. External shading	- Floor U-value (W/m <sup>2</sup> K)	3.44	1.12	0.67
	Length (m)	-	0.07	0.26
	6. Window glazing	Glass Type	Single	Pair
	U-value (W/m <sup>2</sup> K)	5.61	2.54	1.05
	G-value (%/100)	0.83	0.44	0.33

any techniques) and level 2. In addition, the natural ventilation techniques were also investigated.

TRNSYS was employed to assess the indoor thermal environment under different passive design strategies for current and future weather conditions. The TRNSYS simulation was conducted using the weather data from urban climate simulations in Hanoi in June 2013 (for current status) and the GW condition in the 2030s (RCP4.5) projected by MIROC5 [1]. The simulation results of the base model were compared with the field measurement data. There are uncertainties particularly

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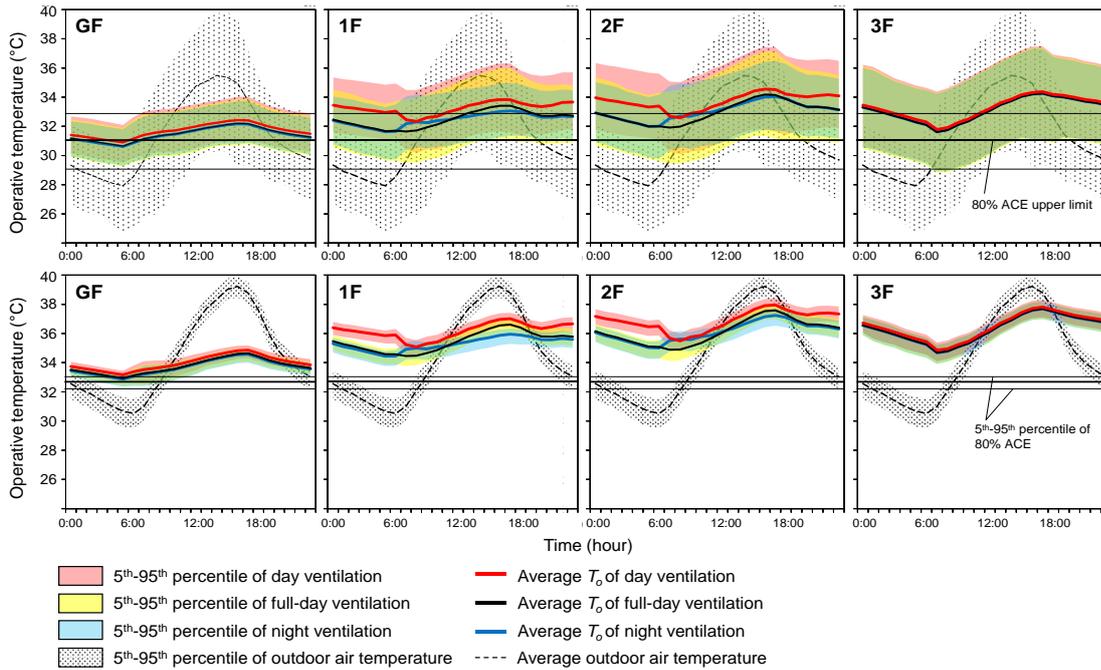


Figure 2: Diurnal variations of operative temperatures under three ventilation techniques in all rooms for (a) current and (b) future weather conditions.

for the relative humidity since the house was occupied during measurement. Nevertheless, the validation results of air temperature ( $R^2=0.86$ ) and relative humidity ( $R^2=0.59$ ) in MB are considered acceptable.

### 3. IMPACTS OF FUTURE URBAN WARMING ON INDOOR THERMAL ENVIRONMENT

Fig. 2 shows the diurnal variations of average operative temperature ( $T_o$ ) under the day, night, and full-day ventilations for current and future weather conditions. Overall, the  $T_o$  increases with the increase in floor level. In the current status,  $T_o$  in GF is up to 2.6 °C lower than the upper floors. This is mostly due to effect of thermal mass. Yet, the daytime  $T_o$  of the upper floors are still lower than the outdoor temperature. In contrast,  $T_o$  on these floors are up to 5 °C higher than the outdoors at night.

The night ventilation (NV) shows the largest reduction of  $T_o$ . In the current status, this technique lowers the  $T_o$  in MB by up to 1 °C, as compared to the day ventilation. The full-day ventilation also performs well although the magnitudes are less than the NV.

The indoor thermal comfort was evaluated using the 80% upper limit of Adaptive Comfort Equation (ACE) [3]. In the current status, all ventilation techniques are not able to meet the required comfort limit throughout the day. In the future condition, the  $T_o$  increases further beyond the comfort limit although the limit also raises following the increased outdoor temperature (Fig. 2b).

### 4. EFFECT OF PASSIVE DESIGN TECHNIQUES ON INDOOR THERMAL CONDITION

Fig. 3 shows the cooling effects of modification technique in MB. As shown, the improvement of window glazing is the most influential. This technique lowers  $T_o$  by up to 0.57 °C from the base condition. Meanwhile, applying internal insulation results in the increase in  $T_o$  by up to 0.43 °C from the base condition. This is mainly because this technique cancels the structural cooling effect. Overall, the proposed techniques are not able to achieve the thermal comfort in MB under naturally ventilated conditions.

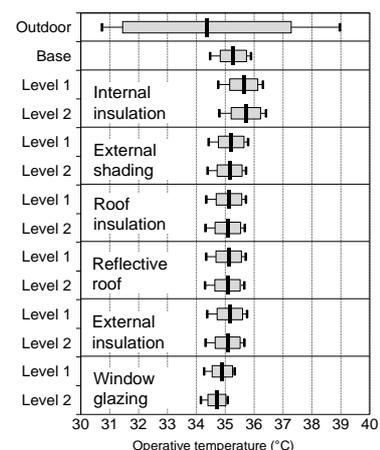


Figure 3: Operative temperature ranges in MB when single passive design technique are applied under the night ventilation in the future weather condition.

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## 5. REDUCTION OF COOLING LOAD

Fig. 4 shows the resulting cooling load from each passive design technique under the NV in the future weather condition. As shown, the internal insulation gives the most notable cooling load reduction. This technique reduces the cooling load by up to 31% compared to the baseline. The second largest reduction comes from the improvement of window glazing.

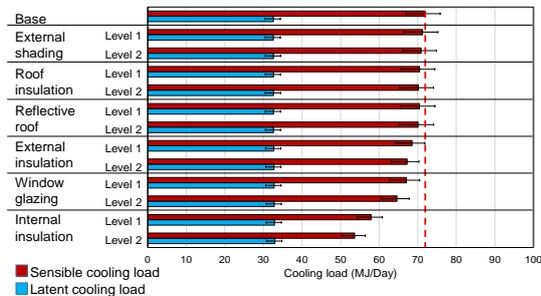


Figure 4: Resulting cooling loads from the application of passive design techniques in the future weather condition.

## 6. CONCLUSIONS

The passive design techniques could improve the indoor thermal environment, but their applications are still not able to meet the comfort level under the naturally ventilated condition in the future. This confirms that the use of AC will become inevitable thus passive design techniques should aim at the reduction of cooling load to adapt to the future urban warming. The cost and benefit analysis of the passive design strategy is an important topic for the future study.

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# Impact of Design Parameters upon the Performance of Transitional Spaces: A Case of Chawls in Mumbai

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**ABSTRACT:** Manipulation of solar radiation and ventilation are key in achieving comfort in the tropics, hence transitional spaces often find their use as passive cooling agents in ethnic Indian architecture. A chawl is an example of a building typology in which transitional spaces find themselves serving plural functions- social and comfort enabling. Unique to Mumbai, chawls can be classified as social housing of the colonial times, consisting of buildings with long corridors, flanked by one room tenements and an enclosed courtyard. This paper focuses on evaluating the performance of aforementioned transitional spaces, through the optimization of their respective design elements. The courtyard is analysed to parameterize the relationship between design features and creating a favourable micro-climate, while the corridor study is aimed at quantifying human comfort as a parameter in transitional space design. The paper culminates with a comparison of performance of the optimized spaces to an existing chawl, emphasizing the method as well as the potential in the inclusion of transitional elements in design.

**KEYWORDS:** Transitional spaces, performance analysis, Chawl, Mumbai, parameters

## 1. INTRODUCTION

Manipulation of solar radiation and ventilation are key in achieving comfort in the tropics, hence transitional spaces often find their use as passive cooling agents in ethnic Indian architecture (Karol et al, 2014). The chawl is an example that brings the concept of transitional spaces to the human scale.

Unique to Mumbai, chawls (Fig. 1) can be classified as social housing of the colonial times, consisting of buildings with long corridors, flanked by one room tenements and an enclosed courtyard.

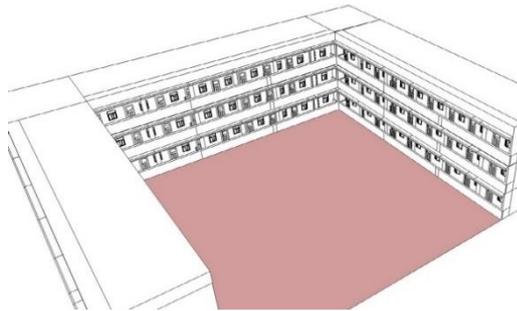


Figure 1: Parts of a chawl- unit, corridor and courtyard

Due to the compact size of the housing units, the transitional spaces in a chawl gain new meaning. While the courtyard became the centre of social activity, the corridors serve a unique function of becoming an extension to the living space. This paper therefore uses the spaces in a chawl to examine how transitional spaces can be optimized to serve as both, passive cooling devices as well as habitable spaces.

The analytical work aims to provide a method through which comfortable transitional spaces can be

designed. The conclusion then utilizes the performance as a means to validate the analytical method, which in turn, parameterises the notion of comfort. The scope of this paper only extends to the analyses of physical/design elements. Testing of user driven factors like clothing and activity are beyond the scope of this paper.

## 2. ANALYTIC WORK

### 2.1 Courtyard analyses

Juneja (2015) states the following factors that influence comfort in a courtyard : Activity level, clothing, air temperatures, mean radiant temperature, air velocity and relative humidity. Upon further delineation, it was observed that shape, surface material and aspect ratio, impact the physical aspects of comfort, while the others are governed by user behaviour. Thus, shape, material and aspect ratio were further studied.

In order to study the impact of shape, various existing forms of courts in chawls were documented and each shape was analysed for its efficacy in reducing incident radiation, using Ladybug (Fig. 2). It was concluded that the form that helps in the reduction is the U shaped built form. This type was used in further analysis.

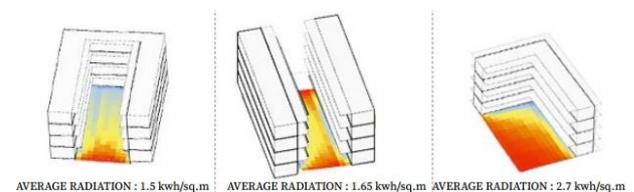


Figure 2: Example for radiation testing of the court

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Further, the aspect ratios of the U shaped courts were calculated. These were then analysed for average incident radiation and induced wind velocity. The results of the analysis were then compiled to form a graph in order to generate a tendency line. Two graphs were generated, one for average incident radiation (Fig.2.1) and one for induced wind velocity. In order to optimize for both, a smaller aspect ratio was chosen to increase comfort. Using these graphs, a point of optimization was arrived at, beyond which the results yield diminishing returns. This optimum ratio was then used in further analysis.

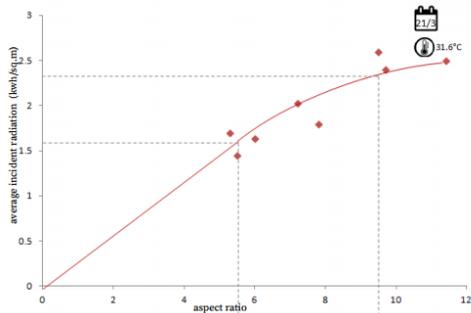


Figure 2.1: Graph of radiation against aspect ratio (after ladybug)

A conceptual courtyard was generated using an aspect ratio and shape derived from the previous analyses to investigate the impact of surface material using ENVIMET. The results are tabulated in Table 1. To gain a clear perspective of the effect on comfort, the PET values were calculated.

Table 2: Surface temperature on the courtyard for different cover materials

	a) Concrete paving	b) Brickbats	c) Paver block	d) Grass
Surf. T	35.2°C	38.3°C	37.2°C	33.3°C
PET	29.1°C	30.9°C	30.7°C	28.6°C

## 2.2 Corridor analyses

The previous section introduces the idea of using the corridor as an extension to the living space, which could also be used for sleeping purposes in the night. To enable both functions of being used as a living space and for thoroughfare, radiation analyses were conducted to arrive upon an optimum corridor depth, in which maximum radiation is reduced while allowing for functional use and maintaining structural integrity. The results are summarised through a graph in Figure 2.2. It can be noted that beyond 2.6m the returns are not significant enough for the extra load on structure and cost it would incur. Hence, a depth of 2.6m was chosen for the corridor.

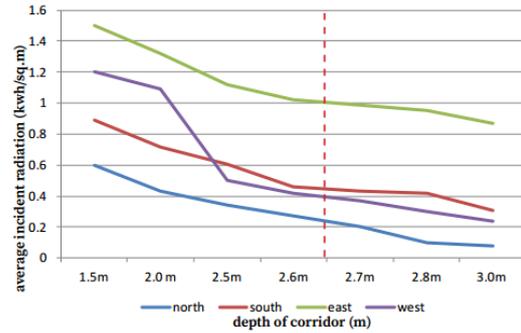


Figure 2.2: Graph plotting incident radiation against corridor depth (after : Ladybug and Karamba)

## 3. CONCLUSIONS

As a means to validate the optimization, the performance of an existing, thereby, un-optimized chawl in terms of design elements were compared to the optimized spaces obtained through the analysis. The chawl performance was monitored using a data logger for the interiors and spot measurements for the transitional spaces. The results are compiled in Table 3. It can be noted that optimized transitional spaces result in better performance of their annexed interior space as well.

Table 3: Comparative analysis of design performance for 21st march, 9am

	Indoor temp unit	PET in corridor	PET in courtyard	Comfort band
Existing	34.5°C	27.4°C	28.7°C	26-31°C
Optimised	27.9°C	26.8°C	26.6°C	

The chawl demonstrates how transitional spaces gain plurality by providing both, passive cooling and habitable spaces. Through their optimization, the transitional spaces in the chawl become illustrative of how a variety of comfortable microclimates increase user adaptive opportunity, which in turn benefit overall performance of a space. Thus, becoming a key in obtaining comfortable, free-running conditions in tropical regions.

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# Effects of Wet Courtyard on the Thermal Environment of Traditional Japanese Houses

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**ABSTRACT:** The purpose of this study was to investigate the thermal functions of internal courtyards in traditional Japanese houses and to identify the effects of water spraying in the courtyards on the thermal environment of their surrounding spaces. It was found that the indoor thermal environment follows the outdoor environment due to the large openings, and proper wind orientation of the buildings improves thermal comfort by sweat evaporation. Moreover, it was determined that the traditional practice of spraying water (Uchimizu) on the courtyard's surface lowered the air temperature above ground and created a cool layer of approximately 10cm. It was suggested that this practice can affect the indoor air temperature of nearby spaces if coupled with wind orientation of courtyards.

**KEYWORDS:** Traditional Japanese House, Courtyard, Spraying Water, Thermal Comfort, Uchimizu.

## 1. INTRODUCTION

Recently, vernacular architecture is re-evaluated for its efficient use of resources and environmental design that adapt to its local climate. Studies carried out in Japanese traditional houses show that these houses could provide thermal comfort by incorporating passive and low energy strategies [1]. The internal courtyard is among the passive design elements that not only demonstrates the Japanese tradition of coexistence with nature but also promotes cross ventilation and daylighting [1]. Interestingly, as a traditional practice, the occupants often throw harvested rainwater on the courtyard to keep the building cool, especially during the hot period. This study investigated the thermal function of courtyards in traditional Japanese houses. Furthermore, the effect of water spraying (*Uchimizu*) on the improvement of the microclimate of the house was also investigated.

## 2. METHODOLOGY

The field investigation was carried during summer from 18<sup>th</sup> to 28<sup>th</sup> August 2017 in the two houses (H<sub>1</sub>&H<sub>2</sub>) located in the historic neighborhood of Takehara City, Japan. H<sub>1</sub> (Fig. 1) and H<sub>2</sub> have built floor area of 175 m<sup>2</sup> and 550 m<sup>2</sup> respectively. Both are entirely made of lightweight wooden structure with *Tatami* infills as flooring and thin sliding doors as partitions. During this investigation the exterior sliding doors (*Shoji*) were open from 9:00 to 17:00 and closed for the rest of the time. The houses have three courtyards which vary in terms of the size and ground cover. To investigate the influence of water spraying on the microclimate of the house, the smaller courtyard (CY<sub>3</sub>) in H<sub>1</sub> and all the courtyards in H<sub>2</sub> were irrigated during the morning and evening (Fig. 5).

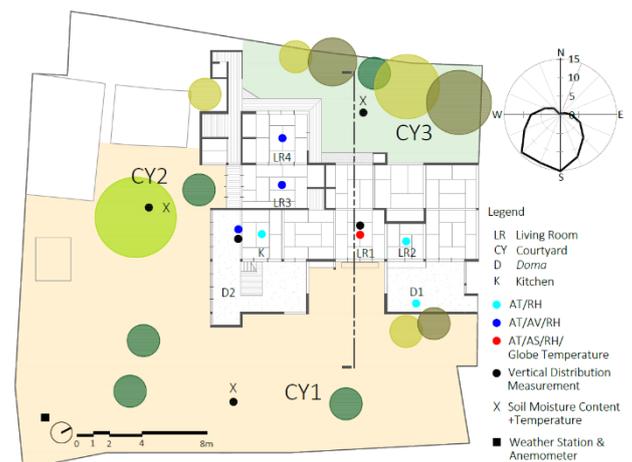


Figure 1: Ground floor plan of H<sub>1</sub> showing locations of the measured variables and the prevailing wind directions.

Air temperature (AT), relative humidity (RH) and air velocity (Av) were measured at 1.1 m height above the floor level (Fig. 1). Vertical distribution of AT was investigated in courtyards, living room and earth floor space (*Doma*). The outdoor weather condition was recorded with a weather station and an ultrasonic anemometer located in the perimeter of the house at the height of 5m and 6m above the ground, respectively.

## 3. RESULTS AND DISCUSSION

### 3.1 Thermal environment in the living room (H<sub>1</sub>LR<sub>1</sub>)

Figure 2 presents the AT and RH in the living room (H<sub>1</sub>LR<sub>1</sub>). As shown, indoor AT follows outdoor AT pattern but falls 0.5 °C below during daytime of a clear sunny day. A difference of 3 °C is recorded at night because of the closed openings. This also explains the RH drop at night.

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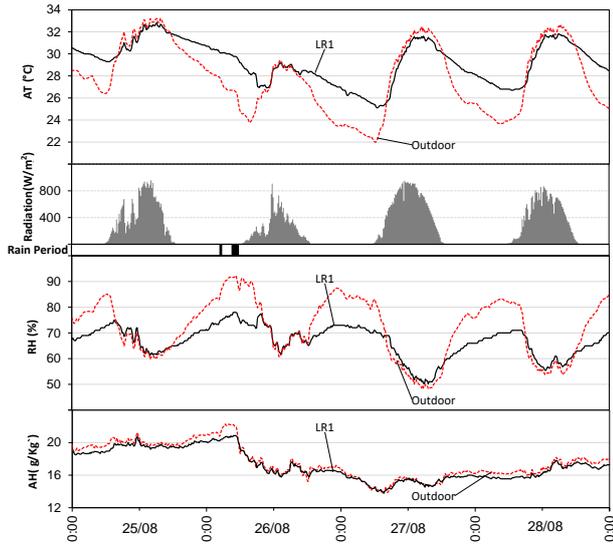


Figure 2: AT, RH & AH of H<sub>1</sub>LR<sub>1</sub> with the outdoor condition.

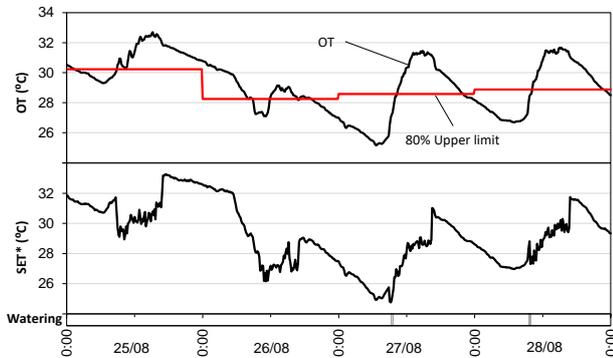


Figure 3: Operative temperature and SET\* in H<sub>1</sub>LR<sub>1</sub>.

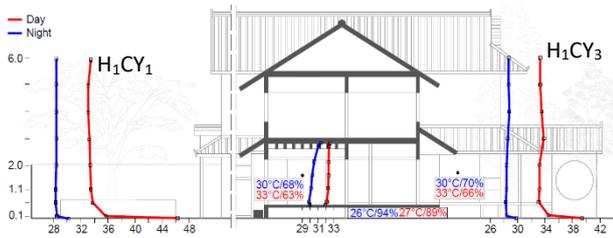


Figure 4: Vertical Distribution of AT during night and day in H<sub>1</sub>CY<sub>1</sub>, H<sub>1</sub>LR<sub>1</sub> and H<sub>1</sub>CY<sub>3</sub> under the dry condition and AT & RH in indoor spaces.

RH was at its lowest during peak hours (50-60%) and exceeded 70% at night. Meanwhile, AT in H<sub>2</sub>LR<sub>1</sub> was 1.3°C lower than outdoor AT during daytime. Moreover, average indoor air velocity of 0.4 m/s in H<sub>1</sub>LR<sub>1</sub> and 0.2 m/s in H<sub>2</sub>LR<sub>1</sub> was recorded during daytime. The decrease in air velocity is related to vegetation density in H<sub>2</sub>CY<sub>1</sub> whereas H<sub>1</sub>CY<sub>1</sub> was relatively open (Fig. 1). Indoor thermal comfort was evaluated using the 80% upper limit of Adaptive Comfort Equation (ACE) [2]. As shown (Fig. 3), the operative temperature (OT) exceeded comfort limits during the afternoon until midnight (58%). Indoor OT was recorded 2.9°C above the limit during the peak hours in H<sub>1</sub>LR<sub>1</sub>. While in H<sub>2</sub>LR<sub>1</sub> OT was 4°C above limits for

64% of the time. On the other hand, SET\* results reveal lower degrees throughout the operating hours in H<sub>1</sub>LR<sub>1</sub> which clearly validates the effects of cross ventilation in providing thermal comfort. Compared to its counterpart H<sub>2</sub>LR<sub>1</sub> received lower air speed (0.2m/s) hence SET\* values are over 30°C most of the time.

Figure 4 shows vertical distribution of AT in courtyards and living room of H<sub>1</sub> at day and night under the dry condition. In the daytime, the surface temperature of (H<sub>1</sub>CY<sub>1</sub>) was recorded 6.5 °C higher than the smaller courtyard (H<sub>1</sub>CY<sub>3</sub>) probably due to the different ground cover and size of both courtyards. H<sub>1</sub>CY<sub>1</sub> is sparsely vegetated and exposed to the direct sunlight while H<sub>1</sub>CY<sub>3</sub>'s surface was shaded and covered with moss. Slightly higher (0.1 m) the AT in H<sub>1</sub>CY<sub>3</sub> was 1.5 °C lower than H<sub>1</sub>CY<sub>1</sub>.

## 3.2 Effects of water spraying

Under the wet condition, a significant drop of 3°C and 2°C is seen at 0.1m above ground in H<sub>1</sub>CY<sub>3</sub> and H<sub>2</sub>CY<sub>2</sub> respectively. Moving vertically, the AT in H<sub>1</sub>CY<sub>3</sub> fell 1 °C and 0.5 °C at 0.6 m and 1.1 m respectively (Fig. 5a). It is assumed that spraying water in the courtyard did not affect the AT of the H<sub>1</sub>LR<sub>1</sub> because the air was coming from the dry courtyard(H<sub>1</sub>CY<sub>1</sub>). But in H<sub>2</sub>LR<sub>1</sub>, probably because the air flow was from wet courtyards few degrees (0.5°C) drops in AT is noted after spraying water.

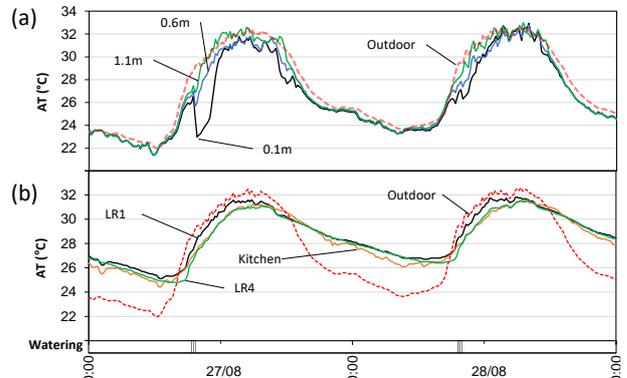


Figure 5: Temporal variations of (a) AT at various heights in H<sub>1</sub>CY<sub>3</sub> and (b) indoor AT in LR<sub>1</sub>, LR<sub>4</sub>, and kitchen.

## 4. CONCLUSION

1. Indoor AT was lower in the living room but followed the corresponding outdoor AT patterns during the daytime. This was due to the large sliding doors with lightweight wooden structure.
2. Cross ventilation between the courtyards improved the airspeed in the living room (H<sub>1</sub>LR<sub>1</sub>) by about 0.4m/s on average and reduced the daytime SET\* values. While the dense courtyard of H<sub>2</sub> reduced the airspeed (0.2m/s) hence increased SET\* values in H<sub>2</sub>LR<sub>1</sub>.
3. Spraying water in the courtyards reduced the surface temperature and created approximately 10cm cool layer above the surface. It is suggested

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that this practice can lower the *AT* of indoor spaces if coupled with wind orientation of courtyards.

## **ACKNOWLEDGMENT**

We would like to thank the LIXIL JS Foundation for generously funding this research and the Takehara city office for providing access to the case study houses.

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## Old Houses for New Lifestyle: Guidelines for the Displaced in East Ukraine Conflict

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**ABSTRACT:** The East Ukraine military conflict has caused a large-scale devastation and displacement of millions of people. Most of the families are forced to live in the conditions unfit for human habitation. This paper is based on a research aimed at defining a settlement strategy for the Ukrainian internally displaced persons (IDPs). The study assumed that the displaced families can be settled in the existing rural houses that have been abandoned due to demographical process. The refurbishment of these houses has the potential to satisfy the required needs. Due to the local cold climate, energy efficiency retrofitting solutions, in particular for heat conservation, were studied and assessed with computational simulation.

**KEYWORDS:** *Refurbishment, Retrofitting rural houses, Thermal analysis*

### 1. INTRODUCTION

The current high proportion of displaced people in Ukraine (1.8 million out 42.6 million [1]) triggered a large-scale crisis in the housing sector. Most of the affected families did not have the resources or social links which would have provided them with accommodation outside the conflict zone. The majority of the displaced families do not intend to return to the areas where they fled from, thus the settlement strategy should be considered as permanent accommodation.

This paper is based on a research aimed at defining a sustainable and economically feasible settlement strategy to help housing the displaced people, a problem which still remains largely unsolved [2]. The general strategy consists in retrofitting the existing abandoned rural houses, adapting these to current lifestyles and increase energy efficiency while providing required safety and comfort for occupants.

### 2. UKRAINIAN CONTEXT

#### 2.1 Geography and Climate

Ukraine is located in Eastern Europe between latitudes 44°N and 53°N and longitudes 22°E and 41°E. The climate in most areas is classified as Dfb by a Köppen-Geiger climate classification system [3]: continental influenced temperate climate with warm, dry summers and cold winters.

The cold season, which typically lasts between 2 and 3 months, is characterised by average negative temperatures, ranging between 0°C and -7°C. The typical heating season consists of 160 days. The warmest months feature commonly temperatures between 18°C and 23°C [3].

#### 2.2 Urbanisation process and abandoned houses

After the break-up of the Soviet Union in 1991, the economy of Ukraine experienced several deep crises.

This triggered significant migration from small towns and villages to the key urban centres in the past 25 years [4]. In big cities, infrastructures became inefficient to serve the expanded populations.

The majority of houses in the Ukrainian rural settlements were built between the fifties and the late eighties. These buildings were erected from brick without any additional insulation and were typically known as “Socialist houses” (Ukrainian: *sotsialistychnyi dim*). The thermal efficiency was not considered to be an important factor since the fuel was cheap and the structure was common for the whole of the then USSR.



Figure 1: Abandoned “Socialist” house [2].

Figure 1 shows the typical abandoned “Socialist” house that could be resettled. Source [2].

### 3. ANALYTIC STUDY AND RETROFITTING GUIDELINES

Due to typically long heating season of 160 days, the renovation strategy is based primarily on working with the thermal efficiency of the existing envelope and basic engineering systems. The main aims are to

lower the energy consumption obtained from fossil fuels,

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Table 1: Heat saving solutions.

	Base case	Additional walls Insulation	Curtains + Carpets (including walls)	2-glazed windows	2-glazed windows+ MVHR	Night Shutters
Exterior Wall U-Value (W/m <sup>2</sup> K)	1.4	0.5	1.2	1.4	1.4	1.4
Roof U-value (W/m <sup>2</sup> K)	0.4	0.4	0.4	0.4	0.4	0.4
Ground Floor U-value (W/m <sup>2</sup> K)	1.5	1.5	1.1	1.5	1.5	1.5
Windows U-value (W/m <sup>2</sup> K)	2.9	2.9	1.7	2.1	2.1	1.7
Heat loss through the external surfaces (W/K)	254	168	207	251	251	248
Infiltration (ACH)	1.5	1.5	1.5	0.5	0.5	0.5
Auxiliary heating load decrease (%)	-	-37.4%	-7.3%	-20.4%	-46.5%	-6.4%
Auxiliary Heating Load (kWh/year)	10963	7980.0	10214	9109	7482	10803
Materials Cost (£)	-	282	810	364	434	112
Annual Running Cost (£)	219	160	204	182	150	216
Payback Period (Years)	-	4	32	8	5	8

to moderate the use of materials and to limit waste production [5].

The study of the traditional Ukrainian dwelling revealed good thermal properties, especially exterior insulation and high internal thermal mass [2]. In addition, materials used for construction of traditional houses are commonly available, and techniques do not require special labour skills [6]. Thus, the traditional construction methods are assumed to be the main source of the envelope's thermal improvement and computational simulations helped assessing various solutions studied.

Table 1 presents the results of computational simulations. Each solution was tested separately to the base case (typical "Socialist house"). In order to assess the impact of each strategy, these were tested with the help of Energy Plus Software. The simulation model assumed two occupants for internal loads, reflecting the typical household of IDPs, and a heating setpoint temperature of 18 °C, in accordance with the local building regulations [7]. The house was set as a single zone with a base case infiltration rate of 1.5 air changes per hour. The auxiliary heating energy was calculated for each solution and compared to the base case. The decrease of auxiliary heating loads is expressed in percentage. In regards to costs, labor costs were excluded as the works were supposed to be executed by the occupants. For the payback period calculation, the existing furnace is set as a source of auxiliary heating since it represents the typical heating pattern in a "Socialist" dwelling.

The study reveals that the most efficient solution in terms of payback period is the application of a layer of 1-1 straw-clay mixture to the exterior wall. It reduces the annual auxiliary heating load by 37.4%, while offering the possibility to be implemented fully by the occupants with existing local materials. Another useful measure is to change the windows to double glazing PCV framed (currently typical and a low-cost option in Ukraine), which improve the air tightness. Thus, the required fresh air can be supplied through a simple MVHR, which in

combination with the new windows reduces almost 47% of the auxiliary heating load.

### 3. CONCLUSION

The study showed that the typical abandoned rural houses in Ukraine built between the sixties and the eighties can be efficiently retrofitted in terms of thermal performance. The work could be performed by the IDPs themselves with a minimum initial investment of £716.

### ACKNOWLEDGEMENTS

I would like to thank Petro Vovchenko for sharing his experience in traditional Ukrainian architecture.

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# Comparison of Solar Radiation Assessment by Sky View Factor (SVF) and Sky Exposure Factor (SEF)

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**ABSTRACT:** This study investigates the relationship between solar radiation received on vertical building façades and two sky exposure performance indicators, i.e. Sky View Factor (SVF) and Sky Exposure Factor (SEF). The study was conducted by using Ladybug for Grasshopper to perform solar radiation simulation on over 300 cases of archetypal urban forms with different morphological settings. Regression analysis was then applied to examine the relationship between X and Y. The findings suggest that though both SVF and SEF have a high goodness-of-fit with solar radiation on vertical building façades ( $R^2 = 0.69$  and  $0.70$  respectively), site coverage should be used as a categorising factor for improved assessment.

**KEYWORDS:** Sky View Factor, Sky Exposure Factor, Simulation, Solar Radiation Assessment

## 1. INTRODUCTION

The increased reliance on renewable energy, including solar power, is a solution to combat against climate change. For densely built-up cities, due to the fixed amount of solar irradiance available locally and the limitation of land space, installing PV and Building Integrated Photovoltaic (BIPV) on building rooftops or vertical façades are options to enhance solar energy penetration. The effective deployment of PV panels in an urban area is important and it is not solely dependent on building design but also significantly affected by the contextual built environment surrounding the buildings that could cause shading and hence reduce energy generation of BIPV. Hence an indicator for shading assessment would be useful.

Sky exposure, a measurement of visual obstruction from a point on a planer surface to the sky, is studied by researchers for evaluating environmental performance in urban environments, such as building energy consumption [1] and urban air temperature [2]. In theory, sky exposure should also be a good reference to estimate the solar radiation receivable on a surface as the reduction of sky exposure would lead to a decrease in the direct normal irradiance received.

However, researchers from different backgrounds have their preferred way for sky exposure quantification and hence there are two different definitions of sky exposure performance indicators [3]. The first is the “geometric definition” of Sky View Factor (SVF), which is commonly used by researchers in urban planning and architecture. It is a measurement of the sky visibility from a point, and assumes that each patch of the sky dome is equally important. This is referred to as the Sky Exposure Factor (SEF) [3]. The second is the “cosine-weighted definition” of SVF. It represents the proportion of radiant flux from the sky to a point [4]. The sky patch closer to

the zenith has a higher weighting than those closer to the horizon. Subsequent reference to SVF would refer to the “cosine-weighted definition of SVF”.

This study aims to 1) examine the relationship between SVF and SEF using archetype urban forms parametrically generated based on several key urban morphological parameters, and 2) compare the correlation between each of the two sky exposure performance indicators and solar irradiance on vertical building façade.

The result of this study gives an insight to researchers of which sky exposure performance definition is a better predictor for the development of urban morphological based solar energy potential or even an integrated environmental performance assessment model.

## 2. METHODOLOGY

Ladybug for Grasshopper (Rhino) is used for solar radiation and sky exposure simulation for this study. This plugin can simulate both SVF and SEF of a point on any planar surface.

In order to have sufficient data for statistical analysis, a modified parent-child archetype form “scenario builder” is developed based on the work by Ignatius [5] to generate 3D models of buildings with variation in urban morphological parameters (Table 1), such as average building height, site coverage and number of massing. The pavilion-type is chosen (Fig. 1) as it is one of the fundamental archetype form for analysis and is representative of tall tower buildings in a city [6].

Densely built-up Singapore was chosen as the case study and the city’s weather file was used for simulation.

After the collection of data, regression is used for the correlation analysis for the combination of morphological parameters and individual ones.

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Table 1: Statistical summary of the archetype form cases.

	Median	Min	Max
Average Height (m)	57.1	16.8	84.0
Plot Ratio	8.0	1.2	24.0
Site Coverage (%)	50	20	80
No. of buildings	26	4	64

## 3. RESULTS AND DISCUSSION

### 3.1 Sky View Factor and Sky Exposure Factor

In this study, 340 cases were generated by the scenario builder and simulated.

Regarding the relationship between SVF and SEF, SVF is lower than SEF in general (Fig. 1). They are in an exponential form ( $R^2 = 0.99$ ) and the growth rate of SVF increases slightly when SEF is higher.

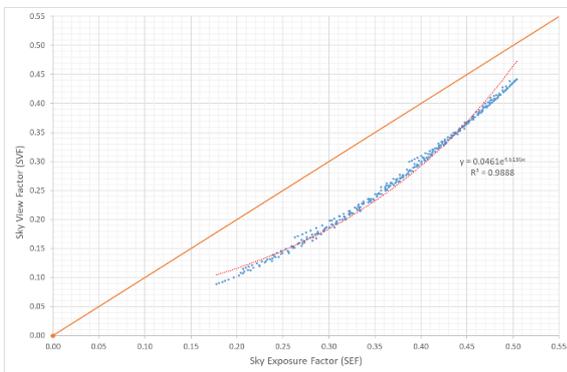


Figure 1: Relationship between Sky View Factor (Y-axis) and Sky Exposure Factor (X-axis).

### 3.2 Solar radiation assessment

In terms of the relationship with solar radiation on façade, both SVF and SEF (average value across the entire building vertical façade) have a relatively high goodness-of-fit ( $R^2 = 0.69$  and  $0.70$  respectively) when linear regression is performed. When only one site coverage setting is selected (Fig. 2), it is observed that SVF and SEF are in a logarithmic function with solar radiation on façade and have a very high goodness-of-fit ( $R^2 = 0.94$  and  $0.95$  respectively).

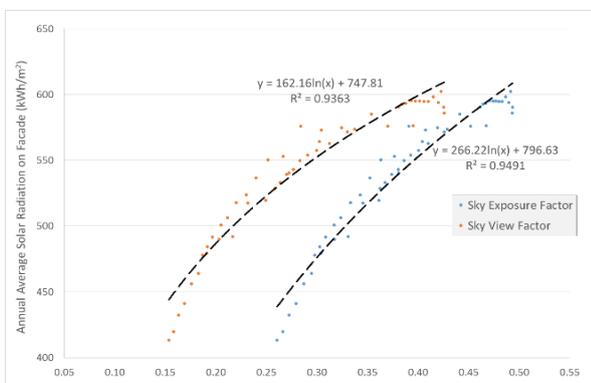


Figure 2: Relationship between annual average solar radiation on façade ( $\text{kWh}/\text{m}^2$ ) with SVF (Orange) and SEF (Blue) (Site Coverage = 50%).

### 3.3 Application and impact on design strategies

Fig. 3 shows the annual average solar radiation on façade and sky exposure performance of some residential and commercial urban forms [7]. The plot ratios for commercial areas are generally higher and plot ratio has a significant impact on both sky exposure performance and average solar radiation on façade.

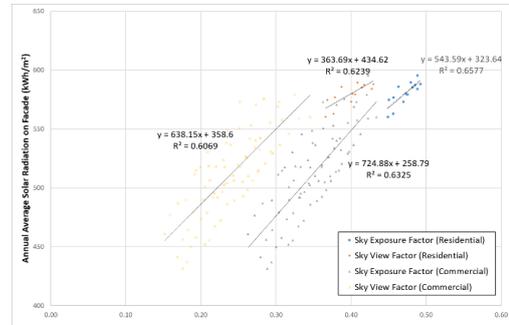


Figure 3: Relationship between annual average solar radiation on façade ( $\text{kWh}/\text{m}^2$ ) with SVF (Orange) and SEF (Blue) (common residential and commercial urban form settings).

## 4. CONCLUSION

This paper presents the assessment of solar radiation on façades by two definitions of sky exposure performance, SEF and SVF. The study shows that:

- 1) Exponential regression model provides a better fit to the data been analysed than linear regression model for the correlation between SEF and SVF (Fig. 1); and
- 2) Both indicators have a similar goodness-of-fit for the relationship with solar radiation on façade and they can be used for accurate radiation assessment. Whilst SEF has a simpler equation, SVF is purposely designed for the calculation of the radiation flux received by a surface.

There are limitations in this study. In the future, other urban forms should be studied and different city weather files of other latitudes should also be used so as to understand whether latitudes would affect the result.

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# Multiscale Parametric Urban Morphology and Energetic Optimization Framework: Case Studies in Toulouse, France

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*ABSTRACT: With the aim of optimizing urban built environments in terms of potentially consumed and produced energy of buildings, a new methodological approach is proposed based on several urban typo-morphological archetypes. Given the complexity to obtain all their characteristics at integrating knowledge of urban planning professionals or architects in a co-design situation, both in terms of produced geometry and materials to be used, a hybrid tool with parametric modeling capabilities and operators on high-level geometric primitives is proposed inside a framework coupling all the tools necessary for energy optimization. It integrates a parametric urban morphology generator based on Rhinoceros/Grasshopper, an energetic assessments tool working at urban scale (Citysim) and a tool controlling the optimization process (ModeFrontier), which gives best urban form solutions using a multi-criteria analysis among best potential solutions inside the Pareto front. This approach appears to give an adapted way for integration of a high level of representation and knowledge on urban archetypes, thereby giving a way to deepen the exploration of new energy-optimized urban forms.*

*KEYWORDS: Urban archetypes, Multi-scale modeling, Parametric urbanism, Urban form optimization, Urban energy*

## 1. INTRODUCTION

The analysis of the urban morphology's impact, based on a reasoned evaluation at urban scale on the reduction of energy demand of buildings and the maximization of the local production of energy, has become a key goal in the area of urban planning and research problem.

Within the French national research "Multiplicities" project [1] our goal is to optimize urban built environments in the European urban landscape context in terms of potentially consumed and produced energy of buildings. The challenge of this project lies essentially in composing the optimization problem from a multi-actor, multi-criteria and multi-scale point of view, staying as close as possible to the practices of urban planning professionals.

Though multi-scale modeling of urban form and its wide effect in climate variables and energy demand in building is still a complex task to achieve, we are developing in this context a methodological approach, aiming at reasonably integrate the different levels of details in the energy modeling process of built environments and dealing with the different scales and levels of details while maintaining a compromise between a good level of accuracy in the results, the urban model's quantitative and qualitative complexity, potential lack in input data, and computational costs.

For this purpose we propose a framework coupling urban form modeling at different city's scale based on a parametric approach, an energetic assessment software and an optimization process tools.

We present this approach and the framework applied to several case studies in Toulouse (France).

## 2. METHODOLOGICAL APPROACH

Urban morphology impact on energy has been well studied by evaluating and comparing the energy performance of different urban typologies at many different urban and climate environments, or by developing methodologies aiming at extracting homogenous representative urban typologies from different urban fabrics at the urban block or at neighborhood scales [2]. Others have simplified and studied archetypal generic urban forms out of real urban landscape context.

Resulting from previous works in this project on sensibility analysis of urban indicators and the material characteristics on the energy of urban forms [1], and workshops with urban planning professionals and architects in a co-design situation, an approach has been defined using several urban typo-morphological archetypes that correctly cover most of the urban forms of the agglomeration of Toulouse, and the different types of development that these urban forms can undergo when proposing an intervention at the urban scale in the context of scenarios (Fig. 1).

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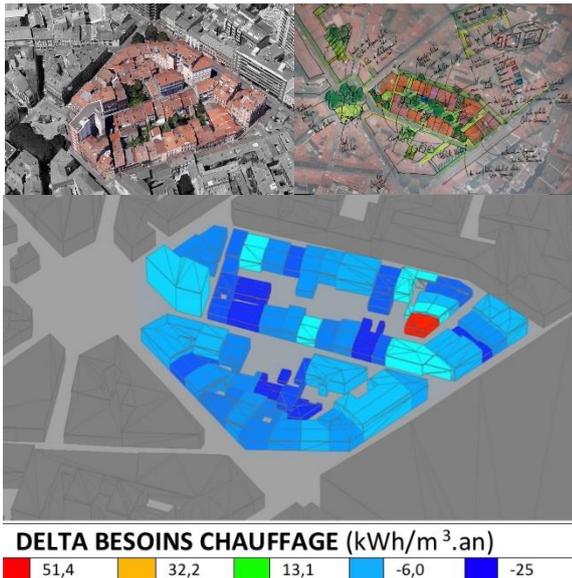


Figure 1: Real city state, proposed urban development and evolution of heating needs assessment

Given the complexity of the process to obtain all the characteristics of this produced urban form at integrating this kind of knowledge, both in terms of geometry and materials, a pure procedural process was too limited, so a hybrid tool with parametric modeling capabilities and operators on high-level geometric primitives has been developed inside a framework coupling all the tools necessary for energy optimization.

### 3. FRAMEWORK

The proposed framework is essentially composed by three coupled tools: a parametric urban morphology generator based on Grasshopper, an energetic assessments tool working at urban scale (Citysim) and a tool controlling the optimization process (ModeFrontier). The coupling between ModeFrontier and CitySim is done by using Grasshopper's add-ons: Ladybug/Honeybee for material and geometric modeling, and modules developed based on GHCitySim add-on to interface to CitySim [6]. The other between Grasshopper and ModeFrontier is done by using a "ModeFrontier integration node" [4][5].

The first archetype case study integrated in the framework is a "continuous building into closed block" typology (as shown on figure 1), which is frequently found in the urban fabric of old center of Toulouse.

The input parameters of the archetype given to the Grasshopper generation's script permit to obtain a complete compatible and realistic urban form with all their geometric and material characteristics by the use of appropriate injection of data into the urban model using Ladybug/Honeybee thermal zones and material functions (figure 2).

The generative parameters include: individual facade building lengths (or global mean value), individual

heights or mean height (and their variability), building width, orientation and amplitude of a graduation of heights, and also material characteristics (wall structure, glazing ratio, albedo).

These values are controlled (as input data) by ModeFrontier through the control over the sampling of the design space for the optimization process.

The different urban scales and level of details are taken into account in generative process for the urban model exported to CitySim solver by producing full detail model characteristics only at the urban archetype city block, by using only surrounding neighborhood buildings (simplified to 2.5D geometry) as solar mask, and by using a city skyline as horizon data for further urban space [1].

Best urban form solutions are further obtained by a multi-criteria analysis among best potential solutions inside the Pareto front given by ModeFrontier.

### 4. CONCLUSION

This paper presents a framework proposing a multi-scale approach of urban typo-morphology energetic assessment, and integrating a hybrid generative method. The proposed framework appears to give an adapted way for integration of a high level of representation and knowledge on urban archetypes, thereby giving a way to deepen the exploration of new energy-optimized urban forms.

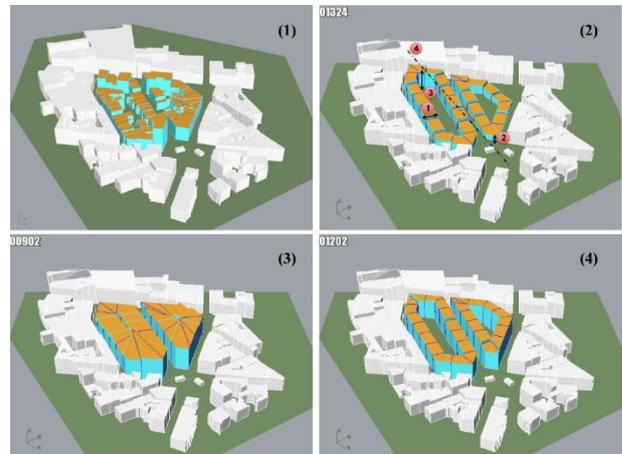


Figure 2: Real state model (1) and generated optimal urban city blocks with morphological some parameters shown on (2)

### ACKNOWLEDGEMENTS

This research project is supported by ADEME within the MODEVALURB Call for Research Project 2015-2. We thank the LESO-PB/EPFL (Citysim solver), and the ESTECO (modeFrontier) support team, for their help.

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# Adaptive Façade Screens: The Design of Bimetallic Façade Screens for Passive Climate Control

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**ABSTRACT:** This study demonstrates how the design of bimetallic façade screens can provide passive climate control for high thermal mass walls in hot climates with large diurnal temperature swings. Three tests were performed using measurements for air temperature, heat flux, and thermal imaging that show solar shading potential of a bimetallic screen in front of a generic wall surface. Results revealed significant thermal reduction to the wall surface and helped identify key environmental, material, geometric, and performance parameters that can influence design. Local temperature differences, bimetallic coefficients of expansion, length, thickness, screen depth and porosity had a considerable influence on performance parameters such as deflection, solar shading, and heat flux reduction.

**KEYWORDS:** Adaptive, Bimetallic, Façade, Screen, Passive, Climate Control

## 1. INTRODUCTION

From prehistoric stone walls to modern buildings, man-made enclosures have largely been designed as static systems. With advances in material science, digital technologies and building construction, architects today have the ability to create complex building enclosures that respond to their environments in dynamic ways. This study demonstrates how the design of bimetallic façade screens can provide passive climate control for high thermal mass walls in hot climates with large diurnal temperature differences.

## 2. ADAPTIVE FAÇADE SCREENS

Adaptive façade screens can block direct solar radiation while also allowing ventilation at the exterior wall surface (Fig.1). Thermal bimetals utilize two laminated sheets of metals with different coefficients of expansion that curl when heated. [1]

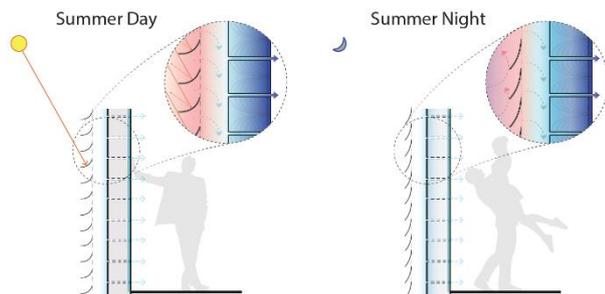


Figure 1: Adaptive façade screen.

During summer days, the bimetallic facade screen heats up and opens to allow airflow and block direct solar radiation. At night, the partially open screen continues to ventilate the wall and provide night flushing. During winter days, the screen opens to allow the low sun angles to heat the high mass wall. At night, the screen closes to help reradiate the heat back into the interior.

## 3. EXPERIMENTAL STUDIES

Laboratory tests were conducted to measure surface air temperature and heat flux differences on a generic exterior wall surface with and without a bimetallic screen during summer conditions. A 250 W radiant lamp was used to simulate peak heating.

### 3.1 Experiment 1: Air temperature measurements

Experiment 1 measured the air temperature difference at a black wood surface (exterior wall) with and without a bimetallic screen. Square wood dowels separated the two surfaces with different depths. A thermocouple was taped to the wood surface and exterior bimetallic screen.

Fig. 2 shows the results of the surface air temperature measurements ( $T_a$ ) at various depths and porosities ( $\phi$ ) with and without a bimetallic screen (RS). The data demonstrates that the bimetallic screen reduces air temperature at the exterior wall surface. The full-shading screen at 3.5 cm from the wall had the lowest air surface temperature in this experiment (blue line). A bimetallic façade screen that provides full shading for a well-ventilated high thermal mass envelope may decrease surface air temperature during peak summer conditions.

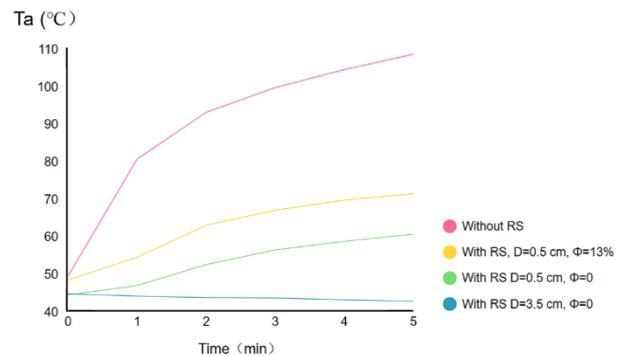


Figure 2: Results of air temperature measurements.

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## 3.2 Experiment 2: Infrared camera test

Experiment 2 used an infrared camera to capture thermal images and illustrates the surface temperature difference between the wall and exterior screen.

Fig. 3 shows the set-up and results of the infrared camera test with and without a screen. Tests demonstrated a 4°C surface temperature difference without any shading and with a fully shading metal screen at a depth of 3.5 cm.

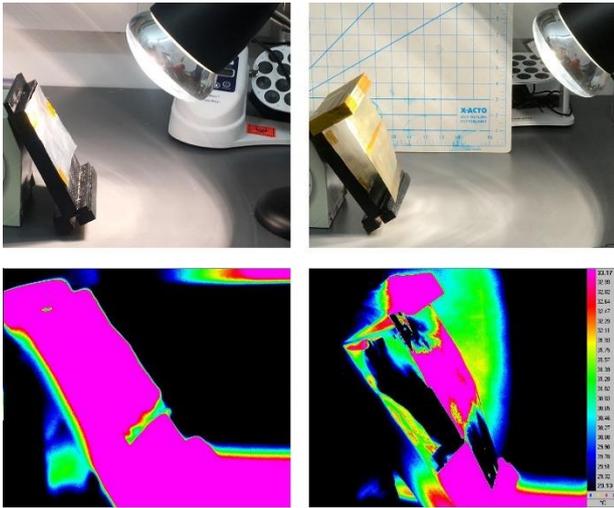


Figure 3: Results of infrared camera test.

## 3.3 Experiment 3: Heat flux measurement

Experiment 3 used a heat flux sensor (greenTEG-gSKIN) to measure the heat flux at the wood surface with and without a bimetallic screen. After the heat flux at the wood surface reached steady state without a screen, a bimetallic screen was added into the test (at 10 minutes), which reduced the heat flux by about 14%. Fig.4 shows the results of the heat flux measurement.

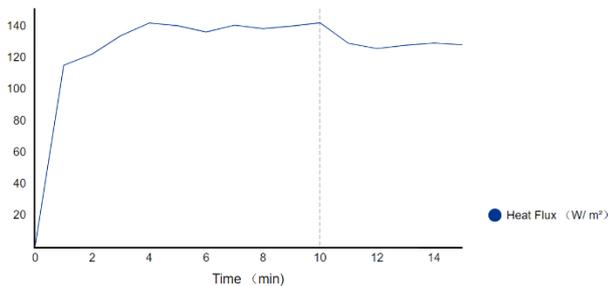


Figure 4: Results of heat flux measurement.

## 3.4 Variables of bimetallic façade screens

In addition to demonstrating a reduction in exterior surface temperature and heat flux, the three experiments above helped identify key parameters to consider during design such as the distance between the screen and wall and also the surface porosity. Additional environmental, material, and geometric parameters can

be identified using the bimetallic formula [2] in the following Equation (1) and table (Table 1):

$$\delta_{\max} = \frac{L_0^2}{8t} (\alpha_2 - \alpha_1) \Delta T \quad (1)$$

Table 1: Variables of bimetallic façade screens.

Categories	Variables			
Environmental	$\Delta T_1$	$\Delta T_2$		
Material	$\alpha_1$	$\alpha_2$		
Geometric	L	t	D	$\Phi_1$
Performance	$\delta$	$\Phi_2$	$\Delta q''$	

where  $\Delta T$ - Temperature difference (°C);

$\alpha$  - Expansion coefficient [ $K^{-1}$ ];

L - Length [cm];

t - Thickness [nm];

$\delta$  - Deflection [mm];

q - Heat flux ( $W/m^2$ )

$\Phi$  - Void fraction (porosity);

D - Distance [mm].

The environmental temperature difference ( $\Delta T$ ), together with the material and geometric properties, determine maximum deflection ( $\delta$ ) of a single bimetallic screen element. The distance between the exterior wall surface and screen (D), along with porosity ( $\Phi$ ), influence the shading and ventilation performance. A high performance bimetallic screen should balance the ventilation and shading effect to maximize the surface air temperature and heat flux reduction ( $\Delta q''$ ).

## 4. CONCLUSION

This paper demonstrates how an adaptive bimetallic façade screen can provide passive climate control by helping to decrease exterior wall temperature and heat flux during peak summer heating hours. The ideal climate for a bimetallic screen would be a location with large diurnal temperature differences, such as a hot desert climate. While this study focused on a small-scale high thermal mass wall for a generic building, the design of bimetallic façade screens could, in theory, be utilized in a variety of buildings and applications, from individual windows on existing residential buildings to entire curtain walls in new commercial constructions, assuming the right environmental conditions.

## ACKNOWLEDGEMENTS

We would like to thank Dr. Solomon Adera from the Harvard School of Engineering and Applied Sciences (SEAS) and the Wyss Institute for Biologically Inspired Engineering for helping us conduct our experiments.

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# Environmental Impacts and Energy Saving Potential of Green Actions for Schools: A Case Study in Northern China

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**ABSTRACT:** This paper discusses the comfort and energy impact of green actions for schools in northern China. Green roof, green façade, tree planting and grass pavement, were evaluated using a case study regarding their outdoor discomfort hours and building cooling demand in summer. Results show that planting trees is the most effective school design strategy in both reducing discomfort time and cooling demand. Green roof and green façade can also decrease the building cooling demand, yet with little effects on the outdoor comfort. Natural grass pavement has only a slight effect on both the outdoor comfort and building cooling demand.

**KEYWORDS:** Greenery strategies, School design, Outdoor thermal comfort, Building cooling demand

## 1. INTRODUCTION

Green vegetation is a useful method for improving the thermal environment in summer in urban areas. Several studies demonstrate how green actions have an important role in the passive cooling of urban planning as well as in saving energy and human thermal comfort [1]. A schoolyard can be regarded as a small community due to its large coverage, population size, and various complex activities. Some researchers have explored the outdoor thermal environment in the university campus [2]. However, little attention has been paid to the outdoor spaces in schools, where approximately 25% of school time is spent for children [3]. Therefore, the green design strategies on schools need to be examined according to their impact on the outdoor thermal performance and building energy demand. In China, school buildings generally account for a large part of the campus area; while for the outdoor spaces, the vast majority part is the playground area, which is prescribed as essential for newly built schools in China since 1980s. In this study, the green actions related to school design, including green roof, green façade, tree planting and grass pavement, were examined in the summer of northern China.

## 2. METHODOLOGY

The software ENVI-met was used to investigate the thermal effects of design strategies on the microclimate of the schoolyard. The temporal variations and spatial distribution of air temperature ( $T_a$ ) and mean radiant temperature ( $T_{mrt}$ ) for different design scenarios were compared. Subsequently, the predicted microclimate data was extracted from the receptors set around the school building, which was used as boundary conditions in DesignBuilder to calculate the cooling energy consumption for the school building.

In this study, the high school attached to Tianjin University (39.1°N, 117.1°E), a typical secondary school

in Tianjin, northern China, is selected as a case study. The red solid line in Figure 1 indicates the boundaries of the school site, of which the dimensions are common among Chinese secondary schools. The month of June was considered due to the common summer holidays in July and August. This study selected June 2 for the simulation input. This day is a representative day of June, of which the average, maximum and minimum temperatures are the closest.



Figure 1: The high school attached to Tianjin University in Tianjin, northern China.

## 3. RESULTS AND DISCUSSION

### 3.1 Green strategies on the school building

The current facade material of school building, white coating, was changed to green façade and green roof respectively. The height of plants is set at 0.10 m. The Leaf Area Index is 2.70 with an albedo value of 0.22. The thermal distributions including air temperature ( $T_a$ ) and mean radiant temperature ( $T_{mrt}$ ) at 14:00 of three models are presented in Figure 2. For the green roof and green façade scenario, both  $T_a$  and  $T_{mrt}$  change very little. No significant variations can be observed for most of the three playing fields.

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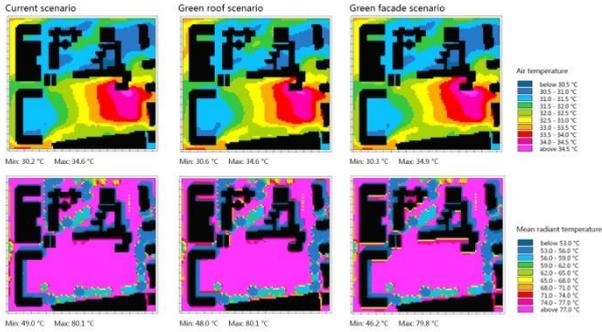


Figure 2: Simulated spatial distributions of  $T_a$  and  $T_{mrt}$  for different building façade models at 14:00 on June 2, 2015, at a height of 1.40 m.

### 3.2 Green strategies on the schoolyard

The study then considered two green strategies on the schoolyard, including tree planting and grass pavement. Figure 3 present the  $T_a$  and  $T_{mrt}$  distributions for the three green design strategies. It can be observed that planting trees leads to an obvious decrease in  $T_a$  in the courtyard, east square and the west part of playground, while for the grass pavement scenario there is only a slight decrease in  $T_a$  on the playground. Considering the thermal comfort, the  $T_{mrt}$  values of the areas with newly planted trees have been significantly reduced, such as the courtyard and east square. However, the central area of the playground shows no variation in  $T_{mrt}$  since no trees are planted there. Little variation in the  $T_{mrt}$  can be observed for the grass pavement scenario for all three areas.

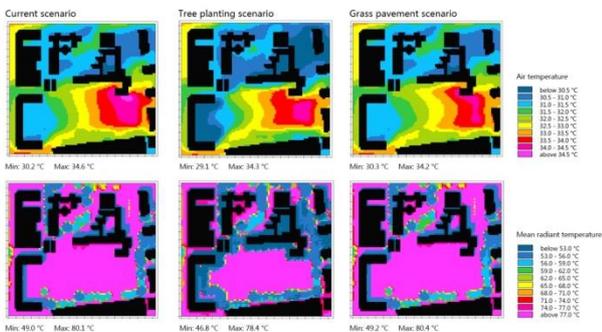


Figure 3 Simulated spatial distributions of  $T_a$  and  $T_{mrt}$  for different landscape designs at 14:00 on June 2, 2015, at a height of 1.40 m.

### 3.3 Outdoor thermal comfort versus building cooling demand

Figure 4 summarizes the school outdoor discomfort hours according to Physiological Equivalent Temperature ( $-6^{\circ}\text{C}$  to  $31^{\circ}\text{C}$ ) and building cooling demand of the simulation day for all evaluated design scenarios. Planting trees appears to be the most effective strategy to mitigate the outdoor heat risk as well as decrease building cooling demand. The discomfort time decreases to 9.9 hours per day, and the cooling energy load reduces to 4,274kWh/day by planting trees. Other three green

strategies also shows reduction on the building cooling demand, but almost no change in the outdoor discomfort hours.

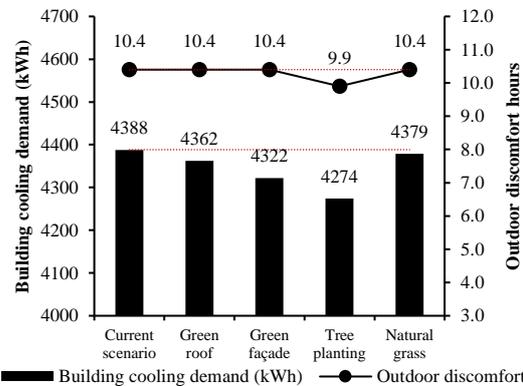


Figure 4: Comparison of building cooling demand and outdoor discomfort hours on June 2, 2015, for all school design scenarios.

### 4. CONCLUSION

The main findings of this study are outlined as follows, serving as a practical reference for school projects in northern China:

- Considering both outdoor thermal comfort and building cooling demand, planting trees is the most effective school design strategy. More specifically, thermal discomfort hours can be reduced, and the cooling demand decreases by approximately 2.6%. However, its outdoor spatial influence is quite limited, i.e., effects only occur under the canopy.
- A green roof and green façade can both decrease the building cooling energy demand, among which the green facade performs best. However, their outdoor spatial influence is quite limited.
- Natural grass pavement has only a slight effect on both the outdoor thermal perception of humans and cooling demand of the buildings.
- Effective heat mitigation measures are easier to apply to a relatively smaller sports field with a higher degree of enclosure (e.g., courtyards) than the open, large-scale areas (e.g., playgrounds).

### ACKNOWLEDGEMENTS

This research was funded by the National Key Research and Development Program of China (Grant No.2016YFC0700200) and the National Natural Science Foundation of China (Grant No.51338006).

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# Energy and Form Revisited: A Typological Study of Energy Producing Buildings

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*ABSTRACT: This paper examines the relationship between solar energy harvesting potential and building form. For the purpose of finding building forms that are desirable for zero energy buildings, the effect of various building geometry and orientation on their energy production and consumption was examined. Formal issues that building designers encounter when designing solar energy producing buildings that employ building integrated photovoltaic (BIPV) were comparatively studied. By analyzing the energy trade-offs between energy production and consumption, it was found that elongation of building mass along the north-south is preferred in terms of energy production from building skins. It was also found that energy consumption is far greater than energy that can be produced from building skins. Thus this study concludes that conserving strategies must be give a higher priority in attaining zero or near zero energy buildings.*

*KEYWORDS: Form Optimization, Solar Energy Production, Building Typology, Building Integrated PV*

## 1. INTRODUCTION

Building form has profound implications on a building's energy performance [1, 8]. Solar energy received on a building's surfaces is determined by its massing scheme. A conventional design axiom is to elongate building mass along the east-west axis to maximize a building's exposure to sunlight and daylight. A corollary of this axiom is to organize interior spaces to locate large spaces in the building's south zone and small auxiliary spaces in north. These architectural conventions are embodiments of passive designs that are intended to utilize natural forces, specifically to harness more solar energy in the winter and less of it in the summer. A south facing surface receives more solar radiation in the summer and less of it in the winter, while an east or west facing surface does more in the summer and less in the winter. In particular, west facing windows experience heat gain from the low afternoon sun, which attributes to cooling load and causes disabling glare. When possible, avoiding west facing windows is a design convention in building design. Therefore, the east-west elongation of building mass, thus having a larger south facing surface area smaller, undesirable east and west surfaces, is a design strategy that provides year-round benefits to building energy performance.

When zero energy design that utilizes both energy production from active systems and passive designs is considered, the validity of the aforementioned design axioms on building form may no longer be valid. From the perspective of solar energy generation, higher solar irradiance is of merit regardless of season, even during the summer, which was not the case in passive solar design. When analyzing energy producing building and/or zero energy design, the relationship between building energy and form should be re-examined.

## 2. RESEARCH GOAL AND SCOPE

This paper examines the relationship between energy and form through the lens of energy producing buildings, i.e., buildings that produces onsite renewable energy. What are building forms that are desirable for zero energy buildings? How much does building geometry and orientation affect energy production and consumption of a building? Form issues that building designers encounter when designing solar energy producing buildings that employ building integrated photovoltaic (BIPV) were examined. By analyzing the energy trade-offs between energy production and consumption, we intended to find optimal building forms for energy producing buildings.

### 2.1 Test building

The base-case building is a medium sized five-story, 50' wide, 100' long, and 65' high building in Phoenix, Arizona, a location with a hot and dry climate. The building type is an office building. The total floor area is 5000 ft<sup>2</sup>. Each floor of the building has 6.5' high strip windows in all walls. The window to wall ratio was 0.5. The onsite energy system consists of photovoltaic panels installed on the rooftop and the four vertical exterior walls. The PV panel size covers 100% of the roof area plus 50% of the exterior walls. The conversion efficiency of the PV systems is assumed to be 15%.

Total solar energy generated from the PV system on exterior surfaces of a series of building geometries were comparatively analyzed. In all of the parametric analyses, the building volumes are constant. A solar energy program developed by the National Renewable Energy Laboratory is used for calculating solar irradiance and electricity produced from PV systems [2]. Energy demands of the test buildings are simulated employing

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eQUEST [3]. Through these comparative analyses, the impact of building form on energy production and energy consumption was investigated, and the desirable building form for zero energy building was pursued.

## 2.1 Floor plan shape

Floor plan shape affects a building's exposure to the sun, sky and outdoor air. Conventional buildings are typically a rectangular shape elongated along the east-west axis so that the building would have larger south and north-facing surfaces and smaller east and west-facing surfaces. For passive designs, the east-west elongation of building mass is a net positive in both seasons. When solar energy generation from PV panels is integrated with building surfaces, this design goal of admitting solar energy in heating season and avoiding it in cooling season is only one of two energy design goals no longer hold true. In energy-producing buildings that employ building integrated photovoltaics or solar panels, a design goal is to maximize energy production regardless of seasons, while minimizing energy consumption. This study compared the energy balance of four different floor plan shapes. Energy production and energy consumption in buildings that have identical volumes but different floor plan shapes, square, rectangular, triangular and octagonal, were analyzed, and their advantages and disadvantages in solar energy production and energy consumption were compared.

## 2.2 Building orientation

Depending on the orientation, rectangular buildings elongated along the east-west axis have a different relationship with the sun. For instance, as the axis of elongation rotates, a rectangular building will have varying amounts of solar radiation on its exterior surfaces and windows. Similarly, a triangular building will have a varying relationship with solar radiation and solar exposure, depending on the rotation of its floor plan. Based on our analysis, it was found that solar energy produced from building integrated PVs was the highest when a building is elongated along the north-south axis. Thus the optimal building orientation for active solar systems is contradictory to the orientation for passive design.

## 2.2 Setback and sloping

A building with an identical floor plan will have different solar exposures, depending on the setback of upper volumes. The setback of upper building mass is desired or required for two primary reasons. In urban planning, the setback profile angle is a classic regulatory tool used to ensure a minimal daylight levels and sky openness in urban outdoor spaces, thus avoiding the street canyon effect created by buildings [4]. The visionary images of Hugh Ferriss explored the impact of setback profile angles on building massing [5]. The solar

envelope was conceived to regulate development in a lot within imaginary setback envelopes that ensure solar access to a building site during critical periods [6]. In building design, a passive design convention is to setback the upper volume to north. Anasazi cliff dwellings in the American southwest followed this classic passive solar design principle [7]. By setting back the upper building mass to north, a building mass cascades from upper to lower volumes from north to south, and sunlight can be admitted to deeper northern interior spaces.

Our analysis revealed that, from the active solar point of view, setting back the building volume toward to the north results in an identical surface exposure to the sun as no setback building; the sums of vertical south wall surfaces and the horizontal roof surfaces of one with setback and no setback are the same. Thus vertical setback does not provide any benefit to BIPV.

## 4. CONCLUSION

From the typological comparison of solar energy production, it was found that buildings elongated along the north-south axis harness more electricity from buildings integrated solar systems. This is a counterintuitive finding as the architectural convention has been that elongating building mass along east-west axis is preferred for the design of climate responsive buildings. However, this finding must be applied to building design in consideration of the fact that, even in the hot and dry desert climate of Phoenix, energy consumption is a more dominant factor than energy production from building skins in the energy balance of commercial/office buildings. A corollary of this that energy conserving strategies must be give a higher priority in attaining zero or near zero energy buildings. Only after when the energy demand of a building has reduced drastically, the building form and solar energy production from their skins play a more significant role in energy self-sustainability of buildings.

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# Evaluating the Building Performance of an Office Building in London to Improve Indoor Thermal Comfort

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*KEYWORDS:* This study evaluates the building performance of an office building in London, which had issues reported concerning thermal comfort of occupants. The research aims to assess the occupants' thermal comfort, and building performance of this building during the winter season. The study undertakes field studies including a questionnaire-based survey, and on-site monitoring as well as building simulation modelling to evaluate the building performance and to validate a simulation model to be used in the second phase of the study concerning energy efficient and cost effective retrofit proposals.

*KEYWORDS:* Building Performance, energy efficiency, office building, thermal comfort

## 1. INTRODUCTION

It has been affirmed that issues within the indoor environment of the workplace has a significant influence on reduced productivity due to factors such as poor ventilation, lighting, and thermal discomfort [1].

Hence, efficient design of office buildings has become increasingly important due to its direct impact on occupants' health, wellbeing, and productivity. Moreover, when buildings fail to provide indoor thermal comfort, occupants may take measures that consume more energy than needed for heating and/or cooling in order to gain satisfactory levels of thermal comfort [3, 4]. This may inevitably undermine the efficiency of the building design and energy performance. The research aims to evaluate occupants' thermal comfort, and building thermal and energy performance of an office building in East London as a case study. The study explores the underlying issues causing occupants' complaints of cold and draught in the winter to help develop feasible retrofit proposals that improve occupants' thermal comfort and, in turn, reduce heating energy demand.

## 3. RESEARCH METHODOLOGY

To achieve the research aim a quantitative research design is adopted comprising three methods of data collection and analysis. An online survey questionnaire was designed and distributed to the building users in 2017 to gain insight into occupants' patterns of using the office spaces, levels of comfort and satisfaction, and overall experience with the indoor environment of their offices in the winter. Secondly, data loggers were fitted on all 3 levels of the building to record air temperature and relative humidity (RH) in winter 2017 (December – March) to facilitate a comprehensive analysis of indoor environmental conditions. Finally, dynamic thermal modelling using Integrated Environmental Solutions

Virtual Environment (IES-VE) is applied for in-depth investigation of the building performance and to create a validated model for the subsequent stage of the study; developing energy efficient and cost-effective retrofit proposals.

## 4. RESULTS AND DISCUSSION

### 4.1 Survey questionnaire

Overall, a 25% response rate was achieved from the survey questionnaire distributed to all 152 building users. The results show that 35% of respondents normally felt cold and 32% felt slightly cool or cool during the working hours in their office in winter. Concerning air movement in the offices, 49% felt it was either very still or still while only 11% reported it was breezy or very breezy although 70% stated that they opened their windows for a few hours everyday, even during the winter. Concerning people's experience with relative humidity in their office, 60% reporting they would rate it as neutral while 27% reported it to be dry in the winter. Furthermore, the majority of the participants used secondary heating systems, 62% electronic portable heaters.

### 4.2 Indoor data monitoring

The indoor air temperature and RH levels have been monitored using highly sensitive data loggers fitted in the central corridors of the three floors of the building to evaluate the indoor environmental conditions associated with occupants' thermal comfort. The results shown in Figure 1 focus on the winter months from 21<sup>st</sup> Dec 2017 until 21<sup>st</sup> March 2018.

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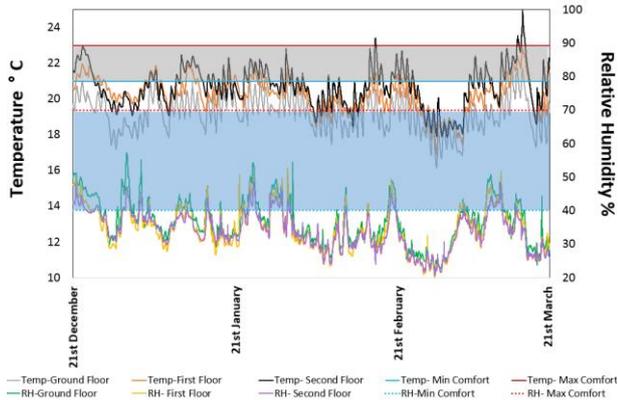


Figure 1: Indoor air temperature and RH of the ground, first and second floors between 21/12/2017 and 21/3/2018

The graph demonstrates fluctuations of indoor air temperature, where the range recorded was generally between 17°C (on the ground floor) and 23°C (on the second floor) whereas the external air temperature reached its highest at 14°C and the lowest at -6°C in winter 2017. However, the Chartered Institution of Building Services Engineers (CIBSE) Guide A [3] recommends that the acceptable indoor air temperature should be between 21° and 23°C in office buildings during the winter season for sedentary activities. In addition, an inside dry resultant temperature of 23°C should not exceed for more than 5% of the annual occupied period [4], which is not the case in this study. From the field monitoring, it was found that the indoor air temperature in the office area on the ground floor was normally below minimum comfort level. As for the measured RH levels, those have been normally below the comfort range (40-70%) reaching 20%. The results of the field measurements show that the main areas of concern with regards to thermal comfort of occupants are the offices on the ground floor followed by those on the first and second floors respectively.

### 4.3 Dynamic thermal modelling and simulation

Integrated Environmental Solutions- Virtual Environment (IES-VE) using ApacheSim for dynamic thermal simulation has been used as a reliable software [6] to simulate the building performance. The input parameters required for modelling include the building geometry and properties of the construction materials, occupancy patterns, internal heat gain sources, and the outdoor air temperature and RH. The building geometry is created using detailed drawings where each floor is modelled to include its specific thermal zones. The outcome is twofold; first, to validate the primary simulations of the base case against indoor monitoring results and occupants' survey; and second, to investigate potential design interventions that can help improve occupants' thermal comfort, and heating energy demand (second phase of the study). The results from IES simulation analysis have been assessed against the

monitored indoor air temperature and RH levels. It was found that the percentage variation in indoor air temperature is between 5% and 15%, which has been asserted as acceptable variation and confirms that IES model can be used as a validated model. The simulation results also showed variance between the ground floor heating load and the second floor heating load (0.1KW).

### 5. CONCLUSION

The empirical data collected and analysed for the office building under study included a questionnaire-based survey, field monitoring of indoor air temperature and RH levels during winter 2017-18, and dynamic thermal modelling. The survey results showed that the majority of occupants suffer thermal discomfort in their offices which were typically cold or cool in the winter. Data loggers validated occupants' experiences where several cold peaks in indoor air temperatures have been recorded throughout the winter months. The results are also corroborated by IES-VE dynamic thermal modelling of the building to understand the building heating demands and help quantify energy and cost savings from the design intervention to be proposed on the second phase.

The results indicate that there are issues of discomfort in the winter that need to be addressed through appropriate design interventions. It has also been found that energy consumption in winter is higher than expected due to the use of multiple heating appliances in office spaces. The issues have been found to be mainly due to the thermally inefficient building fabric. The ongoing work in this study is the building performance evaluation using IES-VE aiming to explore the optimum design intervention to improve the indoor environment and consequently reduce the building loads.

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## Productive Façade Systems at NUS-CDL Tropical Technologies Lab: Final Design and Measurements Strategy

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*ABSTRACT: As a response to the need to find urban solutions to the energy and food dependency in Singapore and to reduce the overall carbon footprint the concept of productive facades is proposed for residential buildings. Departing from the premise that buildings and the urban environment should not solely be the recipient but also the producer of energy, food and water; eight façade design arrangements have been optimised and built at the Tropical Technologies Lab at the National University of Singapore. All proposed facades, with and without balconies, integrates photovoltaic (PV) panels with farming systems as a way to partially supply energy and vegetables to the residents. In addition, the impact of the façade arrangement on indoor thermal and visual performance is also taken into account. The objective of the paper is to present the final design of the productive façade prototypes and the measurement strategy corresponding to the first three months from August till October 2018 in terms of PV electricity generation, vegetable growth and indoor thermal and visual conditions. A comparison with simulation results is expected to be made for four façade systems.*

*KEYWORDS: Photovoltaics, Urban farming, Renewable energy, Façade performance, Measurements*

### 1. INTRODUCTION

The impact of climate change is already producing a larger number of devastating climatic events than previous decades with subsequent life and material losses. As an urgent response to the potential worsening of global warming, a drastic change in the way buildings, neighbourhoods and cities are designed as well as the life style of millions of urban dwellers is needed. These changes should contribute to reduction of both carbon footprint and greenhouse gases (GHG) emissions as well as to prepare and make urban dwellers more resilient for potential energy, food and water scarcity.

Departing from the premise that buildings and the urban environment should not solely be the recipient but also the producer of energy, food and water; eight façade design arrangements have been optimised [1-3] and built at the Tropical Technologies (T<sup>2</sup>) Lab. The laboratory is a collaboration between the School of Design and Environment, National University of Singapore (NUS) and City Development Limited (CDL). All proposed facades, with and without balconies, integrates photovoltaic (PV) panels with farming systems as a way to partially supply energy and vegetables to the residents. In addition, the impact of the façade arrangement on indoor thermal and visual performance is also taken into account.

The 60 m<sup>2</sup> lab (Fig. 1) has been constructed in a relatively unobstructed open area next to NUS staff residences to house 4 projects in its first two years of

operation. Measurements related to the productive façade systems are expected to start in February.

A considerable number of research have focused on Building Integrated Photovoltaics (BIPV) on facades. Other more recent studies has investigated different ways to integrate farming activities inside buildings and on building envelopes. However, so far, apart from author's previous papers, no other study has focused on the integration of PV and farming systems on residential building facades.



Figure 1: View of the Tropical Technologies Lab.

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The objective of the paper is to summarise the final design of the productive façade prototypes and the preliminary measurement results corresponding to the first three months from August till October 2018 in terms of PV electricity generation, vegetable growth and indoor thermal and visual conditions. A comparison with simulation results is made for four façade systems.

## 2. METHOD

The design of the eight façade systems is based on an optimization process which considered 5 performance indicators: PV electricity potential, vegetable production potential, façade energy flow, indoor daylight autonomy and view angle from interior. Variables such as tilt and protection angles of PV panels, number and position of panels and planters were inputs for simulations. (Fig. 2) A semi-automated algorithm was developed in Grasshopper [2] together with Ladybug and Honeybee plug-ins for the simulation and results export into Excel [3]. VIKOR multi-criteria optimization method [4,5] was used for the selection of the best façade arrangements.

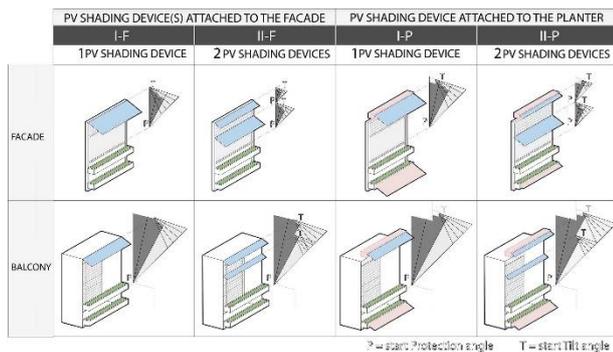


Figure 2: Types of PV configurations and corresponding start of the protection and tilt angles.

### 2.1 Façade description

Two types of façades – façade wall and façade with balcony - were considered for this study as they are representative of common public housing façade for bedrooms and living rooms respectively. The two façades were optimised for four orientations: north, south, east and west. The façades belong to eight identical cells of (WxDxH) 1.8m x 1.8m x 2.6m.

### 2.2 Measurement variables and strategy

A reference meteorological station is placed on the rooftop to measure dry bulb temperature (DBT), relative humidity (RH), solar irradiance, light intensity and wind speed and direction. Solar irradiance is also measured on the vertical positions on each of the façades. Light intensity is measured on the upper planter per façade. Electricity generation and water flow for irrigation are measured per PV module and façade planters. Inside each cell, illuminance, DBT and RH are also measured. Indoor air speed is taken in two cells. In addition, surface temperature on PV modules and façade surfaces are also

monitored. A total of 80 sensors are connected to a central data acquisition system whose energy is supplied from a battery. All the energy used in the lab is generated by rooftop, vertical and shading PV panels.

## 3. FINAL FAÇADE DESIGN

From the façade design optimization eight optimal façade prototypes were selected to be implement at the T<sup>2</sup> Lab. However, taking into account several contextual, practical and research-related reasons, the actual façade arrangement had to be somehow adapted as shown in Figure 3.



Figure 3: Artistic impression of final facade arrangement for the south and east facade orientations.

## 4. CONCLUSION

Measurement results from each of the eight productive façade arrangements will be collected and analysed in order to assess the proposed design and technologies. Comparison with simulations will also be conducted for four façades.

## ACKNOWLEDGEMENTS

This research is funded by City Developments Limited (CDL), Singapore. Our gratitude to SERIS and UNISEAL for the sponsorship of the BIPV as shading devices and the farming system respectively.

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# Defining Building Archetypes for Urban Climate Simulations of the Complex High-Density Environment in Hong Kong

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*ABSTRACT: Building data are required to initialise urban canopy parametrisations in atmospheric models. Improving the precision of such data enhances the accuracy of model outputs and enables us to better simulate the urban surface energy balance and the potential impacts of climate change on cities. This study aims to characterise buildings in Hong Kong using a locally-adapted approach, taking into consideration its subtropical climate, rapid urban development process, and complex high-density environment. We identify 18 building archetypes distinguished by their morphology and use. For these we define building architectural characteristics and human behaviour schedules. These parameters are intended for use in fine scale urban climate simulations with the Town Energy Balance (TEB). Subsequent findings may be applied for urban planning and climate change impact studies.*

*KEYWORDS: Building archetype, Construction materials, Urban canopy parametrisation, High-density city*

## 1. INTRODUCTION

Atmospheric models are effective tools for understanding the potential impacts of climate change on cities. In particular, urban land-surface schemes, like urban canopy parametrisations (UCPs), are constantly being refined to accurately simulate the altered surface energy balance due to urban environments and anthropogenic activities [1]. Buildings form an important component in UCPs because their physical characteristics (e.g. albedo, thermal conductivity) and building energy consumption influence the city-atmosphere interactions. The WUDAPT [2] initiative aims to provide a standardised global database on urban tissue based on local climate zones (LCZs) [3] to facilitate urban climate, environmental, and energy use modelling studies. With a similar objective, the GENIUS database for building architecture has been developed for French cities. It assumes that building architecture is mainly shaped by urban morphology, building use, construction period, and geographic location [4]. A further step has been taken to incorporate human behaviour schedules, inferred from building use, in parametrisations to improve the modelling of spatio-temporal variabilities in anthropogenic heat flux [5].

In this study, we aim to characterise buildings in Hong Kong (HK) using a locally-adapted approach to define parameters on building architecture and human behaviour required for the initialisation of the UCP – Town Energy Balance (TEB) [6], coupled with the Meso-NH model [7]. The results can then be used to inform urban planning and climate change impact studies.

## 2. CHARACTERISTICS OF HONG KONG BUILDINGS

Urban tissue in HK are distinctly different from that of European or American cities owing to its subtropical

climate, high population density, and short urban development history. Here are major reasons why previous approaches may not be suitable for describing the complex high-density urban environment in HK:

- The dominance of high-rise buildings is reflected by the large proportion of LCZ 1 (compact high-rise) and LCZ 4 (open high-rise) in the urban areas of HK [8]. However, within these two LCZ classes, the existence of large variabilities in building height and building use may cause significant differences in building physical properties and energy consumption patterns.
- The prevalence of mixed-use buildings, specifically with commercial use on the ground or podium floors of residential buildings, may pose challenges on defining schedules for occupancy and energy use.
- Geographic locations and thermal regulations on building insulation have largely influenced the choice of construction materials in French cities [4]. In HK, however, reinforced concrete, often in the form of prefabricated component blocks, is used as the structural material for over 90% of skyscrapers [9] and building codes focus on reducing cooling, instead of heating, energy demand [10]. Thus, cooling practices, such as the use of air-conditioners, would also need to be carefully characterised.
- Window design, including the glazing type, window-to-wall ratio (WWR), and shading elements, is another important factor for building performance in HK since building heat intake is found to be dominated by solar heat gain through windows [10]. Controls on “gross floor area” calculation and the preference for unobstructed window views also shaped designs of “bay windows” and curtain walls in HK [11].

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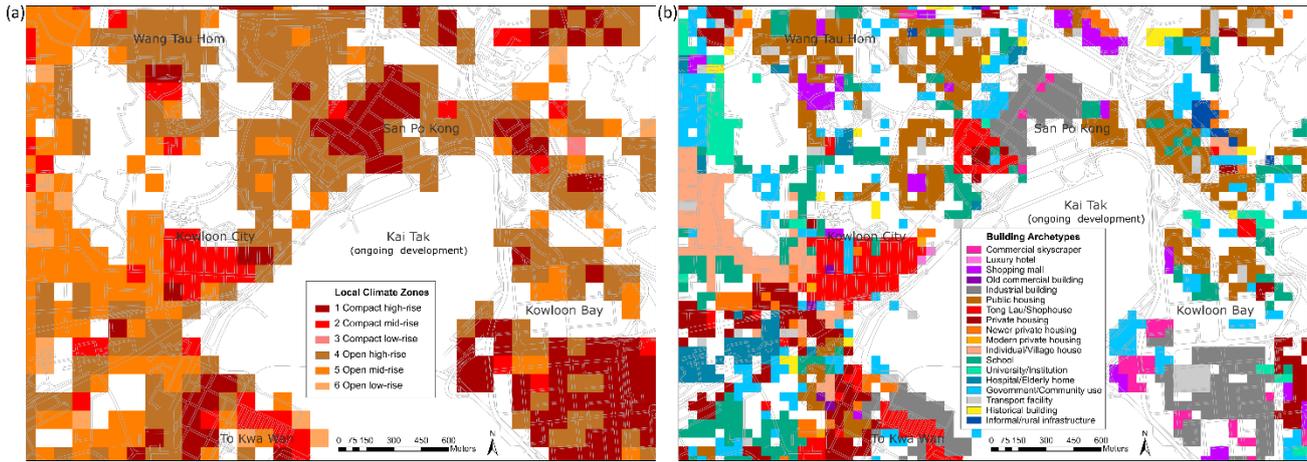


Figure 1: Comparison between the (a) LCZ [3,8] and (b) building archetype classifications of the pilot study area in Hong Kong.

Table 1: Morphological and window characteristics of selected residential building types.

Building type	LCZ	No. of storeys	Glazing type	WWR	Shading
Public housing	4	35-45	Single glazing	0.2	Building self-shading
“Tong Lau”/Shophouse	2	4-8	Single glazing	0.4	Metal overhangs
Newer private housing	1/4	40-60	Tinted single glazing	0.35	Bay windows, little shading
Individual/Village house	5/6	2-6	Tinted single glazing	0.4	Balconies common

### 3. BUILDING ARCHETYPES AND INITIAL RESULTS

A total of 18 building archetypes (Fig. 1b) are identified for HK based on a combination of building type and use. A relative dependency on the construction period is only found for commercial and residential buildings. We then define a detailed description on typical morphology, use, wall and roof materials, WWR, mechanical ventilation system etc. for every building archetype. A few examples are presented in Table 1, highlighting major differences in morphological and window characteristics for various residential buildings. Since no maps of building use and age with sufficient detail are available, mapping of building types is conducted with the aid of ArcGIS and Google Street View for a pilot study area covering parts of the Wong Tai Sin and Kowloon City districts, which is an inner-city area currently undergoing urban redevelopment. Compared to the LCZ classification [3], our initial results provide a much more detailed representation of the urban tissue in the area.

### 4. CONCLUSION AND FURTHER WORK

We define 18 building archetypes in HK which will be used for fine scale urban climate simulations. Further work includes sensitivity tests on the defined parameters and the validation of model results. Findings are expected to contribute to a more precise understanding of the urban surface energy balance and the evaluation of climate-responsive planning strategies in high-density cities.

### ACKNOWLEDGEMENTS

This work is supported by the Vice-Chancellor’s Discretionary Fund of the Chinese University of HK.

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## Chronobiological Aspects of a Window: A Pilot Study

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**ABSTRACT:** *This short paper provides a critical literature review of several domains in the field of daylighting design with respect to their lack of accountability to the chronobiological factors related to daylighting design. The review identifies deficiencies in the current metrics from the quantitative - instrumental, health-effective, to the qualitative - aesthetical to quantify the impacts of daylighting design on occupant's health and well-being. To test the critical analysis, a pilot study was designed to provide a holistic view of how the integration of these domains can address the application and architectural decision making for window design parameters. It is an attempt to elaborate on the glass industry's research and aims to look at the effects of different window design parameters on the transmission of the electromagnetic spectrum within a space's interior. More specifically, it investigates the effects of distance from a window on the transmission of daylight through clear glazing and how the daylighting quantities and qualities transmitted affect occupant health and well-being, with a focus on circadian entrainment. This proof of concept study is seen as a first step to investigate long-debated hypotheses on the mechanisms of daylighting impacts on occupant's health and well-being. The hope is to spur future investigations of the study topic.*

**KEYWORDS:** *Daylighting, Indoor Environment, Health, Circadian Stimuli, Glazing*

### 1. INTRODUCTION

The Lawrence Berkeley National Laboratory has developed many widely available computer programs and repositories including WINDOW, THERM, COMFEN, RESFEN, Optics, IGDB, CGDB, Radiance, and AERCalc. These have been mostly used by glass industry manufacturers to calculate traditional window performance indices (U-values, solar heat gain coefficients (SHGC), and visible transmittances ( $T_{vis}$ )). These parameters are useful in assessing glazing related impacts on thermal comfort, heat gains and losses, condensation control, sound transmission, shading, sun control, energy requirements, and visual comfort (privacy, glare, view). The impacts of these variables on spectral light distribution and color effects, however, have not been fully explored.

Although this glazing specification data is valuable, most designers do not look past these figures to see how they can impact the space's occupants. Window design decisions are usually prescribed in accordance with performance and aesthetics. There should be more awareness of how these design decisions not only affect building performance and occupants' aesthetical perception of the space but also, their impact on occupant health and well-being with regards to their endogenous biological cycles - ultradian (<24h), circadian (24h), infradian (>24h) and circannual rhythms (approximately one year).

These cycles are impacted by daylight's quantity, directionality, color rendering indices (CRI), correlated color temperatures (CCT) and spectral power distributions (SPD). Architectural design parameters that

influence the transmission of daylight through a window and into a space include orientation, window size, window position, glazing type, the use of shading devices, the light reflectance values of the interior space, and the exterior ground plane reflectance properties. In addition, the occupant's position in the space further influences the chronobiological exposure they receive from daylight.

This pilot study is an attempt to elaborate on the glass industry's research on the transmittance of light through clear glass. Its intent is to look at the effects of clear glazing on the transmission of the electromagnetic spectrum within a space's interior at different distances from the window. More specifically, on the biological impacts of how the light that is being transmitted affects measures for circadian entrainment at different seating position within an interior architectural space.

### 2. METHODOLOGY

The pilot study was conducted on a typical afternoon equinox day of ASHRAE climate zone 4C, characterized with overcast sky conditions. The research setting was chosen for a meeting room in Straub Hall, Room 255, at the University of Oregon campus in Eugene, Oregon -USA with an all-glass south-facing wall. The main research questions investigated are: How, and in what degrees would distance from a window during daylight hours impact changes in SPD, CRI and CCT? How would a decrease in illuminance levels (Lux) at various spatial locations away from the window plane impact these daylighting indices and measures for circadian entrainment?

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The study employed spot measurement of SPD, CRI, CCT, and illuminance levels (Lux) using a handheld spectroradiometer (Asensetek Lighting Passport accuracy: x, y : ± 0.002, Illuminance : ± 3 %, CCT : ± 2 %), This data was collected at 5ft intervals from the window to visualize various seating positions and light exposure received by occupants within the space's interior. Based on biological impacts identified in the literature [1-5], these were then converted using the circadian stimulus calculator tool (<http://www.lrc.rpi.edu/cscalculator/>) as an approved measurement for circadian entrainment and circadian stimulus metric, both developed by The Lighting Research Center at Rensselaer Polytechnic Institute.

Measurements were taken every 5ft (1.52m) at: 0ft, 5ft, 10ft, and 15ft, respectively. The following data points were plotted: illuminance levels, SPD, CRI, CCT, circadian light, and circadian stimulus. To expand on these results, the data collected might be further translated into melatonin phase shifts, melatonin suppression percentages and KSS rating of subjective alertness using other proposed tools [1-2]. From this, correlations can be deduced about how effective recommended levels for the quantity of light are with regards to meeting the threshold of biological action spectra.

### 3. RESULTS

The results show that by increasing the distance from the window, illuminance levels, CRI and CCT decrease (Fig 1, Table 1). There is also a noticeable shift in the transmission of spectral power distributions of daylight (Fig 2). More importantly, it is noted that the thresholds for biological effective spectra do not necessarily coincide with the points at which illuminance levels drop below the recommended standards 300 lux for visual acuity and task performance.

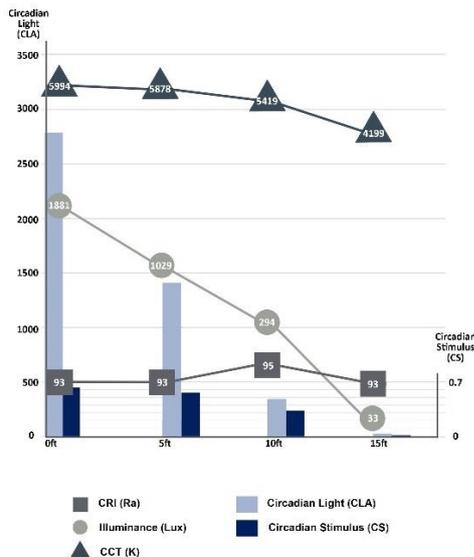


Figure 1: Straub Hall Room 255 Daylight and Biological Impact Analysis.

Table 1: Straub Hall Room 255 Daylight and Biological Impact Analysis.

Distance (ft)	Illuminance (Lux)	CCT (K)	CRI (Ra)	Circadian Light (Cla)	Circadian Stimulus (CS)
0	1881	5994	93	2786.662534	0.634436354
5	1029	5878	93	1406.477482	0.573944033
10	294	5419	95	340.2028125	0.341406406
15	33	4199	93	22.44128301	0.031752467

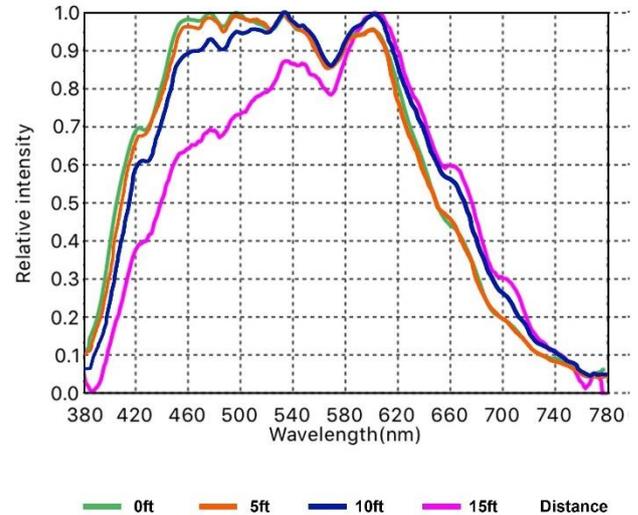


Figure 2: Straub Hall Room 255 Spectral Power Distribution Analysis – Normalized.

### 4. CONCLUSION

What can be deduced from the outcomes of this study is that even though all the units of measurements are decreasing, they are decreasing at different rates. So, it proves that using one metric is insufficient to capture the multiple dimensions of light. By comparing illuminance levels and spectral power distributions at different distances, orientations, and under different glazing conditions – designers can use this data to define zone boundaries for the threshold of biologically effective spectra as opposed to visible transmittance light levels.

This study could then be taken further by assessing occupant perception and preference under these - different daylight and glazing conditions since occupant preferences may or may not be aligned with the conditions which are essentially biologically beneficial to them. This would provide insights on the biophysical component of daylight as opposed to the objective data collected. This pilot study has aimed to initiate future investigations to change the way designers approach decisions regarding window design parameters and help raise awareness of its importance to occupants.

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# Improving Thermal Condition of a Townhouse through the Use of Low-Cost Ventilation System: A Case Study in Chonburi, Thailand

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**ABSTRACT:** Townhouses in a hot and humid region require an economic solution to improve their indoor thermal condition and energy efficiency. One way is by enhancing ventilation to reduce collective heat and promote cooling effect for the residents. A townhouse unit in Chonburi province, Thailand was selected as a case study to investigate effects of a ventilation system on its indoor thermal performance. Results from the field measurement during summer in 2017 showed that, with closed building condition, the use of ventilation system during 2 hours before the residents return home could not provide sufficient air velocities for comfort but effectively reduce the room temperatures and humidities. This could result in energy saving for nighttime air-conditioning system.

**KEYWORDS:** Townhouse, Thermal condition, Ventilation system

## 1. INTRODUCTION

Chonburi is one of the three provinces in Thailand that are the target areas for the development of the Special Eastern Economic Corridor (EEC). This has led to the increasing demand for housing in such area. Townhouse is a popular residential building type due to its reasonable price in comparison with detached house. However, with only 2 sides for openings, residents cannot rely on natural ventilation to improve indoor thermal condition affected by a hot-humid climate. Air-conditioning system has become the main solution resulting in the increase of energy consumption. Since this housing type is aimed for a small investment for both developers and buyers, it is important to improve thermal comfort and energy efficiency of townhouses economically. A low-cost ventilation system is therefore introduced in the current research as a strategy to improve thermal condition of a townhouse in Chonburi.

## 2. CASE STUDY AND MEASUREMENT METHOD

Since Pruksa Real Estates PCL has the biggest market share (23%) of townhouse segment in Thailand in 2017 [1], their standard townhouse design could have an impact on energy consumption of the country. A unit of 2-storey townhouse in Pruksa housing project, Chonburi province, was selected as a case study. It is a middle unit to avoid influence of excessive heat gain from the building sides. Incoming heat is merely from the front, the back and the roof of the unit. The front of the unit faces east. The hypothesis of the experiment was for daytime closed building condition when its residents were out for work and nighttime air-conditioned operation. Turning on ventilation system for a period of time in late afternoon would significantly reduce the amount of collective heat and therefore cool down the

unit for naturally ventilated condition as well as reduce cooling load in air-conditioned situation.

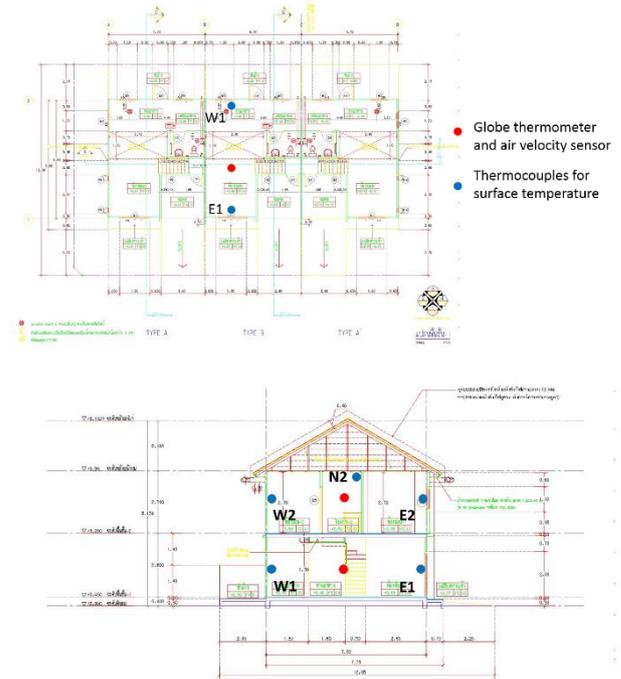


Figure 1: Measurement points

The field measurement took place for 7 consecutive days in May 2017 which was the summer time in Thailand. The non-airconditioned unit was investigated to compare 2 conditions: with and without ventilation system. For the first 5 days of the experiment, the unit was investigated without the operation of ventilation system and the last 2 days of the week of experiment, the ventilation fan was automatically turned on during 4-6 pm which was 2 hours before the residents returned home. The ventilation system included a set of ceiling-

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mounted ventilators without ventilating pipe (Mitsubishi model EX-25SC5T for 690 m<sup>3</sup>/h) and wall vent grilles. Measuring parameters were indoor air temperature, surface temperature, globe temperature, humidity and air velocity. The measurements were taken at 30-minute intervals.

### 3. RESULTS AND DISCUSSION

At 1.5 m above the floor level, indoor air velocities measured from the first floor and the second floor were too low to produce any physiological cooling effect. Indoor air temperatures of the first floor ranged from 30.9-34.9 °C while those of the second floor ranged from 31.6-35.6 °C which were about 0.7 °C higher than the first floor due to the heat gain from the roof. Globe temperatures of the first floor were 31-35 °C which were a bit higher than indoor air temperatures. As a result, the residents could experience resultant temperatures at 30.95-34.95 °C which were higher than the upper limit of comfort at 29.08 °C as calculated according to ASHRAE's adaptive thermal comfort equation [2]. However, globe temperatures of the second floor were 31.2-35.6 °C which were 0.2-0.6 °C higher than those from the first floor but around the same or lower than the indoor air temperatures. Resultant temperatures then became 31.4-35.6 °C which were above the upper limit of comfort. Relative humidities of both floors were above 60% as those from the first floor were 66.6-80.5 % and those from the second floor were 63.8-75.8 %.

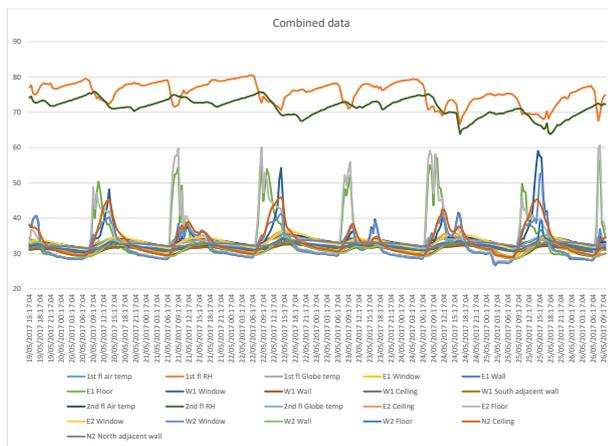


Figure 2: Results from the measurement

Surface temperatures of opaque walls and windows on the east and the west sides were as shown in Tables 1 and 2.

Table 1: Surface temperatures of the 1<sup>st</sup> floor

1 <sup>st</sup> floor	1st Air Temp [°C]	1st Globe Temp [°C]	E1 Window [°C]	E1 Wall [°C]	E1 Floor [°C]	w1 Window [°C]	w1 Wall [°C]	w1 Ceiling [°C]	w1 South adjacent wall [°C]
Max	34.9	35	34.71	33.25	57.14	59.07	34.52	32.66	32.75
Min	30.9	31	29.18	30.17	26.76	26.79	28.61	30.71	30.34
Diff	4	4	5.53	3.08	30.39	32.28	5.91	1.95	2.41

Table 2: Surface temperatures of the 2<sup>nd</sup> floor

2nd floor	2nd fl Air Temp [°C]	2nd fl Globe Temp [°C]	E2 Ceiling [°C]	E2 Floor [°C]	E2 Window [°C]	w2 Window [°C]	w2 Wall [°C]	w2 Floor [°C]	N2 Ceiling [°C]	N2 North adjacent wall [°C]
Max	35.6	35.6	36.48	60.71	36.48	52.91	35.24	39.34	45.92	33.81
Min	31.6	31.2	28.76	27.48	30.86	27.06	28.42	30.61	28.99	31.48
Diff	4	4.4	7.72	33.23	5.62	25.85	6.82	8.73	16.93	2.33

Mean outdoor air temperatures of the experimental days with and without ventilation system during 4-6 pm were 31.5-32.3 °C. By comparing collected data during these hours, it was found that without ventilation system, indoor air temperatures decreased following the outdoor air temperatures by about 0.1°C in every 30 minutes. After turning on the ventilation fans for 30 minutes, indoor air temperatures were reduced by 0.4-0.8 °C and relative humidities were lower than those without ventilation system by 6.5-8%.

### 4. CONCLUSION

In summary, thermal conditions of the case study were always overheated during summer as the resultant temperatures were around 2-6.5 °C higher than the upper limit of comfort zone. Relative humidities were also very high. Under closed-building conditions, the use of ventilation system alone could provide air velocities lower than 0.3 m/s which were insufficient to promote physiological cooling effect. Nonetheless, the ventilation system could effectively reduce the room temperatures by 0.4-0.8 °C. This could have an impact on energy saving for nighttime air-conditioning system due to smaller amount of excessive heat gain during the day.

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# Research on the Climate-Sensitive Parameters of the Traditional Dwellings in Northern China for Adaptation Strategy

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*ABSTRACT: Traditional and vernacular dwellings in many places of China are proved to have paid more subtle attention to the climatic factors in locality. This article summarizes an on-going study aiming to parameterize the climate-sensitive features of traditional dwellings in northern China and to explore the correlations between the transformation of housing morphology and the change of climatic conditions. Mapping techniques can be used to identify the genealogical zones of traditional dwellings based on climate-sensitive features, which can be further optimized to guide local housing design for a better climate adaptation.*

*KEYWORDS: Climate-sensitive Parameters; Traditional Dwellings; Adaptation Strategy; Mapping Techniques*

## 1. INTRODUCTION

As one of the most architectural productive country, China constructs more than 16 billion sq.ft of new building area every year. 75% of these new buildings add to the housing stock [1]. In 2015, the residential sector in China reached the size of 229 billion sq.ft and accounted for more than 12% of the country's overall energy consumption [2]. Given the huge annual scale of homebuilding in China, apparently an environmentally friendly approach is of paramount importance to achieve a greener future.

Despite of heterogeneous climatic conditions in China, modern apartment blocks are often built with very similar form and layout across the country, causing excessive use of energy and/or indoor discomfort. There are many factors behind to this result. Firstly, residential projects are often built with the highest permitted plot ratio to maximise the profit, so room plans have to be as compact as possible. Secondly, building envelope components and windows are commonly produced with standardised modular system for easy installation and cost control. Thirdly, building's thermal specification needs to satisfy the requirements of the national regulation "Thermal Design Code for Civil Buildings" (GB 50176), which simplifies the climate zoning on a vast territory for the purpose of easy operation.

GB 50176 (last updated in 2016) defines five climate zones in China mainly based on the mean temperature of the coldest month ( $t_{min.m}$ ) and/or the hottest month ( $t_{max.m}$ ). For instance, the Cold Zone is associated to the area with  $t_{min.m}$  ranging between 0 °C and -10 °C. Buildings designed in the same climate zone are subject to the same set of criteria on thermal performance. However, these climate zones are huge areas with various geographic, metrological and environmental conditions that are different enough to influence the energy use patterns of households. For example, the Cold Zone has a total area of 420,000 sq.mi which equals

to the size of two France. Housing built in Chengde on its northern boundary and in Bozhou close to the southern tip can be the same although there are more than 500 miles in distance.

In contrast, traditional and vernacular dwellings in many places of China are proved to have paid more subtle attention to the climatic factors in locality, gaining maximum benefit and efficient protection from weather. Many aspects of traditional dwellings reflect the wisdom that has been accumulated from centuries of practice. The article describes an on-going study of traditional dwellings in northern China for a better understanding of their climate-sensitive features and their implications to the modern development.

## 2. INNOVATION OF THE STUDY

Research on climatic strategy of traditional buildings is not a new area. Numerous previous studies have tried to explore this topic from different angles [e.g. 3,4] However, two limits differentiate this study from the past ones. The first is that those studies tend to categorise the wide spectrum of Chinese traditional dwellings into a few isolated types for socio-cultural and environmental analysis. For example, the courtyard house in Beijing (Si He Yuan) is widely studied as a northern China paradigm versus the "central patio" style residence in the Yangtze River Delta (Tian Jing Yuan) as a southern China prototype. This thought ignores the fact that building forms are gradually transformed from one place to another in line with the climate gradient. Thus, there are many "hybrid" housing types that may be used to empirically examine the correlations between building morphology and environmental characteristics. Figure 1 shows the psychrometric chart of several towns in the Cold Zone A from north to south and the typical forms of local residence. A pattern of gradual change for environmental adaptation can be roughly identified.

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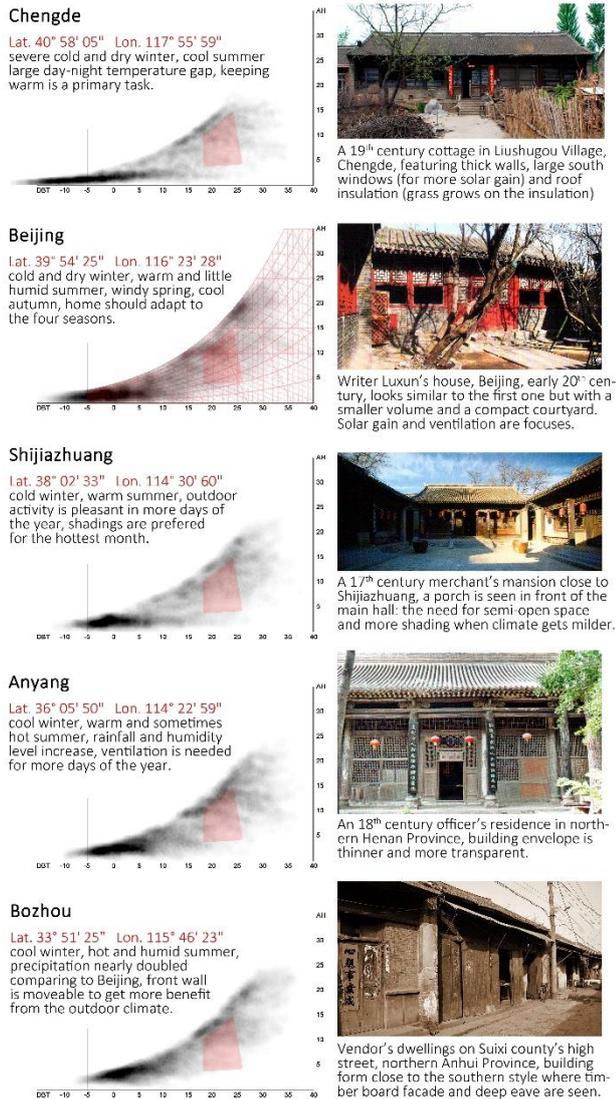


Figure 1: Psychrometric charts of five cities in Cold Zone A and typical dwelling in each place (charts are generated from Chinese standard weather data, images courtesy of MHURD [5])

The second limit is that most of previous research employ qualitative or typological methods to study traditional buildings, few analyses the issue from a parametric point of view. Certainly not all architectural details can be quantified and meaningfully compared. But lots of regional styles, engineering methods and craftsmanship emerged for a reason, and climatic and environmental inputs clearly had a hand. Logically choosing and parameterizing the climate-sensitive features of traditional dwellings will help to understand the rationale behind traditions in a measurable way.

### 3. CONCLUDING MARKS

The study summarised here is still being developed. The focus is how buildings adapt to the transition of climate. Typical houses are sampled and modelled so that their thermal and physical parameters can be computed and indexed. The measurements include solar

gain level, window-to-wall ratio, building shape coefficient, thermal conductivity and resistivity, ideal orientation, surface reflectivity, shading index, vapour permeability, wind shield effect and ventilation rate etc. Then the computation results will be correlated with local climatic data to establish the implication of latter on building dimensions. One of the challenges is to separate economic and socio-cultural elements from environmental considerations. Mapping techniques can be used to identify the geographic distribution of traditional dwellings in line with a meticulous zoning on climatic characteristics. For example, Figure 2 shows the zoning of the optimal building orientation in East China.

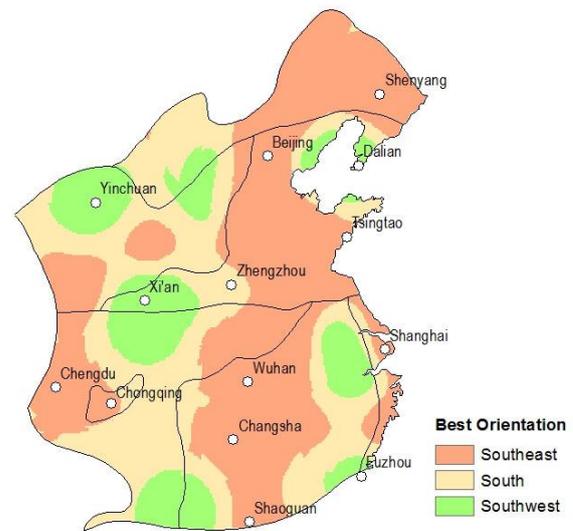


Figure 2: Mapping of the best orientation based on annual solar radiation data during heated and unheated months

### ACKNOWLEDGEMENTS

The author would like to thank the support of the Scientific Research Fund of Beijing Municipal Education Commission (KM201510005034)

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# The Relation between Clothing Insulation and Thermal Comfort of Occupants in Air-Conditioned Offices in Thailand

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**ABSTRACT:** Clothing insulation is one of the main factors that affect the thermal comfort of the occupants. Clothing value is recommended in ISO 9920, which is widely used to estimate thermal comfort. However, the extent to which the thermal environment corresponds to the clothing rate of occupants is still questionable. This study aims to clarify the trend of adapting clothing fitting to the thermal environment in offices located in Thailand by analyzing thermal sensation, thermal comfort, and thermal preference. Indoor environmental quality (IEQ) measuring devices were installed to investigate the thermal environment of two offices in Bangkok, Thailand. Questionnaires following ASHRAE 55 standard were distributed to occupants during their work hours. The results obtained showed that when plotted on a psychrometric chart, the thermal environment was mostly outside the 0.5 clo comfort zone (39% and 64%). The average clothing insulation in case studies was 0.65 clo, which is slightly higher than the normal standard value. The percentage of neutral thermal sensation votes decreased when the value of clothes gradually increased similar trend as to the percentage of neutral comfort votes. PMV calculation deviated from thermal sensation vote about 1 °C when considering thermal neutrality. Probit analysis shows that the neutral temperature of each clothing rate ranged from 24.2°C to 25.6°C. Occupants in less clothing could tolerate a wider range of temperatures than the occupants in more clothing. This study would be applicable to office buildings in the tropical region in terms of both the occupant's behavioral aspects and temperature setpoint.

**KEYWORDS:** Clothing insulation, Thermal Comfort, Air-conditioning, Office

## 1. INTRODUCTION

Thermal comfort plays an important role in enhancing the comfort and productivity of occupants during their working hours. Clothing insulation is one of the main factors that affect the thermal comfort of the occupants which results from both psychological aspect and the indoor environment [1]. However, the relation between clothing rate and the actual thermal environment is still doubtful for people living in tropical regions, where external climate is hot and humid, but people live in the cool indoor environment [2]. This study aims to clarify the trend of clothing that occupants normally wear according to the thermal environment of Thai offices by concerning about occupants votes and standard calculation analysis.

## 2. METHODOLOGY

To understand the thermal environment of the case studies, two office buildings in Bangkok were monitored both by indoor environment quality (IEQ) measuring devices and by questionnaires. Both buildings were identified as open-plan. They were investigated during working hours from March 6th-10th, 2017 and July 25th -28th, 2017, respectively. Devices were installed in both the parameter zone and the interior zone. According to the ASHRAE standard 55 [3] and ISO 9920 [4], the questionnaire evaluated the thermal sensation (TSV), thermal comfort (TCV), and thermal preference vote.

## 3. RESULTS AND DISCUSSION

The results obtained from IEQ measuring devices show that the average indoor air temperature in office A and B was 23.9°C and 23.3°C, respectively. The average operative temperature in office A and B was 24.0°C and 23.5°C, respectively. The average mean radiant temperature for office A and B was 24.0°C and 23.3°C, respectively. The average relative humidity was 57.40% and 56.8%, respectively. When plotted on an ASHRAE psychrometric chart, the thermal environment of both buildings fell within the 1.0 clo comfort zone rather than the 0.5 clo comfort zone, as shown in *Figure 1*. Thermal environment (39%) in office A and B (64 %) was outside the 0.5 clo comfort zone.

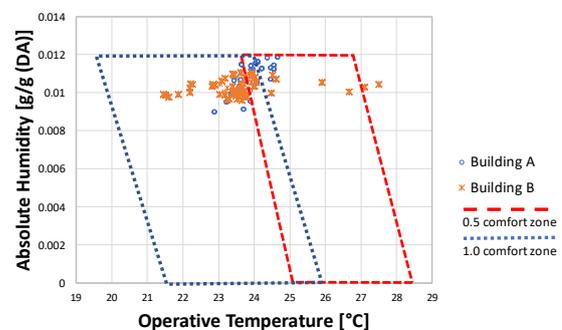


Figure 1: A psychrometric chart of the surveyed buildings.

There were 771 samples divided into 5 categories, namely 0.2-0.4 clo, 0.6-0.8 clo, 0.8-1.0 clo, and 1.0-1.2 clo. The average clothing was 0.65 clo, a value slightly

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higher than that of other in some countries in the tropical region [5] as well as the one presented in ASHRAE [5]. Most occupants felt neutral (44.7%) about the thermal environment of their offices. The percentage of voting neutral (44.7%) nearly equal to the percentage of voting for the colder side (40.2%). Occupants felt more comfortable in the thermal environment when wearing clothing over 0.4 clo. The percentage of occupants voting neutral for the TSV and TCV decreased when the amount of clothing had been increased. The highest of thermal preference was “No Change” (70%) in every group except for the 0.2–0.4 clo group. In total, “Prefer warmer” was far more popular than “Prefer colder” (24% and 6%). According to the PMV calculation, it estimated thermal neutrality (TSV= 0) as 26°C. However, the mean of the actual votes was 1°C lower than the calculated neutral temperature (25°C). A matching point between PMV and TSV was significant to each other when the operative temperature fell into 24°C and TSV was counted as 0.3. The neutral temperature (PMV=0) shifted from approximately –0.68 to –0.71 scale point of the TSV. It is interesting that TSV voted by occupants wearing more clothes is higher than the PMV calculation.

In Figure 2, the probit model of the percentage of dissatisfaction drawn from the subjective votes of “colder than neutral” and “warmer than neutral” were plotted against the binned operative temperature. The result shows that the values of temperature acceptance are 21.9°C–29.2°C, 21.8°C –28.6°C, and 22.9°C –27.3°C. Occupants wearing less clothing could adjust to a wider range of temperature than the ones wearing more clothing. The neutral temperature values of the three categories were found to be 25.2°C, 24.7°C, and 24.6°C, respectively. These values slightly decreased when the amounts of clothing that is worn increased. All values were close to the one found in the previous research proposed by Busch [6], which was a bit higher at 25.5°C.

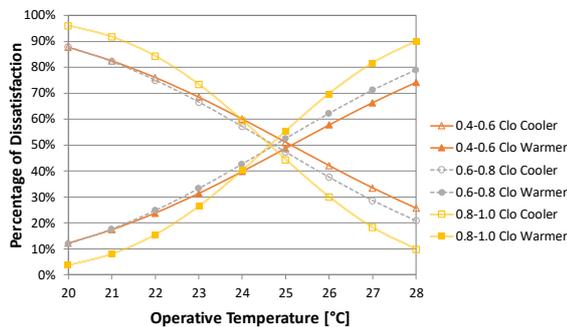


Figure 2: Probit of percentage of dissatisfaction against operative temperature.

## 4. CONCLUSION

In this study, field investigation was conducted in air-conditioned offices in Bangkok, Thailand to investigate the relation between thermal sensitivity and clothing

insulation of occupants. The significant conclusions are listed as follows:

1. Thermal environments for the case studies fell outside 0.5 clo comfort zone when plotted on a psychometric chart.
2. The highest clothing rate was in the range of 0.4–0.6 clo (67.88%). The average clothing rate of occupants reached its highest value at 0.65 clo, which was slightly higher than the standard value (0.5 clo).
3. TSV and TCV in all clothing rates were neutral. Occupants wearing lighter clothes felt more neutral toward the cold thermal environment. 24% of them would like raise temperature.
4. The overall trend of PMV prediction differs from actual TSV by 1 °C. TSV voted by occupants in higher amounts of cloths is higher than the PMV calculation.
5. Neutral temperature values ranging from 24.2°C to 25.6°C (only for 0.4-1.0 clo) decreased slightly when the amounts of clothing rate increased. Occupants found the indoor thermal environment more comfortable when the clothing rate is high. Neutral temperature dropped by almost 1°C when clothing insulation increased over the range 0.1–0.2 clo.
6. Occupants in a lower clothing rate could adjust to a wide range of temperatures in comparison to those with high clothing rates.

Occupants could adjust their clothes in accordance with the lower temperature, which reduced cooling thermal sensitivity. It would be beneficial for the building that the air-conditioning loads could be reduced when changing into a bit higher temperature.

## ACKNOWLEDGEMENTS

The authors would like to thank the companies and the building management teams to facilitate the investigation. We also express deep appreciations to those in surveyed buildings who filled the questionnaire.

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# Assessment of Thermal Comfort in Naturally Ventilated Factory Buildings: A Case Study in Mumbai, India.

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*ABSTRACT: Productivity and Satisfaction of the building occupants is largely influenced by Thermal Comfort. Specifically, in Factory buildings where occupants are constantly exposed to excessive heat produced from machines, it is important to maintain comfortable indoor environment and therefore evaluation of the comfort conditions inside these buildings is necessary. The research aims at assessment of naturally ventilated factory buildings located inside a Factory Premise in Mumbai. Three factory buildings with similar process and architectural features having different orientation and sizes were selected for assessment. The assessment was done based on onsite measurements and thermal comfort survey of the occupants. Key reasons behind discomfort were identified. Based on this assessment and comparison with standards, design guidelines were formulated. There is further scope for validating effect of passive design strategies with the help of Building Simulation.*

*KEYWORDS: Thermal Comfort, Industrial Buildings, Adaptive Thermal Comfort, Naturally Ventilated Buildings*

## 1. INTRODUCTION

Rising urban temperatures has become one of the major concerns today. Mega cities in India like Mumbai now fall into 'Very Hot category' with average summer heat index increasing at a rate of 0.56°C /decade. (Madaani, 2017) As a result of which the use of energy for cooling and air-conditioning of the indoor environment is by now one of the largest sectors in energy consumption. In Mumbai, it constitutes about 40% of total energy consumption (Cox, 2012). In factory buildings, where occupants are constantly exposed to excessive heat produced from machines, installation of active cooling systems is generally avoided as the energy required for creating thermal comfort could make reasonable impact on manufacturing cost.

Thermal discomfort in factories affects health and productivity of the workers. Therefore, it becomes important to evaluate the thermal comfort conditions inside these buildings.

### 1.1. Aim & Objectives

The aim of the research was to assess thermal comfort in naturally ventilated factory buildings located in warm and humid climate of Mumbai. The study intended to analyse methods of measuring thermal comfort in factory buildings and to evaluate the existing comfort conditions in these buildings.

## 2. METHODOLOGY

To assess thermal comfort conditions inside factory building, three buildings located in a large industrial premises at Mumbai were selected as case study. The buildings had common architectural features but were different in terms of size and orientation. The

manufacturing processes of metal engineering are carried out inside all three naturally ventilated factory buildings.

The Indian Model of adaptive thermal comfort (IMAC) and ASHRAE 55-2013 - adaptive thermal comfort model was followed to assess thermal comfort conditions.

Thermal comfort survey was conducted where the subjects were permanent workers from first and second shift in the three buildings. The questionnaire was distributed to 400 occupants and the response rate was 44.75%. On-site measurements and survey were conducted on same day in each building.

### 2.1. Measurements

Key environmental parameters affecting thermal comfort such as Air Temperature, Humidity, Mean Radiant temperature, Air Movement were measured. The measurements were taken in the month of April.

For each building, one weekday and one weekend profile were plotted. Weekday profile was plotted for 12 hrs and weekend profile was plotted for 10 hrs. Architectural data was collected through observations and secondary data collection mainly included architectural drawings and standards.

## 3. FINDINGS

All three factory buildings were analysed based on design parameters, heat gain calculations and thermal comfort survey of occupants.

All the buildings scored 50% against design criteria given in National Building Code (2016) for naturally ventilated buildings. Buildings lacked mainly in design of opening and partitions. Addition of mezzanine floor,

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partitions, and ancillary buildings around, were found to hinder smooth air-flow inside the building.

Heat gain calculation showed that heat gain through building envelope is a major cause of heat gain. Ideal opening to floor area ratio which was calculated based on rate of heat gain was found to be sufficient for two buildings out of three. The existing opening to floor area ratio was found to be reduced than designed ratio.

The Indoor operative temperature was calculated as per ASHARE 55-2013 and Neutral temperature was calculated as per IMAC/NBC standard. It was observed that operative as well as neutral temperatures were out of adaptive thermal comfort ranges specified by both the standards. (Refer to table 1)

Higher operative temperatures were observed on weekends when fans and machinery was not operated.

BUILDING - 3					
Summary for Weekday Temperature Profiles:					
Outdoor Temperature Range (Max - Min) (°C)	Indoor Temperature Range (Max - Min) (°C)	Indoor Operative Temperature range (Max - Min) (°C)	Neutral Temperature calculated as per IMAC (°C)	IMAC /NBC Comfort Range (Max - Min) (°C)	ASHRAE adaptive thermal comfort range (Max - Min) (°C)
35.5-25.20	41.53-28.00	36.50-28.93	28.0	30.14 -25.38	29.18-22.18
Summary for Weekend Temperature Profiles:					
33.00-28.00	35.70-27.00	35.29-27.50	28.4	30.14 -25.38	30.26-23.26

Table 1: Table showing temperature ranges for building 3

The measurements were plotted against thermal comfort survey and observed that even after 70% of reduction in occupancy and activity in second shift, in one of the building; operative as well as indoor ambient temperatures were constantly high. This further validates insufficient natural ventilation and trapping of heat and envelope heat gain. (Shown in Figure 1)

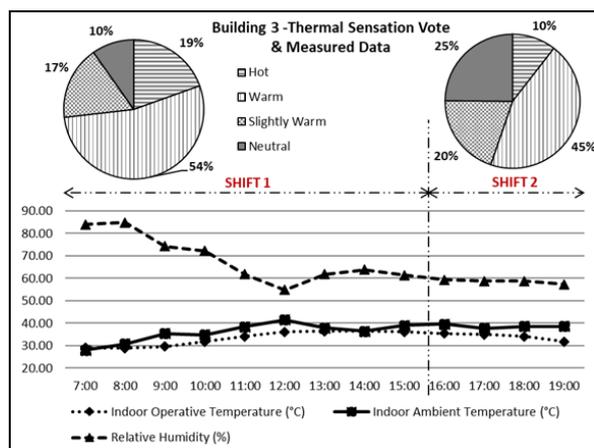


Figure 1: Survey Results compared with measured data

It was also observed that 70%,35%,27% of occupants in building 1,2&3 respectively voted as neutral or slightly warm.

## 4. CONCLUSION

All the buildings were thermally uncomfortable for most of day. It can be said that due to addition/alteration in structures, original building design intent has been lost. This has in turn reduced opening to floor area ratio and resulted in trapping of heat inside building. The building with lesser opening to floor area ratio was found to be highly uncomfortable. It was also observed that building occupants showed acceptance towards temperatures beyond adaptive thermal comfort range.

For existing buildings, effect of passive design strategies for improving thermal comfort can be explored with the help of building simulation.

## ACKNOWLEDGEMENTS

I would like to express sincere gratitude towards all my professors, family, friends and senior management of industrial premise for helping me accomplish this goal.

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# Green Walls Simulation for Subtropical Climates: Sensitivity Tests with ENVI-met V4

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**ABSTRACT:** The presence of vegetation contributes to cooling the urban surfaces and ameliorating thermal comfort. Several studies investigated the effect of vegetation in cities for the last two decades, due to the climate changes caused by the rapid urban expansion [1,4,6,12]. However, there are still few specific studies that investigate these effects for tropical and subtropical cities [5,8]. For this reason, this research aimed to perform sensitivity tests with green walls for ENVI-met model, considering the variables: air temperature, humidity, surface temperature and mean radiant temperature. The method compared different scenarios with green walls, contrasting different soil humidity and different leaf area density using on-site measured data for São Paulo, Brazil. The purpose of the research is to support green walls simulations using ENVI-met, contributing to future studies on tropical and subtropical urban microclimates.  
**KEYWORDS:** Energy, Comfort, Computer Simulation, Green Walls, Urban Greenery, Urban Microclimates.

## 1. INTRODUCTION

Owing to the phenomenon called urban heat island effect (UHI) [9], cities are generally warmer than the surrounding rural areas at nighttime. These changes are partly caused by the large replacement of natural surfaces by urban materials. Concrete, asphalt and masonry surfaces tend to store part of the incoming radiation, while vegetation has lower heat storage capacity and converts a significant amount of the incoming short-wave radiation into biophysical processes and latent heat through evapotranspiration [8].

Previous studies have observed that the presence of green areas has positive health effects [7,12], and the impact is even greater in lower-income neighbourhoods [1], suggesting that urban green areas contribute to reducing urban warming effects as well as human thermal stress [1,12].

## 2. SIMULATION PROCESS

The modelling and simulation process was carried out with the model ENVI-met V4 Science, a prognostic high-resolution microclimatic model, designed to simulate microscale interactions among soil, vegetation and atmosphere. It considers fluid mechanics principles, thermodynamics and atmospheric physics laws, turbulence, air temperature and humidity, radiation fluxes and pollutant dispersion.

To comprehend local greenery parameters, the estimation of Leaf Area Density (LAD) was carried out through an empirical approach, suggested by ENVI-met developers [10] and detailed in personal communications, by counting the total number of leaves inside an imaginary cube with 0.50m x 0.50m x 0.50m, as illustrated in Figure 1. The LAD empirically estimated was used as parameter for sensibility tests.



Figure 1: Area considered for LAD measurement.

For the sensibility tests, the modelling was developed using a 1m x 1m grid, characterized by a single building with 10m x 10m x 15m (x, y, z) and green walls in all façades (Fig. 2), to analyze different parametric scenarios, with the combination of soil relative humidity considering 50% and 60%, and climbing plants with LAD=0.5m<sup>2</sup>/m<sup>3</sup>, LAD=1.0m<sup>2</sup>/m<sup>3</sup> and LAD=2.0m<sup>2</sup>/m<sup>3</sup> [3], besides the variables: air temperature, humidity, surface temperature and mean radiant temperature simulated at 150cm above the soil to quantify potential microclimatic impacts for hypothetical green wall scenarios. The simulation considered 24 hours, using measured data from the central area of São Paulo city [11].

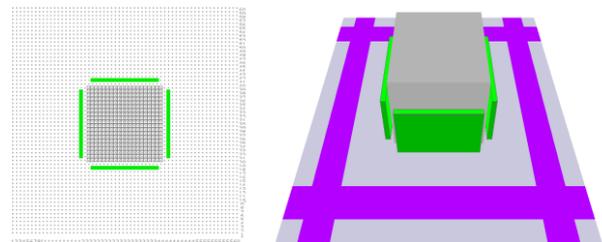


Figure 2: Modelling for parametric scenarios and 3D view for parametric scenarios.

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## 3. CONCLUSION

The results confirm the localized microclimatic effects of the climbing green wall and a distinct behaviour between daytime and night time, equivalent to those caused by other forms of greenery in urban areas. At night, with the lack of evapotranspiration, cooling by the green wall is almost imperceptible. The effect of evapotranspiration is clearly perceived during the day due to a) the slight increase in air humidity by 1.0 g/kg at a temperature of 26°C, and b) the decrease of air temperature, when compared to the scenario without vegetation, of 0.17 °C, 0.36 °C and 0.68 °C (for LAI=0,5m<sup>2</sup>/m<sup>2</sup>, 1,00m<sup>2</sup>/m<sup>2</sup> and 2,0m<sup>2</sup>/m<sup>2</sup>), for a 50% soil humidity, mainly in the leeward direction, as illustrated in Figure 3.

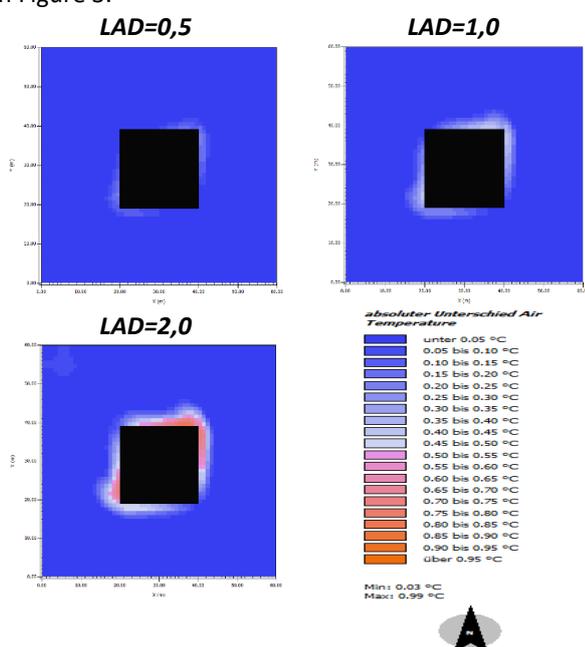


Figure 3: Air temperature gap for LAD=0,5m<sup>2</sup>/m<sup>2</sup>, 1,0m<sup>2</sup>/m<sup>2</sup> and 2,0m<sup>2</sup>/m<sup>2</sup>, compared with no greenery scenario, with 50% soil humidity at 2 p.m., at 1,5 height.

The effects of greenery on mean radiant temperature, despite the LAI increase, are quite localized, making its influence practically imperceptible on the outdoor microclimate under the effect of solar radiation. The increase of soil humidity from 50% to 60% results in increased evapotranspiration leading to a maximum reduction around 0.36 °C on air temperature, at 1.5 m from ground level, for the same LAI. Therefore, vegetation shading results in insignificant variation in mean radiant temperature.

Sensitivity tests suggested very small microclimate effects for the outdoor environment resulting from climbing green walls. Following the model advancements, different green wall technologies should be evaluated for the same purposes. Initial tests show that the model is suitable for further studies, justifying an investment in future research aiming at calibration

between measured and simulated microclimate data for green walls in tropical and subtropical climates and the microclimatic simulation of urban areas with green walls' technology.

## ACKNOWLEDGEMENTS

This research was supported by the São Paulo Research Foundation – FAPESP (Grant #2016/02825-5) and by the National Council for Scientific and Technological Development – CNPq (Productivity Grant 309669/2015-4 and Master Scholarship).

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## A Review on Effect of Overheating in Dwellings on Human Health

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*ABSTRACT: In recent years, heat waves with other human-made health stressors have caused some negative impacts on human health, even resulting in some deaths [1]. The vulnerable populations, such as low-income families, children, the elderly, the homeless, are most susceptible to the health effects of overheating. Therefore, the issue on the effect of overheating on human health has drawn much attention from various research and design fields in recent years. However, the available knowledge is not yet systematically organized in terms of topics, approaches, and solutions. This paper reviews articles in the last ten years on overheating in residential buildings to understand the current research state and emerging efforts made by the domain and explore potential future research directions as well. All the literatures were reviewed according to four categories: research topic, research method, reported result, and solution / strategy. Through analysis of these studies, several features were identified in the study of residential overheating. This study aims to make some contributions to the topic of overheating and provide research suggestions and associated design strategies to the domain of architecture.*

*KEYWORDS: Overheating, Health, Review, Dwelling*

### 1. INTRODUCTION

In recent years, climate change, with other human-made health stressors, has caused some harm on human health. The harm includes heat waves, floods, drought, air pollution, and vector-borne diseases. Heat waves, caused by extreme temperatures, have a particularly a significant impact on human health, even resulting in some deaths [1]. The heatwaves in August 2003 have been associated with 70000 deaths across Europe [2]. In a 2012 Korean study of the elderly in low-income apartments, it is reported that increased body temperature and reduced blood pressure were significantly associated with increased indoor and outdoor temperatures [3]. In the United States, many cities, including St. Louis, Philadelphia, Chicago, and Cincinnati, have suffered dramatic increase in death rates during heat waves [4]. A recent analysis of deaths due to temperature extremes in the U.S. based on death records found an average of approximate 670 deaths per year as resulting from exposure to extreme heat. What's more, climate predictions indicate that extreme heat events will be more frequent and intense in coming decades, and could possibly cause more deaths if without taking any actions [5].

Therefore, this paper reviews related papers on the relationship between overheating threat and health. This is to summarize and analyze the focus of current research and potential research direction in this field. The selection of literature is based on the following three standards: 1. Published after 2010; 2. Cited over 50 times; 3. If the citation is less than 50, then refer to the journal's influence. Then, all the literature is reviewed according to the three categories: research direction, research method, and solutions/strategy. This study aims to contribute to the topic of overheating from the literature review perspective and provide recommendations to designers,

architects, and planners associated to potential overheating issues.

### 2. OVERHEATING AND RESEARCH

This article will discuss the research status of overheating problems in residential settings through the below three aspects: research direction, research method and solution/ strategy.

For the research direction, the research topics are mainly concentrated on these three research questions: 1. How to judge overheating risks; 2. How to determine impact factors; 3. How to reduce overheating risks. With regards to the research question of how to judge overheating risks, some studies examine the current and future risks of summertime overheating. Within the context of a changing climate, some scholars have investigated related factors playing an important role in the performance of buildings. When finding the overheating is indeed threat to occupants, many scholars turned to find possible solutions to reduce the overheating risks. Anna Mavrogianni et al explored the relationship between occupants' behaviors and overheating situations, and quantitatively determined two key strategies of ventilation and shading supply can effectively mitigate overheating risks [6].

Regarding the research method, the widely used research methods are questionnaire, observation, field measurements and monitoring, and associated data analysis and simulation. In particular, data analysis method is often used to judge whether overheating problem indeed exists in a residential building. The questionnaire is normally used to collect the subjective assessment of occupants on indoor environment. Some scholars have used sensors to monitor body temperature to identify user physiological effects by overheating

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problems. The simulation method, e.g. using *Energy Plus* to simulate environmental performance to predict the probability of overheating risks, is frequently used to examine whether proposed solutions are effective to reduce certain overheating risks. Additionally, some studies concentrated on whether a computational simulation model is applicable and accurate to perform such overheating studies through comparing and analyzing occupants' subjective feedbacks and simulating results.

In order to reduce negative impacts of overheating on people health, there are two most popular strategies which are the change of occupants' behaviors and the careful consideration on building insulation upgrades. Particularly, a growing body of literature suggesting that the change of lifestyle on operating a building may have a measurable and great impact on addressing thermal discomfort and potentially reduce the health risk associated with their exposures to high indoor temperatures [7]. In addition, considering the difficulty to change existing urban forms, the change of building geometric forms, proportion and scale, and the reduction of exposed building envelopes which are sensitivity to high temperature would be more implemented [8].

### **3. DISCUSSION**

#### **3.1. Regional trend**

Currently, the studies on this topic were mainly concentrated in the European area. Most of the case studies took European cities as the geographic and climate targets. The impact of overheating on people health has drawn a lot of attentions in developed European areas and shown to be a serious problem if without any controls in the future. However, considering climate warming is a global trend, overheating is also an inescapable presence in many developing countries, such as China, India and hot climatic areas of Africa and South America. The combined effects of rapid urbanization and population growth in these developing countries made potential overheating problems to become difficult and complex. Learning from the lessons of overheating studies in European cities, the change of occupants' lifestyle and the retrofitting existing building structures to improve micro-environmental comfort could be potentially utilized into the overheating problems in these developing countries, but meanwhile the consideration about carbon emissions, ecological effects, and environmental qualities should be also taken into account for such situations.

#### **3.2. Research focus**

Most related studies mainly focused on the civil engineering and other engineering disciplines, such as environmental engineering and material engineering. Then the most proposed solutions are still constrained to the change of building materials and building system such as mechanical shading systems, air conditioning systems,

etc. Few studies would ponder how to reduce overheating risk from the point of view of design approach or improvement of architectural landscape micro-environment. A good design will not only create a comfortable environment, but also help reduce the need for late-stage facilities and the energy-use of heating and cooling. Therefore, it would be a possible direction to consider solutions to address overheating threats in the design track, such as natural resource utilizing (e. g, Natural ventilation, earth sheltered cooling), climatic design, neighborhood landscape, and optimal building forms, proportions, and scales, etc. On the other hand, the lack of considerations of design solutions reflects the poor of awareness of architects on overheating threats. Gupta & Gregg, in their paper of "care provision fit for a warming climate", performed an interview study with design teams and revealed that architects often lack of related consciousness on overheating [9].

#### **3.3. Accuracy of data**

It is necessary to consider the reliability of corresponding data before simulation. Most studies on building overheating risks are at the small to middle-scale structures or environments, in which regional meteorological data rather than local environmental data is normally used for the simulation data input. However, many studies have demonstrated that great discrepancies may exist between micro-environmental condition and regional meteorological one. For example, the wind speed behind highland terrains would be totally different from regional climatic data. Such differences may have great impact on the accuracy of simulation results. Thus, more considerations should be given to the surrounding micro-environment in order to get relatively accurate data and reliable analytical results. What's more, it is necessary to reconsider which particular physical environmental indicators in terms of temperature, humidity, etc. should be taken. For instance, some studies used the mean of the daily maximum temperature for simulation, but some claimed that- the mean is not a good indicator as some variabilities may be overlooked.

### **4. CONCLUSION**

Through our review on related literature, the current research direction on overheating issues mainly focuses on the following three research questions: how to assess overheating risks, how to determine impact factors, and how to reduce overheating risks. Then, the most popular research approaches to investigating overheating issues are questionnaire, simulation, and associated data analysis. In addition, most current research is concentrated in the European region, and the scholars are mostly from engineering disciplines. The architectural field still lacks of related awareness on overheating issues. It also can be found from the literature review that it is necessary to reconsider the data accuracy for simulation

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use, in terms of data types, scales, and calculations. Finally, it has been proven by most scholars that the change of occupants' lifestyle, such as opening windows for introducing natural ventilation, controlling shading systems for cooling purposes, and the upgrade of building enclosure insulations would help to reduce overheating risks.

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## Investigation of the Possibility of Implementation of Community-Scale Solar Within Kuwaiti Neighbourhood Units: A Study on the Effect of Community-Scale Solar Systems on Offsetting Energy Demands in Kuwait.

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*ABSTRACT: Building-integrated photovoltaics (BIPV) can play an important role in supplying the electrical grid with a clean and limitless renewable energy source. This study aims to target a strategy for a solar energy resource in Kuwait's urban areas, which will function as a community solar energy system. The investigation of the possibility of integration of photovoltaics on the roofs of publicly owned buildings such as schools may yield sufficient energy to offset some of the energy loads on utilities or be used by the residential units in those neighbourhood units.*

*KEYWORDS: Energy, Community, Solar, Neighbourhood, BIPV*

### 1. INTRODUCTION

The Kuwait Institute for Scientific Research (KISR) announced that Kuwait tops the world in per-capita energy usage, and pressure on the nation's electricity supply is increasing due to rapid development and the growing population [1]. Kuwait's short- and long-term goals are to ensure that the electric supply meets the growing state's needs. One of the methods for achieving this goal is the implementation of renewable energy, including photovoltaics (PV), an energy-generation technology that uses a renewable and free fuel source, solar radiation, which is plentiful in locations such as Kuwait. PV technology is versatile, modular, and easy and quick to install. Building-integrated photovoltaics (BIPV) is a perfect platform with which to make a meaningful impact on the electricity supply issue. This study will investigate the possibility of PV integration in publicly owned buildings in Kuwait's 'neighbourhood units', which would take the form of mid-scale solar energy generators under a strategy known as 'community solar'.

#### 1.1 Why Focus on Building-Integrated Photovoltaics?

Although solar farms are an excellent approach to solar energy generation, they may require a substantial portion of land, which is a major issue in such a small country as Kuwait. This land can be made available for other applications, as well, such as agriculture or urban developments. On the other hand, BIPV can use existing structures that are largely available and mostly unusable. A study on the potential for BIPV installations on residential buildings in Kuwait revealed that roof space is considered the most suitable location for PV installation in terms of energy generation; furthermore, no other building façades are suitable for PV installation due to shade from nearby buildings and trees, along with window

locations [2]. In addition, Kuwait is located within a predominantly hot and arid region with low annual precipitation; therefore, almost all roofs are flat [3]. Flat roofs are considered the most suitable for solar energy application because the solar panels can be placed and oriented for optimum solar energy generation regardless of the building's orientation [4].

#### 1.2 Kuwait's Neighbourhood Units

Kuwait was planned based on the principle of self-efficient, low-density neighbourhoods consisting of limited populations and amenities to serve these populations, such as schools, mosques, post offices, clinics, and a supermarket [5]. Kuwait's neighbourhood units vary in size and were intended to house an average of 10,000 residents. The units are bounded by roads, and each has its own neighbourhood centre in which the amenity buildings that serve the community's needs are grouped [6].

#### 1.3 Community Solar Power System

The type of construction in this region allows for solar installation on building roofs, whether they are private buildings, such as houses, or public buildings, such as schools. However, as Al-Mumin and Al-Mohaisen [7] discussed, some residential roof surfaces present limitations due to tilt or the presence of mechanical equipment. For this reason, a community solar power system integrated into amenity buildings may represent an alternative approach to increasing energy generation within Kuwait's neighbourhood, as such a concept provides a way to increase solar energy applications within communities where some buildings are unsuitable for solar power installations [8].

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## 1.4 Challenges

One of this study's main challenges is the average Kuwaiti household's high electrical energy consumption, which is almost 128,000 kWh annually [7]; conversely, an average house in Arizona, which shares a similar hot, arid climate, consumes just 13,550 kWh annually [9]. This huge difference in annual electrical energy consumption is based on total built-up area, number of occupants per household, and the highly subsidized electrical energy in Kuwait. The average Kuwaiti house has almost 4 times the built-up area of its US counterpart, almost 3 times the average number of occupants, and customers in Kuwait pay one-tenth of the cost of electrical energy.

## 2. AIM

The aim of this study is to explore the potential for retrofitting and using the existing amenity buildings' roofs in the neighbourhood units and to evaluate a community solar strategy's potential to offset some of the nation's energy demands, along with fulfilling these neighbourhood units' electrical needs.

## 3. METHOD

We started by selecting a neighbourhood unit in Kuwait and investigated the possible available roof space for PV integration. *Helioscope*, a solar energy simulation tool, was tested and verified in comparison with an existing solar energy system in Kuwait; it was then used to simulate the energy generated by potential roof systems in the neighbourhood units. The data for the amount of solar energy generated was then analysed and compared with the energy consumption of the neighbourhood unit's average household.

## 4. RESULTS

The evaluation process concludes with the selection of the Al-Faiha neighbourhood unit to perform the study. It is divided into 9 residential blocks; block 5 houses most of the amenities that serve the neighbourhood unit's population. For the neighbourhood's distributed community solar energy system, 6 school locations were chosen to perform the simulation process. The solar energy system had the following properties: Monocrystalline Silicon panels rated at 360W, fixed tilt, array tilt of 30°, and varied azimuth (the direction the module faces) between 160° and 180°. The simulation resulted in total energy generation by the community solar system of 4,290,100 kWh annually. Based on the annual energy consumption for an average Kuwaiti house, which is equal to 128,000 kWh, the community solar energy system would completely offset the energy demand of 34 houses in this neighbourhood unit.

## 5. DISCUSSION AND CONCLUSIONS

Admittedly, a community solar energy project of this size may not be as large as desired, as 34 houses represent

only 10% of all that neighbourhood unit's houses. But looking at the promising side of such a concept and considering the impact such a system would have if it is multiplied by an order of magnitude, Kuwait has 82 neighbourhood units distributed around the country. A community solar power system similar to the one studied, which is capable of producing 4 GWh annually in each of the 82 neighbourhood units, would introduce an annual total of 328 GWh to Kuwait's energy mix, which would have accounted for 0.65% of Kuwait's total energy production in 2016. That figure may seem small, but the total solar energy generation from building-integrated photovoltaics and utility-scale solar farms similar to those in the United States accounted for only 0.9% of that nation's total energy generation in 2016 [10]. The current study presents a building-integrated community solar power system that utilizes only the available buildings' roof space; if the available roofs can contribute 0.65% of the country's total annual energy production, that figure is promising. We believe that future work requires further investigation to optimize this concept, including the use of other available roof areas in the neighbourhood unit, increased building efficiency, and energy generation exchangeability between adjacent neighbourhood units.

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# Radiant Exergy Analysis on the Process of Human Adaptive Thermal Comfort in Summer

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**ABSTRACT:** This paper describes the results of radiant exergy analysis on the process of human adaptive thermal comfort in summer. A subjective experiment controlling not only indoor thermal environment but also their clothes and posture for removing discomfort was made in 2016 summer. We found that subject's adaptive thermal comfort is related to their cognitive temperature and warm radiant exergy from the interior surface of buildings envelopes. To decrease warm radiant exergy by behavioural controls such as opening the window and the door, and controlling the venetian blind is to decrease their cognitive temperature of the subjects.

**KEYWORDS:** Adaptive thermal comfort, Radiant exergy, Cognitive temperature

## 1. INTRODUCTION

Our thermal comfort is based on the process which consists of physiological, psychological and behavioral adaptation, as well as it is determined by the air temperature, humidity, mean radiant temperature (MRT), air velocity, metabolic rate, and clothes of thermal resistance values [1]. Recent researches have confirmed that thermal comfort is strongly affected MRT, consequently "radiant exergy" from the interior surface of building envelopes [2], and its associated cognitive temperature. However, this relationship between radiant exergy and cognitive temperature has not been clarified adequately. In this study, a subjective experiment in summer focusing on adaptive thermal comfort with cognitive temperature, and radiant exergy was made.

## 2. PROCEDURE

A subjective experiment was made in the room in Geijutsu-no-mori Campus, Sapporo City University for nine days of August 19 to 31, 2016. This room has an eastern face window and a door at the opposite side which a subject can control during the experiment. Subjects were nine healthy male and female students aged 18 to 29 in total and they joined the experiment for 95 minutes from 10:40 to 12:15 per one day.

In the experiment, air temperature, relative humidity, grey globe temperature, and interior surface temperature were measured. The air temperature and humidity were respectively measured at four horizontal points and at three vertical points of the subjects overhead, face, and feet.

In phase 1, the window and the door were closed and the venetian blind was rolled up. Subjects selected two "uncomfortable" points in the room and also selected more two points which they felt "not

uncomfortable" respectively. In this study, we assumed that "not uncomfortable" sensation is equivalent to neutral or more comfortable side at the 7-point scale of comfortable sensation.

Subjects sat on a chair at the 4 points and they also answered their cognitive temperature and thermal sensation (the 7-point scale) of each part of their body.

In phase 2, subjects took environmental control behaviours if they wanted to open the window and the door for cross ventilation, and to pull down the blind for shading. They also answered their cognitive temperature and thermal sensation following phase 1.

In phase 3, subjects took physical control behaviours such as changing their clothes and posture if they want to change. We also recorded their cognitive temperature and thermal sensation following phase 2.

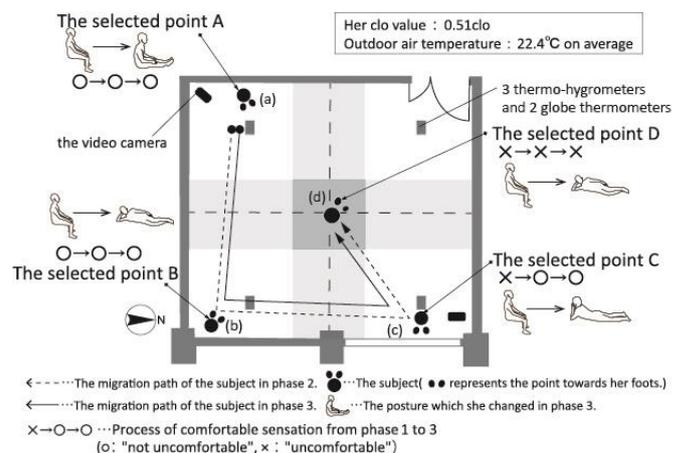


Figure 1: The movement and the sensation of a female subject in the experiment from phase 1 to 3 (2016.08.30)

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## 3. Results and Discussion

Figure 1 shows the movement and the sensation of a female subject in the experiment from phase 1 to 3. Average outdoor temperature was about 22 °C, She felt "not uncomfortable (o)" at the (a) and (b) beside the southern wall surface. On the other hand, she felt "uncomfortable (x)" near the window (c) and the center (d) in the room in phase 1. This is because at the (a) and (b), she felt slightly cool and dark, so that MRT (about 29 °C) at the (a) and (b) are equivalent to room air temperature. At the (c) and (d), she felt slightly hot and bright, so that MRT (about 31 °C) at the (c) and (d) are higher than MRT at the (a) and (b).

In phase 2, she opened the window and the door, so that MRT at the (c) changed from 31 °C to 29 °C. In phase 3, she left off her sandal and turned up sleeves and she changed her posture at the all places in figure 1, so that MRT at the (c) changed to from 29 °C to 27 °C.

Radiant exergy from the interior surface of building envelopes brings "warmth or coolness" feelings to the subjects. In summer, some passive strategies are expected to provide "cool" radiant exergy from the interior surface because MRT is lower than the outdoor temperature [2]. During the experiment, MRT is always higher than the outdoor temperature, so that "warm" radiant exergy is always emitted from the interior surface.

The following equation (1) is for the calculation of the radiant exergy (X) from the interior surface,

$$X = \sum_{k=1}^n f(k) \cdot \epsilon(k) \cdot \sigma \cdot \{ (T_{s(k)}^4 - T_o^4) - 4/3 \cdot T_o \cdot (T_{s(k)}^3 - T_o^3) \} \quad (W/m^2) \quad (1)$$

f - a view factor, a proportion of each interior surface to whole interior surface at the point (0 < f < 1.0)

$$\left( \sum_{k=1}^n f(k) = 1.0 \right);$$

ε - long-wavelength emissivity of each interior surface (= 0.95);

σ - stefan-Boltzmann constant (= 5.67 × 10<sup>-8</sup> W/(m<sup>2</sup> · K<sup>4</sup>);

T<sub>s</sub> - absolute temperature of each interior surface(K);

T<sub>o</sub> - absolute outdoor temperature (K).

Figure 2 shows the relationship between subject's cognitive temperature and warm radiant exergy from the interior surface from phase 1 to 3. Warm radiant exergy decreases at 4 points as well as her cognitive temperature decreases from phase 1 to 3.

At the "uncomfortable (x)" point of (c) in phase 1, her cognitive temperature is 29 °C and warm radiant exergy is 544 mW/m<sup>2</sup> (=0.544 W/m<sup>2</sup>). In phase 2, "uncomfortable (x)" is changed to "not uncomfortable (o)". Her cognitive temperature decreased from 29 °C to 26 °C and warm radiant exergy decreased 250 mW/m<sup>2</sup> by

her environmental controls. Consequently, in phase 3, her cognitive temperature is further decreased from 26 °C to 24 °C and warm radiant exergy decreased to 127 mW/m<sup>2</sup> by changing clothes and posture.

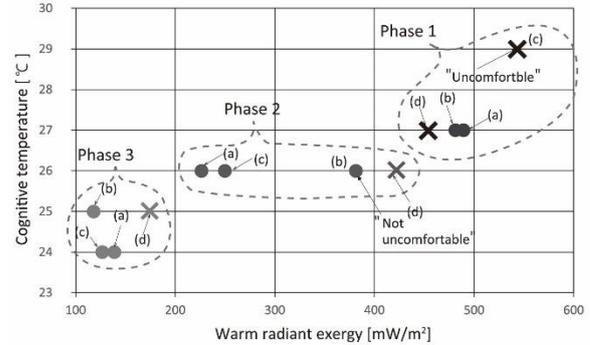


Figure 2: Relationship between the subject's cognitive temperature and warm radiant exergy (2016.08.30, N=12)

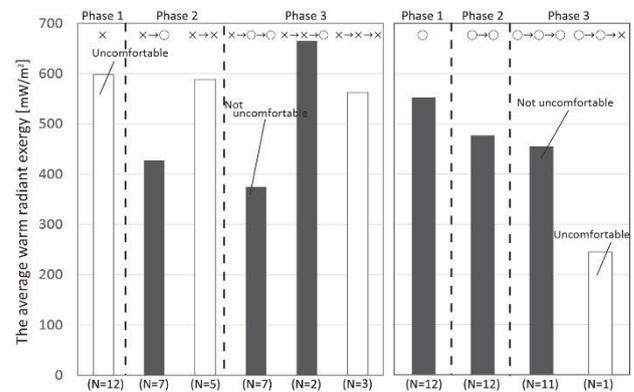


Figure 3: The change of average warm radiant exergy of 6 subjects from phase 1 to 3 (N=24:6 subjects × 4 points)

Figure 3 shows the change of average warm radiant exergy of 6 subjects from phase 1 to 3. In phase 1, the average warm radiant exergy of "uncomfortable" points (N=12) is about 50 mW/m<sup>2</sup> higher than that of "not uncomfortable" points (N=12). 58 % (=7/12) of "uncomfortable" points changed to "not uncomfortable" points in phase 2 by decreasing of warm radiant exergy. That is, 600 mW/m<sup>2</sup> of exergy of the "uncomfortable" points in phase 1 decreases to 400 mW/m<sup>2</sup> of exergy of the "not uncomfortable" points in phase 2. And in phase 3 that is further decreased to 380 mW/m<sup>2</sup>. On the other hand, there are 6 points not related to reduction of warm radiant exergy. These are the reasons not attributable to thermal factors such as comfort for space.

## 4. CONCLUSION

It was found that adaptive thermal comfort is related to cognitive temperature and warm radiant exergy from the interior surface of building envelopes. Reduction of warm radiant exergy from the interior surface in summer can bring "not uncomfortable" sensation with their adaptive behaviors.

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# Characteristics of Cognitive Temperature Scale under the Thermal Adaptation in Summer

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**ABSTRACT:** This paper describes the characteristics of Cognitive Temperature Scale (CTS) under the thermal adaptation in summer. Field measurement and survey in summer for about 640 elementary school students in Sapporo and Kumamoto in Japan from 2009 to 2015 were made. Students put a red sticker on their individual "Thermal Diary Card" when they felt strongly thermal discomfort. They also recorded their CTS to the cards without checking the thermometers. It was found that firstly the CTS are strongly connected to the outdoor temperature in Sapporo and Kumamoto. Secondly, the CTS in Sapporo were around 26 to 27°C when 50% of them felt thermal discomfort. On the other hand, the CTS in Kumamoto were over 30°C. This result suggests that there is significant difference in thermal adaptation to the hot and humid environment in Sapporo and Kumamoto.

**KEYWORDS:** Cognitive temperature Scale, Adaptive Thermal Comfort, Regionality

## 1. INTRODUCTION

Many researches on relationship between thermal comfort in the indoor environment and energy use in the buildings have been made since 1970s. PMV (Predicted Mean Vote) has been utilized as most famous index in the world for evaluating indoor thermal environment and comfort in the room as well as they help designers and engineers to confirm indoor conditions that suit occupants' expectations. However, it is pointed out that the PMV cannot adequately predict thermal comfort or discomfort in the room with natural ventilation in the hot and humid climate in summer [1]. In hot and humid climates there are no current standards that define what those "comfortable" or "uncomfortable" conditions that should be in residential buildings and schools without air-conditioners.

"Adaptive model" as thermal environmental adaptation of the human body has been proposed by Humphrey, Nicol, and Rejal [2, 3]. It is composed of physiological, psychological, and behavioural adaptation as well as it is also influenced by the individual thermal history and the lifestyle. Recently, it was found that thermal adaptive comfort of occupants has been related to the exergy consumption speed within the human body, and warm or cool radiant exergy from the interior surface of buildings envelopes by Shukuya [4].

On the other hand, we have surveyed "Cognitive Temperature Scale (hereafter CTS)" of the occupants since 2009 [5]. "Cognitive temperature" means the output psychological temperature by the occupants for a simple question as "How temperature you feel in this room?" Thermal comfort or discomfort sensation is a concept that corresponds to the "sense-perception" phase as well as CTS is a concept that corresponds to the "cognition" phase.

According to our previous researches, CTS is strongly connected to thermal discomfort of occupants in summer. It is thought that CTS related to personal thermal history and the lifestyle. Furthermore, it will be expected that we are able to clarify the "limit temperature with thermal discomfort" or "the condition without thermal discomfort" for passive cooling buildings.

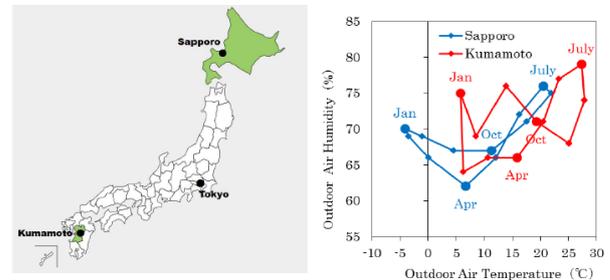


Figure 1: Sites of Sapporo and Kumamoto in Japan (left) and a climograph in Sapporo and Kumamoto (right).

## 2. MEASUREMENT AND SURVEY

Field measurements and survey in classroom of the elementary schools in Sapporo and in Kumamoto in the beginning of September from 2009 to 2015 were made. Figure 1 shows the sites of Sapporo and Kumamoto in Japan (left) and a climograph in Sapporo and Kumamoto (right). Average outdoor temperature in this period is 20.2 °C in Sapporo versus 26.6 °C in Kumamoto. Relative humidity in Sapporo and Kumamoto is about 70 to 75 % during the survey. The reason for targeting elementary school students is to clarify that the difference in thermal history between Sapporo and Kumamoto influences the CTS. In the case of adults, it is often different the place of birth from the place of residence.

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We collected the data of 380 students in Sapporo and 260 of students in Kumamoto. Both schools do not have air conditioners and they always took natural ventilation. Students put a red sticker on their individual “Thermal Diary Card” if they felt strongly discomfort. At the noon, they wrote their CTS to the cards without checking the thermometers in their room from 2009 to 2012. In 2014 and 2015, their teachers told the students the room air temperature after the students answered their CTS. Room air temperature and humidity, and globe temperature were measured at the window and corridor sides, respectively. Outdoor temperature and humidity were also measured.

### 3. RESULTS AND DISCUSSION

The data in 2015 was available only in Kumamoto. CTS of the students, room air temperature, and outdoor temperature in Sapporo are shown figure 2. The above figure in 2009 to 2012, the CTS are distributed around 24.0°C. That is close to the average outdoor temperature (24.4°C) than the average room air temperature (26.4°C) because the students did not check the room air temperature. The bottom figure in 2014, the CTS are distributed around 26.0°C. That is close to the average room air temperature (27.1°C) than the average outdoor temperature (23.2°C). These results suggest that the CTS in Sapporo are originally determined based on outdoor temperature in Sapporo, and the CTS have approached the room air temperature by checking every noon in 2014. The result of Kumamoto shown in Figure 3 has the same tendency of Sapporo.

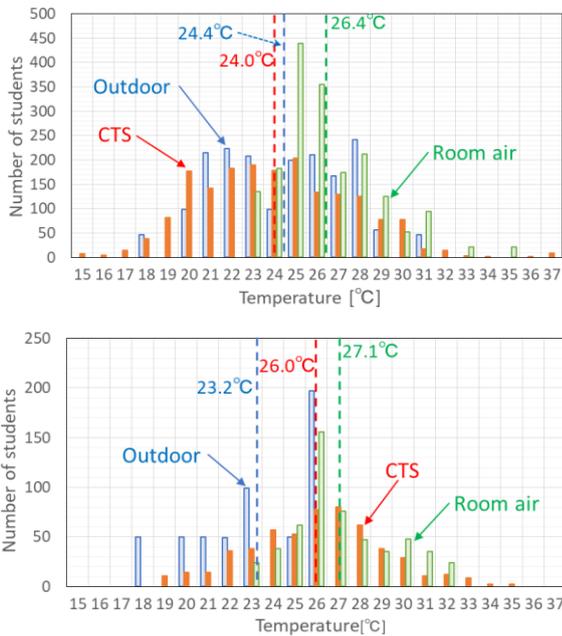


Figure 2: CTS, Room air temperature, and Outdoor temperature in Sapporo (Above: 2009-12, bottom: 2014)

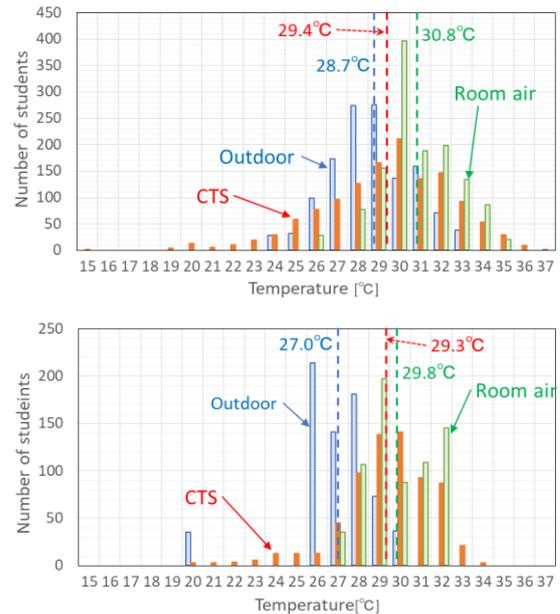


Figure 3: CTS, Room air, and Outdoor temperature in Kumamoto (Above: 2009-12, bottom: 2014, 15)

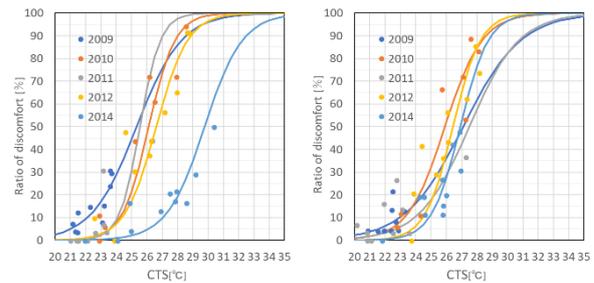


Figure 4: CTS and the ratio of discomfort in Sapporo (Left: at the window side, Right: at the corridor side)

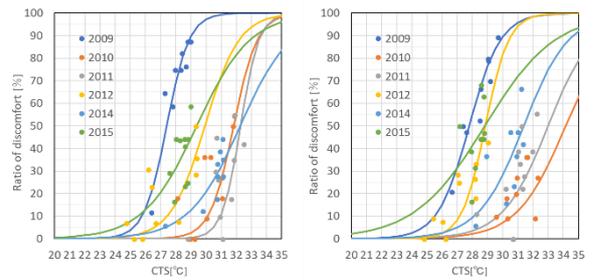


Figure 5: CTS and the ratio of discomfort in Kumamoto (Left: at the window side, Right: at the corridor side)

Figure 4 and 5 show the CTS and the ratio of thermal discomfort in Sapporo and Kumamoto from the result of logistic analysis based on the measured data in 2009 to 2015. In Sapporo, CTS is around 26 to 27°C when 50 % of the students feel thermal discomfort. In contrast, in Kumamoto most of CTS are over 30°C under the same condition, although there are variations.

This result suggests that students in Sapporo and Kumamoto have remarkable differences in tolerance and adaptation to the hot and humid environment. In

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addition, the CTS in Sapporo and Kumamoto have a strong correlation of the maximum of outdoor temperature. In other words, CTS has regional characteristics.

#### **4. CONCLUSION**

This paper showed the relationship between occupant's Cognitive Temperature Scale (CTS) and thermal discomfort in Sapporo and Kumamoto. According to the regional characteristics of CTS, there is significant difference in tolerance and adaptation in Sapporo and Kumamoto.

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# A Study on View Clarity through Window with External Shading Blinds

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**ABSTRACT:** This study is aimed to provide reliable evidences of occupants' view clarity through window affected by direction and angle of the shading blinds for multi-objective design optimization. The study was performed in a lab of Tianjin University in northeast of China, with 18 human subjects, and the data were collected to analyse the relationship between different external shading blinds and view clarity through window. Then the results were used to develop an empirical model to calculate the angle of external shading blinds that can qualify the minimum view clarity level. It can be concluded that the angle of horizontal shading blinds should not exceed 33.2° and the angle of vertical shading blinds should not exceed 48.4° so as to reach the minimum view clarity level.

**KEYWORDS:** External window shading blinds, View clarity, Empirical model

## 1. INTRODUCTION

External window shades can improve building performance with low energy consumption and better indoor lighting & thermal comfort, as well as affect the occupants' perception of the building environment, which is an important issue in current green building research. This experimental study was carried out in a lab with 18 human subjects, and the data were collected to analyse the relationship between different external shading blinds and view clarity through window. Then the results were used to develop an empirical model to calculate the angle of external shading blinds that can qualify the minimum view clarity level. This study is aimed to provide reliable evidences for multi-objective design optimization of external window shades.

## 2. EXPERIMENTAL METHODOLOGY

The experiment was conducted in a lab of the Center for Sustainable Building and Environment, Tianjin University, China. Three rooms in the lab were selected for comparative experiment, and the dimensions of each room is 6m wide × 6m deep × 5m high, with a glass façade facing west (40% window-to-wall ratio). There are plants and yard fence outside the windows. Different types of external shading blinds had been installed outside the windows, and the angle of the blinds can be electrically adjusted (Figure 1, 2).

Eighteen participants (nine female and nine male), aged 16-30 participated in the field study. All participants entered rooms in three groups and sat still for three minutes to adapt to the environment. They were asked to observe through the window with shading blinds for one minute and then complete the questionnaires with seven questions.

The experiments were performed based on four sets of external parameters: 1) different distances from the window, including 1m, 3m, 5m; 2) different directions of

the shading blinds, horizontal and vertical; 3) different sizes of the blinds, 200mm and 300mm; 4) different angles of the blinds, including 0°, 30°, 60° (Table 1). During the experiment, the sun was never within the direct field of view of the participants to avoid the potential influence of glare on view clarity impression.



Figure 1: external shading blinds of the lab

Table 1: Four sets of external parameters

Distance	1m, 3m, 5m			
Direction	Horizontal		Vertical	
Size	200mm	300mm	200mm	300mm
Angle	0°, 30°, 60°			

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Figure 2: inside of the lab

### 3. RESULTS AND DISCUSSION

1152 questionnaires were used in the analysis, with 8064 total responses for all questions collected. A repeated-measures analysis of variance was conducted on the view clarity scores. The results show that:

1) The effect of direction and angle of the shading blinds was proved to be significant on the investigators' overall satisfaction of view clarity, and the interaction of direction and angle was also significant. However, the viewing distance and the size of the blinds did not affect the satisfaction of view clarity.

2) The effect of direction and angle of the shading blinds was also proved to be significant on investigators' visibility of outside information and the accuracy of getting information, view continuity and clarity. The size of the blinds only affected investigators' accuracy of getting outside information.

3) The processed results of the experiment were also used to develop two simplified models for predicting view clarity through window shades (Figure 3, 4):

For horizontal shading blinds:

$$\text{View Clarity} = -0.006 \times \alpha^2 - 0.364 \times \alpha + 68.700 \quad (0 \leq \alpha \leq 90)$$

For vertical shading blinds:

$$\text{View Clarity} = 0.009 \times \alpha^2 + 0.068 \times \alpha + 67.788 \quad (0 \leq \alpha \leq 90)$$

The angle of the blinds ( $\alpha$ ) is the only parameter in the equations. It can be concluded that the angle of horizontal shading blinds should not exceed  $33.2^\circ$  and the angle of vertical shading blinds should not exceed  $48.4^\circ$  so as to reach the minimum view clarity level.

### ACKNOWLEDGEMENTS

This research was funded by the National Key Research and Development Program of China (Grant No.2016YFC0700200) and the National Natural Science Foundation of China (Grant No.51338006).

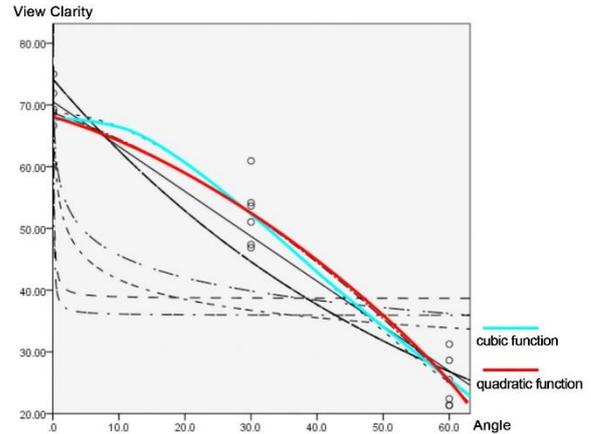


Figure 3: equation of view clarity for horizontal shading blinds

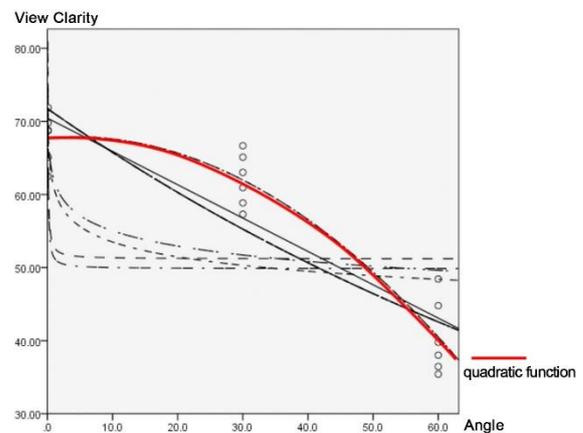


Figure 4: equation of view clarity for vertical shading blinds

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# Multilayer Urban Canopy Modelling and Mapping for Traffic Pollutant Dispersion at High Density Urban Areas

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**ABSTRACT:** A semi-empirical multilayer urban canopy model is developed to estimate vertical dispersion of traffic emissions in high density urban areas. It is motivated by the heterogeneity of urban morphology in real urban cities and the need of quick urban design and planning. The urban canopy is divided into multiple layers, to include the impact of building height variance on pollutant dispersion. The model is derived by mass conservation within each layer through adopting a box model. The validation study indicates that the new multilayer model performs well to model the vertical pollutant transport, and modelling results can mostly follow the trend of the CFD simulations. A case study was conducted to illustrate how to implement this multilayer urban canopy model in the planning practice.

**KEYWORDS:** Urban canopy model, Multilayer, Air pollutant dispersion

## 1. INTRODUCTION

Traffic emission is one of the major sources for air pollution in dense urban areas and its dispersion is highly limited due to closely packed buildings especially near pedestrian level. However, the heterogeneity of urban morphology makes it challenging to model the flow dynamics and pollutant dispersion by CFD and wind tunnel, which require high computational cost. To assist quick urban design and planning process, a semi-empirical morphological method is an alternative solution, and has been broadly documented in air pollution dispersion modelling in the urban canopy[1]. But, most of the models assume uniform building height, which is contradictory to real urban areas. To address the above issue, this study developed a semi-empirical multilayer urban canopy model through introducing the influence of building height variance.

## 2. METHODOLOGIES

### 2.1 Multilayer urban canopy structure

Pollutant dispersion at urban areas is affected by complex flow above and within the urban canopy involving various length scales. One of the main transport mechanisms is turbulent transfer between the street canyon and overlying atmosphere. Adopting a box model, the mass exchange between street and atmosphere is usually represented by an exchange velocity  $u_d$  that is a function of the street canyon geometry and the turbulent flow dynamics [2]. The coupling between external atmospheric turbulent flow and the vortices generated in the shear layer determines the length scale that contribute to the pollutant

transport at the street/atmosphere interface. Therefore the turbulent integral length scale can be estimated [3].

Every layer is characterised by a site coverage ratio  $\lambda_p$  and a frontal area density  $\lambda_f$ . Consequently, the turbulent length scale of the layer with height of  $h$  can be defined as a function of  $\lambda_p$  and  $\lambda_f$  shown as:

$$l = h \frac{\sqrt{2}(1-\lambda_p)}{\pi \sqrt{\lambda_f}}. \quad (1)$$

Taking Hong Kong and Singapore as examples, Fig. 1 gives the distributions of the integral length, which increases with building height and becomes constant when the height exceeds 275m which is consistent with negligible  $\lambda_p$  and  $\lambda_f$ . Below that height, the integral length is nearly a linear function of building height. It indicates that the turbulent mass transport of each layer along the vertical direction is governed by different size of turbulent structure which provides a basis for the present multi-layer urban canopy model.



Figure 1: Vertical distribution of integral length of each layer in metropolitan areas of Singapore and Hong Kong.

## 2.2 Mass transfer between urban canopy layers

The bulk mass transfer across each layer can be modelled by a mass exchange velocity  $u_d$  through adopting a box model approach.  $u^*$  is the friction velocity that is modelled by  $\lambda_f$  using the logarithmic wind profile. The spatially averaged pollutant concentration ( $C_n$ ) can be solved as shown in Fig. 2.

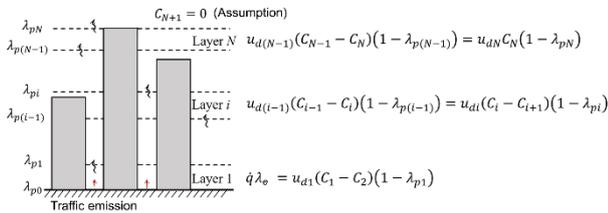


Figure 2: Schematic of multilayer UCM model.

## 3. RESULTS AND DISCUSSION

The present multilayer UCM is tested by comparing with CFD results in cases with different building height variances: two with uniform building height of 60m and 90m, and three with two heights, e.g. 45m and 75m, 40m and 80m, and 35m and 85m. Specifically, there are six columns and ten rows of buildings surrounded by multiple blocks. The study area is located in the centre of the domain and consists of four buildings. The spatially averaged concentration normalized by emission concentration is obtained for comparison as shown in Fig. 3. It is evident that present UCM results follow the trend of CFD results, and building height variance intensifies the difference between UCM and CFD. Through considering non-trivial pollutant at the roof for the case with uniform building height and adding horizontal pollution transport to the case with height of 35m and 85m, the corrected UCM can closely follow the CFD results.

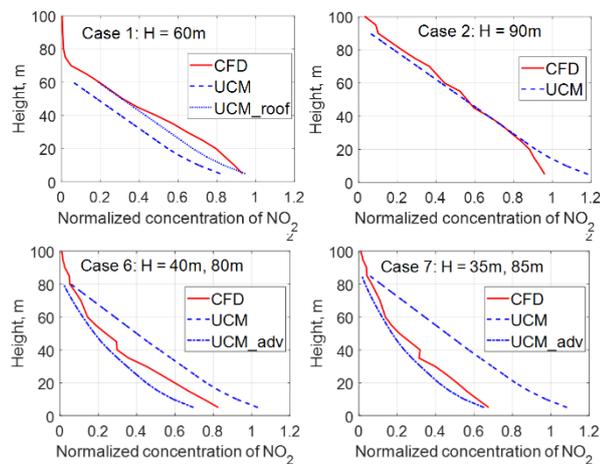


Figure 3: Normalized concentration of  $NO_2$  as a function of height for cases with different building height variances (selected).

## 4. IMPLEMENTATION

The above application of the multilayer UCM and discussion is based on simplified configurations of buildings to evaluate the performance of the new multilayer urban canopy model. In this study, the case study at Singapore is conducted to demonstrate the application of the multilayer UCM in real urban cities. Fig. 4 shows both horizontal and vertical dispersion potential, and provides important information to support evidence-based urban planning.

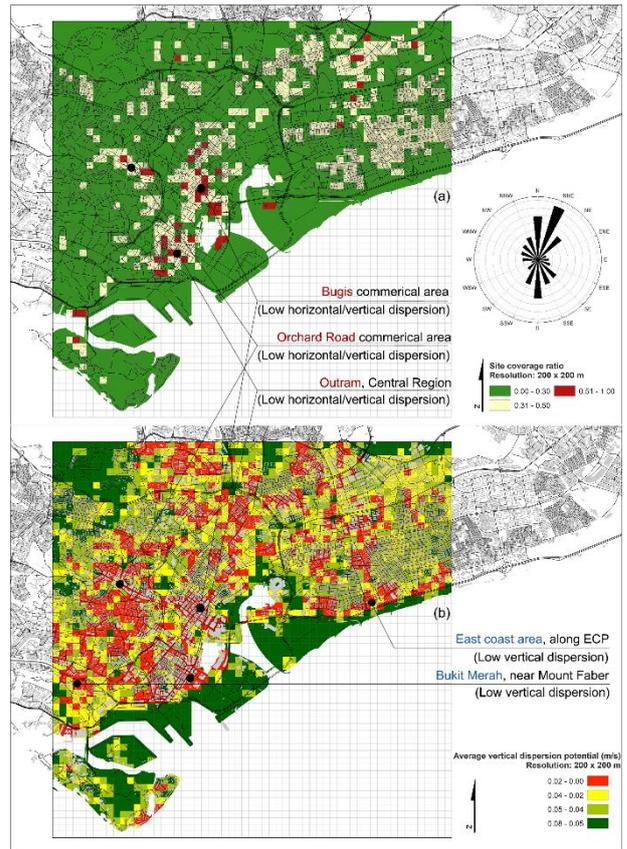


Figure 4: Mapping of horizontal and vertical dispersion potential of traffic emission by UCM for Singapore metropolitan area.

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## Retrofit of an Existing School Building: A Case Study from Hyderabad, India

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**ABSTRACT:** Retrofit of naturally ventilated educational building is an effective solution to the thermal and visual discomfort problems of the occupants. A residential school, located in outskirts of Hyderabad, India. The school functions in an International Baccalaureate (IB) Curriculum. The building has IGBC Platinum rating. The project deals with the retrofit procedure of the Senior Academic Block, which is naturally ventilated. The procedure involved assessment of the existing conditions through climate analysis, thermal images, measurements & occupant surveys. The retrofit design proposal was then presented to the owners and further prioritization and optimization of the scenarios were done based on thermal and daylighting simulations. The tools used for the analysis were EDSL TAS and LightStanza. Replacement of windows and addition of a low-energy cooling system (evaporative cooler) was identified as the best solutions.

**KEYWORDS:** Retrofitting, Thermal Comfort, Visual Comfort, Overheating, Occupant satisfaction survey, EDSL TAS, LightStanza

### 1. INTRODUCTION

To study the degree of overheating taking place inside the academy, thermal images were taken on May 09, 2017 at 12:00 pm. In the month of May, the ambient temperature reaches up to 45°C between 12:00 pm to 04:00 pm.

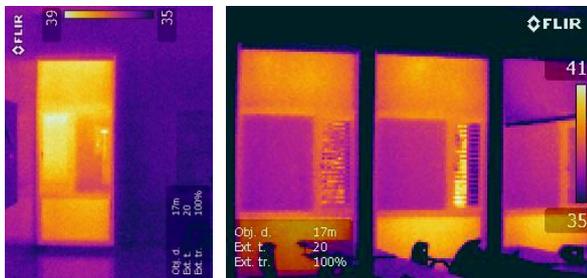


Figure 1: Thermal Images of Windows

Several measurements were taken to understand the problems occurring in the classroom. These included surface temperature, humidity levels, ambient conditions and daylight levels. Thermal Images were captured to give a deep insight into the situation (Fig.1).The images highlighted the roof and wall did not heat as much as the windows heated up. The wall had high thermal mass and the roof is well insulated. The windows are constructed using aluminium, clear glass and pinhead security glass. The windows were a major point of concern to be addressed in order to retrofit the building.

### 2. METHODOLOGY

For appropriate retrofit of a building, a systematic approach was taken in order to maximize the benefits. Retrofitting an existing building has both opportunities

and challenges. Challenges included the uncertainty of climate, functioning of building services, govt. policies and human behaviour, whereas, the opportunities include increase in occupant productivity and better thermal comfort [1]. To ensure best outcomes, the activities were carried out in phases. The phases were:

#### Phase 1: Project Setup & Baseline Study

The scope of the work is defined project goals and targets are set by analysing the existing conditions. The steps for baseline study includes occupant survey, daylight assessment, thermal imaging, issue identification, and climate analysis.

#### Phase 2: Proposing retrofit design solution

Based on the issues and survey responses, several retrofit options are proposed that could be implemented on site. These measures include passive solutions and low energy active cooling system.

#### Phase 3: Baseline simulation & Model Verification

Thermal model & daylight model was developed using EDSL TAS and LightStanza respectively using measured inputs on site. Further, the baseline simulation is validated using the measurements of internal conditions recorded on site which includes temperature, RH & Illuminance levels and thermography survey study results. This helped to understand the behaviour of the building in terms of comfort hour study using IMAC & illuminance levels measured. Zhang *et al* [2] verified the effectiveness of the simulation model and confirmed accuracy for the temperature characteristics with a simulation error less than 10 %. Further, for daylighting

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simulation Ochoa *et al* [3] specifies 20% as the acceptable error limit.

### Phase 4: Simulating the retrofit design solution

Strategies from Phase 2 are simulated in this step and the strategies are simulated as parametric & sensitivity analysis to understand the impact of each retrofit. The analysis was cumulative.

## 3. RESULTS

This section highlights the analysis of findings that were carried out for the study. The results include findings gained through the study of the design intent, climate analysis, occupant satisfaction survey, thermographic survey, daylight study, baseline simulations and proposed retrofit measures.

### 2.1 Occupant Satisfaction Survey

It is evident that during summer months, the thermal sensation of the occupants varied from 0 (neutral) to +3 (hot). Out of 200 occupants surveyed, 131 felt hot in their classroom. During winter months, the thermal sensation of the occupants varied from 0 (neutral) to -3 (cold) and 165 occupants felt slightly cool during winters. Similarly, during monsoon most of the occupants felt comfortable in their spaces.

### 2.2 Thermographic Survey

Thermal images were taken on May 09, 2017 at 12:00 pm. In the month of May, the ambient temperature reaches up to 45°C between 12:00 pm to 04:00 pm. The images included surface temperature, humidity levels, ambient conditions and daylight levels. The images highlighted the high surface temperature of 39°C at the windows whereas the external temperature was recorded to be 37°C at the same time.

## 1.3 Identification of Issues & Strategies

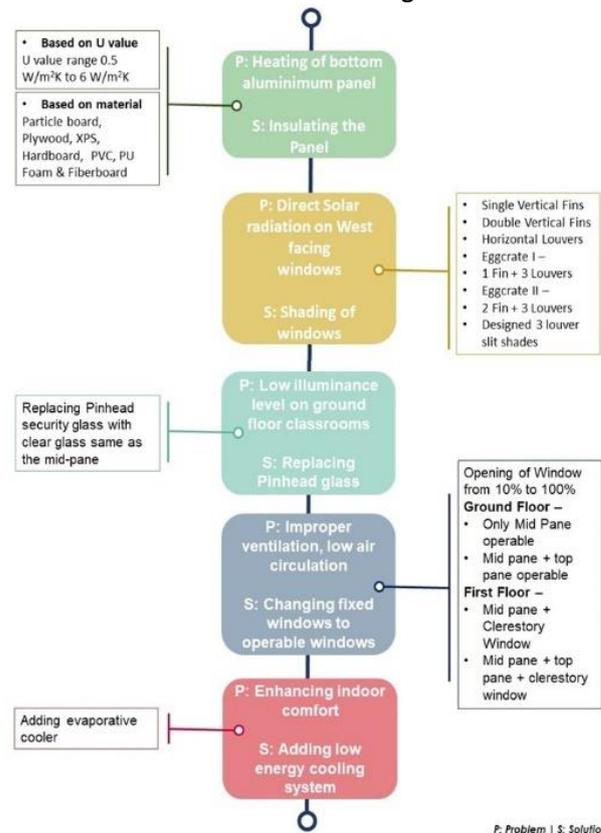


Figure 2: Issues and solutions for retrofit

## 4. CONCLUSION

1. Insulation of Aluminium Panel using 10 mm PU board insulation to reduce the radiative gains.
2. Adding horizontal louvers with slits in between at a distance of 100mm centre to centre on the windows facing west direction to block the incoming radiation during the occupancy hours.
3. Replacing Pinhead security glass with clear glass in the top pane enhances daylight inside the classroom. It also helps reduce radiant heat gains into the classrooms.
4. Converting fixed windows to operable windows which operate to 100% of the opening area in the main windows for ground floor and the clerestory windows combined with top and mid pane has 100% operable area on the first floor. This enhances the ventilation inside the classrooms and provide comfortable thermal environment.
5. Adding a low energy cooling system –Evaporative Cooler to all the classrooms in a centralized manner with a combination of 100% of operable aperture area.

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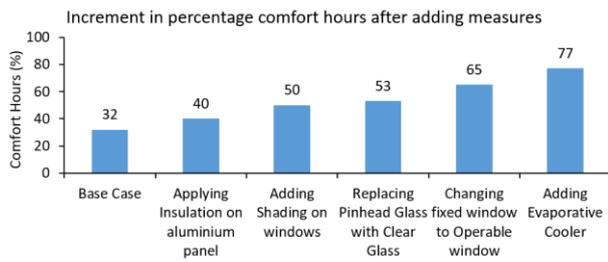


Figure 3: Final retrofit design and percentage comfort hours

## ACKNOWLEDGEMENTS

The authors would like to acknowledge the support provided by the building owners and occupants. The software support was provided by Environmental Design Solutions Limited and LightStanza.

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# Oficity: A New Time-Efficient Tool for Control Fenestration Systems Design.

## Supporting the Early Stage Buildings Design Process

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*ABSTRACT: Currently, office buildings are designed with a high window to wall ratio (WWR), without external solar protection systems (CPS), causing visual and thermal discomfort and high building's energy consumption. Complex fenestration systems (CFS), which include an external CPS, allow the mitigation of these problems. During the design process of a building, it is very important to predict the thermal and visual behavior of the façade systems. There are many validated tools to support the buildings design process that allows evaluating their thermal and lighting performance. Most of these tools require expert knowledge in thermal and visual evaluation methods of buildings. On the other hand, the energy performance of a building highly depends highly on early façade's design decisions. The objective of this paper is to show a new tool to support the design process of office buildings in Chile. This tool allows the simultaneous analysis of the total energy consumption (heating, cooling, and lighting) and the visual comfort conditions in the space of a building. This tool is that it is easy to use and allows reliable simulations in a very short time, which makes it useful and practical for the early stages of the office building design process.*

*KEYWORDS: Energy consumption, office buildings, thermal comfort, visual comfort, simulation tool.*

### 1. INTRODUCTION

The majority of office buildings throughout the world are designed with façades with high window-to-wall ratio (WWR). Identical type of buildings has been built in Chile, a country with high climatic diversity from north to south and from the coast to the Andes mountain range. Façades with high WWR generate severe problems of thermal and visual comfort and require a high heating and cooling energy consumption. To improve the thermal and visual performance of office buildings, complex fenestration systems (CFSs) that include an exterior solar protection system have been shown to be effective in controlling incident solar radiation and light transmission. However, this effectiveness strongly depends on an appropriate CFS design.

In Chile, different studies of office buildings have been carried out, and they show that a high percentage of CFS have not been correctly designed. Measurements of solar and light transmission have also shown that some systems analyzed have critical deficiencies for solar protection or light transmission in façades [1].

To support the design process of a solar protection system as part of a CFS, a simple tool was designed, easy to use, reliable in its results and quick to perform calculations. This tool allows the development of simultaneous simulations of the total energy consumption of an office space, together with evaluating the visual comfort in this space. These simultaneous

calculations are carried out in a few seconds. This tool is **oficity**, it is free and is available on the website [www.oficity.cl](http://www.oficity.cl) and it is supported by PCs, Smartphones and Tablets.

### 2. THE TOOL

The back-end of this tool uses software of wide use in the scientific community and professional experts: **EnergyPlus** for annual energy simulation and **Radiance** for annual lighting simulation. The use of EnergyPlus and Radiance allows the results of the simulations to be highly reliable in the early design stages. The tool is based on a modified *dctimestep* Radiance program that only calculates the work-hours, period of the day with solar radiation, which allows reducing the simulation time.

The simulated space is an office module (Fig. 1). Dimensions of the space may vary according to the user's request. The simulations assume that the simulated space is inserted in a building. Appropriated levels of ventilation are applied in order to achieve indoor air quality. In addition, the office has an automated dimmable lighting system of 10 W/m<sup>2</sup>.

The tool is easy to use, and it requires few inputs:

- City
- Glazed system
- Shading system
- Façade orientation
- Height, width, and depth of the office

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- Window-to-wall ratio
- Number of occupants

It is important to emphasize that the tooling allows the simultaneous evaluation of lighting and thermal performance, which is fundamental for analysis in the design process of a building [2,3].

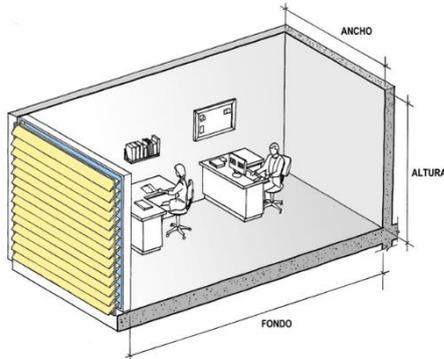


Figure 1: Simulated office space.

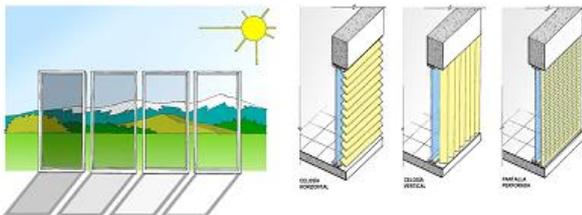


Figure 2: Shading systems available.

**Oficity** incorporates 23 Chilean cities considering the most representative climates of the country.

Glazed systems available are clear simple glazed, clear double glazed, double glazed Low-e, and clear triple glazed.

The solar protections (Fig. 2) available are: (i) without protection, which considers only the window; (ii) tinted glass, where it is possible to change the solar heat gain coefficient; (iii) horizontal louvers and (iv) vertical louvers, where it is possible to set the tilt angle, spacing and width of the louvers; (v) perforated panel, where it is possible to change the perforation's percentage.

The results of **Oficity** use the following metrics: (i) The total energy consumption, which considers artificial lighting, heating, and cooling. (ii) The spatial daylight autonomy (sDA) [4]. dDA indicates the percentage of the area that achieves a minimum of 300 lx during at least the 50% of the annual work hours, (iii) and the annual sunlight exposure (ASE), which indicates the percentage of the area with more than 1000 lx of direct radiation during more than 400 h of work hours.

## 2. RESULTS

Table 1 shows two results of a case of an office of 6 m x 7 m x 3 m located in Santiago, with north oriented

façade, WWR 90%, clear double glazed and three persons. Two shading devices were evaluated, perforated screen panel (PSP) with 20% of perforations and tinted glass (TG) with SHGC of 30%. Simulation takes around 10 seconds.

Table 1: Results of simulation. Total energy consumption, sDA, and ASE.

Shading	Cooling kWh/m <sup>2</sup> year	Heating kWh/m <sup>2</sup> year	Lighting %	sDA %	ASE %
PSP	10.3	0.8	6.7	55	0
HL	88.9	0.0	5.8	57	45

## 4. CONCLUSION

This paper showed a new time-efficient tool called **Oficity** to evaluate the impact of complex fenestration systems in office buildings. The tool is based on EnergyPlus and in a modified version of Radiance *dctimestep* program. The tool obtains results in terms of energy consumption and visual comfort in around 10 seconds. This tool has been shown to be appropriate as support for the early design stages of an office building. It allows the evaluation of the impact of different shading devices to make efficient decisions in this stage of the design of a building.

## ACKNOWLEDGEMENTS

This work was funded by the National Commission for Scientific and Technological Research (CONICYT) under research grant FONDECYT 1141240. The authors also gratefully acknowledge the research support provided by CEDEUS under the research grant CONICYT/FONDAP 15110020.

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# Numerical Analysis of the Improvement Effect on the Thermal Environment of University Buildings in a Humid and Hot City

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**ABSTRACT:** The semi-outdoor space is an important space in the hot-humid climate for preventing indoor environments from overheating and reducing building air-conditioning energy consumption. This paper presents a case study to find out the uncomfortable locations in a university building through field measurement, and proposes strategies for improving the thermal environment in the thermally uncomfortable locations. The improvement effect of the proposed strategies was analyzed using a microclimate simulation tool (ENVI-met) in terms of PMV and etc.

**KEYWORDS:** teaching building, thermal environment, field measurement, numerical simulation, thermal index

## 1. INTRODUCTION

For university teachers and students living in the hot-humid climate, indoor public space and semi-outdoor space such as corridor and courtyard are important places to communicate and relax [1]. Whether these spaces are thermally comfortable is a key factor to keep the teachers and students to stay long or not. Comfortable design for these spaces could play a role in preventing indoor environments from overheating and reducing building air-conditioning energy consumption. The aim of this study is to investigate the thermal environment of indoor public space and semi-outdoor space in a teaching building, and to analyze the effect of the improving strategies.

This paper presents a case study for an university located in a southern China city (Nanning). The study object is a teaching building. The field measurements revealed that there are indoor public space and semi-outdoor space where the thermal environment is uncomfortable. This study proposed improvement strategies from the measurement results and conducted numerical simulations for investigating the thermal improvement effect of the proposed strategies.

## 2. METHODOLOGY

The field measurement and numerical simulation were used to analyze the thermal environment in the targeted building. Typical locations in the indoor public space (corridor passage, courtyard, etc.) were selected as measurement targets where air temperatures, wind velocity, surface temperatures and other thermal parameters were measured on sunny summer days.

Whether the measured locations are thermally comfortable was discussed from the measured data. For the locations where their thermal environment is uncomfortable, improvement strategies were proposed from the viewpoint of bioclimatic design.

## 2.1 Field measurement

### 2.1.1 The study object

The study object is a teaching building with two courtyards in Guangxi University, located in a southern China city, Nanning. Nanning is located just south of the tropic of Cancer, where the summer season occurs between April and November and the highest daily air temperature exceeds 30°C. The monthly mean wind velocity is around 1m/s throughout the year.

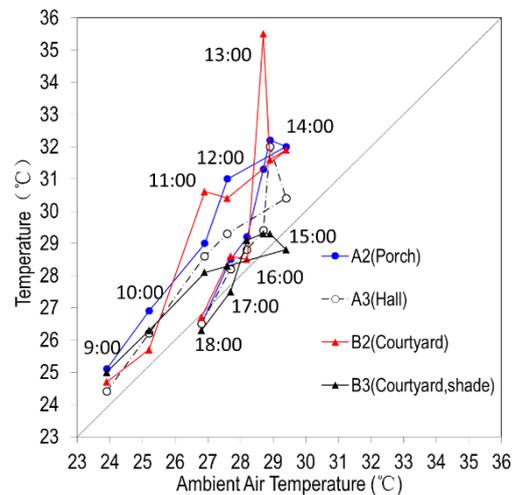


Figure 1: Measured air temperatures on a summer day.

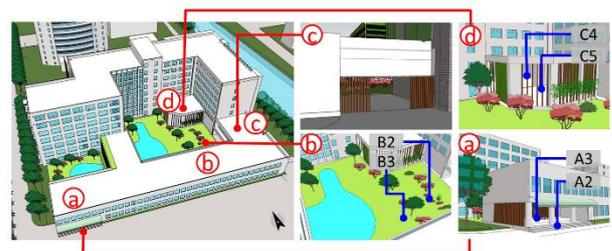


Figure 2: Analyzed locations and improved locations.

## 2.1.2 Results of field measurement

6 measurement points (A2, A3, B2, B3, C4, C5) were selected as analyzed targets in this paper. Their measured air temperatures are presented in Fig.1 and their locations are indicated in Fig.2. A2 and A3 are in the south hall and their ground pavements had high solar absorptance. The air temperature at A2 rose high because the ground pavements were exposed to sunlight during daytime. Although unexposed to sun, the air temperature at A3 was high as much as A2 at 14:00.

B2 and B3 are in the courtyard. The air temperature at B2 was much higher than B3 since the pavement at B2 had high solar absorptance and was exposed to sun. C4 and C5 are in the north hall. Although C4 and C5 had lower air temperatures than ambient air temperatures, there was poor ventilation at the two locations.

## 3. IMPROVEMENT STRATEGIES AND COOLING EFFECT

### 3.1 Improvement strategies

Under consideration of climatic characteristics (hot and humid, weak wind) in the study area and the features of the targeted building, the following improvement strategies were considered [2]:

- (1) Install a 1 meter-long horizontal shade along the porch (location a in Fig.2). Change the concrete wall to a grille and alter the pavement materials in the south hall.
- (2) Change the plastic pavement to soil and plant two shade trees at location B2 (location b in Fig.2).
- (3) Change the closed door to a grille in the east gate (location c in Fig.2).
- (4) Change the window in the activity room to a grille enclosure (location d in Fig.2).

### 3.2 Numerical analysis of the cooling effect

A simulation tool (ENVI-met) was used to simulate thermal parameters [3]. From simulated results, the proposed strategies have the following cooling effect:

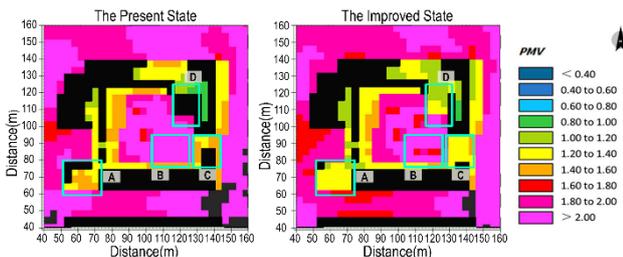


Figure 3: Simulated results of PMV at 1.4m height at 14:00 before and after improvement.

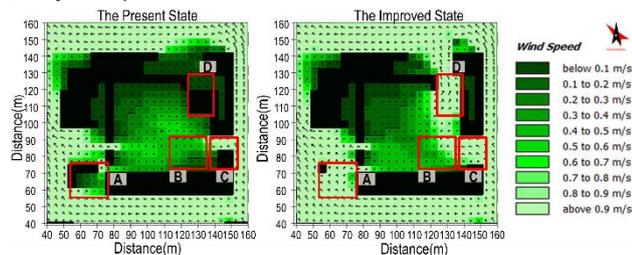


Figure 4: Simulated results of wind speed at 1.4m height at 14:00 before and after improvement.

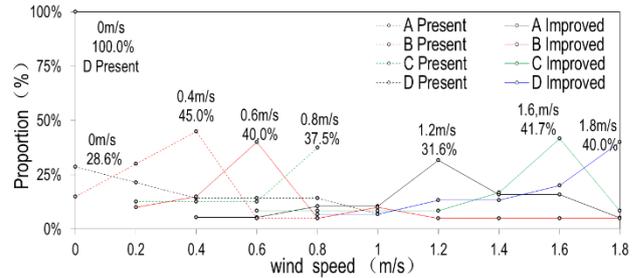


Figure 5: Simulated results of wind speed.

As shown in Figs.3-5, after improving, the ratio of wind speed  $>0.9\text{m/s}$  increased from 21.4% to 89.4%, and the ratio of  $\text{PMV}>1.4$  decreased from 53.8% to 0%. There was an air temperature reduction of  $0.4^\circ\text{C}$  at location a. At location b, the ratio of wind speed  $>0.9\text{m/s}$  increased from 5% to 30%.  $\text{PMV}$  for this location was above 2 before improvement. After improving, the ratio of  $\text{PMV}<2$  decreased 30%; the area of 60% had an air temperature decrease of above  $0.4^\circ\text{C}$ . The ratio of wind speed  $>0.9\text{m/s}$  increased from 62.5% to 92%, and the ratio of  $\text{PMV}<1.4$  increased by 62.5% at location c after improving. At location d, although air temperatures were  $2^\circ\text{C}$  higher and  $\text{PMV}$  increased by 0.2, the wind speed increased up to above  $0.9\text{m/s}$ .

## 4. CONCLUSION

In order to improve the thermal environment in a teaching building, the thermal improving strategies were proposed for the locations where the thermal environment was most uncomfortable under consideration of the field measurement results. Through comparison between simulation results before and after improvement, it was found that the thermal environment can be improved for the targeted area. This numerical method can verify the improvement effect and optimize the proposed strategies based on climatic characteristics and building features.

## ACKNOWLEDGEMENTS

This work was supported from the Guangxi Science and Technology Project (No.AB16380193).

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# Assessing the Photovoltaic Potential of Flat Roofs: Insights from the Analysis of Optimised Array Arrangements

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*ABSTRACT: PV installations on flat roofs offer a wide range of design options, which are usually neglected in urban-scale assessments as these typically assume horizontal or other fixed arrangements. In this study, we analyse the influence of common design parameters (tilt and inter-row distance) in evaluating the potential of PV arrays installed on flat roofs, using three different performance indicators. By comparing optimised arrangements to horizontal ones, we show that the latter could be misleading, unless building- and indicator-specific correction coefficients are applied.*

*KEYWORDS: urban PV potential, building-applied photovoltaics*

## 1. INTRODUCTION

Building-installed photovoltaic systems are a valuable on-site renewable source of energy offsetting the building carbon footprint. Although building-integrated photovoltaic (BIPV) solutions encounter an increasing interest (higher user acceptability, use as replacement of existing envelope cladding), building-applied photovoltaic (BAPV) systems installed as tilted arrays on flat roofs are still a very common solution. In fact, these are generally cheaper than BIPV and provide optimal installation conditions, due to flexible orientation and tilt angle, and good ventilation.

When assessing the photovoltaic potential of a city, a large variety of installation conditions of roof BAPV arrays exists, such as size, azimuth and simple/double orientation (e.g. S or E-W), and tilt angle. However, in solar cadastres the assessment is commonly done assuming that PV panels are installed horizontally [1], [2] or by adjusting the results considering a fixed tilt and spacing [3]. Yet even if a horizontal array would maximise the number of installed panels, such an installation is not technically feasible, because of lack of water drainage and dust self-cleaning. On the other hand, optimal tilt angle and spacing will depend on the specific building and surrounding conditions (in terms of size, shading, inter-reflections), regulatory framework (e.g. self-consumption, incentives) and optimisation objectives (e.g. financial or environmental).

In this study, we compare different tilted installation strategies, maximizing either the financial or the environmental benefits, to simplified horizontal assessments on three flat roofs in a dense urban area. We show that the results are dependent on the roof size and optimisation objective. We finally discuss the relevance of these findings for applications in urban-scale PV potential assessments, such as solar cadastres.

## 2. METHODOLOGY

We assessed the possible installation of PV arrays on three buildings in the city of Neuchâtel in Switzerland, whose characteristics are included in Table 1. Results from tilted array maximising different indicators are compared to those obtained with a simplified calculation model assuming horizontal panels, arranged according to a Cartesian division of the roof surface where the y-axis is North-oriented.

Table 1: Characteristics of the analysed buildings.

Building	A	B	C
Roof area [m <sup>2</sup> ]	459	591	207
Floor area [m <sup>2</sup> ]	1353	3014	880
Orientation	South-East	South-East	South-East
Type of obstructions	Vegetation	Stairwell, chimneys	Stairwell, chimneys

### 2.1 Installation strategies

We selected three possible installation strategies corresponding to three different approaches installers may take in current practice. The first indicator (“energy cost”) exemplifies the approach of an energy utility company that wants to minimise the Levelised Cost of Energy (LCOE). The second approach (“profit”) is aimed at maximising the profit of an investor, considering the cost of both self-consumed and grid-injected electricity, calculated as the Net Present Value (NPV) on a 25-year period. The third indicator (“CO<sub>2</sub> avoidance”) considers the environmental impact of the installation by maximising the avoided carbon intensity with respect to an alternative energy source.

Financial parameters refer to current Swiss local and federal legal framework, with one-time power-based subsidies for <100kWp installations, and a feed-in rate varying depending on the size of the installation, but always lower than the electricity-buying price, which makes self-consumption particularly interesting.

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Estimated income-tax deductions and interest rate (5%) are also included in the financial model.

For the environmental model, we assumed a substitution of the imports from the German grid (conservative value of 300 gCO<sub>2</sub>/kWh [4]) and estimated the carbon footprint of solar panels as 70 gCO<sub>2</sub>/kWh, which is consistent with LCA studies [5].

We studied two typical orientations: South-facing to maximise per-panel production and East-West double-oriented to maximise the size of the installation while matching the building load-curve.

## 2.2 Modelling and simulation workflow

We implemented a parametric study to test the effect of different tilt angles (5-26°, with a 1° step) and distance of arrays (0-195 cm, with a 15-cm step) on the chosen indicators for the two considered orientations. Unlike typical approaches defining the inter-array distance based on a maximum number of shaded hour in the winter solstice [6], our method avoids the arbitrary choice of such a parameter and allows the inclusion of indirect radiation to find the optima for each indicator.

The parametric study was conducted in Grasshopper coupled with Daysim, through the Honeybee interface, to simulate hourly solar irradiances on tilted panels, using a detailed 3D model. The PV yield was calculated using a fixed efficiency of 19.7% and an annual degradation rate of 0.55%, corresponding to a high-tier polycrystalline module available on the market at real installation conditions.

## 3. RESULTS AND DISCUSSION

If we consider the “profit” indicator (Table 2), S-oriented arrays provide the best results for buildings A and B, while an EW orientation gives the best results for building C, as it maximises the number of panels on its smaller roof surface (hence benefiting from peak-power subsidies).

Table 2: Arrangements maximizing the “profit” indicator for the analysed buildings and orientations.

Building	A		B		C	
	S	EW	S	EW	S	EW
NPV [kCHF]	15.5	1.2	26.7	19.1	9.8	10.5
Tilt angle [°]	26	5	26	5	5	7
Spacing [cm]	165	195	165	80	15	0
Power [kWp]	29.0	36.9	27.6	51.1	18.6	21.7
N. of panels [-]	84	107	80	148	54	63
Yield [MWh/y]	24.1	27.6	25.2	41.9	15.6	17.8

Table 3 shows that the electricity yield with optimised tilted arrays is always lower or equal to the one calculated assuming flat panels (simplified method). Similar values are reached when using the “CO<sub>2</sub> avoidance” approach as well as when considering building C, as in both cases the number of installed panels is maximised by using an EW orientation.

Table 3: Yield ratios of tilted arrays to horizontal arrays for the analysed buildings and indicators.

Building	A	B	C
“Energy cost”	0.74	0.73	0.93
“Profit”	0.44	0.38	0.93
“CO <sub>2</sub> avoidance”	0.99	1.03	0.96

Despite the peak-power subsidies and self-consumption benefits, financial-based strategies (“energy cost” and “profit”) favour smaller size, higher-yield South-facing installations for buildings A and B. However, for building C, due to the smaller available roof surface, the array size should be maximised for economy-of-scale reasons, and hence installed facing East-West. Horizontal installations can approximate only the “CO<sub>2</sub> avoidance” indicator. Differently, for the financial indicators, there is no generalizable tilted-to-horizontal ratios, as the roof size, coupled with the incentive/feed-in framework, plays also an important role. Therefore, we can argue that simplified assessments from horizontal estimations (as used in solar cadastres) should consider these factors to determine the optimised arrangement and hence the effective PV potential of flat roofs, whereas this is usually neglected.

## 4. CONCLUSION

Based on the results from simulations on three roofs with similar urban context and under the same climate, we have shown that there is no unique best arrangement for PV arrays on flat roofs. Regulatory and incentive framework, installer goals and roof size are among the factors influencing the results. In the tested buildings, tilted arrays provide 38 to 103% of the energy yield on a hypothetical horizontal installation. In this sense, results from horizontal arrays, often used for urban-scale analyses, should be corrected using building- and indicator-specific ratios, while this is often neglected.

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# Improve Outdoor Comfort in Urban Spaces: Demonstration of Dry Mist Strategies in Tropical Climates

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**ABSTRACT:** Dry Mist technology targets basic human needs by improving micro climatic conditions to create a healthy and comfortable outdoor environment. The technology can be integrated into the design of public spaces, streetscapes, markets, playgrounds and parks to permit intense outdoor activities and to counter the effects of urban heat islands. This paper is about the results of a performance demonstration of Dry Mist Systems in the Cayman Islands. The systems have been successfully tested under tropical conditions in open public spaces, plazas and restaurants.

**KEYWORDS:** outdoor comfort, active cooling, urban cooling, adiabatic cooling, tropical climate

## 1. INTRODUCTION

Water and wind can be combined to create human comfort outdoors. This effect, known as adiabatic cooling, is widely used in warm and dry climates. It is counterintuitive to apply this principle in warm and humid climates. Since 2014, with several demonstrations in Singapore, Doha, India as well as the installation at the BREATHE Austria Pavilion for the EXPO 2015 in Milan it was proved that a Dry Mist concept can create great outdoor comfort. When the flows of air and micro droplets are well balanced, people are not sprinkled with water - they experience only a cool breeze.

## 2. COUNTERINTUITIVE INTERVENTION: DRY MIST FOR HUMAN COMFORT

In warm and humid climates, misting systems are often installed to improve conditions in public spaces. However, people often reject them as they are sprinkled with water droplets and disturbed by noise. When the process is studied with advanced human-

biometeorological models [1], it can be found that fully developed adiabatic cooling and elevated air speeds could, in theory, create a great improvement of outdoor comfort. (see Figure 1 for predictions for tropical climatic conditions at Cayman Islands).

Since then several experiments showed that such a process could be realized with very small droplets created by specially designed high pressure nozzles and a focused air flow. As the droplets fully evaporate and people feel only a cold breeze, the technique was called Dry Mist [2].

In warm and humid environments, visitors seek relief in cool resting areas. A reduction of 3°C in the Universal Thermal Climatic Index (UTCI) is a noticeable improvement. With the Dry Mist system tested, a reduction in the UTCI of about 6°C was measured, even in the very humid tropical conditions of Cayman Islands.

### 2.1 Demonstration to prove perception

Anyhow, many people have bad experiences with conventional misting installations and are not convinced

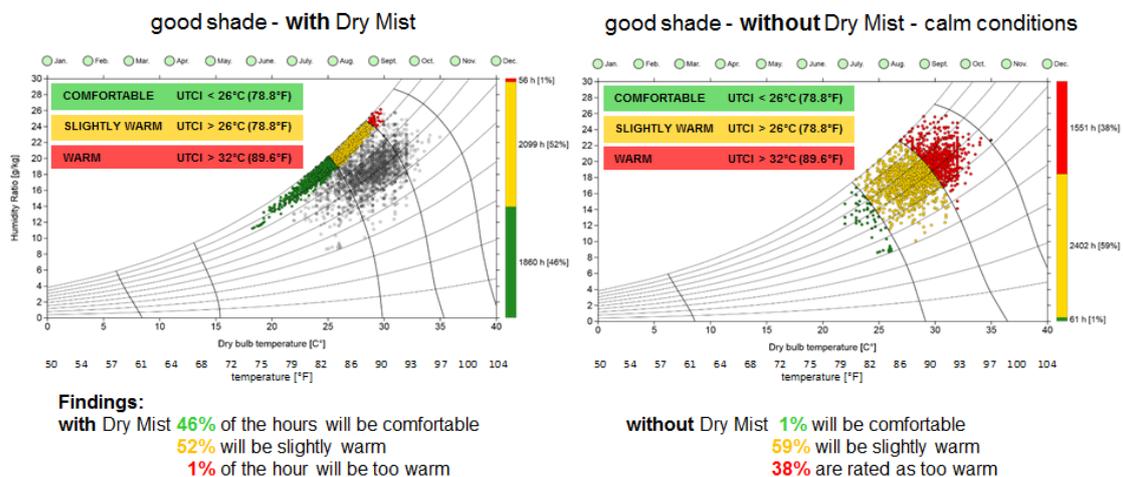


Figure 1: Human Bio-meteorological charts with UTCI comfort envelopes. Predictions for a well shaded streetscape in the tropical climate of the Cayman Islands. The Dry Mist System enhances the perceived outdoor comfort for nearly all hours of operation from too warm (red) to slightly warm (yellow) and comfortable (green).

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by good scientific numbers. Also, people are not familiar with the meaning of advanced outdoor comfort parameters such as UTCI. But people are human sensors! So a series of demonstrations were initiated. For the testing and demonstration in the Cayman Islands the Dry mist systems were installed in several streetscapes, plaza and restaurants. Besides taking scientific readings, movies were taken of visitors passing by. The visitors did not know that they were part of an experiment. Their reaction indicated that the cool breeze was more than welcome; it made them slow down, rest and enjoy the ambience. The direct perception - not the carefully taken scientific readings - convinced the clients to install the Dry Mist system.



Figure 2: People rest and enjoy cool breeze by the Dry Mist Fans at Cayman Islands

### 3. DRY MIST TECHNOLOGY

The Dry Mist Technology fans have been developed to create an adiabatic cooling effect of 4 to 6 °C UTCI with a noise level < 30 dBA at a typical distance of 3 m.

The design is highly energy-efficient. The measured power demand per fan is about 26 W for fan speed 2, 71 W for fan speed 3 and 160 W for fan speed 4. Because of efficient performance, the fans are typically operated at fan speed 3.

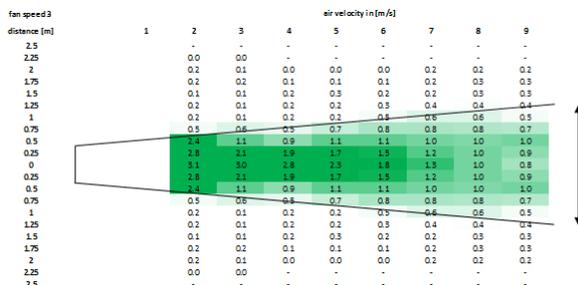


Figure 3: Measured flow pattern and air velocities at optimized Dry Mist Fan for fan speed 3.

Each fan can treat an area between 9 and 15 m<sup>2</sup> while using a maximum of 5.4l of water per hour.

### 3.1 Performance measurements at Cayman Islands

To verify the performance at Cayman Islands and to determine the UTCI, relevant environmental parameters including solar radiation, globe temperature, air temperature, air humidity, air velocity have been measured with data loggers on 6 min sampling rate. Figure 4 shows the reduction of the UTCI with the distance to the Dry Mist Fans. Reference, with 35.4 °C UTCI, is measured in shade with still air. With a fan speed of 3 UTCI is reduced by 5.5 °C at 2 m and about 4.5 at 4 m and. In 9 m distance the reduction is about 1 °C UTCI. Different fan speeds have been tested.

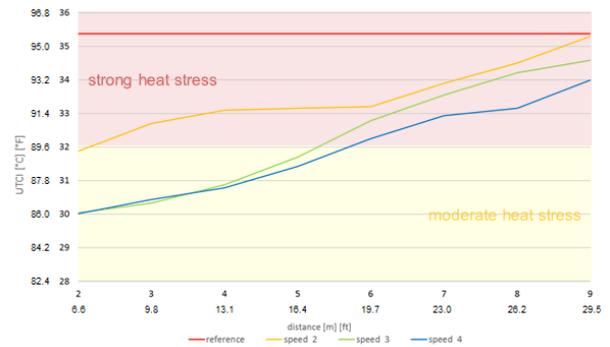


Figure 4: UTCI comfort depending on distance to Dry Mist Fan and fan speed

### 4. CONCLUSION

For outdoor conditions, elevated air speed can be combined with Dry Mist Technology to create human comfort. This low-tech and low-energy solution has the potential to improve public spaces ranging from outdoor train stations to public plazas and parks. The Dry Mist Systems can form part of a holistic outdoor comfort design considering shading and wind [2]. Applying a technical adiabatic cooling process, the Dry Mist Systems can be well integrated with well-watered green areas to mitigate heat urban heat island effects on a local human scale [3,4].

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# Wooden Windows in the Historic Alpine Architecture: Balancing Energy and Conservation Needs

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*ABSTRACT: Energy performance of historic buildings is an urgent matter, but mass implementation of efficient measures faces several challenges (namely, conservation, durability, or comfort). This paper presents the results of a multidisciplinary study of wooden windows in alpine buildings. Different approaches are needed depending whether the original window is maintained or substituted. In the first case, the results of a desk-based study led to the proposal of two new strategies of intervention. In the latter, an interdisciplinary workshop allowed highlighting the deficiencies of current practice whereas simulation results supported the definition of new approaches to address them.*  
*KEYWORDS: Historic building, energy retrofit, wooden window, window shutter, window-wall connection*

## 1. INTRODUCTION

Historic buildings are a big share of the residential built stock. In countries like the UK, Spain, Denmark or France, more than 20% of buildings were built before 1919 and almost 40% before 1945. Energy retrofit of historic buildings could avoid up to 180 Mt of CO<sub>2</sub> emissions annually [1]. In order to minimise climate change and stay within the *2-degree Limit*, national and international mandates on energy efficiency are putting significant pressure on the built heritage.

Windows are a significant source of heat loss in historic buildings [2]. Thus, improving their performance could have a major impact on the energy consumption of the built heritage. Nevertheless, windows shape the building from an architectural point of view and, in those cases where materials were preserved, are witnesses of the artistic and technical skills of a period.

The substitution of original wooden single glazed windows with standardised efficient units would have an unacceptable impact on the external appearance of historic buildings. In addition to that, it is necessary to highlight that often very little attention is paid to the changes in the hygrothermal behaviour of the building increasing the risk of mould growth and condensation around the window. Therefore, new robust and heritage compatible solutions are urgently needed. This paper explores new sympathetic retrofit approaches that improve historic wooden windows' performance while respecting their history and value.

## 2. SCOPE AND METHODOLOGY

Work on historic windows has mainly been focused on the thermal performance of glazing and there is still a significant lack of understanding around how the other components of traditional windows (frame, edge bond, glass-dividers or shutters) can be improved to enhance the overall thermal performance of the installed window and to ensure moisture protection.

This paper will therefore focus on two aspects: (i) the conservation compatible improvement of existing windows by enhancement of the non-transparent part and (ii) the improvement of the connexion between the wooden frame and the wall in those cases where the window should be replaced.

A desk-based analysis of historic alpine window construction allowed the identification of new solutions for the cases where the original window should be kept. The window-wall connection was analysed in several steps. First, a series of workshops with window manufacturers was organised to investigate the current practice and understanding of local trades. Current local approach to window renovation was then investigated and evaluated by means of numerical simulation with a two-dimensional building heat-transfer modelling software. Starting from that snapshot, the window-wall connection was optimized minimising the number of components and energy losses, ensuring an airtight connection, and verifying the moisture protection.

## 3. NEW SOLUTIONS FOR OLD WINDOWS

Studies led by Historic England [3] and Historic Environment Scotland [4] found that shutters are the most effective traditional method of reducing heat loss through timber sash windows. However, whereas in England and Scotland shutters are placed inside and can be folded with the internal panelling, in the alpine region shutters are traditionally placed outwards and fold against the external wall. These therefore require a different approach towards their retrofit that has not yet been explored. Moreover, in some areas of the alpine region, it was custom to replace the wooden shutters with a second glazing layer during the coldest months. These "*winterfenster*" (or winter windows) enhanced solar gains while minimising heat losses [5].

Where wooden shutters are used all year around, combining insulation and materials with high thermal

inertia (such as PCM) would allow not only to reduce the heat loss through the opening at night (fig.1a), but also to make use of the solar gain accumulated during the day when the shutters are open and exposed to the sun (fig.1b). Moreover, embedded PCM in shutters could also moderate the internal climate in summer minimising the increased risk of overheating caused by internal wall insulation (fig.1c,d). Research developed to date have not addressed the performance of traditional shading devices and the potential of solar energy in historic buildings or have proposed solutions that would not be compatible with the built heritage.

Alternatively, reinstating the traditional practice of using removable secondary glazing in winter would be a solution to minimise the heat loss. These temporary interventions would reduce the overall U-value and air infiltration of the window, while respecting the conservation and aesthetics of the façade.

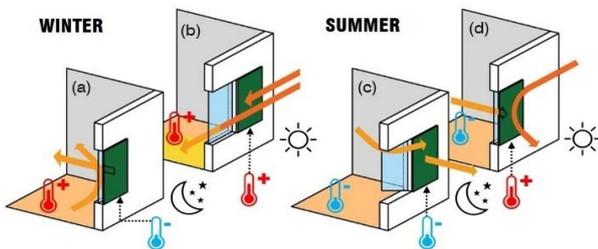


Figure 1: Yearly operation of thermally improved shutters

#### 4. IMPROVING THE WINDOW-WALL CONNECTION

Local construction skills have traditionally developed into different solutions adapted to the particularities of the area. Wooden windows play an important role in alpine construction. In the South Tyrolean Alps (Italy), wooden windows are particularly present both in new and historic buildings. Here, local craftsmen refined window construction by adding the use of a hidden sub-frame that improves the window-wall connection. Nowadays, the industry produces high-quality windows but the connection with the wall is often neglected.

A workshop with researchers, planners and craft companies identified two main problems in recently renovated historic buildings: an increase in the airtightness without raising the ventilation rate accordingly and an improvement of the thermal performance of the window without enhancing the thermal insulation of the wall around it. This has led to scenarios of mould growth and condensation risk. Therefore, three aspects should be improved in the design of the window-wall connexion: (i) internal surface temperatures, (ii) heat losses through thermal bridges and (iii) connection airtightness.

Although tailor made solutions are often needed in the case of historic buildings, the lessons learned in the example below can be translated to many traditional alpine buildings. Simulations showed that window substitution in a 16<sup>th</sup> century building in Bolzano (Italy)

would result in high mould growth risk on the window reveal due to low surface temperatures (fig.2a). Although the application of internal insulation was not possible in the most parts of the building, the surface temperature could be increased by applying a thin layer of insulating plaster on the window reveals (fig 2b). In this particular case, thermal heat losses could be reduced even further as we found a void behind the existing plaster where it was possible to insert an insulation layer of 8-10 cm (fig 2c). This allowed an increase the surface temperature in the critical points to ensure a moisture free connection.

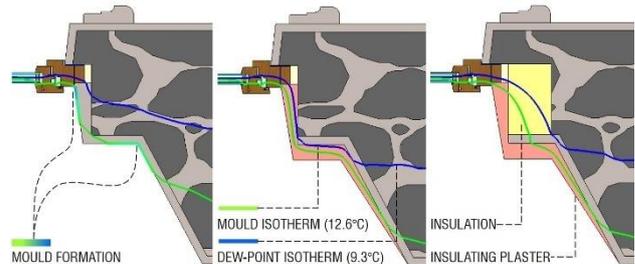


Figure 2: Optimization of the window-wall connection

#### 5. CONCLUSION

We have identified innovative approaches to reduce the heat loss in cases where existing windows cannot be replaced. We propose two strategies that alter only the outer layers of the fenestration while respecting the original window: (i) thermally improved wooden shutters with insulation and PCM coatings and (ii) the reinstatement of the traditional secondary glazing use with the efficient glazing. In cases where it is possible to replace existing windows, we identified the deficiencies of current solutions. In particular, the biggest issue was the lack of attention in the study of the window-wall connection detail leading to an increase of the risk of mould formation in the reveal area.

#### ACKNOWLEDGEMENTS

This work has been funded partly by the EU FESR project “PLANFenster: Planning and optimization of South Tyrolean wood windows and their installation”.

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# Thermal Performance of Laterite Quarry Scrap: An Alternative Material for Cost Effective Construction in Konkan Belt, India

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*ABSTRACT: Laterite stone is an integral part of vernacular architecture in konkan belt of India. Procurement of these stones involve quarrying by small scale industries that have no further action plan in disposal of the scrap generated during the stone cutting. The paper looks at utilising the laterite quarry scrap to make blocks and exploring the opportunities the material holds in terms of its thermal properties, environmental factor, economic factor and structural factor. To establish the thermal properties of the scrap block in comparison to laterite stone and concrete block, a wall module of the respective material was built to determine a comparative decrement factor and time lag. The paper recommends the use of scrap, utilising locally available material, curbing the pollution generated and providing a cost-effective solution for the locals.*

*KEYWORDS: laterite quarry scrap, thermal performance, cost-effective, environmental factor, time lag*

## 1. INTRODUCTION

Laterite stone is widely used for construction and is an integral construction material in the vernacular architecture in the Konkan belt of India. They are easy to cut and harden on exposure to air making it an ideal material for construction. Laterite stones are quarried and in this process lot of overburden or unwanted scrap is generated. These quarries are both manual and semi mechanized. Depending on technique used the scrap generation varies. Most of the quarries are manual and fall under the small-scale industry; hence there is no further plan of action in terms of dealing with the scrap generated. In a manual quarry, every 50-55 cut stones generate up to a 20-25% scrap. After each layer of cut stones this scrap is removed and its disposal is a matter of concern. The laterite quarry scrap can be found in abundance at laterite quarry sites [7][6] [4][1].

## 2. AIM AND OBJECTIVES

The paper looks into utilization of locally available materials as it is an important step towards sustainable construction, reduction in transportation cost, saving embodied energy, and protecting the environment.

The study enquires the feasibility of laterite quarry scrap as an alternative material through quantitative analysis. Primary data was collected through field tests on the laterite quarry scrap to determine its physical composition. The scrap being a by-product of the parent rock, displayed similar characteristics to a lateritic soil [8][9].

## 3. RESEARCH METHODOLOGY

The study explored the opportunities the material holds in terms of its thermal performance, environmental factor, economic factor and structural

factor. To test the thermal performance, the methodology used was to establish its decrement factor and time lag in comparison to the other locally available construction materials i.e. laterite stone and concrete blocks.

To compare and study, the laterite quarry scrap was compressed to be made into blocks with a composition of 80% laterite scrap, 15% lime and 5% saw dust. Blocks were made of sizes 350 mm (L)×230 mm (W) ×190 mm (T).



Figure 1: Showing the blocks being made. (anti-clockwise from top- the block making process and the finished blocks kept for drying)

The blocks were made with lime as binding agent considering the advantages it holds over cement. Thermal testing of the three-wall modules, the concrete block wall, the laterite stone wall and the laterite quarry scrap block wall were conducted using a hot box apparatus according to standards comparable to ASTM C1363 [5][2].

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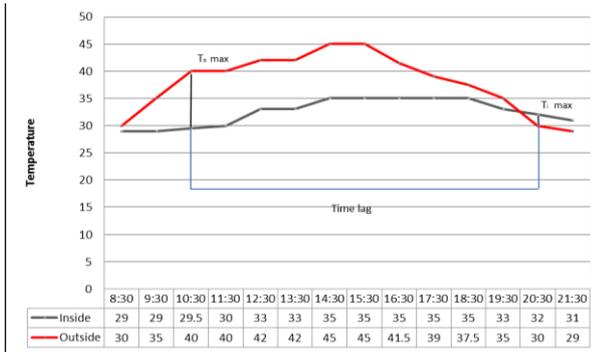


Figure 2: Temperature readings of inside and outside temperature for 190 mm thick laterite quarry scrap wall

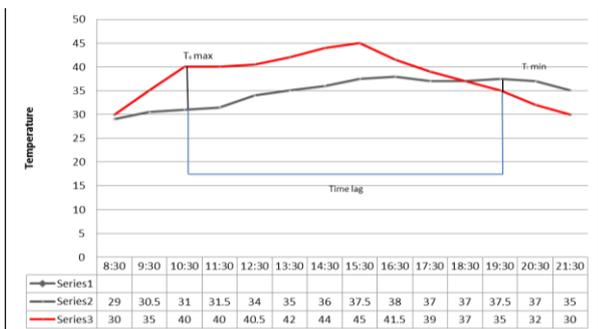


Figure 3: Temperature readings of inside and outside temperature for 190 mm thick laterite stone wall

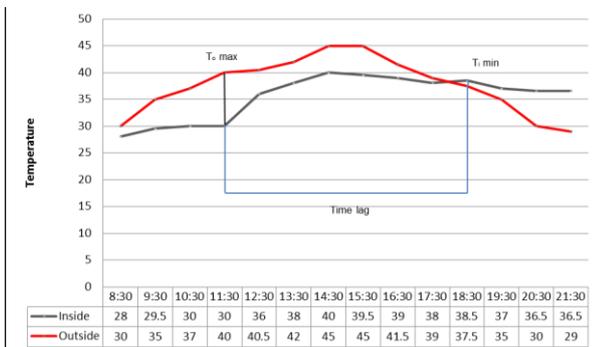


Figure 4: Temperature readings of inside and outside temperature for 190 mm thick concrete block wall

Wall module no	Wall module 1 (Laterite quarry scrap block)	Wall module 2 (Laterite stone)	Wall module 3 (concrete cement block)
Testing date	27:05:2017	28:05:2017	29:05:2017
time	8:30 am to 9:30 pm	8:30 am to 9:30 pm	8:30 am to 9:30 pm
Avg temperature	31 degree Celsius	31.3 degree Celsius	33.3 degree Celsius
RH %	70.9%	71.6%	70.2%
Time lag	8hrs	10hrs	6hrs
Decrement value	0.14	0.09	0.16
Cost of production	16rs	25rs	22rs
Compressive strength	1.88N/sqmm	>3.5N/sqmm (BIS, 2003)	>3.5N/sqmm (BIS, 2003)

Table 1: Recorded data of the tests conducted on the three wall modules along with cost and strength comparison.

The laterite quarry scrap block wall performed comparatively better than concrete block wall but not as well as the laterite stone wall as shown in table 2. This comparison is drawn from the decrement factor and time lag of each wall system.

## 4. CONCLUSION

The experiment shows that the laterite quarry scrap can be used as a construction unit for better thermal performance. Since the compressive strength is not as per the BIS standards, the paper recommends the block to be used as infill material. The compressive strength of laterite quarry scrap block according to BIS standards can be achieved by the block with 85% laterite stone scrap, 12% cement and 3% paddy husk ash, costing INR 23. However, the thermal performance may vary because of presence of cement. [6]

## ACKNOWLEDGEMENTS

Thanking Prof. S. K. Jain for providing the equipment's, place to conduct experiment, constant support and guidance throughout the project. I would like to thank Prof. Roshni Udyavar for her undivided support. My sincere thanks to Nishant Modi for assisting me with the experiments.

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# The Impact of External Façade Shading on the Thermal Comfort of Public Rental Housing under Near-extreme Weather Conditions in Hong Kong

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**ABSTRACT:** The comfort and health of building occupants are significantly affected by the indoor thermal environment, which can be improved by building envelopes with a good façade design. This study aims to explore the impact of façade shading on the indoor thermal comfort by adding external shading panels on a typical public rental housing building in Hong Kong. Potential improvements on thermal comfort, in terms of indoor operative temperatures ( $T_{op}$ ), were evaluated for vertical and horizontal shading panels that were tilted at different angles to the façade. Simulation results on DesignBuilder reveal that horizontal shading panels (with a  $T_{op}$  reduction up to 0.91°C) can achieve a better thermal performance than those oriented vertically (with a maximum  $T_{op}$  reduction of 0.57°C). Moreover, shading panels tilted at 90° to 45° for horizontal panels and at 75° to 0° for vertical panels were preferred for better thermal performances. This strategy can be readily implemented to procure more sustainable public housing without causing obstructions to the window view of occupants.

**KEYWORDS:** Façade shading, Indoor thermal comfort, Operative temperature, Public rental housing

## 1. INTRODUCTION

In recent years, buildings face increasing risks of overheating in summer due to more frequent heatwave weather conditions and the dense urban morphology. Occupants thus suffer from thermal discomfort, higher energy costs, and even heat-related illnesses. The elderly and low-income families living in public rental housing (PRH) estates in Hong Kong are particularly vulnerable to prolonged overheating during the hot and humid summers. Hence, the use of appropriate passive design strategies for PRH is crucial for maintaining the indoor thermal comfort of occupants [1].

Building performance can be significantly improved by applying passive design strategies (e.g. providing shading, adding insulation, improving airtightness) during building retrofits. Adding external shading panels to existing buildings is potentially a popular strategy for local governments because of its ease in implementation. However, window shading designs may be restricted by various considerations on view obstruction, natural ventilation, and indoor lighting. Therefore, the application of shading panels on opaque building façades is explored in this study. Also assessed are the impacts of different shading panel designs on the indoor thermal comfort of a typical PRH building in Hong Kong.

## 2. METHODOLOGY

### 2.1 Building model and weather data settings

Building simulations were performed using the EnergyPlus software v8.5 within DesignBuilder. Standard component blocks were added onto a typical PRH building as shading devices on external walls facing the east and the west (Figure 1). Buildings were simulated under free-running conditions for the design summer week. In order to take into account the more frequent occurrences of near-extreme summer conditions due to climate change, the Hong Kong summer reference year (SRY) weather data [2] was used as input for building simulations in this study.

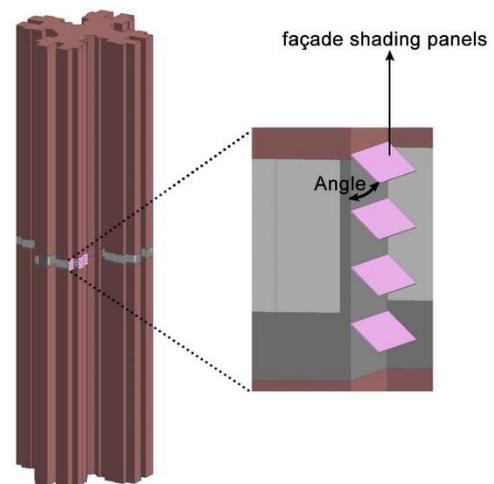


Figure 1: The simulation model with shading panels applied on the opaque façades of a typical PRH building.

## 2.2 Shading types

Two types of façade shading devices, namely vertical and horizontal shading panels, were added onto the eastward- and westward-facing external walls of the PRH building model. The length of shading panels (measured perpendicularly from the wall) was set to 700mm such that it is within the recommended limit in the Hong Kong Practice Note APP-156 [3] and will not be regarded as causing obstructions. The impact on indoor thermal comfort for different designs was then examined by changing the angle between the shading panel and external wall.

## 3. RESULTS

Operative temperature ( $T_{op}$ ) is used as a measure of the occupants' thermal comfort in this study. Though seldom investigated in previous studies, external shading on opaque façades is found to have a considerable cooling effect on the indoor thermal environment. Results show that the horizontal type of shading panels have a better performance than the vertical type, and adding horizontal shading panels can yield a reduction in maximum  $T_{op}$  up to 0.57°C and 0.91°C for eastward- and westward-facing flats, respectively (Figure 2). Furthermore, shading panels parallel (at a small angle) to the façade are able to achieve a greater reduction in indoor  $T_{op}$ . For horizontal shading panels, changing their angles of tilt from 90° to 45° can achieve a larger  $T_{op}$  reduction, but any changes after 45° do not cause further improvements in indoor thermal comfort. On the other hand, vertical panels at large angles from the wall (90° and 75°) perform the worst and are only able to reduce the maximum  $T_{op}$  by 0.10-0.15°C. Whereas, the potential in  $T_{op}$  reduction is almost inversely proportional to the angle of tilt from 75° to 0°.

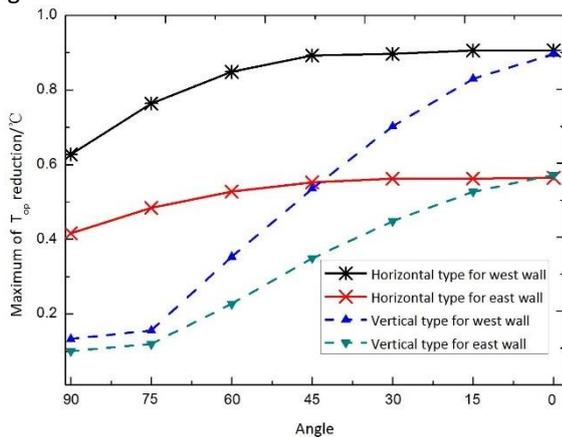


Figure 2: Impact of shading panels at different angles on maximum of  $T_{op}$  for west and east facing façade.

The maximum shading effect by adding horizontal shading panels for flats facing the west is almost double of that for flats facing the east (Figure 3). The simulated reduction in  $T_{op}$  is the most significant during midday (1:00 p.m.) for eastward-facing flats and in the late

afternoon (7:00 p.m.) for westward-facing flats. Those times have a half to one hour delay after the period of façades exposed to the beam radiation.

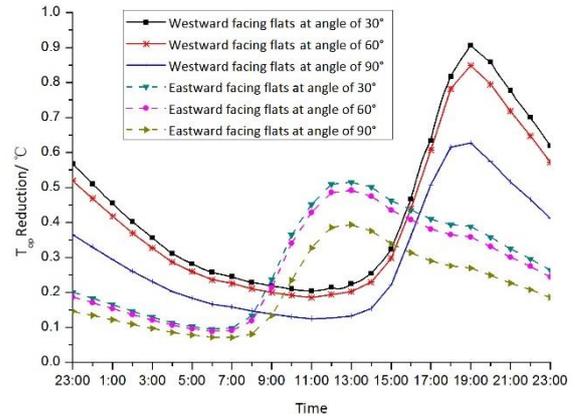


Figure 3: Diurnal variation of  $T_{op}$  reduction by horizontal shading panels at different angles on a typical hot day.

## 4. CONCLUSION

In this study, simulations were performed to evaluate the effects of opaque façade shading devices on the indoor thermal comfort of a typical PRH building in Hong Kong. It can be concluded that shading panels oriented horizontally and at a small angle to the wall are generally more effective in reducing indoor  $T_{op}$ . It should also be noted that changes in angles of tilt are more sensitive between 90° and 45° for horizontal panels and between 75° and 0° for vertical panels.

This initial study on external façade shading can provide some useful references for the local government and architects regarding building retrofits using passive design strategies, which can be readily implemented to procure more sustainable public housing. Further work is needed for a more detailed investigation on other parameters, such as panel size, distance between shadings and walls, and separation between panels etc.

## ACKNOWLEDGEMENTS

This work is supported by the General Research Fund from the Research Grants Council of Hong Kong (14603715).

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# Effects of Urban Morphology on Shading for Pedestrians: Sky View Factor (SVF) as an Indicator of Solar Access

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**ABSTRACT:** This work deals with the particulars of urban design in hot climate cities, where direct solar radiation leads to high temperature. This paper considers old part of Jeddah city as a compact neighborhood case study. We address the correlation between Sky View Factor (SVF) and direct solar radiation by orientation, value and time interval in the old Jeddah area, with the aim of adjusting future morphology in order to enhance outdoor thermal conditions. Results show that the sky view factor (SVF) could be an indicator of solar access in an urban morphology. The objective of this study is to identify and discuss the relationship between canyon geometry (size, orientation) and SVF to see how it impacts solar radiation within the urban street.

**KEYWORDS:** Urban morphology, Outdoor thermal comfort, solar radiation, Compact cities, Hot Climate cities

## 1. INTRODUCTION

Urban morphology has a huge impact on local microclimate which consecutively affects the comfort and responsible of the climate change. Several studies have investigated the relationship between compactness and solar access in urban textures, it is generally agreed that an increase of urban compactness entails a decrease of solar energy. [1]

Old Jeddah city is considered as a compact neighborhood, Jeddah/Saudi Arabia is located at latitude 21° 32' north. It is a subtropical arid climate (BWh) under Koppen's climate classification. [2] Jeddah modern urban design prescribes wide streets. Its urban form is classified as dispersed, where large part of the streets is exposed to solar radiation. The old area, as shown in (Fig. 1), has a mean sky view factor between 20 % and 25 % at ground level. Here we address the correlation between Sky View Factor (SVF) and direct solar radiation by orientation, value and time interval in the old Jeddah area, with the aim of adjusting future morphology in order to enhance outdoor thermal conditions.

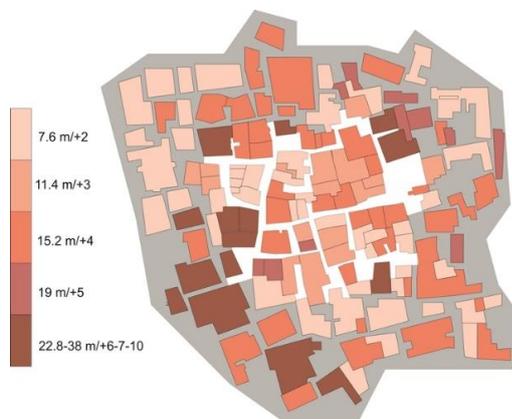


Figure 1: The studied Old area configuration and Building Heights, Jeddah-KSA

## 2. METHODOLOGY

Environmental variables are (air temperature, humidity, radiation, and wind speed) and human factors (clothing and metabolism) [3] this study is focused on radiation as it is the most variable that effects the street level in hot climate cities.

This study aims to framework a methodology that endorses practical and specific actions to improve the future urban settlements by analyzing their solar potential in relation with urban morphology.

The analysis is simulated with Heliodon 2 software [4]. Direct Solar Radiation hours and SVF were simulated for an irregular part of the old city of Jeddah/ Saudi Arabia (Fig. 1).

## 3. BACKGROUND

Climatic conditions in urban canopy layer may differ significantly from each other even in the same overall climate context in a city. They can be affected by a variety of factors such as the geometry of adjoining buildings, the albedo of walls and roofs, vegetation anthropogenic heat release and so on. [5]

In addition, many researchers take the position that at a micro scale, the urban open spaces geometry is the most relevant parameter responsible for the microclimate variation. The urban streets vary in geometry as defined by height/width ratio, sky view factor (SVF) and the orientation. This directly influences the absorption and emission of incoming solar and outgoing long wave radiation which has a significant impact on the temperature variations within the street as well as the surrounding environment. [6]

Nevertheless the wide knowledge developed on this topic, a quantitative analysis of the global impact of urban compactness on pedestrian thermal comfort is still lacking. In addition, the amount of solar access in

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different urban canyons shows that the impact of the geometry and orientation of the street canyon affect the outdoor environment and solar access [7].

## 4. RESULTS

A portion of the old city Jeddah, Saudi Arabia was simulated (Fig. 1) with its building shape and height, and mapped the direct solar radiation and Sky View Factor, see (Fig. 2); the results in this case show that the correlation between the Solar Radiation and the SVF is not always reliable. If the SVF is low then the Solar Radiation hours and intensity is supposed to be less.



Figure 2: Solar Radiation hours and SVF simulation with Heliodon on 21<sup>st</sup> June

Masoud [2] evaluated the Solar Radiation to observe the differences with the Sky View Factor in the old and the new layout of Jeddah, Saudi Arabia on the 21<sup>st</sup> of Jun. The result of the study confirms that the old area has a lower mean Sky View Factor at ground level than the modern area. But, in addition our new results give the following in this specific study.

- The old area, as shown in (Fig. 1), has a mean Sky View Factor between 20 % and 25 % at ground level.
- The simulation shows that a space may have a high SVF in a compact area with a lower Solar Radiation access than expected. As shown in (Fig. 2), point (1) this space has **48.7%** of SVF and **7 hours** of Solar Radiation.
- Correspondingly at North-South Orientation Street it gives a low SVF and a low Solar Radiation. As shown in (Fig. 2) point (2) the

street has a 25% of SVF and **4 hours** of solar radiation period.

- Nevertheless, the simulation revealed at an East-West orientation street a low SVF and a higher Solar Radiation access. As shown in (Fig. 2) point (3) the street has a **25%** of SVF and **7 to 9 hours** of Solar Radiation. This demonstrates a contradiction of previous studies that approves that when the H/W ratio of a street is high it gives a lower Solar Radiation.

## 5. CONCLUSIONS

The sky view factor (SVF) could be an indicator of solar access in an urban morphology. The simulation findings at the low latitude Jeddah in the old area morphology, gives that the sky view factor (SVF) in the East-West orientation is not a reliable indicator of the Solar Radiation access but gives a sufficient approximation in the North-South orientation. The study results could be applied to any city located on low latitudes with a similar climate.

## ACKNOWLEDGEMENTS

The authors thank the Spanish Ministry of Education for supporting this work under project code: BIA2016-77675-R. And special thanks to the Ministry of Education of the Kingdom of Saudi Arabia for supporting and funding this work.

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# Importance of Prevailing Sky Conditions and Building Orientation for the Assessment of Spectral Daylight Characteristics on Façades

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*ABSTRACT: Spectral information is fundamental in understanding the human responses to light. In order to assess the impact of light on visual and non-image forming effects (NIF) in more complex surroundings, in addition to spatially and temporally resolved daylight measurement, spectrally resolved information is required. This paper focuses on the inclusion of spectral aspects of daylight to specify the potential when planning for NIF aspects in urban structures, to reduce energy consumption for electric lighting for this purpose. It introduces a novel model to describe spectral characteristics on façades in the built environment in function of prevailing daylight conditions (location, sun position, season and time of day) and the building orientation. These orientation-dependent spectral characteristics of daylight on façades are represented in spectral daylight potential diagrams (SDPD).*

*KEYWORDS: Spectral Measurements, Spatial Distribution, Non-Image Forming Effects, Daylight, Urban Structure*

## 1. INTRODUCTION

For many years, scientists have been studying the correlation between the built environment, human perception, and the resulting well-being. The discovery of the intrinsically photosensitive retinal ganglion cells (ipRGCs) in the eye in 2002 [1] offers new insights into this correlation. These receptor cells are important for the regulation of the non-image forming (NIF) responses, affecting for example the circadian rhythms, sleep quality, alertness, and sleepiness. Although, research has shown that the amount, duration and timing of light exposure, as well as spectral power distribution (SPD) and the direction of light received at the eye are relevant parameters in these processes, the spectral characteristics of daylight in planning are typically set to one fixed correlated colour temperature (CCT) or expressed with a global spectral irradiance. This paper presents advanced techniques for the inclusion of spectral characteristics of daylight when planning for NIF aspects in urban structures, to reduce energy consumption for electric lighting.

## 2. COLORIMETRIC INFORMATION OF DAYLIGHT IN THE PLANNING PROCESS

The colour of daylight is temporally and spatially variable and the NIF effects of light during daytime depend on both the distribution and spectral composition of light. However, currently in the daylight planning only the luminance distribution of the sky is taken into consideration, even though research has shown that lighting conditions that provide the same light level at the eye, but have a different SPD, will have a different effect on the users. The inclusion of colorimetric information of daylight is as yet either based

on integral measurements or is assumed to have a CCT of approximately 6500 K. Both approaches assume a uniform distribution of colour over the sky's hemisphere, even though various studies have found that the spectral power distribution of light from distinct parts of the sky (sky patches) can vary widely depending on the orientation and time [3-4;6].

To enable the inclusion of the NIF effects in daylight planning and thereby consider people's biological, psychological and physiological needs, additional information about the colour of daylight from subdivisions of the sky's hemisphere is required [5]. The accurate characterization of the spectral characteristics of daylight for NIF studies is therefore realized by direction specific spectral data. In addition to highly accurate methods to characterize daylight spectral characteristics, on the basis of our work we are developing a simplified method suitable for practical application.

## 3. SPATIALLY, TEMPORALLY AND SPECTRALLY RESOLVED DAYLIGHT MEASUREMENTS

To describe the spectral daylight characteristics, spatially and temporally resolved spectral measurements of daylight have been carried out at the TU Berlin since October 2014 with a spectral sky scanner. The spectral power distribution between 280 and 980 nm from 145 sky patches is measured every two minutes [5]. These measurements are subsequently used to assess the effects of building orientation and prevailing daylighting conditions (season and time of day, sun position, location, and sky types) on spectral daylight characteristics on the façade.

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## 4. SPECTRAL DAYLIGHT POTENTIAL DIAGRAMS

As a result of the variability of daylight, a dynamic range of spectral characteristics is offered at the façade. This dynamic range is represented in spectral daylight potential diagrams (SDPD). These diagrams were proposed by Diakite et al. [2] based on single measurements from the TU Berlin spectral sky scanner. These SDPDs consider weather conditions throughout the year. They can either be used directly by designers or can be included in software to gain insights into the NIF impact of orientation, weather conditions and, in future, the effect of obstructions in the urban environment.

## 5. SNAPSHOTS OF DIFFERENT SKY CONDITIONS

A parameter study was conducted with the orientation specific data of prevailing daylight conditions measured for Berlin. In order to show the dynamic bandwidth of CCT on façades in a city structure throughout the year, the paper presents the CCT due to direct light on facades for all orientations and different weather patterns, with defined sun positions (temporal, as directly linked to location, season and time of day) and building orientation. These SDPDs offer snapshots of different sky conditions. The effect of the individual sky areas on the spectral daylight situation on the façade depends on:

- sky types (CIE Sky 3 'Standard Overcast Sky' and CIE Sky 12 'Standard Clear Sky, low luminance turbidity'),
- orientation of the building,
- sun position expressed in season and time of day (UTC: 9am and 12pm).

We found that although the color temperature of 6500 K, currently used in planning, can be approximately assumed for an overcast sky (Fig.1), for clear skies the CCT not only reaches higher values, but also depends on the orientation of the building and varies throughout the day and season depending on sun position (Fig.2).

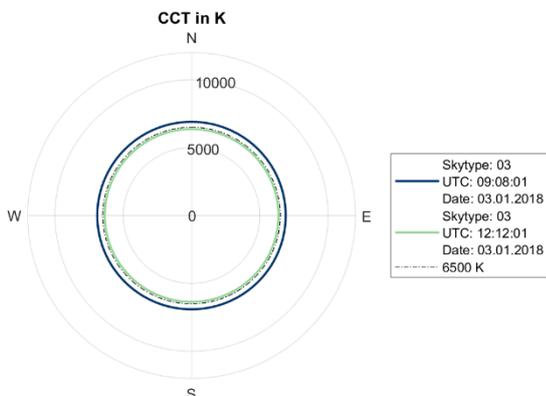


Figure 1: SDPDs showing a CCT of 6500 K currently considered in daylighting design and CCTs for an overcast sky for two different sun positions

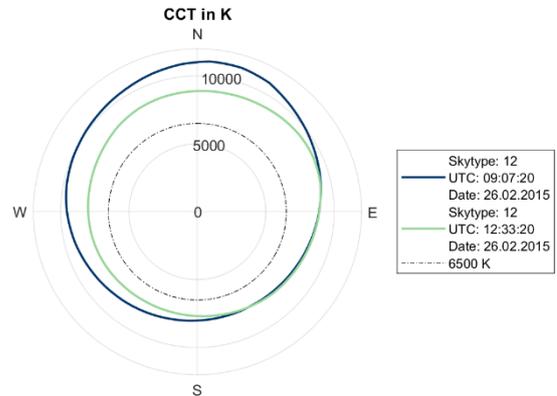


Figure 2: SDPDs showing a CCT of 6500 K currently considered in daylighting design and CCTs for a clear sky for two different sun positions

## 6. CONCLUSIONS

This work provides the framework for an innovative colorimetric approach to consider spectral characteristics of daylight in more detail. These SDPDs offer an indication about the deviation from 6500 K and consequently the actual increase of NIF effectiveness. When planning for healthy living within the 2-degree limit the implication of this study is that daylight has a higher potential to induce NIF effects than is shown in standard simulations, leading thus to further energy-saving potentials for electric lighting.

## ACKNOWLEDGEMENTS

This work is funded by the Velux Stiftung [grant number 1087].

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# Climatic Potential for Low-energy Cooling Strategies in India

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**ABSTRACT:** This study presents an analysis of the outdoor conditions Indian cities to determine the potential for deploying natural ventilation and several low-energy cooling strategies in residential buildings to lead the country on the path of becoming an energy efficient economy. The analysis showed that the potential for natural ventilation increased substantially when the temperature limits were based on the IMAC model for mixed-mode buildings. Locations in the composite climate showed the potential for a mix of operation modes/strategies while those in warm and humid indicated dehumidification as a prominent strategy.

**KEYWORDS:** Low-energy cooling, India, Residential buildings, Climatic potential, Thermal comfort

## 1. INTRODUCTION

The demand for residential cooling is driven by better living standards, higher thermal comfort expectations, greater disposable income and urbanisation, which leads to dense high-rise apartment buildings. Today, 31% of the Indian population of 1.3 billion live in urban areas; by 2050 this will increase to 50%, or 992million people [1]. The floor area of India's residential stock will increase by over 500% by 2030 [2] justifying why this work focuses on new build rather than retrofit. Space cooling currently represents 30% of total building energy consumption with sales of air conditioners in the residential sector increasing by a similar rate each year. If unchecked, the CO2 emissions from Indian buildings could increase by 700% by 2050 [3] so strategies that provide cooling without the use of energy intensive air conditioning will be critical to avoiding irreversible climate change.

This study is a part of a larger international collaborative research project that explores the prospects for reducing energy demand for residential air conditioning through the avoidance of refrigerant-based air conditioning, the advancement of technological developments and the delivery of new design guidance. This paper focuses on studying the outdoor conditions of several Indian cities to determine the potential for deploying natural ventilation and several low-energy cooling strategies in residential buildings to lead the country on the path of becoming an energy efficient economy.

## 2. METHODOLOGY

To study outdoor conditions, the new set of weather files developed by Indian Society of Heating Refrigeration and Air-conditioning Engineers (ISHRAE) were used. These Typical Meteorological Year weather files were created with the help of white box technologies [4]. Weather files for 59 locations were available. Of these 56

were in the cooling dominated climate zones, namely hot and dry (n=11), warm and humid (n=25) and composite (n=20) and were selected for analysis.

The outdoor temperature data was used to determine the number of comfortable hours based on the India Model for Adaptive Comfort (IMAC) [5] for naturally ventilated and mixed-mode scenarios. At this stage, the authors felt the need to use humidity thresholds, in addition to the IMAC temperature thresholds, to do more robust calculations for comfortable hours. An extensive literature review revealed the absence of a consensus among researchers on the matter humidity limits [6,7,8,9,10,11,12]. However, the authors noted a recurrence of 30-70% relative humidity (RH) limits and decided to use the same for further analysis to categorise the outdoor conditions into nine modes of operation as shown in Figure 1. A similar analysis was done using the ASHRAE Standard 55 adaptive model and the humidity thresholds.

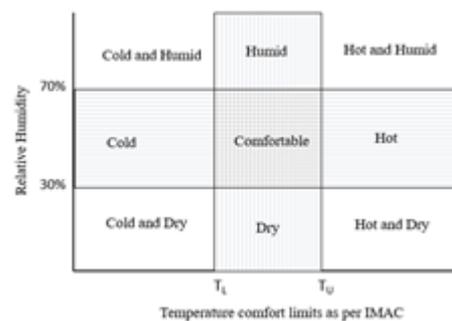


Figure 1: The logic for categorization of annual hours based on temperature and humidity thresholds

## 3. ANALYSIS

A sample of the analysis is presented in this section. Figure 2 shows a summary of hours categorised in the

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nine modes of operation for the 11 locations in the hot and dry climate zone. The grey bands indicate the % of hours that fall outside the range of applicability of the IMAC-NV model. Cities of Bikaner and Jaisalmer have almost 50% hours where the outdoor temperatures exceed the upper and lower applicability limits of the model. This may be due to the occurrence of extreme temperatures owing to their proximity to the Thar Desert. Figure 3 also shows that it is possible to meet the IMAC-NV requirements for thermal comfort by just using natural ventilation for 13% (Jaisalmer) to 30% (Surat) of the year. Despite being categorised as hot and dry locations, dehumidification comes across as an important low-energy strategy in Surat, Solapur, Aurangabad, Akola and Ahmedabad. A similar analysis was done for IMAC-MM (Figure 3) and ASHRAE-55 adaptive models for other climate zones.

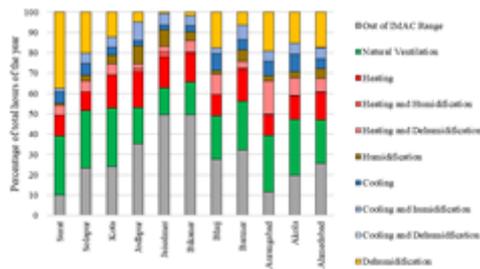


Figure 2: Hot and dry: Summary of comfort hours of different operation modes based on the IMAC-NV model

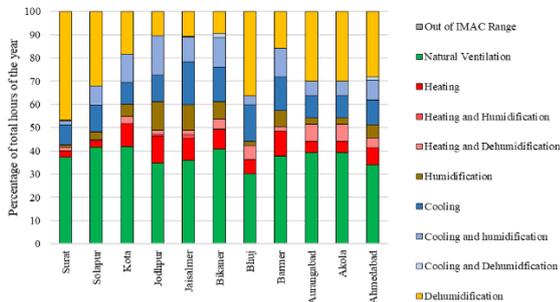


Figure 3: Hot and dry: Summary of comfort hours of different operation modes based on the IMAC-MM model

## 4. CONCLUSIONS

The analysis showed that for all 56 locations, the potential for natural ventilation increased substantially when the temperature limits were based on the IMAC-MM model compared to the IMAC-NV model. Locations in the composite climate show a potential for a mix of operation modes/strategies while those in warm and humid indicated dehumidification as a prominent strategy with a potential of providing comfort for almost 50% of the year.

It is also important to note in this analysis that the climatic potential does not account for the building. The numbers reported in this paper indicate the potential that is offered by the outdoor conditions alone. A well-designed building envelope would only increase the potential for passive strategies to provide more comfort

hours and reduce the loads. The results from the analysis presented in this paper will be developed into a tool to be used by architects and designers at the concept stage to understand the applicability of the nine operation modes for a specific location.

## ACKNOWLEDGEMENTS

This research is part of an International research collaboration for the project ‘Low Energy Cooling and Ventilation for Indian Residences (LECaVIR)’ and is currently financially supported by the Engineering and Physical Sciences Research Council (EPSRC) under the reference: EP/ P029450/1.

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# Household Energy Consumption of Residential Buildings in the Tropics: Factors Affecting Cooling Energy

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*ABSTRACT: This paper aims to reveal the detailed household energy consumption patterns in four major cities of Indonesia and Malaysia. A total of 1,437 households of landed houses and apartments were surveyed during 2010-2014. The detailed household appliances and gas consumption were investigated through face-to-face interviews and measurement. The results showed that overall, annual average energy consumption in landed houses (15-28 GJ) is about 1.3-2.3 times larger than those in apartments (12-14 GJ). The energy consumption for cooking accounts for the largest proportion in all the case studies, ranging from 29% to 66% of the total. The energy consumption for cooling include those for AC and fans and they account for 21% to 22% on average in Jakarta and Johor Bahru respectively. The profiles of CO<sub>2</sub> emissions were similar with those of energy. The factors affecting household energy consumption for cooling energy are also discussed.*

*KEYWORDS: Household Energy Consumption, CO<sub>2</sub> emissions, Residential buildings, Cooling, Tropics*

## 1. INTRODUCTION

Household energy consumption for cooling has been rapidly increasing in hot-humid climates of Asian developing countries and it is projected to increase much further not only due to the further economic growth but also due to the local and global warming [1]. This paper aims to reveal the detailed household energy consumption patterns in four major cities of Indonesia and Malaysia. A total of 1,437 households of landed houses and apartments were surveyed during 2010-2014. The detailed household energy consumption as well as resulting CO<sub>2</sub> emissions were investigated. Furthermore, factors influencing the increases in energy consumption for cooling were analysed.

## 2. METHODOLOGY

The surveys were conducted in Jakarta (2013), Bandung (2011, 2014), Surabaya (2013), Indonesia and Johor Bahru (2010), Malaysia, respectively. Face-to-face interviews using a questionnaire form were carried out in several major types of houses to obtain the detailed information about the household appliances (e.g. usage time, ownership level, etc.), whereas electric capacity of all the appliances was measured by electricity checker (MWCO1, Osaki). Meanwhile, the gas and kerosene consumptions were also investigated by the interview.

The electricity consumption for household appliances was estimated by multiplying the number of appliances by their usage time and the measured electric capacity. Then, the total household energy consumption was calculated by combining the energy consumption of all appliances and gas/kerosene consumption. The CO<sub>2</sub>

emissions were calculated through multiplying the energy consumption for each fuel type by its corresponding CO<sub>2</sub> emission factor.

## 3. OWNERSHIP LEVEL OF HOUSEHOLD APPLIANCES

Table 1 shows a summary of socio-economic profile of respondents in respective case studies. As shown, the annual average temperature in Bandung is approximately 4-5°C lower than the other cities because of its relatively high altitude of about 768 m. Household income was standardized as the income ratio by considering local currency and survey year.

The average ownership levels of the household appliances were analysed. In terms of the cooling appliances, fans were well penetrated (more than 70%) among the households except for the landed houses in Bandung. On the other hand, the ownership level of AC was relatively high in landed houses of Johor Bahru (64%), landed houses in Jakarta (33%) and apartments in Bandung (35%).

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Table 1: Socio-economic profile of respondents.

	Jakarta	Bandung		Surabaya	Johor Bahru
	Landed house	Landed house	Apartment	Apartment	Landed house
Sample size	300	250	300	309	278
Daily mean air temperature	28	23	23	28	27
Average household size (person)	5	5	2	4	5
Household income ratio (%)					
< 6.0	0	0	0	1	10
6.1 – 8.0	35	23	43	74	83
8.1 – 10.0	64	75	57	25	7
>10.0	1	2	0	0	0
Total floor area (%)					
50 (m <sup>2</sup> )	37	26	99	100	36
50 – 99	29	32	1	0	54
> 100	34	42	0	0	10

## 4. ENERGY CONSUMPTION AND CO<sub>2</sub> EMISSIONS

Figure 1 shows the annual average energy consumption in the four cities (secondary energy). Overall, annual average energy consumption in landed houses (15-28 GJ) is about 1.3-2.3 times larger than those in apartments (12-14 GJ). In particular, the landed houses (terraced houses) in Johor Bahru consume the largest energy (28 GJ) among the present case studies.

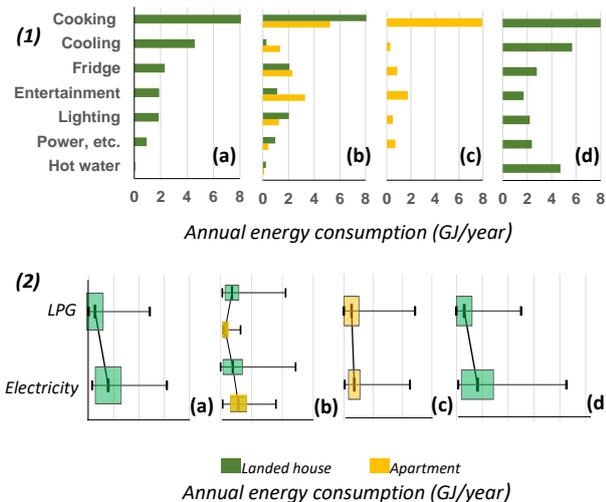


Figure 1: Annual energy consumption (GJ/year) by (1) End-use; (2) energy source; (a) Jakarta; (b) Bandung; (c) Surabaya; (d) Johor Bahru.

The energy consumption for cooking accounts for the largest proportion in all the case studies, ranging from 29% to 66% of the total. Most of the households use LPG for cooking (Fig. 1(2)). The energy consumption for cooling include those for AC and fans and they account for 21% to 22% on average in Jakarta and Johor Bahru respectively (see Figure 1). Meanwhile, the contribution of cooling is much lower (2% to 10%) in Bandung as well as in Surabaya (3%). This is because the temperature is relatively low in Bandung, while the surveyed apartments in Surabaya are public apartments and therefore they are not equipped with air-conditioners. The annual energy consumption per person in apartments of Bandung is particularly higher (8.1

GJ/person) than that in apartment and landed houses of other cities (Figure 2(1)). This is mainly because the average household size of Bandung's apartments was much smaller than the others (see Table 1). The unit energy consumption per floor area shows relatively similar patterns except for cases of Surabaya and Johor Bahru (Figure 2(2)).

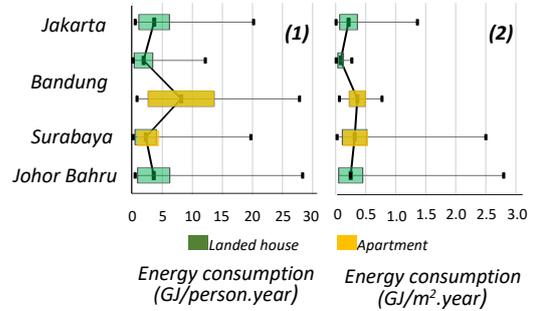


Figure 2: Annual energy consumption per (1) person (GJ/person.year); (2) unit floor area (GJ/m<sup>2</sup>.year)

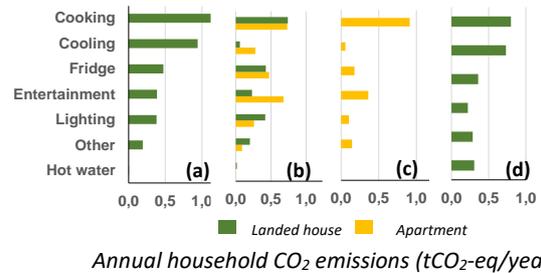


Figure 3: Annual household CO<sub>2</sub> emission (tCO<sub>2</sub>-eq/year) for (a) Jakarta, (b) Bandung, (c) Surabaya, and (d) Johor Bahru.

Figure 3 shows the annual average household CO<sub>2</sub> emissions. Overall, the CO<sub>2</sub> emissions in Indonesian cases are increased more than that of Malaysian case (Johor Bahru). As shown, the calculated CO<sub>2</sub> emissions range from approximately 1.9-3.5 tons CO<sub>2</sub>-eq for landed houses and whereas those for apartments are about 1.5 and 1.8 tons CO<sub>2</sub>-eq.

Table 2: Results of multiple regression analyses on Annual household cooling energy consumption

Variables	Annual cooling energy consumption ( $\beta$ -value)					n=1,437		
	Jkt L	Bdg L	Sby A	JB A	L	L	A	Total
Floor area	0.26	0.23	0.25	-0.05	-0.16	0.17	-0.14	0.46
Monthly income	0.26	-0.02	0.10	-0.03	0.13	-0.16	0.27	0.29
Household size	0.08	0.00	0.07	0.01	0.07	0.11	0.04	0.20
Household's age	-0.10	-0.06	-0.14	-0.10	0.13	-0.03	0.35	0.26
Lot area	0.30	0.38	-	-	0.19	0.20	-	-0.17
Building's age	-0.03	0.05	-0.02	-	-	-	-0.56	-0.56
Window opening	-	-	-0.05	-0.13	-0.12	-0.10	-0.76	-0.57
R <sup>2</sup>	0.46	0.27	0.13	0.03	0.05	0.15	0.17	0.43

Jkt=Jakarta; Bdg=Bandung; Sby=Surabaya; JB=Johor Bahru; L= landed; A=apartment

Multiple regression analyses were carried out to further analyze factors affecting household energy

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consumption caused by cooling in respective cities (see Table 2). As shown, in total, “monthly income”, “household size” and “household’s age” are considered to explain energy consumption caused by cooling at 1% significant level. Therefore, It is important to anticipate the increase of the above factors will increase cooling energy consumption of residential buildings in tropics.

## **5. CONCLUSION**

This paper provided the detailed profiles of household energy consumption and CO<sub>2</sub> emissions as well as factors affecting cooling energy consumption.

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# A Study on Climate Responsive Design of Open Residential Neighborhoods in a Southern Chinese City

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*ABSTRACT: As the demand for urban living space has expanded dramatically in China, high-rise/high-density residential quarters gradually evolved into an inevitable urban living pattern. Because gated residential quarters have given rise to a series of urban social and economical problems, a recent trend in residential development is the so-called open residential neighbourhoods (ORN) or open urban block. Due to smaller plot size, mixed functions and more open geometry, the microclimatic effect of building form, layout and greenery can be different with that of typical gated housing quarters in Shanghai under the hot-summer cold-winter building climate zone. By selecting a typical block as object, this paper conducted parameterized numerical simulation to verify and quantify the impact of different building layout and greenery type on outdoor microclimate of ORN, and to provide reference for optimizing the layout of high density residential quarters, as well as design strategies for the actual planning and evaluation process.*

*KEYWORDS: Open block, Outdoor thermal comfort, ENVI-met, Building layout, Greenery*

## 1. INTRODUCTION

Resulting from the population booming and resource scarcity in China, high-rise/high-density residential quarters gradually evolved into an inevitable urban living pattern, especially in first-tier developed cities, e.g. Shanghai. However, the high-density living environment, while releasing more land for the construction and service of public facilities, also brings about a series of environmental problems. Among them, the deteriorating outdoor thermal comfort and the increasing building energy consumption are among the most serious challenges we face.

On the other hand, gated residential quarters, the dominant pattern of developing commercial housing over the previous two decades, has given rise to a series of urban social and economical problems, a recent trend in residential development is the so-called open residential neighbourhoods (ORN) or open urban block [1]. Simply speaking, comparing to commonly-seen gated residential quarters, ORN features smaller block sizes, denser and narrower street grids, mixture of residential with commercial, and pedestrian-friendly streets and pocket parks right in block. Urban form has a profound effect on microclimate and building energy consumption[2-4]. Due to smaller plot size, mixed functions and more open geometry, the microclimatic effect of ORN building form, layout and greenery can be different with that of typical gated housing quarters in Shanghai under the hot-summer cold-winter building climate zone [5]. Can vertical greening play a bigger role in ORN in terms of combating excess urban heat? Will increased anthropogenic heat from streets, nearby offices and shops elevate the heat island intensity within a ORN? What are the overall impact of density and form

in local climate? The aim of this study is to investigate the cooling potential of various microclimate modification strategies under the emerging urban development and renewal pattern of ORN in Southern Chinese cities, so that to improve the living quality of residents, increase the utilization rate of outdoor public space and reduce the overall energy consumption.

## 2. METHODS

Using an urban block in Hongkou District, Shanghai as a case study, this paper conducted numerical simulation to quantify the impact of different design strategies to mediate site microclimate, including building form, layout and greenery. The site under investigation is adjacent to Hongkou Port. It covers an area of 38,400 square meters. The urban planning document demands an open residential neighbourhood with FAR of 1.5 and building density of less than 40%. Based on these, four layouts are designed, and different roof and vertical greening are respectively allocated. As the reference, a traditional gated residential block is also modelled for comparison. Simulation scenarios are shown in Table 1. The three-dimensional microclimate model ENVI-met 4 is used[6]. One typical summer day in Shanghai was chosen for simulation. The initial wind speed is 3.1m/s and the wind direction is 135° (southeast). For the Configuration file, the model grid is 130\*140\*30( $\Delta x = \Delta y = 2m$ ;  $\Delta z = 3m$ ). Fifteen measurement points have been placed in squares and streets with high pedestrian density of each model.

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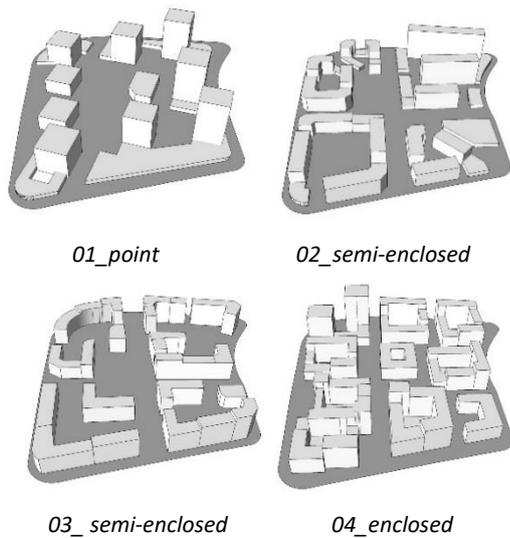


Figure 1: Four forms of layout models

Table 1: Scenarios for Envi-met Simulation

Building layout	Green roof	Green wall all facades	Green wall south only	Green wall west only	Green wall east only	Green wall north only
Case 00	-	-	-	-	-	-
Case 01	01_GR	01_A	01_S	01_W	01_E	01_N
Case 02	02_GR	02_A	02_S	02_W	02_E	02_N
Case 03	03_GR	03_A	03_S	03_W	03_E	03_N
Case 04	04_GR	04_A	04_S	04_W	04_E	04_N

### 3. RESULTS

Compared with the traditional neighbourhood, the mean Ta is decreased by [0, 0.2] °C and [0, 0.3] °C in case 03 and case 04, and increased by [0.1, 0.4] °C in case 01. Case 02 is basically consistent. This result is largely due to the impact of building form/density on shading. Buildings in case 01 are more interspersed with less shaded spaces between buildings. For case 03 and 04, building density is higher while height difference is lower, which is propitious to create shaded spaces. For the mean Tmrt from 13:00 to 16:00, case 04 is the lowest, followed by case 01, case 00, case 02 and case 03. (Fig.2)

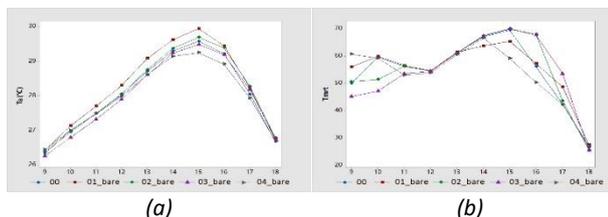


Figure 2: (a) air temperature and (b) mean radiant temperature of different building layout during the day

Fig.3 shows the air temperature distribution for various layouts. The point layout has the averagely highest Ta. At the central spaces, Ta is about 0.6 °C higher in case 01 than in the other three cases. While in case 03

and 04, the courtyards enclosed by buildings enjoyed relatively low Ta.

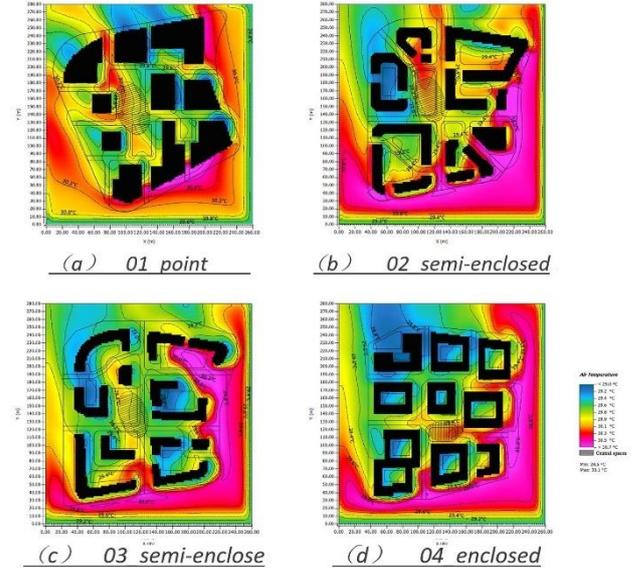


Figure 3: Ta distribution of 4 building layouts at 3pm

Considering Ta change by different vertical greening, the all-greened scenario causes the greatest Ta decrease in pedestrian level, followed by south and east ones, then north and west. Taking case 04 as example, daytime Ta change ranges between [-0.6, 0.1] °C if all the four facades are greened. When only south, west, east or north is greened,  $\Delta Ta = [-0.4, 0]$  °C, [0, 0.4] °C, [-0.3, 0.1] °C, and [-0.1, 0.1] °C, respectively. PET change ranges between [-0.8, 1] °C, [-0.6, 0.8] °C, [-0.8, 0] °C, and [-1, -0.2] °C for case 01, 02, 03 and 04 respectively. With vertical greening added, the all-greened scenario causes the greatest PET reduction in pedestrian level, followed by south-greened and east-greened ones.

The present result is lower than that observed in a HK study [7] who found mean Ta decrease up to 1.7°C with all four façades greened with equivalent FAR as compared to 0.4°C in our simulation. The mean PET decrease up to 6°C compared to 1.8°C in our simulation. The discrepancy can be attributed to differences in climate, building layout, model setup and plants set in the model.

The preliminary results indicate that: 1) various building layout pattern has different impact on outdoor thermal comfort. Enclosed ORN has more positive impact on thermal environment than the interspersed ones. 2) green façade has greater effect on enclosed building layout than semi-enclosed and point ones. 3) green facade plays a more important role in the cases which building height difference is smaller. The orientation of greened facade should be considered too. 4) in hot-summer and cold-winter climate zone like Shanghai, taking building orientation and economic rationality into consideration, south-greened and east greened yield

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better thermal benefits in daytime in pedestrian level, which will have certain effect on pedestrian activity.

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# Performance Evaluation of an Energy Efficient Educational Building in India

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**ABSTRACT:** Buildings consume 33% of total energy (24% domestic and 9% commercial) in India and this is growing at 8% per annum. Reliance on fossil fuel and increasing demand for energy has led to having an unregulated energy use in buildings in India. Despite multiple instances of green buildings existing throughout India wide-scale adoption of green building practices have not been observed. This leads to higher than predicted energy use. Building Performance Evaluation is essential to reduce this gap and help buildings perform better. Despite the improvements in building systems and services, energy efficient building design and implementation – there is a growing gap observed between the intended and actual performance of buildings leading to higher than expected energy use. The purpose of this study is to understand this performance gap for a university building. The study evaluates the actual performance of this building through on-site measurements and provides feedback for the building to perform better.

**KEYWORDS:** Performance evaluation, Educational building, Performance goals, Monitoring, On-site measurements

## 1. INTRODUCTION

India is experiencing an unprecedented construction boom. It is estimated that the total constructed built-up area in India would increase by nearly five times from 2005 to 2030 [1]. The International Energy Agency (IEA) reported that buildings in India are responsible for 41% of total electricity. The need of the hour is to reduce the environmental impact of buildings and this makes energy efficient buildings an imperative for all future construction in India.

Current codes and rating systems do not have a mandatory evaluation procedure to validate the energy performance through the life of the building. Studies indicate one of the most important reasons for this gap is the lack of proper input by energy consultants, architects, and engineers at various stages of building. This is especially true in India where various stages of construction process happen in isolation. A stringent methodology that helps to embed Building Performance Evaluation (BPE) in the design process is essential to reduce the performance gap. The purpose of this study is to understand the reasons for a gap for Indian context through one case study building.

## 2. SCOPE OF RESEARCH

A recently-built and occupied university building (academic block) located in hot and dry climate for India is selected for evaluation. This building is a certified building with performance targets. This study will help understand factors that lead to performance gap. This study is part of the Newton Fund sponsored UK-India Learn-BPE project and the methodology steps are based on the UK BPE methods developed by Rajat Gupta and Matt Gregg [2, 3].

## 3. METHODOLOGY

The methodology for this study includes the groundwork for monitoring the building which includes instantaneous measurements, logging, surveys, and interviews. The following steps elaborate the methodology followed:

- Understanding the design intent of the building
- On-site measurements
- Analysis of results to evaluate the performance of the building and uncover discrepancies between design intent and actual performance
- Potential actionable gaps

### 3.1 Performance goals for case study building

The building has a total area of approximately 35,600 m<sup>2</sup> with 47% conditioned area and 23% window-to-wall ratio. Types of spaces include labs, classrooms, tutorial spaces, faculty areas, seminar halls, and boardrooms. The goals are divided into assets and operations where design intent focuses on assets and enabling operations, but not directly responsible for the operation. The energy goals for building are listed in Table 1.

Table 1: Performance goals of building

Performance Goal	Asset	Operation
Light pollution reduction	Interior lighting power densities should not exceed 80% and 50% for building facades and landscape features as defined in the standards.	Non-emergency interior lighting automatically to turn off during non-business hours. Natural override capacity is provided for after-hours use.

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Performance Goal	Asset	Operation
Daylight 75% of spaces and views of 90% of spaces	90% of the spaces have direct lines of sight to perimeter glazing	
Optimize energy performance		Academic block- 43.1% energy savings
Controllability of systems- lighting and thermal comfort	90% of spaces should have manual control switches for lighting, 50% of the occupant have controls for thermal comfort.	Occupant use of controls in spaces
On-site renewable	Required 7.5% of total energy- Solar PV	Operating solar PV and proper generation, according to the requirement

## 3.2 On-site measurements

To evaluate the above-mentioned energy performance goals, several variables were monitored and compared with the design phase variable to understand the gap. Surveys and interviews were carried out to understand the building's use and the system use. Constant involvement of on-site officers helped expedite the process. Table 2 shows the list of on-site measurements which were carried out to evaluate the building.

Table 2: On-site measurement activities

Walk-through and interviews with the facility manager
Photographic survey of components and systems
Installing Data Loggers
Evaluating renewable energy technologies on site
Survey of controls and user- interfaces
System installation and commissioning review
Data collation

## 3.3 Data analysis and comparison

The building studied was evaluated based on the performance goals. The findings are divided into design intent vs as-built and operation evaluation. The following summarizes the findings from the field study:

Findings of design intent vs as-built (asset)- Solar Photovoltaic (PV) (10.1% of the total energy consumption) according to the energy requirement are installed on site. 100% of spaces have manual control switches for lighting. 93% of the occupants have access to an operable window. There are no occupancy sensors in the building. 34% of the occupants have a thermostat control for spaces. More than 90% of the spaces have direct lines of sight to perimeter glazing.

Operational effectiveness (non-asset)- Energy performance index for this building is 26.5 kWh/m<sup>2</sup>. year. This cannot be compared to the required energy savings due to the lack of calibrated energy model for comparison. According to the survey of user control interface, all space types had ease of access to the interface.

Fan and lighting control in all spaces were well designed. However, certain spaces (classroom, personal cabin, and open office) did not have access to thermostat control. Uniformity ratio for lighting levels was high (>0.5) in all classroom spaces. For the year of monitoring (2017) annual solar generation is 3% more than required.

## 3.4 Feedback for building operation

For the building to perform better, lighting in the spaces should be properly used, blinds should be not drawn unless there is direct glare. Proper maintenance of ductwork and HVAC systems is required for efficient use of systems. Thermostat for more spaces, if provided, may lead to higher satisfaction of occupants. Proper use of operable windows during winter time is recommended to reduce internal CO<sub>2</sub> levels.

## 4. CONCLUSION

This study was carried out to evaluate the performance of an energy efficient institutional building in India. This study helped in understanding the framework required for performance evaluation for buildings in India. The field study was extensive in nature and can be replicated to evaluate green rated institutional buildings in India.

## ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of the Newton Fund through the Royal Academy of Engineering (RAEng) Industry-Academia Partnership Program for financially supporting the Learn-BPE project [Grant number IAPPI\74]. The authors would like to thank Prof. Prasad Vaidya for his feedback for this study. The authors acknowledge the maintenance and design team of the building for access to resources for this study.

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## An Urban Vulnerability Index for Cities in the Middle East

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*ABSTRACT: There is a growing consensus on the influences of heat waves and increased temperature as among the most threatening climate change phenomena to human mortality. In addition, the effect of heat waves is exacerbated significantly in cities as a result of urban heat islands effect. Such intensification of heat waves combined by potentially prolonged periods of extreme temperature will pose huge risks on human mortality in the built environment. Over the past decade, a number of metrics in literature have been developed to assess human thermal risks and their response to extreme climate conditions. However, most of these metrics take into account socioeconomic factors, housing characteristics and climatic risks without looking at the spatial characteristics across the city. Yet, the combination of these factors on an urban resolution haven't been largely explored yet, specifically for vulnerable population with low access to adaptation resources and minimum potentials for ventilation. The paper presents the framework of an urban vulnerability index based on identifying parameters that correlate with thermal discomfort on urban block level and building level. The study analyzes a historical residential neighborhood in Cairo, Egypt to examine the applicability of the proposed index in understanding levels of vulnerability under extreme temperatures.*

*KEYWORD: Climate change, Vulnerability Assessment, Building Simulation, Middle East*

### 1. INTRODUCTION

The global consensus on the impacts of climate change alongside with scarcity of energy resources have raised questions related to the development of the built environment over the course of the next twenty to thirty years. With the ongoing efforts to reduce Carbon Dioxide (CO<sub>2</sub>) emissions and transition to cleaner energy resource, many cities have developed adaptation strategies to face increasing risks from climate change. Since the first assessment report of the International Panel of Climate Change (IPCC, AR1), vulnerability assessment has been gaining a significant interest as a useful approach to examine impacts associated with climate change in urban areas and as a decision support tool [1-3]. Yet, there is a gap in the availability of suitable frameworks that could outline which urban environment characteristics drive high vulnerability to climate change.

The paper proposes an urban vulnerability index as a diagnostic framework to identify and assess sensitivity of the built environment in the Middle East region, particularly focusing on impacts of temperature increase on urban liveability. The proposed index framework is based on addressing vulnerability as a function of three main parameters: exposure, sensitivity and adaptive capacity under heatwaves risks. The developed framework entails typology as an approach to identify what sets of urban configurations characteristics have higher risk under climate change events such as temperate increase. This is achieved through identifying a number of parameters that correlate with thermal discomfort on two levels: urban block scale (outdoor comfort using the Universal Thermal Climate Index (UTCI) as the analysis metric and building scale (Indoor

thermal comfort). In addition, the paper presents an overview of typology approaches to examine urban performance. Results from the review provide an extended methodology framework that include other important metrics that are relevant in tailoring adaptation strategies on the urban level.

### 2. METHODS AND FRAMEWORK

The paper is divided into two main sections with two outcomes. The first part of the paper presents an overview of typology analysis as an approach to understand energy and thermal performance. The main outcome is an extended typology framework that combines building and urban parameters that are significant for climate change vulnerability analysis. The second part proposes an assessment index to measure environmental vulnerability of urban areas, specifically in Middle Eastern cities under projected temperature increase.

Whereas all previous studies of vulnerability assessment have only focused on social and economic parameters, the paper uniquely examines spatial urban variations within a city and identify what set of characteristics are associated to higher levels of risks to temperature increase. Thus, this work led to an assessment index that can be used to measure and predict vulnerability ranges for other urban settings with similar characteristics. In order to understand what physical characteristics associated with potential risks from temperature increase are, the paper focuses on the impacts on human health indoors and urban liveability outdoors. Thus, the influence of different building types and urban configuration is investigated by examining

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consistent physical characteristics of urban systems. These characteristics as presented in Figure 1. All these characteristics are examined for three urban block types identified (historical block, mixed block of new informal buildings and old historical building and complete informal building) in a typical summer day (21<sup>st</sup> of June) in peak hours between 12 pm and 2 pm in Cairo.

The framework entails three layers of analysis as presented in Figure 1 below: exposure layer, sensitivity layer and risk layer. Exposure represents the degree & direction of change in climate variables [4, 5]. Changes in air temperature and wind speed between current and future climate conditions are used as a representation for exposure.

Sensitivity layer includes physical characteristics that determine how an urban system is affected [4, 5]. Thermal autonomy simulation indoor and outdoor was tested under current and project climatic condition by 2020. For outdoor, Universal Thermal Climate index (UTCI) was used as an indicator of thermal discomfort under temperature projection Differences in discomfort hours indoor and outdoor is used as a representation for exposure percentage across the three urban typologies. Risk layer represents the portion of urban population that have higher vulnerability to climate change impact. This level of analysis includes socioeconomic factors like population density, age distribution, and income level. All data are collected from site survey for the three representative urban blocks. Results from the thermal comfort simulation were examined with comfort survey and population age distribution to identify levels of risks.

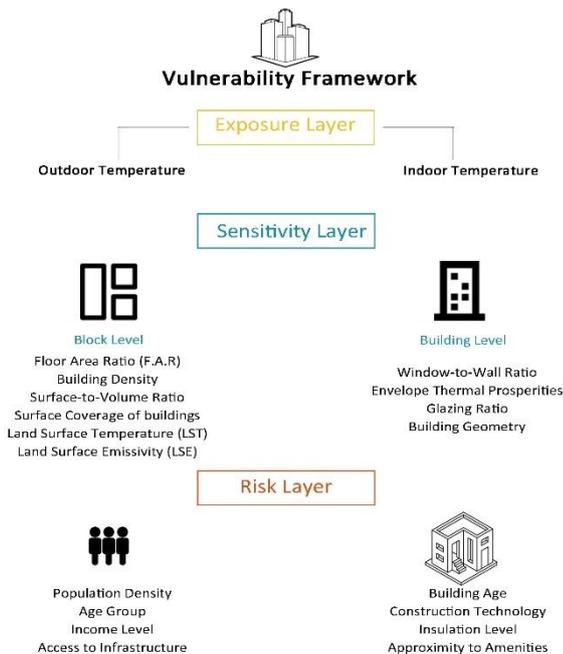


Figure 1: Vulnerability Assessment Framework

The paper examines a historical residential neighbourhood in Cairo, Egypt named Al-Darb AlAhmar

to examine the applicability of the proposed index in understanding levels of vulnerability. Al-Darb AlAhmar is an old historical neighbourhood in Cairo that is part of the old Fatimid Cairo. The neighbourhood includes a unique mix of buildings, where some buildings date back to 1800s, buildings that was constructed in the 1970's and other informal buildings that were recently built in 2011. The main motivation behind this work is to understand how such methodology can be extended to other urban settings in the Middle East with similar climatic conditions and urban characteristics.

### 3. Study Contribution and Expected Results

The study sheds light on the impacts of the variability of urban characteristics on climate change vulnerability assessment. Three urban block types are examined in Al-Darb AlAhmar neighbour in Cairo, Egypt. The discrepancy between the physical characteristics of a typical historical urban block (Type A) and informal block (Type C) indicates that higher vulnerability is correlated with informal urban block. Generally, the three urban block types performed relatively similar in terms of outdoor thermal comfort except in the mixed block of historical and informal buildings, taller informal buildings had a negative impact on existing passive ventilation strategies and outdoor comfort levels.

Results from the study highlight the impacts of urban physical characteristics on indoor and outdoor thermal comfort conditions under projected climate conditions. Such parameters are significant for urban planners and policy makers to identify and prioritize which urban areas require higher levels of intervention and adaptation and what proportion of population will be mostly affected. Additional results from the study include urban typologies with their physical characteristics and associated levels of vulnerability across the vulnerability layers as shown in figure 2 below.

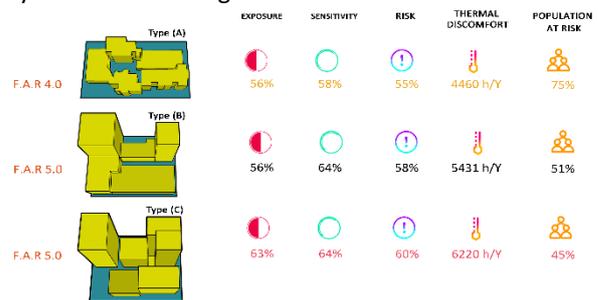


Figure 2: Initial results from E.S.R Index in the three urban typologies of Al-Darb AlAhmar.

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# Assessing the Energy Savings and Payback Period for Various Levels of Compliance with Energy Conservation Building Code (ECBC) -2017:

A Case of an Office Building in Vishakhapatnam.

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*ABSTRACT: Buildings consume 33% of total energy (24% domestic and 9% commercial) in India and this is growing at 8% per annum hence, there is a need for energy efficiency in the building sector. The revised version of Energy Conservation Building Code (ECBC) was published in June 2017 after ten years. The new version of ECBC goes beyond minimum compliance and has two additional levels of ECBC 'plus' and 'super' which include prescriptive requirements and alternative performance goals based on energy use intensity. This paper assesses the energy savings and payback period for the prescriptive of ECBC-2017, minimum compliance, plus and super levels for an office building in Vishakhapatnam. It also demonstrates alternative cost optimized solutions for these three levels of ECBC. The office building is a real building in design stage according to the current construction trends that do not comply with previous ECBC version 2007 for all building systems. The availability & cost of equipment and material to reach the ECBC 2017 levels is assessed with a market survey. Since ECBC 2017 is a new code that has yet to be adopted by local building departments, this study shows the energy benefits for ECBC minimum compliance, ECBC plus and ECBC super levels. Further, this paper also demonstrates how simulations can be used to find more cost-effective approaches to reach ECBC 2017 performance levels using the whole building compliance approach.*

*KEYWORDS: prescriptive compliance, whole building performance, simulation, energy savings, payback period, cost optimized solutions*

## 1. INTRODUCTION

Buildings account for 33% of the total annual energy consumption. They stand second in terms of annual energy consumption after industries[1]. The Energy Conservation Building Code (ECBC) developed by Bureau of Energy Efficiency (BEE) is an important step towards energy efficiency in building sector. It provides prescriptive requirements and alternative performance goals based on energy use intensity for energy-efficient design of buildings in five climate zones of India. It includes prerequisites for Building envelope, HVAC system, lighting and service hot water systems, pumps and motors. This code is applicable to the buildings with connected load greater than 100 KW or demand greater than 120 kW.[2] Compliance of ECBC is currently voluntary in many states. ECBC 2007, too was not implemented by many Urban Local Bodies (ULB). Hence, there might be certain challenges for implementation which includes the cost and the value it offers to the building project.

The ECBC was revised in June 2017 after ten years. The new version of ECBC goes beyond minimum compliance, and has two additional levels of ECBC 'plus' and 'super' which include prescriptive requirements and alternative performance goals based on energy use intensity ratios.[3] It is estimated that adoption of ECBC 2017 for new commercial buildings throughout India will

lead to reduction of 50% energy use by 2030. This is equivalent to monetary savings of INR 35,000 crore and reduction 250 million tonnes of CO<sub>2</sub> .[4]

## 2. PROBLEM IDENTIFICATION

The Building selected for the study is a demonstration project and part of United Nation Development Programme(UNDP), Global Faculty Initiatives(GEF) initiative. ECBC 2007 is notified in Andhra Pradesh since 2014.

The office building will be headquarter of an MNC with built up area of 7800 sq. m, wall to window ratio of 30% , G+4 structure and will be operated in single shift. The construction of the building is similar to the current trend in India.

ECBC 2017 is a new code that has yet to be adopted by local building departments. Hence, it is important to quantify the energy savings that result from the requirements of ECBC-2017, the availability of equipment and materials to meet these requirements and assess their incremental cost. This paper assesses the energy savings, incremental cost and payback period for the prescriptive requirements of ECBC-2017, minimum compliance, plus and super levels for an office building in Vishakhapatnam. Further this study also demonstrates how simulations can be used to find more cost-effective approaches to reach ECBC 2017

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performance levels using the whole building compliance approach.

## 3. METHODOLOGY

There were two aspects of the study.

1. Market analysis to assess market availability of the material and calculating first cost of material and equipment.
2. Energy analysis to calculate energy savings for the prescriptive compliance with ECBC min, Plus and super levels. Energy savings for the cost-effective bundles for compliance by Whole building performance approach.

### 3.1. Market availability:

Energy conservation measures were listed (prescriptive & supplementary) and market survey was conducted to assess the availability and cost of materials and equipment as per standards mentioned in ECBC. Further, it was determined that all the material and equipment's are available based on the prescriptive requirements of ECBC.

### 3.2. Energy Analysis:

Energy simulations are done in eQuest DOE 2.2, which is an industry standard simulation tool. Energy models are prepared for Design case, (which has similar construction as per current market trend) and prescriptive versions of three incremental stages of compliance. Energy simulation was also done for each ECM and associated first cost were calculated.

The range of incremental costs for all the measures is between ₹40/m<sup>2</sup> to ₹908/m<sup>2</sup>. The highest incremental cost is for HVAC systems and lowest is for Envelop measure for providing external shading device.

Following measures has maximum energy saving potential in various categories;

- The best window assembly with U-value-1.63 W/m<sup>2</sup>k, SHGC-0.24, VLT-38 can achieve energy savings of 11.6%,
- Lighting design with LPD of ECBC super can achieve energy savings of 15.2%.
- Water cooled VRF system with COP of 4.8 can gain energy savings of 18.1% which is highest amongst all the individual ECMs.

Measures for envelope, shading, or lighting reduce the cooling load and enable a reduction in the cooling system size which results in first cost reduction. When this is included in calculation of net incremental cost these measures are very cost effective. These measures are selected in the cost-effective bundles.

Using the prescriptive compliance approach the ECBC, ECBC plus and ECBC super version of the office building in Vishakhapatnam, the energy savings achieved are 17%, 25% and 33% respectively as compared to the base case current practice building. The incremental cost

(₹/m<sup>2</sup>) for these are 845, 1229, and 1454 and the payback periods are 4.3, 4.3 and 3.9 years respectively.

Using the Whole Building Performance approach, it was possible to achieve the compliance of ECBC, ECBC plus and ECBC super levels with much lower incremental cost a compared to the prescriptive version. The energy savings achieved for these bundles for ECBC minimum, plus and ECBC super are 17%, 29% and 38 % and the net incremental cost (₹/m<sup>2</sup>) are 87 ,292 and 429 with payback period of 0.4, 1 and 1.3 years.

In practice, when the prescriptive compliance path is used, energy simulations are not deployed so it is not possible to estimate the first cost savings due to reduction in cooling system size. However, for the WBP compliance path the energy simulations need to be done. If simulation are done for each measure it gives the opportunity to estimate the cooling system capacity reduction, calculate net incremental costs and create cost effective measure solutions for compliance for all three levels of ECBC.

## 4. CONCLUSION:

The outcome of the study suggests the bundle of ECMs with lower incremental cost as compared to prescriptive measures for various stages of compliance ECBC-2016, plus and super by using the whole building compliance approach.

The study suggests that energy efficient strategies for building envelop have a small impact on the annual energy savings and higher implementation cost as compared to other measures. Lighting measures and HVAC measures has relatively lower first cost and higher savings.

## ACKNOWLEDGEMENTS

The study is guided by Professor Prasad Vaidya, Building Energy performance program, CEPT University, Ahmedabad. And special thanks to Ar. Surya Kakani for providing the required drawings and details of the building.

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# Measuring Infiltration Rates & Leakage in Residential Buildings of Ahmedabad Using Blower Door Method

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**ABSTRACT:** *The need to achieve thermal comfort in residences and strong dependence of air conditioning systems has led to huge energy consumption. In order to reduce the energy consumption of residences and properly size the air conditioners, air leakage needs to be reduced by tighten the building envelope. One such approach to quantify the air leakage is the use of blower door, which uses a powerful calibrated fan to depressurize or pressurize the house at an induced pressure to measure air flow (air leakage) from the house. In this study, 23 residences of Ahmedabad, 12 bungalows and 11 apartments were measured for air leakage. The study is also a first step towards developing methodology to conduct an air tightness test in residential buildings. For comparison, mean normalized leakage (metric for air leakage) of the 23-measured residence was 2.1. Due to old age construction, bungalows have more leakages than apartments. High air flow rates can be observed in buildings with intentional openings, inferior quality windows and cracks on walls. Retrofitting those windows, sealing the intentional openings in an air-conditioned space can lead to huge energy savings for air-conditioned spaces.*

**KEYWORDS:** Air tightness, Blower door

## 1. INTRODUCTION

Best architectural and engineering practice in meeting codes and standards includes keeping building construction air tight and maintaining adequate ventilation. In practise, post occupancy air change rates may not meet design intent, possibly due to multiple factors i.e. infiltration/exfiltration from cracks & openings in the building envelope, change in building construction etc. A large body of research has shown significant energy savings potential and reduction in HVAC equipment size by tightening the building envelope. From an energy point of view, it is always favourable to reduce air leakage by tightening the building envelope, but without a dedicated ventilation system the indoor air pollutant concentration may increase. Infiltration may reduce these concentrations; however, it is not possible to control infiltration/exfiltration exchanging through leakage area, which possibly leads to an unwanted increase in the energy consumption of the building.

This study intends to find the air leakage in bungalow and apartment houses of Ahmedabad, and to estimate their natural infiltration rates. The study is also a first step towards developing methodology to conduct an air tightness test in residential buildings. The buildings of Ahmedabad are typically naturally ventilated with partial mechanical ventilation in some spaces, these design components are big contributors to higher ventilation rates. The need to achieve thermal comfort in residences, and strong dependence on air conditioning systems, will led to increase in the number and size of air-conditioned spaces, which means that spaces which were naturally ventilated earlier will be converted to air-

conditioned spaces. Then, air leakage becomes a prominent factor in energy consumption, and increasing air tightness will be required for energy savings. Estimating the infiltration rates of existing Indian dwellings, will help in properly sizing of air conditioning systems for residences (tighter the building envelope, lower the air conditioning system size).



Figure 1: Cracks and gaps between the window frame and wall

## 2. Research methodology & analysis

A convenience sampling of 23 residential buildings was selected for the study, comprising of 11 apartments and 12 bungalows, were selected for air tightness measurement in Ahmedabad. Measurements were conducted from 26th Feb to 9th Apr 2018, in clear sky conditions and wind speed under 2m/sec (7km/hr) as mentioned in (ASTM,2007).

Normalized Leakage (NL) and Equivalent Leakage Area(ELA) are useful metrics to compare air leakage area for wide range of buildings sizes and was calculated for this study using equation mentioned in (Sherman,1980). From the entire measured data set, 74% buildings NL lies within the range of 1 to 2.50, which means there is 2.5-time difference in NL among the 23 measured

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residences. Mean NL for the measured building is 2.1, while geometric mean (G.M) is 1.97. The standard deviation for the measured building was 0.77.

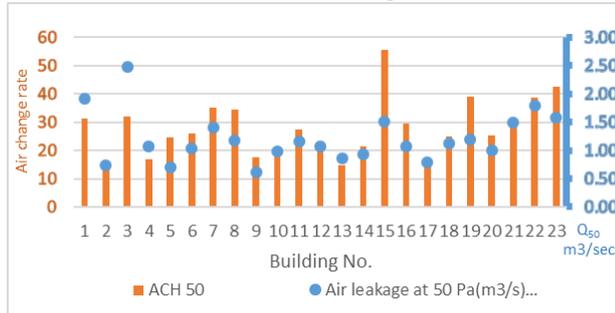


Figure 2: Air change rate and leakage rate at 50 Pa

Building No. 1,3,7,8,15,19,23 have the highest air change rate, above  $30 \text{ h}^{-1}$  at 50 Pa as seen in Figure 2. This phenomenon of extremely high air change rate is only observed in buildings where either there is intentional opening above the window or in any other place, or the windows or door do not bolt together, making them open wider during pressurization test.

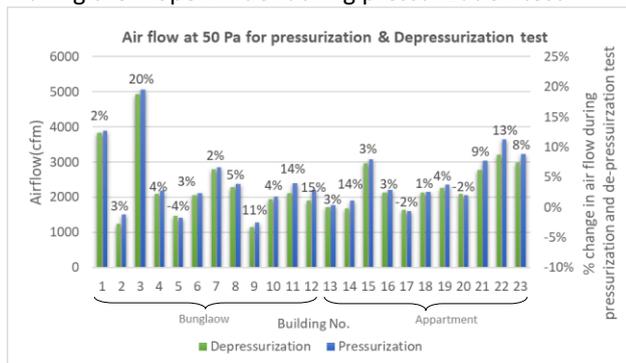


Figure 3: Air flow results during pressurization and de-pressurization test

There was difference in air flow observed during pressurization and depressurization test. The difference in air flow was due to the change in air leakage area. In depressurization test, due to negative pressure created inside the building, casement windows are sucked in towards their frames (the air flow is from outside to inside), making the windows more airtight hence reducing the airflow. While, in the case of the pressurization test, due to positive pressure inside the building, making the windows leakier, hence the air flow is increased. The difference in air flow results for depressurization and pressurization test at 50 Pa for measured buildings are shown in Figure 3. It can be observed from the graph that the percentage change in air flow between pressurization and depressurization test vary from 1% to 20%, while Building No. 5 & 20 has negative percentage which means air flow for depressurization was more than pressurization, which is an anomaly in the data set.

Table 1 shows that, residences which were constructed before 1984 (more than 34 years) has  $Q_{50}$  value greater than  $1.5 \text{ m}^3/\text{sec}$ , which signifies as the age of the building gets older, the air leakage found on these homes are higher than the recently constructed homes. This might be due to weathering of materials, cracks formation due to thermal expansion and contraction of thermal mass/plaster over the period. There is huge variation found in air leakages in residences constructed before 1984 as standard deviation of those buildings is 0.50.

Table 1: Age and air flow of the building

Age of the building	No. of buildings	Avg. $Q_{50}$ ( $\text{m}^3/\text{s}$ )	Geometric mean	Std. Dev.
≤1984	9	1.57	1.49	0.50
1984-1994	7	1.07	1.05	0.20
1994-2004	5	0.99	0.98	0.16
2004-2014	2	0.78	0.76	0.22

### 3. CONCLUSION

The objective of the study was to develop a methodology to conduct an airtightness test using blower door. Another objective of the study was to quantify the air leakages in the residential buildings of Ahmedabad. Conclusion here can only be made for the 23 measured residences, hence it cannot be extrapolated for entire building stock of India or Ahmedabad. However, the measurements do provide some information on what the air leakage rates in typical Indian bungalows and apartments might be expected. Due to old age construction, bungalows have more leakages than apartments. High air flow rates can be observed in buildings with intentional opening, inferior quality windows, it can be concluded that those buildings will have high energy consumption due to high air leakage in these homes. Retrofitting those windows, sealing the intentional openings in an air-conditioned space can lead to huge energy savings for those spaces.

### ACKNOWLEDGEMENTS

The authors would like to The Energy Conservatory, Minneapolis, for the support in providing the Minneapolis Blower door kit for the research. Without this professional graded equipment, this study won't have been possible. I would also like to acknowledge M/S InfoAnalytica for giving funds to CEPT endowment office, which helped in the purchase of the equipment.

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# Distributed Rule of Solar Radiation for Building Heating in Western China

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**ABSTRACT:** In order to reveal the distributed rule of solar radiation for building heating in the Western China, south oriented surface solar radiation, optimal inclination angle solar radiation of solar PV panels and heating degree days were used as districted indicators to study the solar radiation zoning in western China. Method of mode calculation was used to obtain the missing data of south oriented surface solar radiation. 4 cities are selected as verification points to obtain the critical direct solar radiation needed for calculation. Through the comparison of the 3 models, the direct solar radiation calculation model suitable for the western region is found. According to the ten-year average of the above three indicators, the clustering analysis method was used to get the solar radiation zones for building thermal utilization in the Western China. The rule of solar radiation intensity of each zone was summarized from the perspective of building heating.

**KEYWORDS:** Western China; Building thermal utilization; Solar radiation; Direct solar radiation; Distributed rule

## 1. INTRODUCTION

Western China belongs to the heating zone, where heating energy consumption is very huge in winter. However, the ecological environment here is fragile and lack of fossil fuels badly, especially in Tibet. Based on this, a wealth of solar energy resources can be exploited in Western China. Carrying out studies on thermal utilization of building solar energy buildings can effectively alleviate the current situation of energy shortage of the region.

The effective utilization of solar energy in building heating must be studied from the distribution rule of solar radiation in Western China. Zuo Dakang [1] mapped the distribution of solar radiation in China through horizontal globe solar radiation. Wang Bingzhong [2] established the solar radiation zone of China through the globe annual solar radiation, sunshine hours and solar energy available time. However, the above studies are based on climatology or geography point of view, which are seldom used for building heating.

## 2. CALCULATION OF DISTRICTING INDICATORS

In order to reveal the distributed rule of solar radiation for building heating, and guide the solar heating design of buildings, south oriented surface solar radiation, optimal inclination angle solar radiation of solar PV panels and heating degree days were used as districted indicators to study the solar radiation zoning in western China.

### 2.1 South oriented surface solar radiation

In China, the collector part of solar energy house is usually placed on the south side of the building, which will obtain the maximum collector efficiency. The south oriented surface solar radiation reflects the most

intuitive value of the solar radiation received by the south wall.

South oriented surface solar radiation includes southern direct radiation, diffuse radiation and reflected radiation received from ground. Its calculation models include Klucher model, Hay model, etc. The strong diffuse radiation of China's sky occupies a large proportion of the global solar radiation. In addition, the Hay model considers the anisotropic factors of sky diffuse, which is simple to calculate. Accordingly, the Hay model is suitable.

$$\bar{H}_v = \bar{H}_b \bar{R}_b + \bar{H}_d [\bar{H}_b \bar{R}_b / \bar{H}_o + 1 + 2(1 - \bar{H}_b / \bar{H}_o)] + 1/2 \rho \bar{H} \quad (1)$$

where  $\bar{H}_v$  - monthly average south oriented surface solar radiation(MJ/m<sup>2</sup>);

$\bar{H}_b, \bar{H}_d, \bar{H}_o, \bar{H}$  - monthly average direct radiation,

monthly average diffuse radiation, monthly average astronomical radiation and monthly average total radiation on horizontal surface(MJ/m<sup>2</sup>);

$\rho$  - ground reflectivity;

$\bar{R}_b$  - monthly average the ratio of the amount of direct solar radiation on the south oriented surface to the horizontal surface.

The 45 city stations were selected as data points within the scope of 12 western provinces. Radiation data types obtained from the National Meteorological Data Network are mainly horizontal globe solar radiation, in the meantime, only a few stations have diffuse or direct solar radiation. In order to calculate south oriented surface solar radiation, it is necessary to get diffuse or direct radiation. Therefore, the model method is used to

calculate, and the following three common of which were used for suitability verification.

1) Diffuse model, Liu-Jordan model [3], are mainly calculated by using the clear sky index. The expression can be summarized as:

$$H_d / H = a + b\bar{k}_t + c(\bar{k}_t)^2 \quad (2)$$

where  $a, b, c$  – coefficient,  $d, e$  in the post are the same;  $\bar{k}_t$  - monthly average clear sky index.

2) Jiang Yingni [4] put forward a model which considers sunshine rate according to formula 2.

$$H_d / H = a + b\bar{k}_t + c(\bar{k}_t)^2 + d(\bar{S} / \bar{S}_0) + e(\bar{S} / \bar{S}_0)^2 \quad (3)$$

Where  $\bar{S} / \bar{S}_0$  - monthly average sunshine rate.

3) Weng Duming [5] proposed a model which can calculate the direct radiation value.

$$\bar{H}_b = \bar{H}_0 \left[ a(\bar{S} / \bar{S}_0) + b(\bar{S} / \bar{S}_0)^2 \right] \quad (4)$$

By Comparing the measured values with calculated values of the Lhasa, Ejin-Banner, Kunming and Chengdu stations, it is found that the Jiang Yingni model is most suitable for the radiation calculation in Western China.

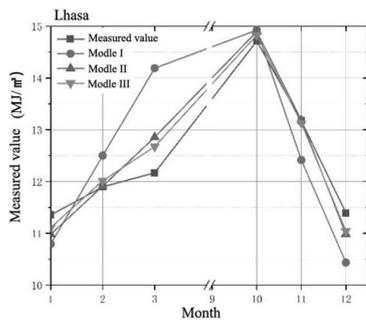


Figure 1: Three model calculated values and measured values contrast in Lhasa

## 2.2 Optimal inclination angle of solar PV panels

The PV panel and the horizontal plane will form a tilted angle called the optimum angle of inclination. Yang Jinhuan points out that the determination of the best angle of inclination should follow continuity, uniformity and maximum. In this paper, the above principles are followed when the best angle of inclination is determined. That is to say, the solar radiation obtained by PV panels is guaranteed a balance and maximum amount within half a year in winter.

Calculation method of the southward radiation is also used to calculate the solar radiation on the tilt plane, the factors of angle of inclination  $\beta$  from which is considered barely.

$$\bar{H}_\beta = \bar{H}_b \bar{R}_{b\beta} + \bar{H}_d \left[ \bar{H}_b \bar{R}_{b\beta} / H + 1 / 2(1 - \bar{H}_b / \bar{H})(1 + \cos \beta) \right] + \frac{1}{2} \rho \bar{H} (1 - \cos \beta) \quad (5)$$

where  $\bar{H}_\beta$  - monthly mean of globe radiation a day on the tilting surface, MJ/(m<sup>2</sup> · d).

$\bar{R}_{b\beta}$  - monthly average the ratio of the amount of direct solar radiation on the tilt plane to the horizontal surface.

To ensure the maximum solar radiation at a certain angle in winter for half a year, this paper adopts the method of trial calculation to make the  $\beta$  from 1° ~ 90° at a resolution of 1°. When the sum of the values of each month is the largest, the tilt angle is the optimum angle of inclination within half a year in winter.

## 3. DISTRIBUTE SOLAR RADIATION ZONE

According to the solar radiation data of 46 meteorological stations in western China between 1990 and 1999, south oriented surface solar radiation and optimal inclination angle solar radiation of solar PV panels solar radiation were calculated by equations (1) and (5). Enter them and the known number of heating degree days into SPSS to complete the cluster analysis.

In the end, the analysis obtained 4 regions that can assess the potential of solar energy heating in western China.

## 4. CONCLUSION

This paper gives the distributed rule of solar radiation resources of building thermal utilization in the western region, which can guide the design of solar heating in local buildings. The clustering analysis method was used to get the solar radiation zones for building thermal utilization in the Western China according to the ten-year average of the above 3 indicators. The rule of solar radiation intensity of each zone was summarized from the perspective of building heating.

## ACKNOWLEDGEMENTS

This work was supported by the National Natural Science Foundation of China (No. 51578439) and National key point research and invention program of the thirteenth (No. 2016YFC0700208-03), and Tianjin Municipal Science and Technology Foundation (No.14JCYBJC432 00).

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# Evaluation and Factor Analysis of Town Residential Coal Utilization in Northeast China

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*ABSTRACT: Town housings are facing good prospects and will play an important role in energy-saving and emission reduction in the future. As the main energy resource for heating, coal utilization in the severe cold region is worthy of attention. With data from the 2016 Northeast towns investigation, this paper estimated coal utilization in town housing by calculating expenditure. The investigation covered 4 aspects: basic household information, family living conditions, residential housing characteristics and energy utilization. Town residential coal utilization in Jilin Province is the most, while Liaoning Province is the least. Household appliances, cooking fuel, central heating, heating tools, housing area and monthly income are analysed as factors of residential coal utilization.*

*KEYWORDS: Coal utilization, Energy consumption, Town housing, Severe cold region, Northeast China*

## 1. INTRODUCTION

Research on housing energy consumption in China started late compared to developed countries. Most studies concentrate on cities as data are easy to obtain. [1,2] With the rural reconstruction, rural housing energy consumption also draws attention. [3-5] However, town housing energy consumption is a combination of both city and rural areas, which not only makes data difficult to obtain and analyse but makes relevant research quite promising. Coal, as one of the main energy resource, owns high proportion in both city and rural areas for heating. [6,7] With complex energy type and heating demand, the severe cold region shows great energy utilization differences and conservation potential, which make it worthy of attention. [6] Northeast China, containing Heilongjiang, Jilin, and Liaoning Province, is considered as the severe cold region of China. With the 2016 Northeast towns investigation data, this study evaluated coal utilization in Northeast towns and analysed factors. The evaluation method of this paper provides an easy way to calculate energy utilization in towns that lack data. According to the analysis of these factors, future research can further propose targeted energy-saving strategies.

## 2. DATA

Data comes from the 2016 Northeast towns investigation organized by the government. Each province elected four towns as representatives. Sample families were randomly selected and questionnaires were filled by an adult family member. To meet the requirements of obtaining 100 valid questionnaires in each town, researchers conducted a one-one survey and answered respondents' questions timely.

Although questionnaires are not for energy usage, coal utilization can be analysed by four related aspects of

information, obtaining the basic household information, family living conditions, residential housing characteristics and energy utilization.

## 3. EVALUATION OF TOWN RESIDENTIAL COAL UTILIZATION

Due to the limited education, respondents cannot provide specific data on energy utilization. Various types of fuel, specifically non-commercial fuel, and the fuel efficiency differences also make it difficult to evaluate. Therefore, this study estimates coal utilization by calculating expenditure. According to data obtained, such as monthly housing expenditure, rental fees, daily electricity consumption and water consumption, together with the charging standard in each province, the average household heating expenditure can be calculated. So the annual coal expenditure can be evaluated by removing central heating expenditure. The annual coal expenditure of sample towns is about 1028 RMB in Heilongjiang Province, about 3924 RMB in Jilin Province and about 65 RMB in Liaoning Province.

## 4. FACTORS OF TOWN RESIDENTIAL COAL UTILIZATION

The results are different from city or rural areas. [3] Based on the questionnaires, factors can be analysed.

### 4.1 Household appliances

The top three family appliances in towns are colour TV, refrigerator and washing machine(Fig. 1).

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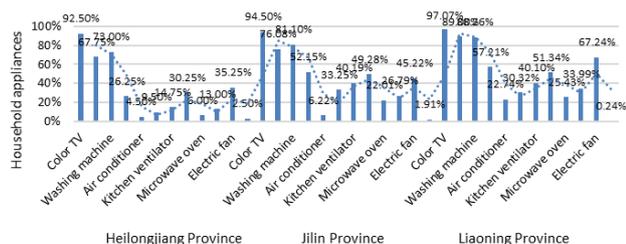


Figure 1: Household appliances of the sample towns.

The low proportion of air-conditioning (11%) indicated that most families regulate room temperature by burning fuel. About 10% of households use solar water-heaters, which means solar energy for heating is feasible in cold regions.

## 4.2 Household cooking fuel

The main cooking fuel is firewood and straw (42%) in Heilongjiang Province, bottled gas (41%) in Jilin province, bottled gas (51%) in Liaoning province (Fig. 2). While rural families mainly take firewood and straw as main cooking fuel. [3] Great differences could be seen between towns and rural area.

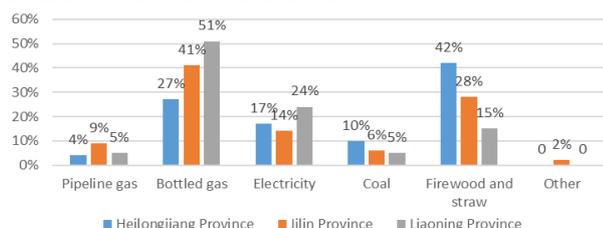


Figure 2: Household cooking fuel of the sample towns.

## 4.3 Central heating

The popularization rate of central heating in Heilongjiang(1%) and Jilin provinces(16%) is much lower than that in Liaoning Province(72%). The household annual coal utilization in Jilin Province is higher than Heilongjiang Province, but less coal is used for cooking. Therefore, Jilin Province prefers coal as heating fuel better than Heilongjiang Province, while Heilongjiang Province prefers non-commercial fuel for heating, such as firewood, and straw.

## 4.4 Heating tools

Town families use traditional heating tools “Kang” and stoves whose fuel are coal, straw, and firewood. These heating tools are still used before and after central heating. Kang heating is similar to floor heating in city dwellings with a scope limitation, the temperature drops quickly beyond a certain distance. To heat rooms without a “Kang”, pipes were built to get heat from cooking smoke before it is exhausted.

## 4.5 Housing area and monthly income

Residents' monthly income represents residents' economic level. By means of Pearson correlation analysis

(Table 1), there is a significant positive correlation between residential housing areas, monthly income, and residential coal utilization. Economic income determines whether residents can afford coal utilization, housing area affects the amount of coal utilization. There's little correlation between monthly income and residential housing areas, as most residential houses are self-built (69%), the direct economic pressure is weakened.

Table 1. Pearson correlation analysis of residents' monthly income, housing areas, and coal utilization

		Residential housing areas(m <sup>2</sup> )	Monthly income (RMB/month)	Residential coal utilization
Residential housing areas(m <sup>2</sup> )	Pearson correlation	1	.022	.990**
	Significance (bilateral)		.657	.000
	N	423	418	420
Monthly income (RMB/month)	Pearson correlation	.022	1	.161**
	Significance (bilateral)	.657		.001
	N	418	418	418
Residential coal utilization	Pearson correlation	.990**	.161**	1
	Significance (bilateral)	.000	.001	
	N	420	418	420

\*\* . Correlation is significant at the 0.01 level (2-tailed).

## 5. CONCLUSION

This paper estimated the residential coal utilization in towns and analysed influencing factors. Town housing in Jilin Province has the most coal utilization, while Liaoning Province has the least. Households in towns and rural areas have shown great differences in heating modes and coal utilization. Household appliances, cooking fuel, central heating, heating tools, housing area and monthly income have influenced residential coal utilization in town. Town housing energy-saving showed enormous elevate space for improvement.

## ACKNOWLEDGEMENTS

Supported by the National Natural Science Foundation of China (Grant No. 51678178).

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# The Impact of Occupants' Energy Use Behaviour on Building Performance: a Case Study of a Tower Block in London

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*ABSTRACT: This study assesses the building performance of a residential high-rise tower block in London, which, through preliminary studies was found to consume significant energy for heating. The aim of the study is to explore the effect of the dominant occupancy and heating schedules of the building on predicting the heating energy consumption of the building in the winter months in comparison to the benchmark profiles. A series of questionnaire-based survey and building simulation analysis were performed to understand the occupants' energy use behaviour and its effect on building energy use. The results show that buildings' physical issues including damp and mould caused in-efficient building envelope. To reduce the dampness and condensation effect and increase the thermal comfort, the occupants use considerable heating energy and as a result, the actual energy use patterns of the building are different from the benchmarks profiles, which caused uncertainty in predicting the building performance.*

*KEYWORDS: Building Performance, Energy Efficiency, Occupants' Behaviour, Retrofit, Council Housing*

## 1. INTRODUCTION

Building energy use accounts for more than 40 percent of the global energy consumption [1]. Studies assert that occupants' energy use behaviour and their socio-demographic background may have a considerable effect on the intensity of energy used in buildings [2]. In addition, occupancy and energy use schedules associated with energy consumption are one of the main factors of uncertainty in predicting the building performance [2, 3]. However, there is a lack of consensus on approved methodologies of occupants' energy use patterns to be inputted into simulation tools [4]. For instance, a research study on ten different building typologies explored the occupancy and energy use profiles for energy simulation to develop energy calculation methods. The study showed that the average schedules cannot predict the actual energy required and highlighted the importance of realistic hourly profiles [1]. Considering the feasible and prominent occupancy and energy use patterns in building simulation may yield reliable outputs and reduce the gap between the predicted and actual building energy use.

This paper focuses on the effect of occupants' energy use behaviour on the energy performance of a 22-storey tower block in London Borough of Newham (LBN). The aim of this study is to explore the significance of occupancy and energy consumption schedules on predicting building energy performance using DesignBuilder (DB) dynamic building simulation tool.

## 2. RESEARCH METHODOLOGY

The methodology is based on a questionnaire-based survey, to gain more insight into the occupants' energy use behaviour, and building simulation modelling to explore the impact of occupancy and energy use patterns

on heating energy consumption in the winter season. The primary studies including water ingress survey, structured interviews and field monitoring demonstrated that the thermally inefficient building envelope caused damp and mould as well as a significant increase on the heating energy use [6]. To improve the building energy efficiency, LBN Council has planned to retrofit the building. This study attempts to analyse the impact of occupancy and energy use profiles on predicting the building performance using dominant patterns obtained from the survey and compared them against the benchmark methodologies. The study aims to identify the most feasible occupancy and energy use profiles to predict the reliable heating energy use and support the Council's retrofit plan.

## 3. RESULTS AND DISCUSSIONS

### 3.1 Questionnaire-based survey

A questionnaire survey on the occupants' energy use behaviour and their lifestyles was conducted to understand issues affecting home energy performance. 108 questionnaires were distributed among the occupants of the building that includes one-bedroom and two-bedroom flats and more than 30% of the questionnaires were completed, which is an acceptable number [1,2]. According to the results, around one third of the properties have a single occupant while one third of the properties are occupied by four to five occupants including children. Notably, 46% of the households admitted that they had to use more heating energy to reduce the condensation and cold. The results of the survey demonstrate that there is a correlation between the age of the occupants and the heating energy consumption. As the occupants' age band increases, they tend to use less heating in winter ( $r = -0.322$ ,  $p < 0.05$ ) and

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as the members of the households with children increase, the hours that heating is kept on rises as well ( $r = 0.412$ ,  $p < 0.01$ ). In addition, the damp and condensation problems in the flat correlate strongly with the heating energy bills ( $r = 0.626$ ,  $p < 0.01$ ), which confirms the occupants' complaints regarding heating energy use. From in depth analysis of the results, two representative flats were selected as the representative occupancy and heating energy consumption patterns to be incorporated into the simulation model. The dominant patterns were selected based on the highest and the lowest levels of occupancy with the associated high-energy use profiles (Flat A with one occupant and Flat B with 5 occupants including three children).

## 3.2 Simulation analysis

Building simulation analysis using DB software was conducted to assess the building energy performance using standardised occupancy and energy use patterns (SAP2012 and TM59), which use the average national domestic buildings patterns, against two representative patterns (Flats A and B). It should be noted that both flats have serious damp and condensation issues that have an impact on the heating energy use. The standardised methods exclude considering the effect of physical issues within the properties including condensation and damp on the energy use profiles and as a result, the predicted energy performance in the problematic properties might be different from the actual energy performance. Figure 1 presents the heating energy use patterns of flats A and B as well as SAP 2012 that applied to DB simulation model to predict the heating energy use of the tower block.

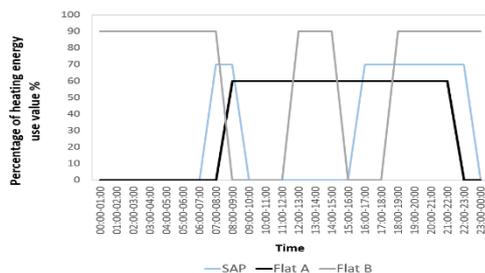


Figure 1: Heating energy use patterns applied to DB model

The results from the simulation show that the monthly heating energy consumption of the building in the winter using SAP2012 and TM59 patterns is 15067 kWh and increases to 25112 kWh using Flat B scenario while it increases to 21094 kWh using Flat A scenario (Fig. 2). It was found that because of the variances in occupancy patterns and the dampness and condensation issues of the case study, the heating period in the winter season is longer than the suggested patterns in guidelines. In addition, the occupants' energy use behaviour have an impact on the intensity of the heating

energy use and causes a significant difference in the simulation outputs.

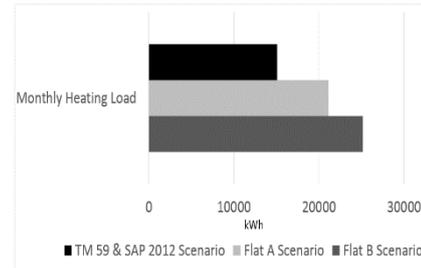


Figure 2: Predicted heating energy use of the tower block in a typical winter month using different scenarios in DB tool

## 4. CONCLUSION

In this study, the importance of the occupancy and heating energy use profiles on predicting the energy performance of the case study was explored. Based on the initial studies, 50% of the surveyed properties suffer damp and mould problems and to reduce the issues experienced, the occupants tended to use more heating energy. A questionnaire-based survey conducted on the occupants' energy use behaviour showed that the occupants' energy consumption behaviour and their socio-demographic backgrounds causing different energy and occupancy patterns compared to the standardised profiles. Two representative high and low patterns were identified from the questionnaires and building simulation modelling was performed using the dominant patterns as well as the benchmark patterns. It was found that the predicted monthly heating energy use of the building in the cold season is considerably higher using dominant scenarios compared against the standardise patterns. The study shows that it is not always possible to rely on standard methodologies for predicting the building performance for a building with hydrothermal issues, as the occupants' energy use patterns are different. To obtain reliable simulation results, the occupants' energy use behaviour as well as occupancy and energy use patterns need to be methodically considered as a key parameter.

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# Energy Use Prediction of Buildings with Different Methods of Calculating SHGC of Shaded Windows

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*ABSTRACT: Building energy simulations carry out detailed calculations for energy prediction for each and every part of the building geometry. For the fenestrations, details about the glazing, the frame and the shading device are taken as simulation inputs. For the glazing part the typical inputs are the U-Value and the solar heat gain coefficient (SHGC) value for the glazing. Although the SHGC value is a standard value for a glazing type, there are different calculation methods to account for the impact of shading devices into the SHGC values. The impact of SHGC value through two different methods are studied in terms of solar gains (kWh) through fenestration and cooling energy. The results are also compared with the results of the simulation model in which the shading devices are modelled and the manufacturer's SHGC value is considered instead of effective SHGC value. Further, the impact on cooling energy reduction is determined and compared for different latitudes, climates and overhang depth. The results show that the cooling energy reduction obtained from the methods with detailed heat transfer mechanisms are closer to the results obtained from the simulation with the physical shading device.*

*KEYWORDS: Solar heat gain coefficient (SHGC), Effective SHGC, Shading devices, Solar gains*

## 1. INTRODUCTION

Building energy simulations are used for carrying out detailed calculations for the energy use prediction of the building. Several studies in the past have shown that the fenestrations account for significant heat load increment in the building. The heat gained through fenestrations in the building can be identified through simulations. To accurately predict the heat gains through fenestrations, details of the fenestration like window opening size, the glazing material, window frame material, window frame size, shape and size of the shading devices are given as an input to the simulation engine. Also, the other important inputs for the glazing are the U-value and the solar heat gain coefficient (SHGC) of the glazing material. The SHGC value considered in the simulation is typically that is provided by the manufacturers. This values are derived under standard testing conditions prescribed by associations like the National Fenestration Rating Council (NFRC) [1].

Shading devices are the most effective way to cut down on the direct radiation. The cut in the direct radiation on the glazing due to the addition of shading device will reduce the SHGC as there will be a direct reduction in the radiation falling on the glass. As the radiation falling on the glazing and the exterior and interior temperatures vary with time, the SHGC would vary accordingly. The shading devices are additionally modelled to identify the impact of solar gain. However, there are different calculation methods that take into account the effects of adding shading devices and provide combined value of SHGC. This is done by taking into account the manufacturer's SHGC value and the dimensions of shading device used. This gives an

effective SHGC value that can be considered as an input to the simulation without modelling the shading devices. Two of such methods are studied in this research and compared with the simulation results.

## 2. BACKGROUND

The heat gain due to direct incident solar radiation is defined as Equation (1):

$$q_b = E_D(T + NA) \quad (1)$$

where  $q_b$  is the heat gain through the fenestration in units of energy flux per unit area,  $m^2$ ,  $ED = ED\cos\theta$  is the direct solar irradiance on the glass with solar transmittance  $T$ , solar absorptance  $A$  and the inward flowing heat fraction  $N$ . The quantity in the parenthesis in equation 01 above is termed as the **solar heat gain coefficient** (SHGC) [2]. For the ease of comparison, standards like National Fenestration Rating Council take into consideration standard inside and outside conditions and direction of incident radiation. SHGC is a unit-less value ranging between 0 to 1.

The Energy Conservation Building Code(ECBC)[3] of India, 2017, defines a methodology to take into account the effect of shading devices by proposing a Shading Equivalent factor (SEF). The effective  $SHGC_{eff}$  is then determined using Equation (2) as:

$$SHGC_{eff} = SHGC_{prescribed} * SEF \quad (2)$$

wherein the  $SHGC_{prescribed}$  is from the prescription for the climate type and SEF is determined from the projection factors (PF).

The variation in the SHGC values all throughout the year is taken care in the study by Kohler et al. (2017) [4].

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The weighted average of the SHGC ( $SHGC_w$ ) values have been taken out for annual and seasonal variation by using the Equation (3):

$$SHGC_w = \frac{\sum_{t=1}^{8760} SHGC_t * I_t}{\sum_{t=1}^{8760} I_t} \quad (3)$$

where  $I_t$  is the combined diffuse and direct radiation that is incident on the window at a timestep  $t$  and  $SHGC_t$  is the SHGC at the timestep  $t$ .

Both the above mentioned methods are used to calculate the adjusted SHGC for the windows with shading devices. But since both the methods have different calculation procedures, the values of SHGC determined are different from each other. The differences due to the changed SHGC values are studied through energy simulations. Both the derived values are used as inputs in the simulations. Since both the adjusted SHGC values will have the effect of shading device added to them, no physical shading device would be needed in the simulation model.

The impacts due to the differences can be compared to the model which has the standard SHGC value and the shading device is used in the simulation model. The impacts can be compared on the basis of the differences in the solar gains through fenestrations and the cooling energy of the buildings.

### 3. METHODOLOGY

The study is carried out for six cities in India i.e., Chennai, Bangalore, Pune, Mumbai, Kota and Dehradun. The cities are located on 4 different latitudes with an equal difference of 6 degrees. Double glazing with 6 mm clear glass and 12 mm air gap is used in the study. Window size of 5.2 x 1.2 m (WWR 40%) is used. The model is shown in (Fig. 1).

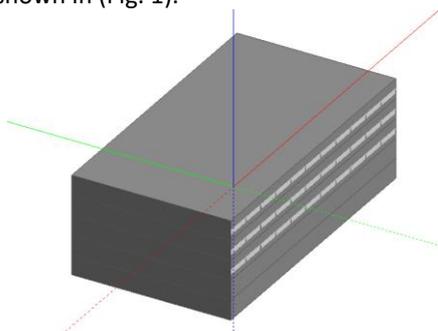


Figure 1: Model used for simulations

### 4. RESULTS

There is a difference in the amount of solar gains that are predicted by using eSHGC and wSHGCs values. The difference in the solar heat gains get lesser as the latitude increases. As shown in Fig. 2, the use of eSHGC for an overhang of 1.2 m predicts 60% more solar gains than the use of wSHGCs for the city of Chennai. This difference reduces to 30% for Dehradun with all the other cities

falling between the two. The amount of reduction in solar gains is dependent upon the location and the climate of the city.

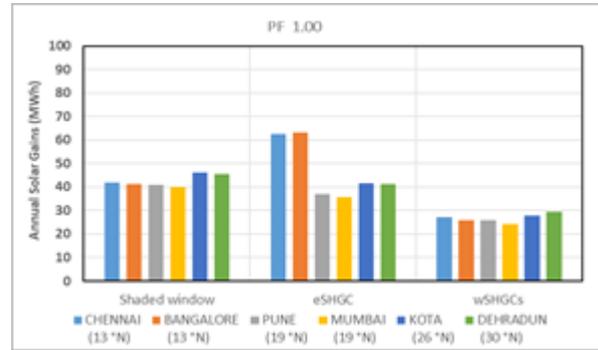


Figure 2: Difference in solar gains

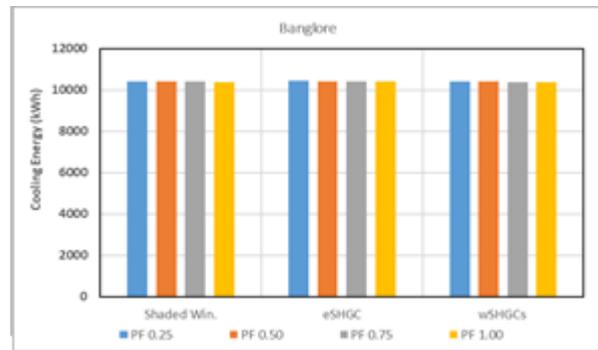


Figure 3: Difference in cooling energy

As observed in Fig. 3, the maximum difference between the total cooling energy when using eSHGC and wSHGCs is negligible. The maximum difference of 0.30% is found for the cities located below 15 °N. Even though the reduction in solar gains is up-to 75%, its impact on the cooling energy is not accountable. The 25% difference in the eSHGC and wSHGCs values does not make more than 0.5% difference in the total cooling energy.

### 5. CONCLUSION

As the wSHGCs calculation uses detailed heat transfer calculations, the SHGC value predicted, when used in simulations gives the closest results to the geometrical simulations. The different calculation methods do not have a significant impact on the cooling energy for commercial building as most of them are internal load dominated.

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# Evaluation of Daylight Performance of the New Workshop Building at CEPT University, Ahmedabad

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**ABSTRACT:** This study evaluates the daylight performance of the newly built workshop building at CEPT University, Ahmedabad, India using calibrated Radiance simulations with Lightstanza user interface. The building houses model making, wood, metal, ceramics & clay workshops. The methodology included field measurement of illuminance at the task plane, long term measurements, and surface material characteristics, calibrating the daylight model, and calculations of lighting energy savings. The calibrated model of the building has a RMSE (Root Mean Square Error) and an NMBE (Normalized Mean Bias Error) of less than 4%. The daylighting performance of building could achieve 4 points for LEED v4 with 93% $sDA_{750/50\%}$  and 0.4% $ASE_{1000/250hr}$ , and meets ECBC (Energy Conservation Building Code) daylighting requirements. It achieves a  $DA_{750}$  of 46%, and the current manual switching response to daylight saves INR 86,424 per year. The Daylight Glare Probability (DGP) analysis showed that the spaces inside the workshop are likely to experience glare issues during the summer months, mostly between the time period 5-6 PM when direct sun penetrates in to the space.

**KEYWORDS:** Daylight performance, Daylight simulation, Calibration, Annual performance, Visual comfort

## 1. INTRODUCTION

Studies on daylighting have been done for office buildings but are limited for industrial buildings where lighting is a major electricity consumer [1]. The lighting power density (LPD) allowed for a workshop facility is 14 W/m<sup>2</sup> [2], and therefore such buildings can have high lighting energy use. Daylighting also improves work productivity and health and can help in avoiding accidents caused by poor illumination.

This study evaluates the daylight performance of the workshop building at CEPT University, Ahmedabad, India. It uses calibrated Radiance simulations with LightStanza user interface to assess the visual comfort and lighting energy savings. Ahmedabad has a clear sky climate throughout the year except for monsoon months. The workshop facility is an industrial building with 3 bays with high ceilings, north-facing windows and large clear spans (Figure 1) to accommodate the need of each activity.



Figure 1: Interior view of one bay of the workshop.

## 2. METHODOLOGY

The daylighting design intent & daylight strategies used were recorded by collecting data from sources.

Field measurements for surface reflectance and illuminance values were done. The grid size and work plane height were referred from LEED[5] for daylight compliance. Illuminance data at one point was recorded for one week at 15-minute intervals. The 3-D model of the building with geometry and material definition was created in Sketchup and the daylight simulation was performed in Lightstanza[3]. The differences between the onsite measurement data and simulated results were reduced by correcting inputs such as details of furniture arrangement and dust factor on the glazing. The calibration goal was acceptable range of error for NMBE ( $\pm 5$  to 10%) and RMSE (15 to 30%). After calibration, annual daylight simulations were performed to evaluate the performance using daylight metrics: Spatial Daylight Autonomy( $sDA$ ); Annual Sun Exposure( $ASE$ ); Useful Daylight illuminance( $UDI$ ); and Daylight Glare Probability ( $DGP$ ).  $DGP$  values from rendered images in Lightstanza are analysed to understand the scale of visual comfort.

## 3. RESULTS & ANALYSIS

### 3.1 Calibration process

The measurements were done in model-making studio since it is representative of the workshop in terms of its characteristics, hours of operation and purpose.

The monitoring was done to calibrate the model while keeping the door partition and north facing garage doors closed for Point-In Time (PIT) results. For calibration, first it was assured that the results of outside illuminance were close for measured and simulated values. The error that occurred due to 'CIE clear sky' condition was 21%, whereas error due to 'climate' sky

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condition (TMY weather file of Ahmedabad) was only 0.09%. Hence, the latter option was used.

In Figure 3, the difference in illuminance values between all the gridlines lie in the range of 180 to 380 lux. After changing the furniture layout from as-built to the existing one, the range became narrower i.e. approx. 50 to 80 lux. There was no noticeable change after closing the partition door. Accounting for the Visible Transmittance (VT) by using a correction factor for dust had the maximum impact i.e. it affected the direct sky component of daylight the most as compared to the other two steps (Table 1).

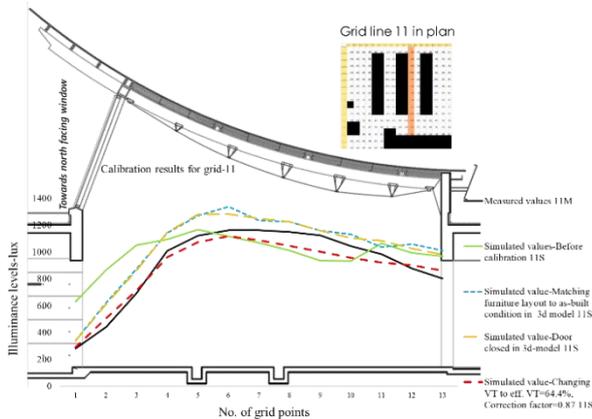


Figure 2: Comparison of measured and simulated illuminance after calibration-Grid line 11

Table 1: Results of calibration

Calibration steps	Results %		Acceptable range of error
	NMBE	RMSE	
1. Before calibration	(-31.1) %	31.2%	
2. Matching furniture to as-built conditions	(-11.3) %	11.4%	
3. Closing the partition doors	(-12.4) %	12.5%	NMBE: ±5 and 10%
4. Accounting for VT reduction due to dust. [Effective VT=64.4%]	(-3.76) %	3.78%	RMSE: 15-30%

### 3.2 Performance Analysis

sDA and ASE simulation is done as per LEED compliance requirements for regularly occupied spaces. Corridors, storage areas, service areas and spaces with area < 250 sq. ft. are not considered.

The UDI simulation was done as per ECBC 2017 daylight requirements. UDI was calculated as per the points on the grid that received illuminance levels in the range of 100-2000 lux for 90% daylit hours of the year.

The workshop building meets the performance thresholds for sDA<sub>300/50</sub>, ASE<sub>1000/250hr</sub> and UDI<sub>100,2000lux</sub> to be 0.4%, 93% and 41% respectively.

### 3.3 Daylight glare probability (DGP) analysis

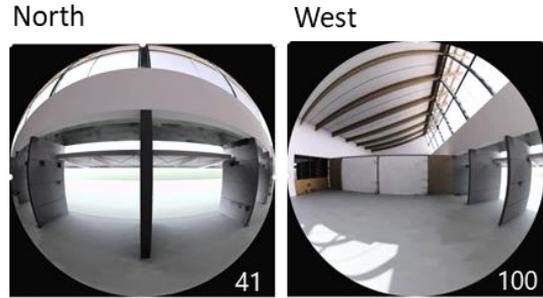


Figure 2: DGP results for summer solstice for a point at eye level located near the garage doors at 5 pm

In Figure 4, the highest DGP value is for a point located near the garage doors (since it has maximum view angle towards the north openings when compared to the other two points). Figure 4 analyses the range of glare for 6 points located at different spaces in the workshop. The glare is disturbing for point 2 and lie in the range of perceptible and imperceptible for other points during occupied hours.

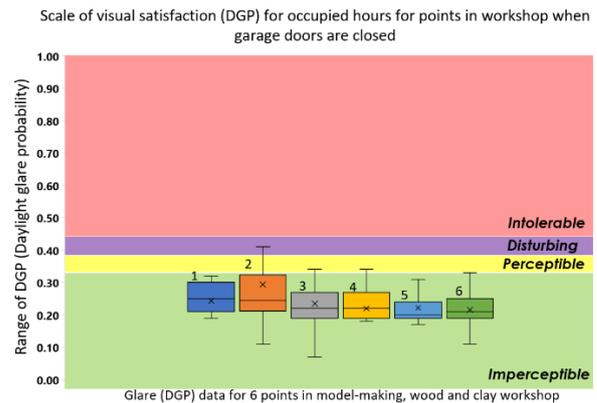


Figure 4: Analysis of glare for 6 points in the workshop from north openings for various occupied hours

### 3.4 Lighting energy savings

The building occupants manually control the lights in response to about 400 lux as per the critical point used by the photosensor to switch the lights on. This control strategy is estimated to save about INR 86,424 per year.

### 4. CONCLUSION

In terms of daylight performance, the workshop building is performing exceptionally well. The workshop building is LEED and ECBC daylight compliant. As per the LEED scorecard v4-option 1, the building can achieve 4 points. Daylighting in the workshop saves INR 86,424 per year. In terms of glare related visual comfort, the spaces are likely to experience glare issues during equinox (21<sup>st</sup> March) and summer solstice (21<sup>st</sup> June) mostly between 5-6 PM. For months of equinox (21<sup>st</sup> September) and winter solstice, the spaces are visually comfortable.

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## **ACKNOWLEDGEMENTS**

The authors would like to acknowledge the building owner and the architect for providing information. The software support was provided by Lightstanza [3].

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## Simulation Tools and Design Practice: Choosing the Right Technology

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*ABSTRACT: This abstract focuses on how to better adapt design aid software in daylighting to the architectural and urban design process. Reflecting on why daylighting evaluation tools are seldom used in the design process, we highlight the fact that current validated tools cannot provide results in a timely manner compatible with the design process. Users do not need the same precision of results during the various phases of design process. Much more importantly they need information at the right time. We show that cumulative ray-tracing is a good candidate for results better suited to the design process, we call this type of method "Instant Method".*

*KEYWORDS: Daylighting, Computer simulation, Design practice, Real-time analysis*

### 1. INTRODUCTION

This paper looks back at 25 years of our researches in daylighting and software tools created following these researches in order to highlight key elements in the design of useful daylighting software tools for architectural and urban designers.

It is the objective of the paper to stress out that different methods and capabilities induce different uses in practice. It also stresses out that the integration in the design process depends on the language used, the data needed and available, and the time needed to run an actual evaluation. It shows that it is important for software designers and researchers to carefully choose among the available methods to build tools most useful to architectural and urban designers for daylighting.

This work is supported by the Ile de France Region within Innov'Up framework.

### 2. EVALUATION TOOLS IN ARCHITECTURAL DESIGN

The use of evaluation tools during the design of architectural and urban project has long been a subject for debate among researchers, engineers and practitioners. Beyond academic debate, it is well-known that a large number of architects and urban planners use little if no software to evaluate daylighting during the design phase, in particular early design phase<sup>1</sup>. It does not mean that no practitioner uses such tools but that it is often the case. The survey by Weytjens et al<sup>2</sup> showed that "most of these tools [for Energy Analysis] are not in tune with the architects' approach and are not suitable for early design stages, when major decisions are made" and that they are used by less than 10% of the architects (with the exception of regulatory tools). In their study they identified major factors for this lack of use, namely: simplicity, intuitive tool usage, and time to use the tool along with speed, and minimum data-input, ability to quickly create, test and compare alternative designs, link with CAD software. Along these

lines the American Institute of Architects (AIA) states<sup>3</sup> that "building Energy Modelling tools designed for architects need to: have architect-friendly (graphic) interfaces; be open-source and easily exchange information with other professional software; correspond in their sophistication to the complexities of building design; allow for increasing levels of information to be added; match the level of detail at each stage of design; keep pace with the design process; generate outcome predictions quickly; provide client-friendly (graphic) output.

### 3. FAST EARLY RESULTS FOR EARLY DESIGN

To get valid results, daylighting software rely heavily on complex and time-consuming simulation like ray-tracing method<sup>4</sup>. Reliable tools such as Radiance<sup>5</sup> provide results that can be quite useful to evaluate a project. However, these tools are seldom used in design practice. In order to contribute to solve this duration problem, we chose to use ray-tracing techniques that are specifically able to give progressive results. We called our development "Instant Method".

In classical ray-tracing simulation, users need to wait several tens of minutes or hours to get results, in particular for luminance. The important thing is that user needs to wait for the calculation to be completed. However, in design, very often the user has no need for a complete result set and is not willing to wait. The user wants to quickly test alternatives and results are needed within a few seconds to check them, make adjustments, rerun and again.

User must wait during the design process and he/she will be "allowed" to continue his/her design only when all simulation results are ready. Freedom is not given to the user to get only the results he/she needs at a particular design step. Problem is that the design process is far too complex and varies too much to decide beforehand what is the required precision/quality of

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results. Most of the time, valid simulation tools can only be used for global and final verification. We need to give user the freedom to study what he/she needs to study when he/she wants to study it with the level of precision he/she needs.

### 4. DESIGN OF EVALUATION TOOLS

This necessity of freedom has a deep impact on the design of adapted evaluation tools. It means that we should be able to produce results in a timely manner, what we call "Instant Method". Techniques such as accumulative rendering can be nicely adapted to produce instantly an image that progressively refines itself. That way it is the user who decides when the information provided is good enough for his/her needs. A few seconds may be enough to decide that adjustments are needed; that a material is ill-adapted; etc. As design evolves, the user can go into more details and more precise and lengthy simulation. Hence the request that the quantity/quality of information follows the advancement of design can be answered.

Below is an example on a complex 3D-model using accumulative ray-tracing "Instant Method". Figure 1 is produced on an average laptop in 30 seconds, figure 2 in 12 seconds. Details level is low but sufficient for first understanding and decision-making. It allows to see luminance and illuminance.

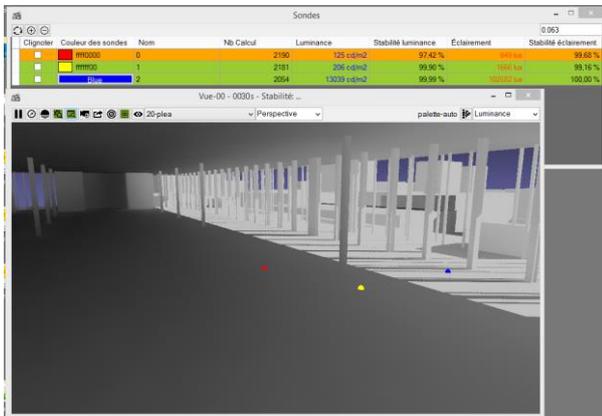


Figure 1: 30 seconds luminance image with 3 numerical values

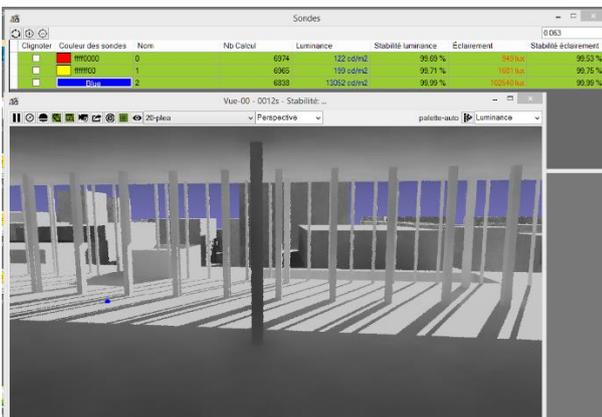


Figure 2: 12 seconds luminance image with 3 numerical values

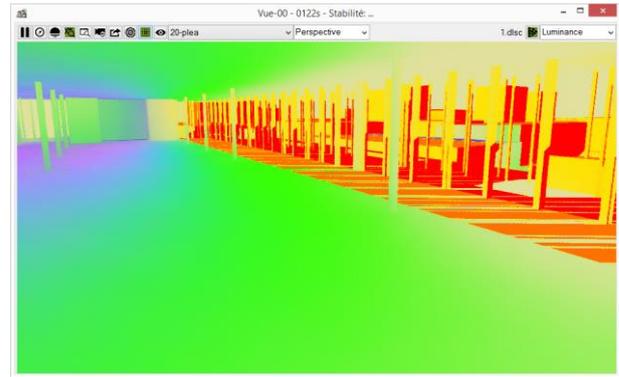


Figure 3: 2 minutes false color image via palette of luminance

Image 3 shows that it is also possible to give sophisticated distribution of luminance on the interior envelope that refines progressively. Figure 3 is a 2 minute calculation that can be continued to get more details and smoother image. We validated the quality of the results and their progressive refinement against full Radiance calculation to find less than 5% difference.

Using these Instant images, a variety of indicators can be calculated and progressively refined. For example, a refining DGP<sup>6</sup> can be obtained in a few seconds with a value less than 1% different from the final DGP obtained in an hour. That value can be coupled with a stability index (that we are working on) to show how confident a user can be in the result.

### 5. CONCLUSION

This paper discusses the fact that daylighting tools are still little used in the design of architectural and urban projects. We state that daylight software design is ill-adapted to the architectural design process. It should give to the user the freedom to access fast results without waiting for definitive results. It implies that technologies founding these software need to be carefully chosen in order to allow for this freedom, like with accumulative ray-tracing "Instant Method".

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# The Thermal Performance Study of New Rammed-earth Dwelling in Rural Area in Anji, China

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**ABSTRACT:** Building a house using traditional rammed earth construction technique helps farmers to reduce the building cost and improve thermal comfort by using passive thermal strategies. Experimented in 2006, in rural area with cold winter and hot summer (Chinese official division of climate zones), by building a 264 square meters house, thanks to the support of Generalkonsulat der Bundesrepublik Deutschland in Shanghai, it cost 80'000 RMB. Furthermore, this cost can be reduced to half if the farmers built it themselves. The building has been renovated in recent years and this study is based on its current state. This paper will present the scientific research of the different passive design strategies of this modern rammed house, employed to ensure thermal comfort without a mechanical heating or cooling system. The composition of the loam, the structure of the roof, the orientation and the surrounding local bamboo are the main contributors. The data were collected every 10 minutes for air temperature and relative humidity and were used to analyse the indoor conditions. This research will be of great importance not only for the energy efficiency, but also for the re-appreciation of the traditional residence construction method.

**KEYWORDS:** cold winter and hot summer, new rammed-earth dwelling, passive strategies, data logging

## 1. INTRODUCTION

Due to climate changes and rising living condition requirement in China, energy consumption has been an essential issue for dwellings. (Glicksman et al, 2006). For the rural area in China, thermal comfort requirements in domestic buildings will lead to 21% of the energy demand in building sector. (GBPN et al, 2013).

This research is focus on hot summer and cold winter region of China, where the average relative humidity is commonly exceeding 70% and the average temperature is 2-5 °C in the coldest month. According to this weather condition, in January 2013, Ministry of Housing and Urban-Rural Development responded that in south of China, when the temperature goes below 5°C, decentralized heating system will be mainly applied.

From the previous studies carried out both in China and abroad, the thermal inertia of sandy loam in this case is around  $1450 \text{ J m}^{-2} \text{ K}^{-1} \text{ s}^{-1/2}$  (Minke, Jun, Otto, Tiegang.). From the research by Prof. Minge, a rammed house building retains a relative humidity of 50%, and it will increase and decline by 5% - 10%. Loam preserves timber and other organic material, like straw inside.

## 2. NO.3 RESIDENTIAL DWELLING: SITE CONTEXT AND DESIGN

The project being analysed is a rammed-earth dwelling located in Anji County, Zhejiang Province at 30.6°N, 119.7 °E. The owner of the dwelling, Mr.Ren Weizhong is a famer without professional background of architecture, but through several ecological experiments and four built houses over the past ten years, he became an expert in rammed-earth dwelling. In his research, the

water resistance has improved dramatically by adding proper percentage of lime. In this paper, the No.3 Residential Dwelling, named The German Building, is chosen to measure and study (Fig.1). Covered by a modified insulated sloped roof (a top soil mixer layer of 75% recycled sawdust and 25 % clay in volume, a middle benzene board layer and a bottom waterproof membrane layer), the building has 6 rooms across two floors with the height of 5 meters to 6.3 meters. The external walls with the thickness of 0.35 meter are composed with natural earth, local sandy soil and slaked lime in the proportion of 5:4:1.

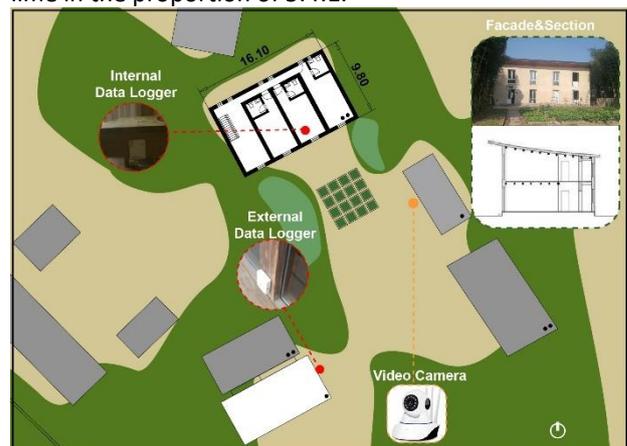


Figure 1: Site Context

## 3. MONITORING METHODOLOGY

Two Onset HOBOTM data loggers were installed externally and internally to measure air temperature and relative humidity (Fig.1). To verify the accuracy of the

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measurement, the data logger temperature measurements were cross-checked.

Besides, in order to obtain accurate weather condition data (weather station is far from the site and weather varies frequently), an auto-video camera was installed (Fig.1) to check the sky condition (Fig.2).



Figure 2: One-day example of sky condition record from 8am to 6pm on 23<sup>rd</sup> February.

## 4. MONITORING RESULTS

The whole monitoring lasted from 24<sup>th</sup> January to 31<sup>st</sup> March in 2018 and experienced from cold period to mild period. On the whole, as shown in Figure 3, the internal air temperature remained quite stable when the external air temperature fluctuated greatly; the relative humidity performed a similar trend with the air temperature. The occupant used the air conditioner occasionally to heat the room for about 1 hour while showering (marked in blue). The selected typical days (marked in green and dashed lines) were chosen and the monitoring results were analysed below:

1) The thermal performance was once tested in 2007 with un-insulated roof (Ma et al, 2006). Compared to their results, within the similar weather condition, the internal air temperature with the insulated roof was averagely 2.3 K higher than the one without insulated roof.

2) In the cold period from 4<sup>th</sup> to 6<sup>th</sup> February, the rammed-earth wall remained the internal air temperature steady from 7.1°C to 11.9°C, while the external temperature ranged from -5.9°C to 7.0°C.

3) On the sunny days, the rammed-earth wall absorbed the solar gains during the day and released the heat during night when the external temperature cools

down. On a cloudy day followed by a sunny day like 5<sup>th</sup> March, the internal air temperature did not vary with the trend of external air temperature, but decreased steadily and slowly.

4) In the mild period from 27<sup>th</sup> to 31<sup>st</sup> March, although the external temperature varied widely from day to night, the internal air temperatures were stabilized in the comfort zones from 18.1°C to 22.5°C.

## 5. CONCLUSION

In the hot summer and cold winter region of China, where there is a large difference in temperature between day and night, the rammed-earth dwelling behaved well in saving energy consumption because of the good thermal performance of high thermal inertial rammed-earth walls. Besides, the insulated roof plays an important role for decreasing heat flow in winter. Thus, the rammed-earth dwelling is adequate especially for rural area.

### Scope for Further Study

The monitoring will be made continually to test the thermal performance in summer this year. By collecting integrated data, the thermal simulation studies will be undertaken using the dynamic thermal simulation software.

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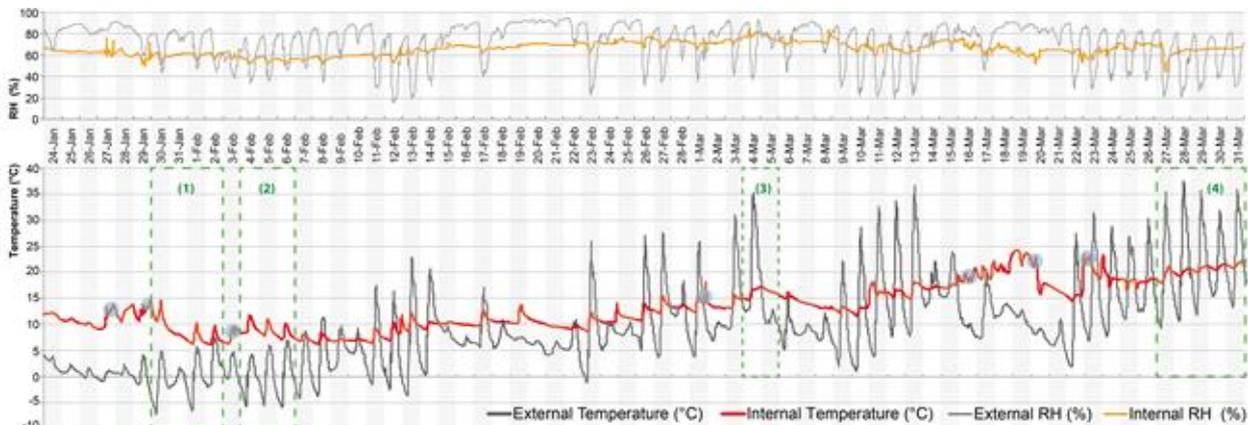


Figure 2: Data logger results.

# Daylighting Proposal for Subway Platforms through Light Pipes: An Application for São Paulo's Saúde Station

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**ABSTRACT:** This paper presents an application of the Light Pipe Dimensioning Model (LPDM) on the design of systems which guide daylight into underground boarding platforms on typical subway stations found in the city of São Paulo. The dimensioning model resulted in two different design proposals, which were empirically tested using a scale model (1:20) as a source of data for performance comparisons. Polished aluminium light pipes, with 95% internal reflectance, were designed and distributed along the train boarding platform. The illuminance data obtained one meter above the floor shows how the distance between two pipes affect the quality of the distribution of light in the space.

**KEYWORDS:** Light pipe, Daylighting, Light Pipe Dimensioning Model, Predictive Model, Light pipes efficiency

## 1. INTRODUCTION

For the past few decades, mostly in big cities, there has been noticed an increase in the number and diversity of areas occupied in underground spaces, especially those serving means of public transportation. Subway stations are largely illuminated by artificial solutions and both regular workers and passengers are affected by the quality of the light provided. Meanwhile, daylighting shows characteristics that contribute not only for the visual effects or energy efficiency but improve the permanent occupants' health, as daylight affects users psychologically and physically (PEREIRA, 2016).

Through the use of unconventional lighting systems such as light pipes, it is possible to guide daylight into underground spaces. LUZ et al., 2017, emphasizes the potential presented by light pipes in improving the lighting systems in underground subway stations.

This paper presents a daylighting design proposal that applies the use of light pipe systems in order to provide an illuminance autonomy of at least 200lx for the period between 10:00 am and 3:00 pm on a typical boarding platform layout of the subway stations in the city of São Paulo. This work is part of a research which aims on demonstrating the applicability of light pipes as a daylighting guidance system. The Light Pipe Dimensioning Model (LPDM) has been applied to specify the light pipes required dimensions.

## 2. METHOD

The method for designing the system of light pipes to be proposed for the underground space of the subway platform is mathematical predictive, applying the Light Pipe Dimensioning model (LPDM) (LUZ, 2014), which is based on the Lumens Method and uses the Light Pipes Efficiency (LPE) obtained by the Luminous Efficiency Predictive Model of Light Pipes (LEPMLP) to input the lumens flux into the equation (LUZ, 2009 and LUZ et al.,

2010). The LPDM determines the number of pipes necessary for obtaining the average illuminance required in that space.

## 3. SCALE MODEL

In order to verify the predicted results, an empirical inductive method was adopted, through the analysis of 1:20 scale physical models under real sky conditions.



Figure 1: Scale physical model.

Due to the limitations presented by the construction and transportation of the model, there has been selected a delimited section, comprehending the areas of interest for the study. The physical model representing this section was built using foam board covered with black paper on the outside and with coloured paper on the inside, simulating the reflectance of the surfaces on the subway station. The light pipes used in the model, which were the ones considered when dimensioning the system, are made of polished aluminium, with 95% internal reflectance. On the external opening there was a transparent cover and over the internal exit there was a diffuser acrylic.

## 4. RESULTS

### 4.1 Dimensioning the system

From a series of dimensioning designs proposed for different spaces in a subway station, there has been designed two distinct systems for the underground

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platforms, with different sized pipes and varying quantities of those.

Considering the area of the platform equal to 544 square meters and its depth resulting in a 6 meter length pipe, the average illuminance of 200lx during the stipulated time from 10 a.m. to 3 p.m. was assured by the number of pipes demonstrated in Table 1. There has been taken in consideration values of external illuminance equal to 20000 and 13000lx, corresponding to frequencies of occurrence of 70 and 80% for the city of São Paulo.

Table 1: Parameters and results for the dimensioning model

Horizontal square section (m)	External illuminance (lx)	Φ pipe (lumens)	Number of pipes required
0,8	20000	8064	6
0,8	13000	2574	10
0,6	20000	3960	13
0,6	13000	2574	20

According to the results obtained from the LPDM, and fitting the design into the restrictions of the existing building, two layouts for the arrangement of pipes throughout the platform were developed. The first (Fig. 2) consists of 10 pipes of 0,8 meter horizontal squared section, allocated regularly along each side of the lateral platform.

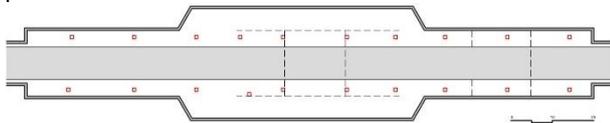


Figure 2: Proposal 1- 0,8 meter section pipes.

A second proposal intends to heighten the number of pipes at the same time as reducing their horizontal section for 0,6 m. The outcome was a configuration of 13 light pipes with the described features and the complementation of 3 pipes with the former section of 0,8 m (Fig. 3). The irregularities were caused due to the limitations presented by the building, and the position of the pipes was conditioned by the sidewalk located above the platform, where the pipes would rise to capture light.

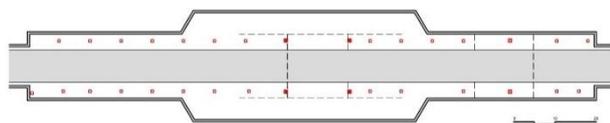


Figure 3: Proposal 2- 0,6 meter section pipes.

## 4.2 Use of scale physical models

Through the use of scale physical models under real sky conditions, there has been collected data of illuminance from inside the model by a series of line positioned sensors, which is presented on Figures 3 and 4, according to each hour of the day.

The results obtained by the measurements for the 0,8 meter section pipe (Fig. 3) demonstrate quantitative

autonomy of the system right below the exit of the pipe. However, the proposed distribution of the pipes do not guarantee a homogeneous lighting throughout the length of the platform, as a consequence of the distance between two pipes.

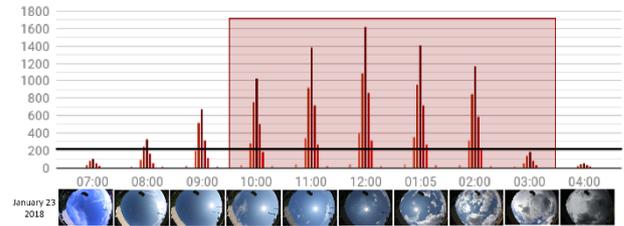


Figure 4: Proposal 1: Illuminance (lx) per sensor for each hour.

For the second proposal (Fig. 3), the results show smaller rates of illuminance but, as the sensor is located further from the pipe, the values demonstrate a less intense decrease, when compared to those from Proposal 1, indicating a better distribution.

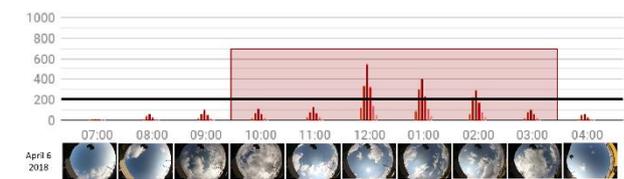


Figure 5: Proposal 2: Illuminance (lx) per sensor for each hour.

## 5. CONCLUSION

The LPDM is a good tool to determine the number of light pipes necessary to start the design project. The lighting design could be improved in many underground spaces by use the light pipes. With simple light pipes, made only of polished aluminium, transparent material on the external opening and a current diffuser on the exit it is possible to obtain high illuminance levels during six hours per day in many different places.

## ACKNOWLEDGEMENTS

The authors would like to thank CNPq, PIBIC, FAPESP, LABAUT, and LUMINAE.

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# Reflecting Energy Use Patterns and Lifestyles in Home Using Data Mining Techniques

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*Most methods to analyse and understand the residential energy use features rely on invasive measurements, such as energy monitoring systems, which eventually affects the reliability of pattern classifications. This paper, thus, adopts a non-invasive method using unsupervised data mining algorithms to analyse hourly energy consumption data in order to learn the occupant's lifestyle and energy consumption behavioral patterns. The study analyses hourly energy use of 298 households in Texas in 2015, using an online open source data set - Pecan Street Dataport. This study scientifically identified household's energy use features and associated behavioural patterns through a multi scale observation of the clusters. As the contribution, this study takes the house age and size into account as these variables may significantly affect building energy use patterns. Second, it takes dissimilarity measures into account by using TSclust R package for clustering time series. And third, introduces a method of multiscale observation of clusters in order to interpret the lifestyle patterns. Finally, the results demonstrated how data mining techniques might be utilized to help investigating energy use data from the behavioural perspective.*

**KEYWORDS:** Energy consumption behaviors, data mining, clustering, lifestyle patterns, residential occupants

## 1. Introduction and background

Residential sector accounts for 40% of the total energy consumption in the U.S. Existing studies have reported that the underlying lifestyle patterns of the occupants may greatly affect their residential energy use [1]. In particular, understanding household's energy use features and patterns enables us to investigate and compare different strategies for home energy efficiency, such as normative energy feedbacks, smart controls of thermostat, energy efficient retrofitting, and interactions between users and environment. However, most methods to analyze and understand the household energy use features rely on invasive methods, such as surveys, observations, or appliances energy monitoring devices, which limit the data collection procedure, attaining sufficient sample size and the reliability of pattern classifications. Thus, in this work, we propose to employ a non-invasive approach using clustering analysis based on utility energy use data. Clustering is known to be an unsupervised learning task aiming to group a set of unlabelled data objects into homogeneous groups or clusters[2]. Montero and Vilar(2014) stated that the first step in mining time series is to decide between "shape-based" or "structure-based" similarity concepts[2]. The shape-based similarity approaches, such as the Euclidean distance, are based on reducing dimensionality and measure the similarity regarding the "proximity between geometric profiles". The structure based approach, on the other hand, measures similarity in terms of "underlying correlation structures", i.e. the change in trend patterns [2].

## 2. Research gap and contribution

Several studies on clustering residential or no residential load shapes have not sufficiently addressed the type of dissimilarity concept underneath their clustering methods [4-5]. In addition, while these projects use common raw data mining approaches such as K-means, some scholars argued that K-means has been outperformed by other methods such as various modified versions of hierarchical clustering[3].

Furthermore, despite of lots of load profiles/shapes clustering studies being conducted in recent years, as for the architectural domain, working out how to interpret and then present the clustering results with connections to architectural features is probably the most crucial and creative aspect.

The unique contributions of this research include: 1) taking the house age and size into account as these variables may significantly affect building energy use patterns; 2) taking dissimilarity measures into account by using TSclust R package for clustering time series[2]; and 3) introducing a method of multiscale observation of clusters in order to interpret the lifestyle patterns.

## 3. Description of Research and methodology

The data used are utility energy usage profiles at granularity of one hour in kWh of a total of 298 houses in Texas in 2015, obtained from the Pecan Street Dataport[6]. For each house we created an 8761 dimensional time series object in R. 36 houses were removed as outliers. The gaps in time series that were not exceeding 15 days in row were filled via linear

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interpolation. As shown in Figure.1, elbow diagram, average silhouette method, and gap statistic suggest the optimal number of clusters to be either 2, 3 or 14.

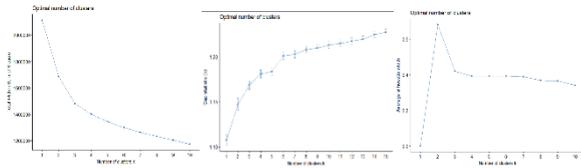


Figure.1: Optimal number of clusters. From left to right: Elbow method, Average silhouette method, Gap statistic.

We used R TSclust package to test different dissimilarity measures with different linkage methods and compared the results of the hierarchical clustering for 2 to 6 clusters (Table.1). The best clustering was obtained from using hierarchical algorithm with complete linkage, and correlation based dissimilarity measure for 6 clusters.

Table 1: Clustering results. Using hierarchical clustering, complete linkage, and diss.cor dissimilarity measure.

#clusters	Cluster sizes	pearson gamma	dunn	dunn2	ch
2 clusters	103 139	0.291	0.747	1.023	7.046
3 clusters	43 139 60	0.291	0.73	0.999	4.95
4 clusters	43 94 60 45	0.339	0.737	0.999	5.347
5 clusters	43 55 39 60 45	0.347	0.743	0.999	4.752
6 clusters	43 55 39 42 18 45	0.393	0.757	0.996	4.621

Table 2: The initial grouping.

Group	Age	Square footage	#data points
1	Less than 10 years	Under 2000 sqf	15
2	Less than 10 years	Above 2000 sqf	46
3	Between 10 and 20 years	Under 2000 sqf	51
4	Between 10 and 20 years	Above 2000 sqf	79
5	More than 20 years old	Under 2000 sqf	65
6	More than 20 years old	Above 2000 sqf	42

The hierarchical clustering split the data into 6 groups with 18, 39, 42, 43, 45, and 55 members. The initial hypothesis of this study was that houses with similar age and square footage normally consume a similar size or scale of energy use, and the difference between their energy consumption would be determined by the true energy use habits, patterns, and occupancy schedules. Therefore, after doing the clustering we put the houses into their relevant age and square footage groups. Table 2 shows criteria for grouping.

## 4. Research Results

We evaluated the meaningfulness of the clusters within each group through a careful observation of the energy plots in different scales. Here we take group 4 as an example(table.2). For interpreting and evaluation of meaningfulness of the life style patterns, data are summed to average on various intervals. In this sense, Figures 2 and 3 show time versus the scaled average of energy use on daily, weekly and seasonally basis in group 4. Each of the 6 colors represents the average of the time series in that cluster.

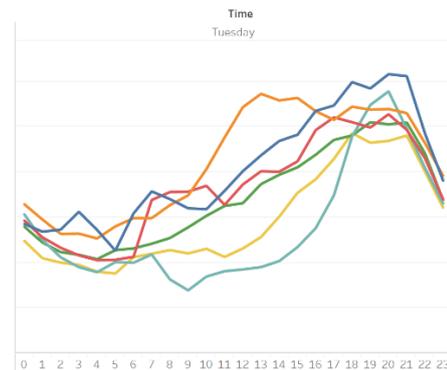


Figure 2: Average energy use of houses over 24 hours (group 4) on a weekday (Tuesday).

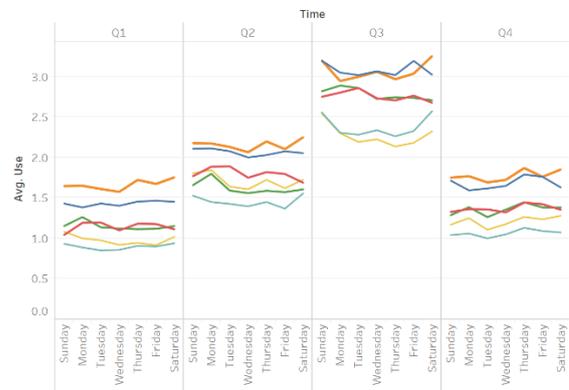


Figure 3: Average weekly/seasonally energy (Houses in group 4)

Cluster	Feature 1 (weekly scale)	Feature 2 (daily scale)	Feature 3 (daily scale)
1 (Blue)	Higher use on Sundays and Fridays	High Morning energy use 6-7am on weekdays	No morning peak on weekends
2 (Orange)	Higher use on weekends and Thursdays	No morning peak on weekdays	No morning peak on weekends
3 (Red)	Lower use on weekends and Wednesday	High Morning energy use 6-10am on weekdays	High Morning energy use 6-10am on weekends
4 (Blue green)	Higher use on weekends and Thursdays	High Morning energy use 6-7am on weekdays	No morning peak on weekends
5 (Green)	Higher use on Mondays	No morning peak on weekdays	No morning peak on weekends
6 (Yellow)	Higher use on Mondays and weekends	High Morning energy use 6-10am on weekdays	No morning peak on weekends

Table 3: Extracted lifestyle patterns for each cluster.

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The summary of the multi-scaled observation of the clusters and the extracted lifestyle patterns are presented in Table 3. Features 1, 2 and 3 are the three components that form the lifestyle patterns of each cluster.

## 5. Conclusion

This paper adopted a non-invasive method using supervised data mining techniques to analyze hourly energy consumption data in order to learn the occupant's lifestyle and energy use behavioral patterns. It presented the best dissimilarity measure for doing hierarchical clustering of hourly energy profiles. It suggested a multiscale observation of the clusters in order to extract lifestyle patterns. These results have potential applications in energy feedback interventions, residential energy use behavioral modelling, and energy efficient design and retrofitting strategies to promote energy saving behaviors.

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6. Data available at <https://dataport.cloud/>

# Steady-State or Transient Heat Balances for Comparable Energy Demand Calculations?

## A Case-Study based on a Sandwich Lightweight Structure

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**ABSTRACT:** Energy demand calculations are very common nowadays due to various regulations and assessment methods around the world. Depending on local regulations they are usually carried out with either simplified steady-state energy balances or with dynamic simulations. Hereby, most steady-state calculations are based on the same temperature difference between inside and outside over a whole heating period or on monthly mean values compared to hourly data for transient calculations. In a case study on a sandwich-lightweight structure it became evident that dynamic calculations with transient weather data show results where the energy demand is approximately up to 50 % lower than steady-state calculations according to a German standard. Therefore, steady-state calculations cannot be recommended without restriction e.g. for sustainability assessment.

**KEYWORDS:** Heat balance, Steady-state, Transient, Energy demand, Lightweight structure

### 1. INTRODUCTION

The reduction of energy consumption in buildings is a universal goal. Therefore, a lot of regulations have been established to minimize energy consumption of new buildings [1]. Many of those regulations rely on standards that represent the energetic behaviour based on heat balances as shown in [2]. However, some mandatory standards, like those in Germany, define the heat balances with steady-state boundary conditions, whereas especially lightweight constructions can show highly dynamic effects.

This case-study utilizes the model of a factory workshop structure with an insulated concrete floor slab, a steel frame bearing structure and sandwich panels for the envelope of the building. By using both standard and transient energy demand calculations, astonishingly high divergences were found.

### 2. MODEL-SET-UP

The factory workshop model was established for a lightweight demonstration project in Germany [3].

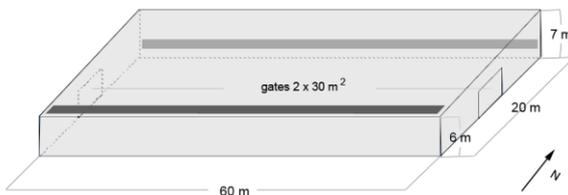


Figure 1: Overview – dimensions of the factory workshop

It is a modular structure with 1200 m<sup>2</sup> floor space. Sandwich panels with 10 cm of polyurethane insulation and anthracite grey steel sheets of 0.5 mm thickness were used. It has two rows of windows, one in the north façade and another one in the roof near the south-façade

(Fig. 1). The U-values of the principal building parts are compiled in table 1.

Table 1: Overview – U-values and areas

building part	area [m <sup>2</sup> ]	U-value [W/(m <sup>2</sup> K)]
floor	1200	0.35
roof (sandwich-p.)	1201	0,24
wall (sandwich-p.)	910	0.24
roof windows	60	1.9
façade windows	60	1.3
gates	30	1.2

For the calculation of the energy demand steady-state (DIN V 18599 [4], monthly mean data) and dynamic (TRNSYS, hourly data) methods were used. Standardized indoor boundary conditions were applied according to DIN V 18599 part 10: Commercial and industrial work. Hereby working hours, mean temperatures, necessary ventilation (volume flow per person), illuminance by natural or artificial lighting, as well as internal heat sources like machines and workers are given. Other standards like ASHRAE 90.1 [5] recommend hourly dynamic calculations or give specific requirements on minimum insulation (U-values) depending on the climate zone without the need of a simplified steady-state energy demand calculation.

Outdoor boundary conditions for whole Germany as a single climate zone according to the standardized and monthly steady-state calculations are defined with a representative climate data set from the city of Potsdam near Berlin. This is comparable to the European Zone 5A Cool Humid in ASHRAE 169 [6].

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## 3. STEADY-STATE AND TRANSIENT CALCULATIONS

The three main differences of steady-state and dynamic methods influencing the calculated energy demands are

- the length of the time steps
- the principle solution of the Fourier-equation for heat conduction
- radiation and convection effects on surfaces of the building parts

### 3.1 Length of the Time Steps

For dynamic calculations much more accurate data are necessary, because not only outdoor, but also indoor boundary conditions vary (Fig. 2).

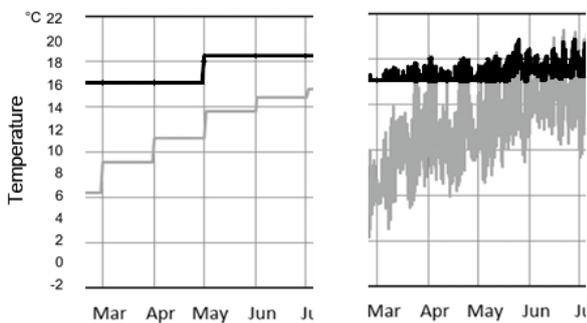


Figure 2: Monthly steady-state and transient boundary conditions (outdoor: grey, indoor: black)

### 3.2 Solution of the Fourier-equation

Usually, both steady-state and dynamic methods apply only one-dimensional solutions of the Fourier-equation (1) calculating heat transfer through walls, roofs, windows, etc. The main difference is that any kind of heat storage effect in building parts is neglected by steady-state calculations. Here, neither density  $\rho$  nor specific heat capacity  $c$  of a building material is taken into account.

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha} \cdot \frac{\partial T}{\partial t} \quad \text{with} \quad \alpha = \frac{\lambda}{\rho \cdot c} \quad (1)$$

### 3.3 Radiation and Convection on Surfaces

Dynamic calculations of radiation and convection effects provide much more realistic temperatures on surfaces compared to steady-state calculations. High temperatures up to 90 °C can occur on steel sheets when they are exposed to direct solar radiation, due to a high absorption coefficient ( $\alpha$ ) and a low absolute heat capacity. Tests show [7] that applying outdoor air temperatures is not reasonable for heat transfer calculations with metal surfaces.

## 4. RESULTS OF STEADY-STATE AND TRANSIENT CALCULATIONS

The results of the case-study always show lower heating demands for dynamic calculations. The

difference of the heating demand in Potsdam is 27 % less. All calculations give the effective energy for heating, because no cooling energy demand is necessary for the factory workshop in this climate zone:

- 46.7 kWh/(m<sup>2</sup>a) steady-state
- 34.0 kWh/(m<sup>2</sup>a) transient

Another variation was conducted using Mannheim in a slightly warmer part of Germany (similar to the edge of ASHRAE climate zone 5A).

Table 2: Steady-State calculations of the heating demand and variations of transient calculations (identical models)

Variation	Energy demand [kWh/m <sup>2</sup> a]
Steady-state, Potsdam	46.7
Transient, Potsdam	34.0
Transient, Mannheim	25.2

## 5. CONCLUSION

Transient energy demand calculations have been shown to result in lower values in this case-study, using a very special kind of a lightweight building. Such a construction shows dynamic effects due to low heat storage capacities. When direct solar radiation heats up the surface of steel sheets during the working hours, the heating demand will be reduced. Even lower heating demands can be calculated with transient methods, when a specific location provides a slightly warmer micro-climate.

If transient calculations differ up to almost 50 % compared to standardized calculations, it seems to be essential to revise the German standard for proofing a low energy demand e.g. for sustainability assessment.

## ACKNOWLEDGEMENTS

This project was funded by FOSTA, Düsseldorf, Germany (Forschungsvereinigung Stahlanwendung e.V.).

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# Acoustic Brickwork: Computational Design and Analysis of Scattering Properties

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*ABSTRACT: This research is focuses on developing and analysing brickwork bonds by a parametric design model combined with a simulation model for scattering performances. Scattering of sound enegy of surfaces is important to understand how sound energy is maintained and distributed in spaces. The results show that modular brickwork with little periodic changes have specific scattering at specific frequencies, rather than equal scattering performance. This suggest that scattering can be designed in response to patterns and, or, should be mixed if diffusion is intended to approach more general scattering performances across frequencies.*

*KEYWORDS: Brickwork, Acoustics, Simulation, Scattering performance*

## 1. INTRODUCTION

This research is of general interest as sound influences all humans directly and indirectly through poorly designed acoustic environments. This is evident in healing environments [1], educational environments [2] office environments and urban space environments. On a positive aspect, acoustic for sensorial and aesthetics conditions, helps humans to orient themselves spatially and feel pleasure, such as in well-designed concert halls, lecture room etc. [3][4]. The background of solutions various broadly according to specific acoustic aim. Predominantly, in architectural acoustics, absorption properties are in focus, to control the loudness and reverberation time (RT) of a space. Such processes includes porous, resonant and membrane absorbers, which in combination create the basis for absorption across most frequency bands. Less in focus is the scattering and diffusion of sound, which is the way surfaces distributes sound energy when reflecting of a surface. Scattering panels are often very specified panels, designed particularly for the use. Recently, an intricate scattering design has been shown in relation to the Hamburg Elbphilharmonie. The background for the design is the use of a milling robot, creating thousands of unique panels [5]. While above approaches offers design solutions to scattering and in some cases diffusion properties, they are often complex and time and economical expensive to create, as seen in the Elbphilharmonie. Hence, the background for potential solutions is to research existing geometries, such as masonry brickwork, which through geometric articulation and modularity can combine both scattering control with economic feasibility. It was in this research attempted to design and test the scattering properties of standard masonry bricks in various configurations, developed using a parametric design model. The paper

presents the idea, design experiment model, brickwork designs through computational processes, simulation results and conclusions.

## 2. METHODS

The work includes methods focused on computational techniques for design, analysis and visualization in relation to brickwork bonds and acoustic simulation of scattering coefficients based on these design variations.

### 2.1 Design model

The computational design model is constructed in the Rhinoceros/Grasshopper software developed by McNeel Inc. Each brick is based on a Danish Standard (DS) brick, where articulations of the wall surface can follow a multitude of configurations by side displacements, depth displacements and rotations. A series of 5 configurations has been studied and analysed, with a planar reference surface as additional test case.

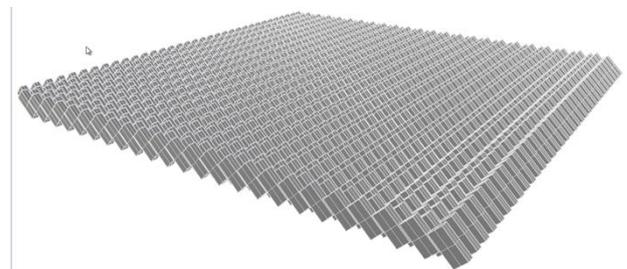


Figure 1: One of the developed and simulated brickwork

### 2.2 Analysis model

The scattering analyses method include an experimental Finite Volume Method (FVM) implemented into the software Pachyderm for Rhinoceros, developed by Arthur van der Harten [6]. The simulation model is

based on a hemisphere where sound distribution is analysed in respect to the specific design geometry. The brickwork simulation models are 16 m<sup>2</sup>, 4x4 meters, which is similar to the dimensions of full scale empirical measurements following the ISO-17497 standard [7]. Simulations are done from 63-2000 Hz.

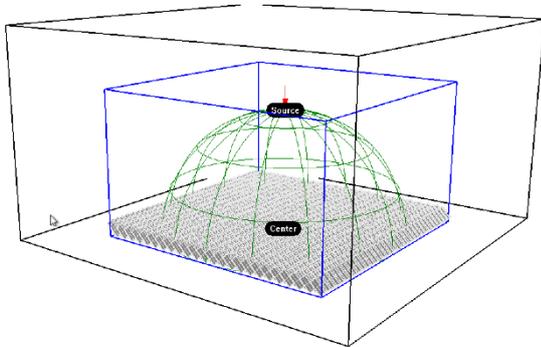


Figure 2: Screenshot of simulation model in Rhinoceros.

### 3. DESIGN EXPERIMENTATION

The computational design model is then explored through manual variations of the brick assembly bond. Adhering to the DS dimensions, the bond cannot be arranged as modular configurations in all dimensions, which means that rows or columns must be kept, while rows or columns are displaced. Further displacement is possible in the depth direction of the wall, and rotation of bricks are possible, creating rhythmic variations in addition to displaced bricks. Following the initial experiments with mapping the scattering performance of the modular brick assembly, studies have been conducted with a search procedure, using the Grasshopper module Goat developed by Rechenraum [8]. The deterministic search procedure is chosen due to the relative low set of variables, compared to a large set, which may require stochastic based processes. This approach allow the articulation of bricks and bonds to a general spreading of sound across frequencies, as seen, or more localized and targeted scattering, which allow the brickwork to be composed by a designer for particular acoustic design properties.

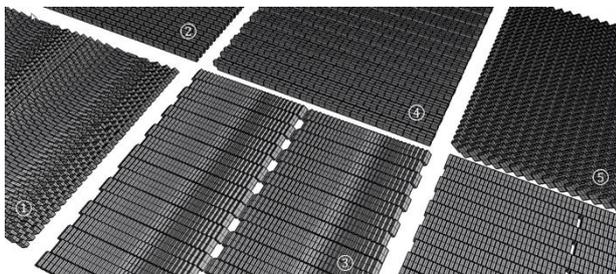


Figure 3: 5 brickwork bonds configurations.

### 4. RESULTS

The design model allows for a series of modular based composition to be created, which in turn create

specific scattering conditions of the walls, figure 4. The results show that combinations of patterns can create scattering across larger frequency spans, while singular patterns create local high/low scattering performances at more specific frequencies. This suggest that scattering can be designed in response to patterns and, or, should be mixed if diffusion is intended to approach more general scattering performances across frequencies. As a result, designers have the possibility to synchronize pattern making with scattering qualities, articulating simultaneously optical and audible architectural phenomena.

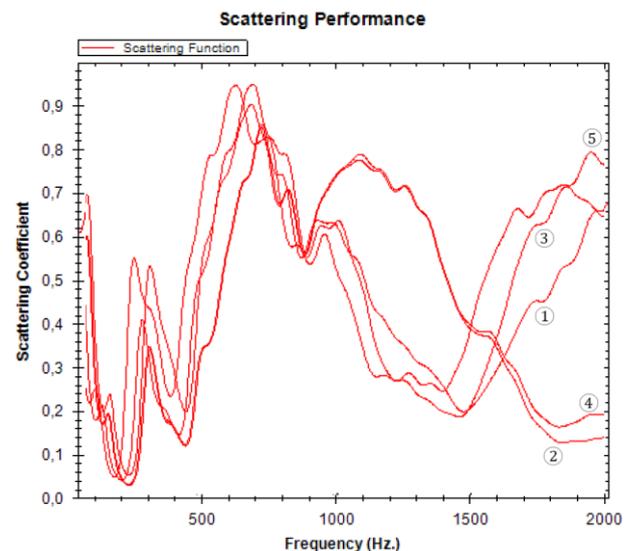


Figure 4: Scattering performance of the 5 brickwork bonds See numbering for relation to brickwork in figure 3..

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# Economic and Socialized Housing: An Initial Quantification of Embodied Energy in the Philippines

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**ABSTRACT:** This study aimed to quantify the embodied energy of economic and socialized housing units in Davao City, Philippines and listed down the construction materials that contributed significantly to the total embodied energy and at the same time correlated these materials to the embodied energy. Embodied energy coefficients of construction materials were sourced out from existing literatures since there were no available standards and studies conducted or published in the context of the Philippines. A bill of materials/quantities was prepared for each housing unit in order to compute the embodied energy. The research findings showed that an average of 9,477.74 MJ/m<sup>2</sup> of embodied energy was computed among the housing units. The results also showed that building materials such as cement, reinforcing bars (steel), gravel, and sand, have significant positive correlation with the embodied energy alongside the house unit floor area. The result further showed that the embodied energy measured per square meter (MJ/m<sup>2</sup>) was higher compared to the existing and published studies conducted. Implications to housing delivery were also pointed out for policy-making which could be adopted by the housing authority.

**KEYWORDS:** Embodied energy, Economic and socialized housing

## 1. INTRODUCTION

One of the main concerns globally is the reduction of greenhouse gasses (GHG) in the atmosphere. A critical boundary of two degrees Celsius requires the reduction of CO<sub>2</sub> by 50 to 80% until the year 2050 [1]. As the population continues to rise, so is the need for shelter, the most fundamental need of the human population. It is inevitable that the building industry continues to grow as the need for human habitation increases every year that contributes largely to the degradation of the environment. Residential developments accounts much of the industry's total output from single detached housing units to high-rise condominium projects. And worldwide, buildings used about 30 to 40 % of the energy in construction, operation, and maintenance [2] which a lot of countries try to lessen over time.

The study on embodied energy of construction materials has been on-going for the last two decades with standards set and periodically updated by numerous countries around the world. In the context of the Philippines, there are no published studies regarding the quantification of embodied energy especially on residential buildings. It is on this premise that this study is conducted taking into account the economic and socialized housing units in one of the metropolitan cities of the Philippines.

## 2. ECONOMIC AND SOCIALIZED HOUSING IN THE PHILIPPINES

The Economic and Socialized Housing Law or *Batas Pambansa 220 (BP 220)* sets the minimum design standards and requirements for economic and socialized

housing projects for the average and low-income earners in the Philippines [3].

### 2.1 Economic and socialized housing in Davao City

The City of Davao is the largest city in the Philippines in terms of land area located in the island of Mindanao, south of the Philippines. There is a steady increase in residential developments in the City. More land is allocated specifically for economic and socialized housing from 927.41 ha. in 2012 to the proposed 3,393.38 ha. for the period 2013 to 2022 (Table 1).

Table 1: Proposed land area for economic and socialized housing in Davao City, Philippines (2012-2022).

Type	Area	Percent to total
Economic	2,903.71	1.19
Socialized	489.67	0.20
Total	3,393.38	1.39

## 3. EMBODIED ENERGY

Embodied energy accounting aims to sum the total energy consumed over a product or building's life-cycle. This includes measuring the energy used into raw material extraction, transport, manufacture, assembly, disassembly and/or decomposition. Researchers on embodied energy used different methods in determining the embodied energy coefficient of materials but nevertheless produced significant outputs for better comparison and consideration.

### 3.1 Embodied energy coefficient

The embodied energy coefficient is generally presented in the MJ/kg scale. The University of Bath

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Inventory of Carbon and Energy – ICE database [4] contain absolute values, and explain the factors which have been taken into account. And thus, it is this premise and with the unavailability of embodied energy coefficient values in the Philippines, that this study used the University's ICE database.

## 3.2 Embodied energy of housing units

A total of 30 economic and socialized housing units coming from different housing developers in the City where considered in the study. A complete bill of materials of each housing units where obtained to determine the total amount/weight of construction materials used which were then used to determine the embodied energy of each housing unit using the “cradle to grave” embodied energy.

Figure 1 presents the embodied energy of the housing units in MJ/m<sup>2</sup>. An average of 9,477.74 MJ/m<sup>2</sup> of embodied energy was computed with house numbers 3, 4, 5, 17 and 20 having the least embodied energy of around 3,000.00 to 5,000.00 MJ/m<sup>2</sup>. On the other hand, house numbers 7, 10, and 26 resulted to a high embodied energy ranging from 15,000.00 to 20,000.00 MJ/m<sup>2</sup>.

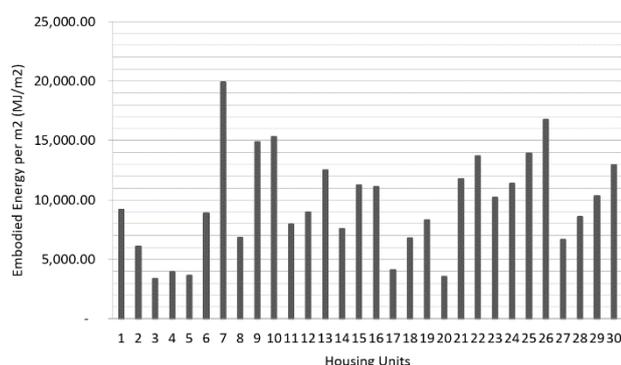


Figure 1: Embodied energy of housing units per m<sup>2</sup>.

A correlation between the embodied energy and each of the construction material was also calculated (Table 2a and 2b) which shows that cement, sand, and gravel (the main components of concrete) having high positive correlation together with reinforcing bars and steel (metals) as main components for the structural part of the housing units. Glass also resulted to high positive correlation.

Table 2a: Correlation of embodied energy to materials.

	Floor Area	Cement	Sand	Gravel	CHB	Earth
Pearson Correlation	.554**	.890**	.715**	.835*	.112	.680
Sig. (2-tailed)	.001	.000	.000	.000	.557	.000
Sum of Squares and Cross-products	1.035E8	3.933E10	1.594E11	2.368E11	4.395E9	1.828E11
Covariance	3569241.176	1.356E9	5.498E9	8.165E9	1.516E8	6.305E9
N	30	30	30	30	30	30

Table 2b: Correlation of embodied energy to materials.

	Glass	Electrical	Wood	Boards	Rebars	Steel
Pearson Correlation	.658*	.196	.347	.526**	.887**	.551*
Sig. (2-tailed)	.000	.300	.060	.003	.000	.002
Sum of Squares and Cross-products	88770737.413	75707128.635	1.964E9	5.156E9	3.082E10	1.787E10
Covariance	3061059.911	2610590.643	67734090.643	1.778E8	1.063E9	6.163E8
N	30	30	30	30	30	30

## 4. CONCLUSION

The conventional construction materials used in the economic and socialized housing units, such as cement, sand, gravel, reinforcing bars and steel, contributes to the total embodied energy of the housing units. It is now a challenge to the housing developers and even to the government agencies that delivers these housing package, to look for alternatives for these construction materials. An embodied energy of 4,000 – 7,000 MJ/m<sup>2</sup> for future housing packages could be proposed which is comparable to single-family conventional house prevalent around the world. A look into the BP 220, it does not only set the minimum design standards but also as a forward-looking guide to develop sustainable construction materials and building systems “within the generally accepted levels of safety, health, and ecological consideration” [3].

## ACKNOWLEDGEMENTS

Acknowledgement is given to my design students who helped me in the conduct of this study.

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## **DESIGN AND PRACTICE**

Implementation of scientific and academic findings comes down to design and practice. This track looks into practical design options—both in theory and actual case studies—in smart, sustainable, and healthy urban development, for example:

- passive low energy design, eco-design and vernacular architecture
- low energy design tools for practice
- policies and government regulations on a low energy future
- professional practice and design of passive low energy architecture

# The 5 Degrees of Forced Climate Refugees: Negative Carbon and Positive Energy Eco-Cycle Housing Solutions

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*ABSTRACT: Severe climate and weather events together with political conflicts linked to climate change are the most pressing driving forces for critical numbers of people to leave their homes seeking safe haven. Climate refugees are becoming the next captious challenge we will face. Temporary refugee settlements prove to have high environmental burdens given the short lifespan of the industrial materials produced with high embodied carbon that they are built with. Despite this finding, alternative natural-based low impact materials with a carbon neutral production and construction process do exist. This paper presents the outcomes of a one-year project in designing and constructing a negative carbon and positive energy eco-cycle home. The idea is to achieve a self-sufficient and low impact temporary shelter design with the lowest carbon emissions during construction and after demolition. The design complies with premium passive house standards and was constructed in an experimental urban living lab for proof of concept. The house is now under monitoring to evaluate its performance. The project was carried out in Sweden, but the methodology could be applied in other climatic contexts.*

*KEYWORDS: Climate refugees, Eco-cycle design, Negative carbon, Positive energy, Urban living labs*

## 1. INTRODUCTION

The world has recently witnessed a surge of disasters associated with climate change. There is an acute need for sustainable, quick, and economic housing that can provide temporary shelter for climate refugees (Fornalé and Doebbler, 2017). Emergency shelters seldom touch upon passive means in achieving indoor thermal comfort and energy efficiency (Borge-Diez et.al, 2013). The main focus is on time and cost efficiency while energy efficiency and impact on the environment often remains a secondary goal (Dabaieh and Borham, 2015). Temporary shelters are mainly constructed using industrial material with high embodied energy and carbon in the construction process, ignoring the potential of using natural materials with minimal carbon footprint. The latter are also cost and time efficient solutions and suitable for acute and temporary building purposes (Dabaieh, 2017a&b).

This paper discusses a proof of concept for an eco-cycle refugee shelter. This shelter is designed to be energy self-sufficient, depending mainly on passive means for cooling, heating, daylight and natural ventilation, and it is equipped with necessary everyday features (Dabaieh and Alwall, 2018). Passive systems like Trombe windows, green walls, an Earth Air Heat Exchanger (EAHE), green roofs and a cool roof were used (Dabaieh, 2017a) in addition to passive strategies like orientation, shading, thermal zoning, high thermal mass and reducing thermal bridges. The building's main skeleton is made from straw, reeds, and clay and uses wooden frame bearing walls. This experimental house applies building performance simulation, material lab testing, and urban living lab test cells for proof of concept

as a three-phase methodology. The experimental refugee house was built in 11 working days using the help of 7 refugees who were trained onsite. The house is now under monitoring for one year as part of a post occupancy evaluation in Lund, Sweden in order to assess the performance, verify the feasibility and design efficiency of the passive systems, and calculate its actual energy consumption and production. The house after construction is shown in fig. (1).

## 2. METHODOLOGY

This research project applies an experimental urban living lab for proof of concept. The project followed three main phases explained below:

- Architectural design and building simulation:

The house prototype was designed applying premium passive house standards for the Swedish climate. The design target was to reach a negative carbon and positive energy performance by using natural materials as the main building skeleton and passive means for heating, cooling, daylighting and natural ventilation. Four building performance simulation programs; DesignBuilder, DIVA for Rhino, TRNSYS and ANSYS were used to assess the building performance. The design was rectified and adjusted after several simulation runs to achieve the targeted performance levels.

- Lab testing, LCA, LCC and energy calculations:

Several material lab tests were conducted to test the performance of the suggested building materials, which are mainly straw, reeds and clay. Tension, compression, water resistance and fire proofing together with other thermophysical measurements for thermal conductivity, diffusivity and heat capacity were tested. The results

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informed the design and the simulation was re-made to comply with final expected building performance levels. In this phase a detailed life cycle analyses (LCA) and life cost analysis (LCC) were conducted to measure the total impact of the building and the payback time. The estimated energy consumption and energy production were also calculated in this phase.

- Living lab test cells and proof of concept:

To test the performance of the three main passive solutions, Trombe windows, green walls and the EAHE, test cells were needed for a preliminary assessment. Together with the eco-cycle system for black and grey water treatment, organic waste for biogas production and testing the zero-energy earth fridge and the dry cloth and dish washing pedal machines, the test cells were incorporated in the building's main skeleton during the construction process.

### 3. RESULTS & DISCUSSION

The outcome of the simulation showed 40 % less energy would be consumed per year for heating and cooling demands than the amount set by the Passive House Standards. That is due to using the three passive systems; EAHE, Trombe windows and the green wall. TRNSYS simulation results are shown in fig (2). The ANSYS simulation also showed the effective performance of the green wall and the open cycle EAHE for natural ventilation complying with Passive House Standards. The energy calculations showed an annual surplus of 200 kWh/m<sup>2</sup> which could be sold to provide a source of income for refugees. The LCA calculations showed a negative carbon output of - 1.2 KgCO<sub>2</sub>/kg due to using natural fibres (straw, reeds and wood). In addition to the low-tech approach in the main building construction, the raw material was sourced from nearby the project site. The main building components are recyclable or can be easily returned to nature as compost. The payback time was calculated as 10 years, which might not be cost efficient unless it is granted a temporary building permit in Sweden, specifying that it is to be demolished after 15 years.



Figure 1: The refugee house after construction.

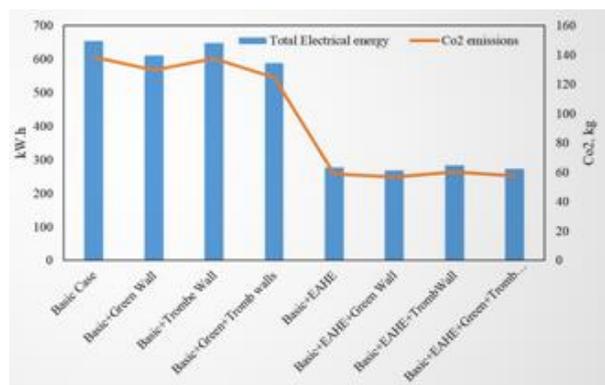


Figure 2: The TRNSYS simulation for heating and cooling using the three passive systems and the equivalent carbon emissions for electricity consumption.

### 4. CONCLUSION

This study shows how refugee housing can be quick, affordable, and designed and constructed using eco-cycle means with minimal impact on the environment. Refugee housing can help prevent the mounting increase of climate change effects and reduce the impacts of associated humanitarian crises. Architects, among other professionals, must find innovative solutions for applying appropriate low-impact, affordable technology to improve the lives of affected populations.

### ACKNOWLEDGMENTS

The author would like to acknowledge the funds from Crafoord, Åforsk, ARQ, Stft. Mellby Gård & Alimi. Sincere thanks to Elin Schnipper, Mohamed Elbanga and Ahmed Serageldin for their help with the simulation, lab testing and visualisations.

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# Assessment of Energy Consumption in Cluster Redevelopment: A Case Study of Bhendi Bazar in Mumbai

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**ABSTRACT:** Cluster Redevelopment is a new concept in the city of Mumbai. Its regulations were laid down by the government in 2009. The concept of cluster redevelopment encompasses a group of buildings defined by a boundary as specified by the municipal authority (in this case, Mumbai), which may be dilapidated or approved for redevelopment. The study analyses the effect of cluster redevelopment in the form of renewal of old group of buildings as compared to refurbishment or restoration - on energy consumption. The methodology includes methods of assessment to determine increase or decrease in energy consumption in cluster redevelopment based on different criteria such as carpet area of the units, building envelope and its architectural elements. Results show that as the area and number of units increase the Energy consumption increases and the EPI (energy performance index) decreases as compared to the base case. The energy consumption per unit area declines by 29% in the proposed cluster redevelopment as compared to the original settlement. It is recommended that although new development is spacious and provides more light and ventilation, aspects such as glass type, traditional architectural features and consumer behaviour are critical in the reduction of energy consumption

**KEYWORDS:** Cluster Redevelopment; Energy Consumption; Energy Efficiency

## 1. INTRODUCTION

Cluster Redevelopment, a new concept introduced by the Urban Local Body (ULB) governing Mumbai was introduced in 2009. The scheme entails the clubbing together of buildings for redevelopment on a site which has to be strategically planned and designed leading to redeveloped residential and commercial spaces. The minimum plot size required for cluster redevelopment is 4000 sq.m, defined by a road boundary or drainage line on all its four sides (Mehta, 2011). The cluster redevelopment is applicable in South Mumbai at present and is being considered for implementation in the Eastern and Western Suburbs.

Bhendi Bazaar, which houses a dense and historic urban settlement in South Mumbai, is one of the first projects undergoing Cluster Redevelopment in the city. The developer, Saifee Burhani Upliftment Trust (SBUT), has proposed the project with the aim of upgrading the lifestyle of people, currently residing in dilapidated low-rise structures spread over an area of 16.5 acres. The proposed scheme has 9 sub-clusters and is expected to develop high-rise buildings and open spaces along with provision of a luxurious lifestyle in the existing congested locality. Bhendi Bazaar was developed in the 'Chawl' or dormitory fashion designed to house single men who had moved to the city for earning a livelihood.

## 2. AIM AND SCOPE OF STUDY

In a redevelopment scheme, existing tenements are accommodated in larger spaces while a new saleable area is also constructed to make the project viable. This will lead to an increase in energy consumption. If the

Cluster Redevelopment scheme is approved for the suburbs, the energy consumed may affect Mumbai's total electricity supply scenario. This study aims to assess the energy consumption in Cluster Redevelopment Scheme in comparison to the existing settlement through the case of Bhendi Bazaar.

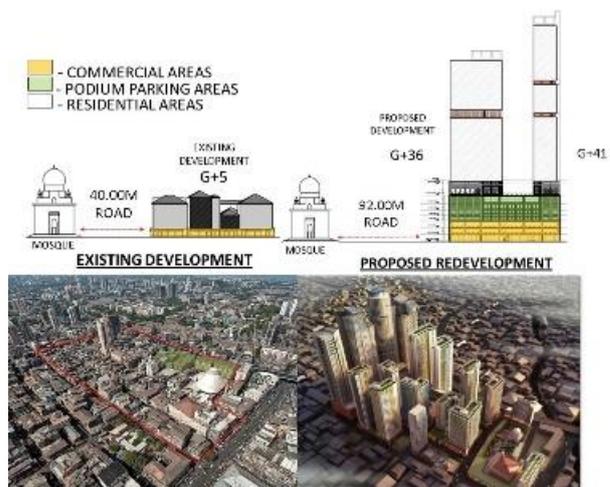


Figure 1: Existing settlement (left); Proposed redevelopment (right)

## 3. METHODOLOGY

For the study, Cluster 3, which is undergoing construction and whose magnitude of increase in built-up area is proportional to the total proposed redevelopment, was chosen. Different typologies were identified in the residential and commercial sector and a sample of 44 houses and 5 shops was selected based on the number of existing buildings in Cluster 3. The

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assessment comprised of two parts – analysis of the typologies with respect to change in energy consumption, and analysis of change in the building envelope. Stratified random sampling of the commercial and residential typologies was conducted through administration of house-to-house survey questionnaire. People’s aspirations, observation of the existing spaces, photographs and analysis of electricity bills formed a major part of data collection. Interviews of major stakeholders such as SBUT CEO, were also conducted. The total energy consumption – existing and projected - was calculated based on above data.

## 4. RESULTS AND FINDINGS

The Cluster Redevelopment Scheme led to an increase in carpet area of 64% from the existing settlement for the full Bhandi Bazar project. Residential typologies were established based on carpet areas ranging from less than 100 sq.ft to 1500 sq.ft and more. The houses with carpet area between 100 – 450 sq.ft comprised the highest number of units and also the maximum energy consumption. In the proposed scheme, minimum size of tenement will be 350 sq.ft and more (Master & Dravid, 2015).

Existing commercial typologies were found to comprise of 21% foam and upholstery shops, 18% retail cloth stores and 11% office spaces. Heavy-duty repair and hardware and Eateries consumed 34% of the total commercial energy consumption. The energy consumed by air conditioners, refrigerators and fans was the highest in the existing settlement. As per survey, demand load for the existing residential sector is more than the designed demand load in the proposed redevelopment by 2%.

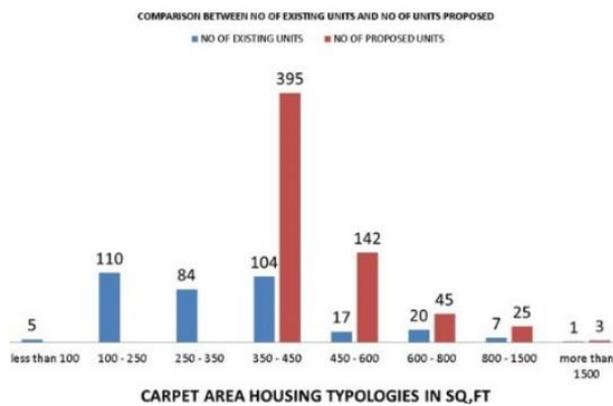


Figure 2: Total number of housing units in Residential Sector

With increase in carpet area of 61% in cluster 3, the Energy Consumption increased by 38% inclusive of common area loads and aspirations in the proposed redevelopment but the Energy Performance Index (EPI) in proposed redevelopment (31.85 kwh/m<sup>2</sup>/year) decreases by 37% as compared with existing development (50.53 kwh/m<sup>2</sup>/year).

It was found that if the use of energy efficient appliances (BEE star-rated) are considered to be used by residents and if the number of appliances increases with addition of aspirations, then the Energy Consumption increases by 56% in the proposed redevelopment whereas the EPI in Proposed Redevelopment (35.64 kwh/sq.m/year) decreases by 29% of the existing development.

As per the calculations, the building envelope analysis showed that Window to Wall Ratio (WWR) of the proposed development is 50% which are within norms specified by the Energy Conservation Building Codes (ECBC) 2007. As per envelope survey, in the existing settlement the lower carpet area tenements, on lower floors had higher occupants and poor comfort conditions, increasing use of air conditioners and subsequent energy consumption and vice versa for the houses with large carpet areas, on higher floors with sloping roofs and better ventilation.

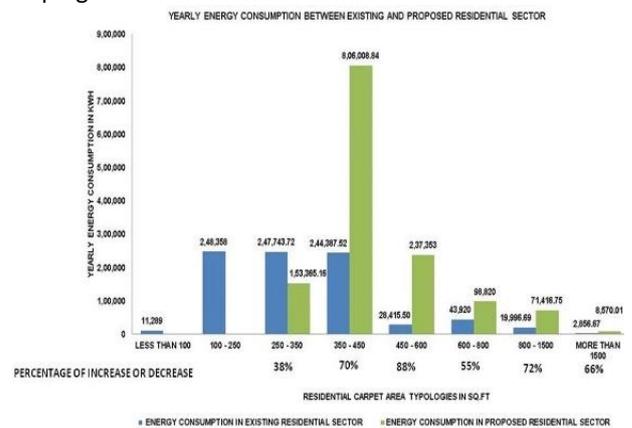


Figure 3: Energy Consumption in Residential Sector

## 5. CONCLUSION

From the study of cluster 3 of Bhandi Bazaar, it can be concluded that cluster redevelopment in a land parcel can lead to a net increase in energy consumption of up to 56% of existing development; but there is also a subsequent increase in carpet area to the extent of 61% providing more habitable spaces. With increased open spaces and better light and ventilation, as well as use of energy efficient appliances by users, the energy consumption per unit area actually declines by 29%. Thus the scheme can be considered for redevelopment in the suburbs of Mumbai.

## ACKNOWLEDGEMENTS

A sincere thanks to my parents, thesis guide Prof. Roshni Udyavar Yehuda for the guidance and support, SBUT and its CEO; Mr. Abbas Master for all the co-operation which was required for the collection of data and all who, directly or indirectly, have lent their helping hand in this project.

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## Hybrid Adaptability: Zero-Emission Lifetime Homes in the Remote Rural.

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*ABSTRACT: The cost of living rurally, already higher than urban areas in terms of food, transport and energy, is exacerbated by energy inefficient and inflexible homes, which has had detrimental impacts on the viability and sustainable growth of rural communities. Following on from community land buy-outs in the late 1990's, the communities on the Island of Eigg and the Knoydart peninsula in the remote north west of Scotland have facilitated innovative measures which have been central to lowering their CO<sub>2</sub> emissions and maintaining the viability of their off-grid locations. Central to Eigg's strategy has been the implementation of a world-first zero-emission grid combining LZCGTs, battery storage and smart controls, telecommunications networks and shared equity land policies to encourage self-build housing. Notwithstanding, there is a lack of appropriate community-led, affordable, adaptable, grid-integrated housing models which remains a significant barrier to encouraging new people to move into the community to ensure its long-term resilience. The following paper discusses parameters for the design of alternative hybrid zero-emission housing typologies that have the capacity to cater for varied tenures and lifestyles, including live-work and rentable space, providing lifetime homes and energy balancing scenarios through their in-built flexibility.*

*KEYWORDS: Zero-Emission, Housing, Hybrid, Adaptable, Micro-Grid*

### 1. INTRODUCTION

In response to Land Reform Acts the communities of Eigg and Knoydart initiated community buyouts of their land in the late 1990s and subsequently implemented a number of specific measures to facilitate developing near autonomy in their energy, food, water and telecommunications requirements making them exemplar models of low-emission, self-sustaining development. In order to help make housing affordable to individuals the communities have also developed forward looking shared-equity land policies to promote self-build.

However, despite these initiatives, the delivery of suitable, affordable, low-energy housing has remained a primary barrier to improving community resilience. With the exception of private self-build, mainstream housing models currently available are restricted by typology and largely standard spatial arrangements. Similarly, the home energy systems for supplying space and water heating, the largest community energy demand by some margin, still rely predominantly on coal and to a lesser extent LPG gas and diesel for their energy supply.

In common with many remote rural areas in Scotland, the lack of appropriate housing on Eigg and Knoydart limits community growth which affects the local economy, labour market, and prevents potential inhabitants relocating to the area to take up available job opportunities. Essential to future community housing supply is the development of planning and housing spatial models that respond to the specific tenure and lifetime flexibility requirements intrinsic to these remote

communities. Inadequate workspaces and community facilities reduce the possibilities for diversification in business and lifestyle. New housing also needs to integrate with the characteristics of the unique micro-grid in order to capitalise on 'lost-energy' from the grid, minimise space and water heating costs and ensure a secure energy supply. Currently, appropriate, adaptable housing is the key missing component needed to make the step-change to a nearly zero-emission, sustainable and resilient community.

### 2. RESEARCH METHODS

The contexts of Eigg and Knoydart were studied to develop a new typology for adaptable housing that responds to its social and economic requirements and would support the sustainable growth of the community. Surveys and qualitative analytical studies were used to understand social, physical, environmental and economic conditions existing in each community. Research identified the range of housing needs for full-time residents, seasonal workers, short-term volunteers, and visitors, while also taking into consideration the fact that full-time residents may have more than one job role and work full- or part-time from home. Qualitative design studies using creative practice approaches developed alternative 'hybrid' housing models that integrated specific requirements across a number of criteria including: cost, footprint area ratio, ownership models, tenure, programme variations, renewable energy integration, income generation, and self-build techniques using locally grown timber.

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## 3. RESULTS

While off-site industrial production that has been the focus of recent trends in housing development offers the possibility for houses to be constructed and deconstructed efficiently to meet changing needs, shortening the functional life of the house significantly increases embodied energy costs which become a much greater proportion of the total energy costs. Significantly, a shorter lifespan increases the capital cost of the house for the home owner as this has to be recovered within the duration of a conventional mortgage. With unpredictable change being an essential quality of modern society, the functional limitations of current housing is inhibiting longevity due to the inability of the internal spaces to respond to the requirements of changing family circumstances. Families are forced to undertake the potentially costly and stressful process of moving rather than their home being able to accommodate change over its lifetime [1]. Current mass-market housing models are generally inflexible, spatially, programmatically and technically. They are commonly based on types with clearly delineated party walls, volumes with 'fixed' dimensions and rigid internal subdivisions creating small inflexible cells.

Flexible housing models can potentially extend the useable lifespan of a house through in-built adaptability by accommodating new or different uses and allowing for multiple spatial and functional configurations at any given point in time [2]. New forms of hybrids, can be seen as combining positive spatial traits of alternative traditional house types to produce 'spatial variations' that can adapt for an unknown future and are responsive to the immediate needs of various people and target groups in the community. The hybrid is not a final solution, but provides a spatial framework for changing social, demographic and community property demands which is particularly important in the rural context where accommodation stock is limited [3]. Programmatic hybridity offers the potential to respond to the long- and short-term needs of the contemporary rural environment and support social and economic sustainability through flexible and adaptable space (Figure 1).

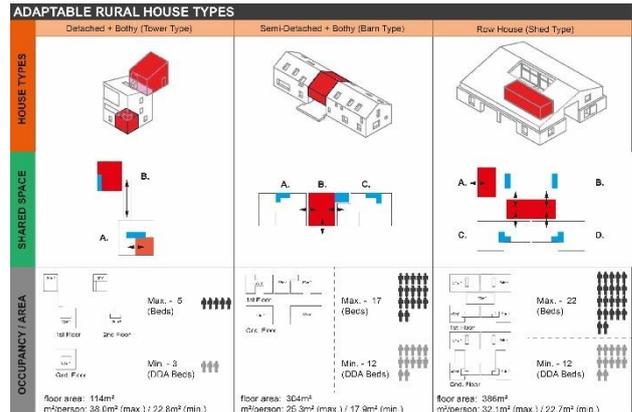


Figure 1: Potential configurations of adaptable space

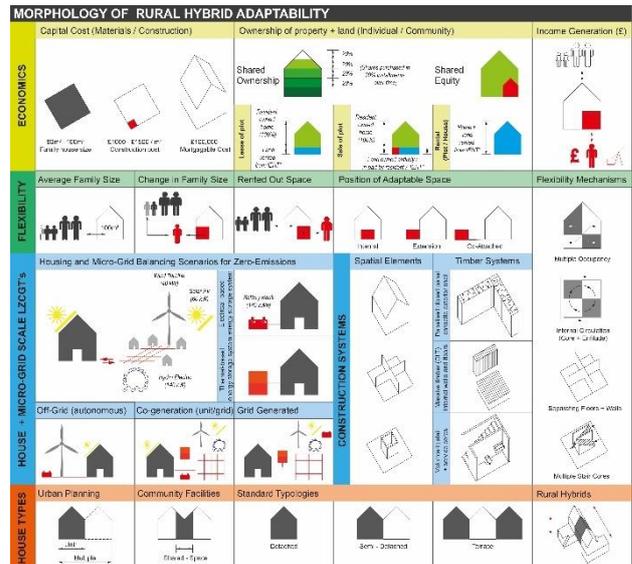


Figure 2: Morphology of Rural Hybrid Adaptability

## 4. CONCLUSIONS

The results were used to develop detailed strategies for facilitating flexibility across a number of criteria offering the opportunity to increase population density and variety of demographic, attract new skills and support the local economy for longer term sustainability. The resulting typology provides a framework in which new hybrid housing types can be derived through alternative concepts of flexibility including new ownership/equity models, energy balancing models with the renewable micro-grid and internal subdivision and sharing of spaces within and between units to facilitate social and demographic changes over time (Figure 2).

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## Urban Climate and Energy Consumption: An Approach to Construct a Climatic Oriented Planning

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*ABSTRACT: This paper proposes an innovative method for integration of urban climatic maps methodology with energy aspects, aiming to support the sustainable urban planning. Using the city of Belo Horizonte, Brazil, as a case study, the urban climatic map associated with energy consumption was constructed based on climatopes concept and multicriteria decision analysis method. The results show the combined effects of these variables in terms of their contribution to increase of thermal load in the urban system and recommendations for urban planning decisions.*

*KEYWORDS: Energy Consumption, Climatic Map, Urban Planning*

### 1. INTRODUCTION

Climate and energy approaches are relatively new as a tool for urban planning. There are now studies relating urban heat island to urban energy system, and vice-versa [1]; however, approaches that integrate the mutual effects of energy-climate models and climate are relatively new and rare. Besides that, there is still a gap between the knowledge produced in studies in urban climate and their application in city plans [2]. About energy, models have been developed to analyze the energy performance of urban sectors and cities and / or to evaluate strategies to improve current conditions, reduce energy consumption and environmental impact [3]. Usually, approach on urban climate does not account the impacts of energy consumption.

One possibility to connect these subjects is to use an inter-disciplinary platform to transfer climatic and energy consumption knowledge to planning language. The methodology that can be applied is the urban climatic map (UCMap) [4]. There is not one single method for drawing up these maps and the studies carried out until now have used different techniques and layers for making their analysis [5]. This paper proposes an innovative method for integration of this methodology with energy aspects, aiming to support the sustainable urban planning, applying it for the city of Belo Horizonte, Brazil.

### 2. METHODOLOGY

The urban climatic map associated with energy consumption data for Belo Horizonte was constructed based on climatopes concept [4] and multicriteria decision analysis method [6]. It consists of four steps: a) selection of variables of land use, wind and energy; b) construction of the layers, c) definition of the criterion weighting, and d) construction of the climatic maps.

Land use data were selected based on the VDI recommendations [4] and on previous research done in Belo Horizonte [7]. It was represented by the building volume (BV) and the percentage of open areas (Openness - Op). The air paths were vector lines of the main incoming wind and corridors in the city. The energy consumption (E) was described by the amount of energy consumed by residential and mixed-use buildings combined with their use of air conditioning, calculated based on the census data [8] that cover all the city.

The capacity of the variables to contribute to the gain or loss of energy in the urban system was considered to establish the weights, supported by the knowledge driven evaluation [6]. For the layers BV and E, the lowest values have the lowest weight, considering their contribution to the heat storage (low = 1, medium = 2, high = 3). Op, on the other hand, produces an effect of loss of energy to the urban system. Thus, the weights assigned were: high = 1, medium = 2, low = 3.

BV and Op were combined individually with energy, (Fig. 1). It results in two thematic maps, in which class represents the sum of weights according to the decision matrix established in Table 1.

Table 1: Decision matrix.

E	BV	Class	E	BV	Class	E	BV	Class
low	low	2	med.	low	3	high	low	4
low	med.	3	med.	med.	4	high	med.	5
low	high	4	med.	high	5	high	high	6

E	Op	Class	E	Op	Class	E	Op	Class
low	high	2	med.	high	3	high	high	4
low	med.	3	med.	med.	4	high	med.	5
low	low	4	med.	low	5	high	low	6

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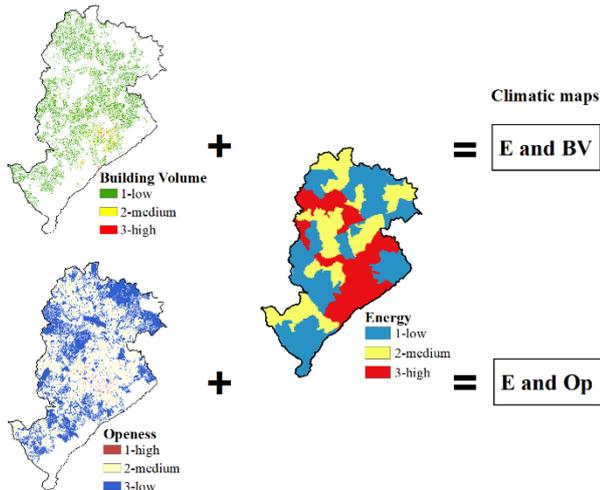


Figure 1: Map algebra applied to construct the climatic maps.

### 3. RESULTS

The thematic maps (Fig. 2), representing the relationship between energy, buildings, open spaces, and air flow, shows the combined effects of these variables in terms of their contribution to increase of thermal load in the urban system. These results allow to distinguish activities and measures in different locations, and to analyse how to improve energy consumption by using climate potentials.

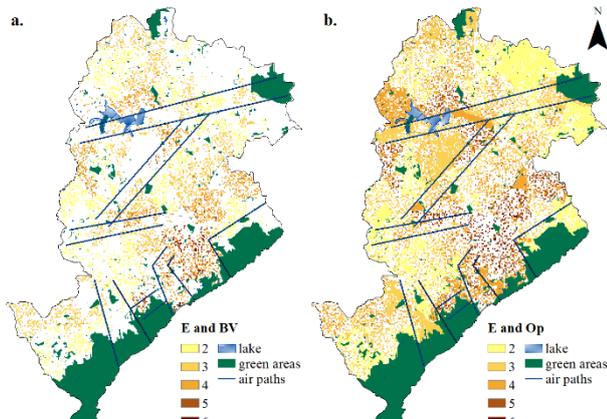


Figure 2: Energy consumption associated with land use data: building volume (a) and openness (b).

The layers E and BV combined (Fig. 2a) indicates that most of the city is represented by classes 2 and 3, where the energy consumption and the density of buildings are low and medium but also have a high daily heat load. Classes 5 and 6 are concentrated in the central part of the city, where is situated the downtown. These classes are also represented in a short area in the southeast, occupied by a high-income population, where the energy consumption is the highest. Class 4 is concentrated in the northern region, where BV are low but due to high income inhabitants the energy consumption increases. Especially here, urban climate potential is not applied in an efficient way as the air paths are not used for ventilation, which raises the energy consumption.

Considering the combination of the layers E and Op (Fig. 2b), the distribution of the classes is similar to Fig. 2a. In the central part of the city, there is an increase of areas of classes 5 and 6. Despite the presence of low density in the upper part of these areas, Op is still low, while E is high. In this case, the urban heat load may lead to a higher air condition energy use. Class 4 appears as a combination of medium E and Op so both parameters are moderate. Here, shadow programmes would improve both energy and thermal comfort conditions. As recommendations for urban planning, it is important to preserve areas with air paths and low classes (2 and 3) of E and BV and E and Op. These planning actions can be taken according to ventilation and heat balance to control urban density or improve the wind corridors.

### 4. CONCLUSION

The methodology of urban climatic maps allows a multidisciplinary approach which aggregates knowledge of climatology and urban planning in an easily language for planners. Combined with energy consumptions, this method gives an even broader aspect. One of the advantages of this methodology is the possibility to update the data used to construct the thematic maps and to add other layers on the analyses, improving the recommendations for urban planning.

### ACKNOWLEDGEMENTS

This research was supported by FAPEMIG (Fundação de Amparo à Pesquisa do Estado de Minas Gerais).

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# Rehabilitation of the Public Residential Building Stock of Barcelona Applying Sustainable Strategies: Case Study

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**ABSTRACT:** Climate scientists warn that “time is running out to prevent global environmental collapse” [1]. Global CO<sub>2</sub> emissions increased again in 2017, after three years of stagnation. This was the conclusion drawn from two studies that confirmed the forecasts of experts who recently participated in the Bonn Climate Summit (COP 23). [2] It is therefore increasingly urgent to cut emissions and thereby avoid the most catastrophic effects of climate change. Only then will it be possible to achieve the objective of not exceeding an increase in average global temperature of 2°C that had been established at the Paris Climate Summit. Here, we report on a case study of energy rehabilitation involving a publicly-owned residential building constructed in Barcelona in the 1960s and a plan to convert it into an Nearly Zero Energy Building (NZEB): “EU Directive on the Energy Performance of Buildings” (2010/31/EU). [3].

**KEYWORDS:** Nearly Zero Energy Building (NZEB), Passive house principles, Energy modelling software.

## 1. INTRODUCTION

The construction industry is one of the productive sectors that need to take most action if we are to achieve the aim of drastically reducing CO<sub>2</sub> emissions. Even so, the regeneration of suburban housing estates remains a complex task and an important challenge facing the majority of Europe’s major cities. Most of the publicly-owned residential buildings in and around Barcelona are now over 50 years old and were built when the building regulations relating to energy budgets were very lax (Fig.1). As a result, they tend to consume a lot of energy and to generate excessive CO<sub>2</sub> emissions. Furthermore, their maintenance and refurbishment has now become the most important activity of Barcelona’s construction sector. This explains why the current applied research is of particular importance. As well as improving the quality of life of their residents, the energetic retrofit of these old buildings will also help Barcelona to meet the objectives of the Paris Climate Summit.



Figure 1: Existing social housing in the Vallbona area of Barcelona managed by the local housing agency (PMHB)

## 2. METHODOLOGY

This paper summarises applied research in which specialised software tools were used to verify the performance of the energy solutions that were designed. The most important contribution of this project lies in its objectives and the methodology used. In this article, the authors highlight the three main design considerations followed to convert existing buildings into NZEB. The first relates to the local climate of the city of Barcelona, which is a basic factor in NZEB transformation. The second involves making a diagnosis of the existing building based on currently available data relating to its energy consumption and CO<sub>2</sub> emissions. This involved analysing and evaluating the passive behaviour of the building, its cladding and energy systems. The third, and final, element is a theoretical review of the most suitable strategies for producing energy from renewable sources. This was carried out using a wide variety of software tools which provided information about the best strategies to employ. The study showed that it would be relatively easy to meet the “Passive house” standards that we had used in the EnerPHit Retrofit [4]. The measures that we took could be placed in one of three categories according to their main objectives:

- Minimising energy demand by applying passive strategies: Increasing insulation and improving solar radiation control, natural lighting and heat recovery ventilation.
- Increasing the energy efficiency of the building systems and improving its management systems.
- Replacing conventional energy sources with renewable sources.

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By applying this combination of strategies, the building's energy consumption was significantly reduced, by up to 50%. Due to the optimal levels of solar radiation received in Barcelona, the rest of the energy required to meet the NZEB [5] could be provided by a solar, thermal and/or photovoltaic unit installed in the building itself. (Fig.2)



Figure 2: Proposal for NZEB rehabilitation

### 3. CONCLUSION

The EU has introduced legislation to ensure that buildings consume less energy. A key part of this legislation concerns the Energy Performance of Buildings Directive which was first published in 2002. This required all EU member states to enhance their building regulations and to also introduce energy certification schemes for existing building stock. At the same time, the refurbishment of existing buildings would provide an opportunity to create local jobs, stimulate the economy and generate cost savings. Taking into account the fact that most retrofits are performed in a step-by-step manner, it is important to understand the consequences of lock-in effects; retrofit processes that are started now and based on shallow measures cannot achieve a high level of energy efficiency in 20-30 years. As the life cycle of most building components, and especially of those forming the shell of the building, is 40-60 years, no further improvements to this moderate efficiency would be expected in subsequent decades. It is thereby crucial to start with deep retrofit measures in order to ensure future efficiency levels. Only by doing this will it be possible to make our building stock fit to provide a sustainable energy supply. The potential for reducing energy consumption through improving our building stock is very significant, but many barriers remain before we can turn these policy goals into recommended steps of action. In Barcelona, which is a city with a pleasant Mediterranean climate, housing is generally built without giving much concern to its energy efficiency and this is reflected in its energy consumption. In fact, in Barcelona, residential demand for electrical energy represents 35% of total energy consumption. The biggest

challenge facing all NZEB rehabilitation projects is how to find the best fit between energy saving design with the use of on-site renewable energy [7]. The proposed strategies can be grouped together according to the two main principles of NZEB rehabilitation: reducing and producing. The main contribution of this research lies in the methodology used. It could be used as the basis for the future rehabilitation of public housing stock in Barcelona and also in other European cities. It could therefore make an important contribution to meeting the objectives of the Paris Climate Summit.

### ACKNOWLEDGEMENTS

This applied research has been developed as part of a collaborative agreement between the Polytechnic University of Catalonia (UPC) and the "Patronat Municipal de l'Habitatge" (PMHB). It has also benefitted from input from students of the MSc course in "Arquitectura y Sostenibilidad: Elementos de diseño y técnicas de control ambiental": Ariadna Auge, Ignacio Furnies, Sebastiao Paradanta, Eliana M<sup>a</sup> Rodriguez and Oscar Ramirez. Under our leadership, have developed a graphical approach and drawn plans and renderings that have greatly helped us in the development of this project.

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# The Environmental Consequence of “Urban Renewal”: Lessons from Two Reconstructed Urban Villages in Inner-City Shenzhen

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**ABSTRACT:** The urban village is a unique phenomenon in China that thousands of former rural villages have been rapidly urbanized along with the surrounding built environment. The government, developers, and urban planners positioned these urban enclaves as to have terrible environmental quality and support wholesale demolition during urban renewal. Given the absence of environmental knowledge of urban villages and the evaluation of environmental impacts after reconstruction, this research examined urban heat island (UHI) and outdoor ventilation of two reconstructed urban villages in inner-city Shenzhen. Significant UHI during the day and night in the two reconstructed urban villages and strong wind conditions of some edge spaces were captured. Sky view factor, greenery planning, and the porosity of ambient environment provide directions to address the above-identified environmental problems.

**KEYWORDS:** Urban renewal, Urban villages, Urban heat island (UHI), Air ventilation, Environmental adaptability

## 1. INTRODUCTION

The urban village is a unique urban phenomenon in China where thousands of former rural villages have been rapidly urbanized along with the surrounding built environment. These urban enclaves not only provide affordable housing and employment opportunities for massive migrant workers but also play a crucial role in establishing and supporting city eco-systems [1]. The government, developers, urban planners and most environmental researchers presume that urban villages all present an unhealthy living environment and should be reconstructed into modern buildings during urban renewal [2-3]. However, the urban heat island (UHI) effect in many megacities of China, such as Shenzhen, has been dramatically intensified (around 1.0oC) within only three decades when numerous large-scale high-rise building blocks were built. This leads to exceedingly high energy consumption and frequent heatwaves, which are threatening public health and social well-being [4-5]. Given the absence of environmental knowledge of various types of urban villages and the environmental impacts after reconstruction, systematic and objective evaluation is urgently necessary.

This research aims to expose some environmental problems of the demolition-oriented mode of urban renewal in China and identify the critical morphological and environmental factors for decision makers and urban planners before the launch of an urban renewal project. Through examining urban heat island intensity (UHII) and air velocity ratio (VRw), this paper has analyzed the outdoor environmental performances of two reconstructed medium-sized urban villages in Shenzhen. Findings of the research can provide insights into the setting of a more specific benchmark for urban design/renewal in Shenzhen and other cities of China.

## 2. SAMPLE SITES

Yunong (YN) and Caiwuwei (CWW) are two medium-sized urban villages with strategic locations in inner city Shenzhen (subtropical monsoon climate). YN is located in the edge of Shenzhen’s new CBD in Futian District (near Futian Checkpoint and Shenzhen River), and CWW is located in Shenzhen’s financial center in Luohu District. The original YN had a random high-density mid-rise pattern, while the original CWW possessed a regularized high-density mid-rise pattern. Most urban villages in Shenzhen and other cities of China possessed these two typical building forms. During 2005-2011, YN and CWW were demolished and reconstructed into a commercial & residential complex (shopping mall + podium garden + residential towers) (Fig. 1). Such a modern building form has been the most prevailing option for urban village renewals in Shenzhen today.

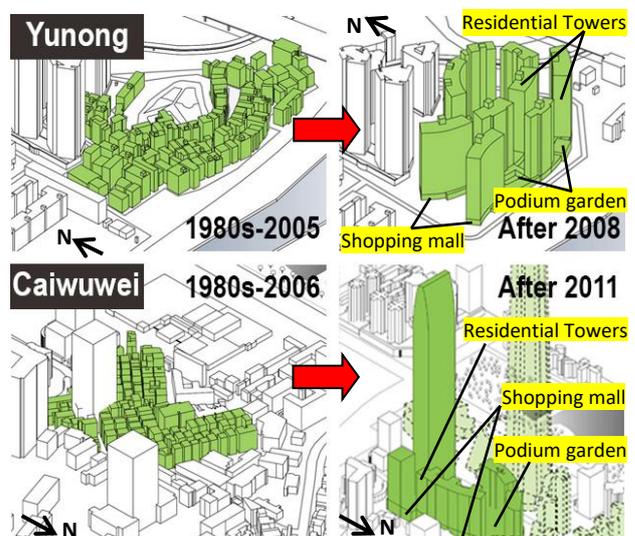


Figure 1: Original YN and CWW and their reconstructions

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### 3. METHODOLOGY

Site observation and mapping identified several popular outdoor spaces with various characteristics in YN (6 inner spaces and 8 edge spaces) and CWW (7 inner spaces and 8 edge spaces) for measurement. Sky view factor (SVF) along with canyon orientation indicate geometric characteristics of each tested space. Total site factor (TSF) indicates daytime solar admittance. On-site mobile measurement captured the microclimatic conditions of current YN and CWW at the pedestrian level on Oct. 7, 2017 and Oct. 8, 2017 respectively (09:00-22:00). Air temperature ( $T_a$ ), relative humidity (RH), air velocity ( $v$ ) and globe temperature ( $T_g$ ) were collected by weather tracker Kestrel 5500 and TM-188D. All measurements were taken under sunny or partly cloudy day and clear night weather conditions.

### 4. RESULTS & ANALYSIS

Most outdoor spaces in the reconstructed YN and CWW have good openness and strong solar admittance. However, CWW has a higher greenery coverage (GCR) than YN (Table 1). Test results show that outdoor spaces in these two sample sites presented significant UHI effect. Average UHII in YN and CWW during the daytime was 2.14°C and 2.65 °C respectively and decreased to 1.58°C and 2.17 °C during early nighttime respectively. In the morning, YN and CWW also presented strong UHI effect (UHII<sub>YN</sub>=2.26°C, UHII<sub>CWW</sub>=2.90°C). The edge spaces in YN and CWW exhibited higher daily UHII than the inner spaces by 0.61°C and 0.45 °C respectively (Fig. 2).

Table 1: Geometric characteristics of spaces in YN and CWW

Site	BCR (%)	FAR	GCR (%)	MBH (m)	Avg. H/W	Avg. SVF	Avg. TSF
YN	47.18	8.28	4.03	62.08	2.93	0.28	0.554
CWW	44.41	9.29	10.89	116.57	2.49	0.25	0.546

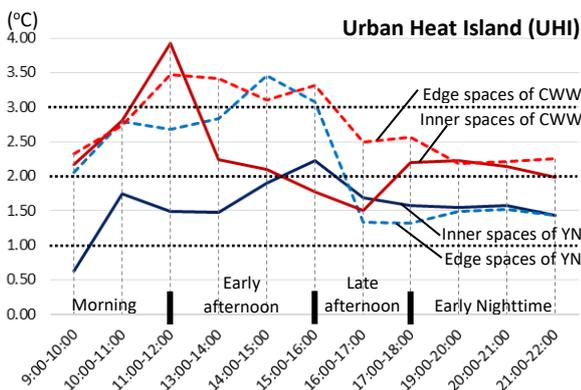


Figure 2: Hourly UHII within a typical summer day of Shenzhen

Most outdoor spaces in YN and CWW presented very weak wind condition at the pedestrian level (avg.  $v \approx 1.0$  m/s). However, YN exhibited much better outdoor ventilation capacity than CWW (YN- $VR_w=0.25 < 0.50$ ; CWW- $VR_w=0.08 < 0.50$ ) due to its location near Shenzhen River, the higher porosity of ambient environment, and

very low tree coverage. However, the southern area of YN (along the Shenzhen River) presented much stronger wind field throughout a day with the average air velocity reaching up to 5.17m/s, making it unsuitable for outdoor activities and then having very low utilization.

In addition, Spearman correlation analysis shows that SVF appeared positively related to UHII and mean radiant temperature with the coefficients of 0.467 ( $P < 0.05$  level) and 0.764 ( $P < 0.0001$  level) respectively. Also, correlation degree between SVF and daytime UHI (positive correlation) was much higher than nighttime UHI (negative correlation). Nevertheless, a significant correlation between SVF and  $VR_w$  was not found.

### 5. CONCLUSION & URBAN DESIGN IMPLICATIONS

To conclude, the common environmental problem in the reconstructed YN and CWW is the high UHII during both the day and night. This negative impact can be mitigated by a higher greenery coverage with diverse vegetation types, while the effect was limited in the case of CWW. SVF plays a dominant role in affecting solar insolation and outdoor thermal environment. The specific problem of YN is the strong wind field of its edge spaces where greenery is absence. While the remaining urban villages with high-density mid-rise patterns in Shenzhen mostly present low UHII in the daytime. These urban villages occur urban cool island in the afternoon and exhibit close thermal environmental performances with the nearby urban parks and urban waterscapes [3,6]. A city needs diverse morphological patterns to weave and consolidate its self-adaptive networks to respond the occurring environmental and social changes. This paper advocates a more rational attitude to excavate the distinct role and features of each urban village in order to achieve a sustainable urban renewal. This also helps to establish a framework for ecological resilience-inspired urban development.

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# Housing Policy for Particularly Vulnerable Tribal Groups: A Case of Baiga Tribe in India

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*ABSTRACT: The paper aims to critically analyze the housing policy Pradhan Mantri Gramin Awaas Yojana (PMAY), a social welfare flagship program, created by the Indian Government, to provide housing for the rural poor in India. The case study of Baiga tribe (aboriginals) is taken to understand its vernacular architecture and the impact of housing scheme on the Baiga's traditional settlement. A brief study of settlement pattern is done. The dwellings provided by housing scheme are analysed on various aspects like architectural, social, cultural and economic, to identify the gap, why Government policy, schemes, development programme, and implementation fails to address the basic needs of Particularly Vulnerable Tribal Groups (PVTGs). Methodology includes literature review from various sources, site visit, photography, survey and interviews. Vernacular dwellings and the new dwellings provided by the scheme are documented and analysed. Result and findings addresses that the recommendations made in 'the revised scheme of PVTGs' 2015 by Ministry of Tribal Affairs, Government of India under 'Housing and Habitat' is not taken in consideration by the implementing agencies. The paper concludes that Government must ensure the correct implementation of scheme at ground level. The scope of the paper is limited to Baiga tribe of Madhya Pradesh.*

*KEYWORDS: Housing policy, Primitive, Vulnerable tribe, Tribal culture, Baiga*

## 1. INTRODUCTION

India has rich tribal culture and heritage. Most of the tribes live close to the forest as their livelihood and economy depends on the forest. Tribes have emotional and spiritual beliefs with the forest and wildlife therefore they conserve and protect the living heritage. Due to low level of literacy, primitive level of technology and economically weak, tribal population is declining. Total 75 tribal groups are identified in 18 states and 1 in Union territory of Andaman and Nicobar Island [1]. Government has named them as Particularly Vulnerable Tribal Groups (PVTGs) because their condition is vulnerable as compared to other tribes hence require special schemes and development programmes for their protection and survival.

Ministry of Tribal Affairs, Govt. of India is implementing 'Scheme of Development of Particularly Vulnerable Tribal Groups (PVTGs)' to comprehensively plan their socio-economic development while retaining the culture and heritage of the community by adopting habitat development approach and intervening in all sphere of social and economic life, so that a visible impact is made in improving of the quality of life of PVTGs [1]. Madhya Pradesh has around 46 tribes from which Baiga tribe is taken as a case study.

## 2. AIMS AND OBJECTIVES

The paper aims to critically analyse the Housing Policy 2015 (Conservation-cum-Development Plan) for PVTG's. The objective is to study the impact of dwelling provided Pradhan Mantri Gramin Awaas Yojana (PMAY) on

traditional Baiga settlement in terms of housing pattern, material, form and lifestyle.

## 3. METHODOLOGY

Literature review includes study from various sources like books, journals, government reports, online articles etc. Reconnaissance survey of site was done to study the existing Baiga dwellings and new dwellings provided by Pradhan Mantri Gramin Awaas Yojana (PMAY). Interviews were conducted to understand aspiration, perception and satisfaction of the tribal's.

## 4. HOUSING POLICY FOR PVTGS

Pradhan Mantri Gramin Awaas Yojana (PMAY), previously Indira Awaas Yojana (IAY), is a social welfare flagship programme, created by the Indian Government, to provide housing for the rural poor in India [2]. Under this scheme, it is emphasized that Conservation-cum-Development (CCD) Plans should focus on strengthening of institutional framework in the PVTG areas and that the activities undertaken should be sustainable and aimed at long-term socio-economic development of the PVTGs [1].

## 5. BAIGA TRIBE

Baiga tribes are known as lords of jungle, their livelihood depends on shifting cultivation. They are surviving by eating roots, leaves and fruits. Baigas have excellent knowledge of plant species therefore also known as medicine man. They believe themselves as son of the Mother earth and hence do not plough believing

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that it will scratch the breast of their Mother earth. Baigas tribe do not settle in one place, keep making new shelters in certain period of time due to their work culture. Marriages are done within the tribe. They are fond of dance and music.

## 6. HABITAT OF BAIGA TRIBE, KEOCHI, AMARKANTAK

### 6.1 Vernacular Tradition

The settlements have evolved as per the landform and natural setting (Fig. 1). They make their own dwelling from the locally available material for example sun dried mud blocks or rammed earth is used for walls, wooden logs, battens are used for trusses and terracotta tiles are used for roof covering (Fig. 2). Mud is used as mortar as well as plastering. The spaces are evolved as per the lifestyle and work culture. Courtyard is used for daily activities. Semi-covered space around the courtyard, leads to a room where cooking and sleeping spaces are segregated by grain bins. Backyard is used as bathing, wash area, medicinal plants nursery. They have separate space for domestic animals like goats, pigs, hens etc. The walls are painted and have floral pattern whereas flooring is done with cow dung.



Figure 1: Settlement pattern and Baiga dwelling  
Source: Author



Figure 2: Vernacular construction techniques  
Source: Author

### 6.2 Housing Scheme- PMAY

Housing scheme PMAY mentions that efforts should be made to maintain the traditional architecture of the PVTGs. In so far the issue of culture is concerned, this will include conservation of culture of the PVTGs including documentation of their lifestyle, traditional medicine and medical practices, art, folklore, sports, music, dance, crop food etc [1]. But the implementing agencies have introduced a typical design or prototype with modern materials (Fig. 3) where mud blocks are replaced by burnt bricks, mud mortar with cement mortar, steel as reinforcement is introduced, sloping roof with the flat roof.

## 7. RESULT AND FINDINGS

During the site visit it was found that, recommendations made by Ministry of Tribal Affairs, Govt. of India under 'Housing and Habitat' are not taken in consideration by the implementing agencies while planning and design of dwellings for Baiga tribe.



Figure 3: Settlement pattern and dwelling under PMAY

Source:

[http://rural.nic.in/sites/default/files/PMAY%28G%29\\_PPT\\_CR M\\_Orientation.pdf](http://rural.nic.in/sites/default/files/PMAY%28G%29_PPT_CR M_Orientation.pdf)

In Pradhan Mantri Gramin Awaas Yojana (PMAY) the settlements and dwellings are neither designed as per the social and cultural needs of the family nor respecting the natural setting or landscape of the region. The locally available materials are not used which changes the character of vernacular architecture and for which they are not at all accustomed. For example as these dwellings are located in the dense forest where rainfall is high, sloping roof is best suited as per the climatic condition of that region, instead flat roofs are now constructed. Traditional and cultural knowledge systems are completely neglected. People are not able to perform rituals, customs, beliefs, festivals and other ceremonies related to birth or death, as dwellings do not address social and cultural needs of the family. That is why Government policy, schemes, development programmes and its implementation fail to address or meet the basic requirements of Particularly Vulnerable Tribal Groups (PVTGs).

## 8. CONCLUSION

The Government should make an effort to integrate tribal vision in the decision making, policy formulation, and implementation. Integration of traditional and cultural knowledge in contemporary design and use of modern techniques in vernacular architecture will give a sustainable solution to conserve the culture of PVTGs.

## ACKNOWLEDGEMENTS

We are grateful to Baiga tribe who cooperated in the site survey and generously shared their knowledge.

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# Thermal Performance of Village Dwellings in SW China: The Impacts of the ‘New Vernacular’

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**ABSTRACT:** *This paper addresses an emerging issue for village communities located particularly in SW China. Government inspired efforts to redevelop rural villages combined with aspirations of local residents have led to the replacement of the traditional, predominantly wood-construction house with a modern, mainly concrete, alternative. The new houses have modern facilities (such as for washing and cooking) but also very different thermal characteristics and are found with large windows and more restricted air flow. There is normally little involvement of professionals in appropriate ways that would allow optimisation of design for future comfort and energy efficiency. This paper describes some analytical studies of typical design options and identifies some influencing parameters. The research justifies the need for, and development of, a tool suitable for use by village committees/groups and their advisors that will provide decision-support for optimisation of comfort and energy use.*

**KEYWORDS:** *villages, dwellings, China, thermal performance, temperature*

## 1. INTRODUCTION

Since 2005 rural areas in China have been an important focus for Government policies with much encouragement for redevelopment and improved economic prosperity. In the SW of China this has led to many villages considering an emphasis on attracting tourists to visit scenic and traditional communities and to spend money and in some well-located villages, this can lead to useful income flows.

In other places a more fundamental approach to renovation has been taken with poor buildings being classified under four levels of essential repair and remediation applied accordingly. Figure 1 shows such a dwelling being classified by a team from the Jinghong Design Institute in a village in Xishuangbanna SW China.

There is however, an opportunity to provide more sophisticated renovation and development and to consider wider sustainability remediation. This could include for example the range of issues analysed by Li and Ng [1]. Other authors have suggested that design options focused on passive solar and ventilation control were important features for future design guidance [2].



Figure 1: Dwelling being assessed for renovation (authors).

## 2. DESCRIPTION OF DWELLINGS

In rural villages two styles are beginning to predominate: the traditional dwelling constructed mainly from wood (for structure and walls) with roofs of tile or shingle – the ‘old vernacular’; and perhaps what might be termed a ‘new vernacular’ style in which residents replace the old building with one made largely from concrete blocks with tile roofs and large windows. They also increase size and height by extending over more of their original plot (see figures 2 and 3).



Figure 2: Typical Traditional Style Dwelling (authors).



Figure 3: Typical New Style Dwelling. (authors)

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In both styles it is the first (upper) floor which accommodates family life whilst the ground floor is used for storage or commercial activities. A third style of house was also considered – that of an earthquake resistant dwelling. The layout and use of this type was significantly different from the others two and it was discarded from the final analyses.

## 4. ANALYTICAL PROCEDURE

Information was collated on typical house designs from visits and from previous studies (see [3]). In addition, a pilot study of temperatures experienced in different rooms of dwellings in Jingna Town (Man Meng Xin Zhai) was carried out directed by the authors.

There is a substantial variation in construction but key characteristics can be identified. From this normalised building plans and construction features were developed which were then be extracted and used in an energy/environmental simulation model (DesignBuilder). The software was used in a parametric fashion to compute outcomes for a range of scenarios in which window area fraction was varied along with air change rate and construction details. This produced data allowing comparison in terms of internal temperatures and energy use predictions.

Large numbers of data were produced from which only a summary can be presented here.

## 5. SUMMARY OF RESULTS

The buildings perform quite differently due to the major variations between materials and air-tightness as well as solar heat gains through windows. These are clearly quite different in the two styles of construction however despite this, modes of use and daily life within the dwellings was observed to vary little.

A comparison of some selected aspects of the data is given in table 1. Overall the results indicated for free-running mode that the new dwelling was typically 2.2°C warmer than the traditional in the coolest month but also 1.7°C warmer in the hottest month. This outcome was also reflected in simulations for the buildings with heating and cooling systems provided: more energy was required to maintain comfort in the traditional dwellings in cool months and more needed to provide for cooling of new dwellings in summer.

## 6. CONCLUSIONS

It is clear that each dwelling type has positives and negatives with respect to thermal performance judged solely on the data produced. This is only part of the analysis as there are a number of other considerations. The dwelling occupants are eager to bring their properties up-to-date with modern amenities fitting their perception of a modern lifestyle though use of building is very similar to that of previous generations.

Significantly, the new buildings are constructed with little use of information or advice on how the thermal performance of the dwelling could be improved. In maximising the use of the plot area solar availability and ventilation has not often been considered.

Meanwhile for dwellings constructed by registered professionals there is recognition of the need to address earthquake resistance, this is not the case for dwelling commissioned directly by residents.

There is therefore significant potential for impacting beneficially on the process if stakeholders can be engaged and information of the right type made available in the right format. The authors propose that this could be enacted if linked to existing activities being undertaken in rural regeneration and revitalisation schemes.

*Table 1: Comparison of average temperatures in January and July for traditional and new style dwellings (data show variations according to window area and ventilation rate)*

window area fraction	air change rate (ach)	winter (°C)	summer (°C)
traditional dwelling			
0.3	0.25	13.0	23.1
0.3	1.0	12.9	22.9
0.3	2.0	12.8	22.8
0.5	0.25	13.2	23.2
0.5	1.0	13.1	23.1
0.5	2.0	12.9	23.0
0.7	0.25	13.4	23.4
0.7	1.0	13.2	23.3
0.7	2.0	13.1	23.2
new dwelling			
0.3	0.25	14.6	24.3
0.3	1.0	14.5	24.2
0.3	2.0	14.3	24.1
0.5	0.25	15.6	25.1
0.5	1.0	15.5	25.0
0.5	2.0	15.3	24.8
0.7	0.25	16.1	25.4
0.7	1.0	15.9	25.2
0.7	2.0	15.7	25.1

## ACKNOWLEDGEMENTS

The authors acknowledge the support of the Vernacular Architecture Group (UK) in making funds available for research that contributed to this paper, and also the support of Chongqing Jiaotong University. The research is also linked to the AHRC UK Sustainable and Creative Village Research Network – SW China.

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# Sustainable Building Practice and Guidance for Dai Villages, Southwest China

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*ABSTRACT: This paper studies the Dai houses and villages in Xishangbanna, Southwest China. Dai is one of 55 ethnic minorities in China. By comparing the field study of Dai houses carried out in the 1990s and the field study for two villages in 2017, the research investigates two key aspects. Firstly, it considers the influence of new building materials and technologies and impacts brought in by rapid urbanization, together with changes in the traditional integrated relationship between houses, village environment, and surrounding environment. Three key impacts on rural development in the region were identified. Secondly, the project explores the development of the research methods for vernacular houses in China. The focuses of investigation, starting from anthropological studies in the 1950s, now include greater consideration of environmental context. Research found that architects and academic scholars can support the interface between policy, academic studies and practices on rural development for decision-making. Medium term planning is needed in order to provide link between current practice and long term sustainable aims.*

*KEYWORDS: Dai houses, vernacular houses, rural development, village environment, sustainable development*

## 1. INTRODUCTION

The Dai ethnic group is one of 55 minorities living in Southwest China who has shared cultural elements with other Tai people in Southeast Asian countries. The traditional Dai houses and villages together with surrounding forests and fields formed an integrated ecological system [1]. The systematic studies of Dai houses and culture were first carried out by anthropologists and scholars in other disciplines in the 1950s. Since the 1990s, rapid urbanization in adjacent cities, new materials and associated technologies introduced to the area had great impacts on design and construction of village houses. By comparing the field study of Dai houses carried out in the 1990s and the field study of two villages in 2017 by authors, this paper identifies three important aspects that have significant impacts on sustainable development in the region. Firstly, the transformation of Dai houses that took place in 3 phases, due to the usage of new materials. Secondly, the changing relationship between new houses and existing village environments and the surrounding area. Thirdly, the interaction between individual design and construction activities and external support from government and professionals.

The project also explores the development of the research methods of vernacular houses in the regions. The investigation of vernacular architecture and villages in Southwest China were primarily based on anthropological studies introduced by scholars in the 1930s. Contemporary studies, however, have included more considerations of building design, construction and environmental context. Both research and practices on rural development explore more of material, technology, spatial arrangement, function and tectonic

consideration. New methods indicate that architects and designers can support the interface between policy, academic studies and practices on rural.

## 2. EVOLUTION OF DAI HOUSES AND VILLAGES

The traditional Dai villages situated in an integrated surrounding environment meant that there was a close link between traditional ways of building and the Dai people's understanding of the relationship between human settlements and natural environment. Throughout history, the shared beliefs and knowledge of construction between builders and householders allowed flexible but coherent changes for Dai houses to occur within an ecological system (see figure 1). Field studies of Dai villages in Xishuangbanna in the 1990s as part of author's PhD study demonstrated changes brought in by new materials and technologies. After new materials such as bricks and concrete were used for construction, the shared knowledge of building between builders and householders changed.

### 2.1 Changes of Dai houses in three phrases

Since the 1980s, new materials such as bricks began to be used in extensions with the main parts of house remaining as timber. Research shows that spatial arrangement in those houses for different functions and relationship with the environment were maintained with small modifications (Figure 2).

The fundamental transformation came in the 1990's when the buildings started to be built almost entirely from bricks or concrete (see figure 3). The lack of knowledge of new materials or understanding of the associated technology not only led to dangerous structures being built in earthquake areas, but also

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created a huge waste burden for the ecological system. New houses, built by non-professionals, required repair, amendment and rebuilding because of the risks related to flooding and earthquakes. The lack of knowledge of new materials and technologies made it difficult for villagers to participate in the decision making process of building their own houses. Very often the decisions were made by based on the cost they could afford and to maximize the size of house on the available site.



Figure 1: Traditional Dai timber house (authors).



Figure 2: Dai house with brick extension (authors).



Figure 3: Dai concrete house (authors).



Figure 4: Village environment (authors).

Case studies of two villages showed that one had kept many traditional styles houses, despite being built between 2008 and 2011. Houses in this village were primarily built by a local carpenter with help from the householders. The second had more concrete houses and paved village roads (Figure 3). The inter-relationship

between houses, buildings, streets, and open spaces (see Figure 4) in these two cases were further analysed.

The outcome of the case study investigations showed that there is fundamental change of operations in the village with new houses, roads and facilities being added. It is concluded that there is a need to gain a much more realistic understanding for the future of how the villages might operate in the new environment.

## 2.3 Targets linking current practice and long term aims

The transformation brought by new materials and construction, led to top down procedures initiated by the municipal government and planning department aimed to support villagers. This had three key aspects: training builders to have knowledge of brick and concrete construction; identification and classification of dangerous houses; and repair or re-building of houses at risk together with financial support. These are effective methods particularly for families that had financial difficulties, though bottom up process are also an important part of the whole system [2-3].

Guidance documents distributed to construction teams have worked well in the region for promoting good practice and focusing on two aspects. Firstly, an emphasis on good quality construction and structural safety. Secondly guidance for tourist towns and villages to design and build in harmony with the traditional context. In order to develop this further, it is necessary to include a framework of sustainability measures in the guidance books to direct current practice with medium-term targets in order to achieve long term aims. Those include, for example, consideration of orientation, ventilation, lighting, and the relationship between houses and village environment.

## 3. CONCLUSION

As a result of examining the changes in new village houses and their impacts on the existing village environment, we argue that there is a need to consider systematic changes of academic research, design and construction practices, together with government policy and support for sustainable development in rural areas.

## ACKNOWLEDGEMENTS

The authors acknowledge the support of the staff at the Jinghong Design Institute in Xishuangbanna who facilitated access to the villages mentioned in the study.

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## Thermal Comfort Description of Urban Structure Types

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*ABSTRACT: The human outdoor thermal comfort is strongly influenced by urban structure types. Therefore, it is important to analyse the relationship of these parameters to support decisions in urban planning. This paper presents a methodology to analyse the thermal comfort for the city of Belo Horizonte, Brazil, based on a map of climatopes, a map of air temperature and a distribution of PET calibrated classes in the city. The case study represented the impact on thermal comfort at night (3 AM). Despite this initial approach, it may be satisfactory to urban planning applications.*

*KEYWORDS: PET index, urban structure types, climatic map, thermal comfort*

### 1. INTRODUCTION

The built environment in urban areas influences the climatic parameters contributing to the formation of the urban climate, which has an important impact on thermal comfort of the cities' inhabitants, mainly to the users of public open spaces. To represent the impact of urban structure types on thermal comfort, the simple consideration of air temperature as an indicator is not adequate. One way to translate it for planning recommendations is by using a thermal comfort index, such as the PET (Physiological Equivalent Temperature) [1]. This study presents a methodology to analyse the impact of urban structures on the thermal comfort conditions in Belo Horizonte, Brazil, based on an urban climatic map with an urban structure type classification and a map of air temperature correlated with the calibration of the PET index.

### 2. METHODOLOGY

This is a follow-up study which is based on results of previous researches on the calibration of the PET index for the local population [2] and on a map of climatope for the city of Belo Horizonte [3].

In this study, the methodology is divided in three steps: data treatment of air temperature, definition of the impact of climatopes on thermal comfort, analyses of air temperature with climatopes, considering the impact on thermal comfort.

At the first step, the air temperature ( $T_a$ ) data were collected at 25 points distributed into the city during 15 consecutive days in March / 2009 - rainy season and high temperatures [4]. To spatialize the data for the whole city, an interpolation applying the method Inverse Distance Weighting (IDW) was done using the mean air temperature at 3 AM, representing the nocturnal cooling. For each class of PET, a corresponding range of air temperature was determined (Table 1), derived from

the index calibration for the city [2], and the respective human thermal sensation were established [5].

A correlation between the climatopes classes and their impact on thermal comfort were established as well (Table 2). In the definition of the climatopes, which are areas with similar microclimatic conditions [6], the ventilation and the heat balance were considered based on the description of land use, wind field and topography. The air temperature measurements were used in order to have a better understanding of heat loss during the night.

Table 1: PET and the correspondence with air temperature

PET (°C)	$T_a$ (°C)	Thermal sensation
< 15	< 18	Cold
16 to 30	18 to 30	Comfort
> 31	> 28	Hot

Table 2: Climatopes and the impact on thermal comfort

Climatope classes	Urban climate analysis	Impact on thermal comfort
1	Negative thermal load and good dynamic potential	Moderate cooling
2 – 4	Low thermal load and good dynamic potential	Neutral
5 – 6	Some thermal load and some dynamic potential	Moderate warming
7 – 8	High thermal load and low dynamic potential	Warming

To verify the thermal comfort impact due to urban structure types, the climatopes map was crossed with the air temperature (Table 1, Fig. 1). The result was a map of the city classified accordingly to the potential impact of the urban structures on thermal comfort.

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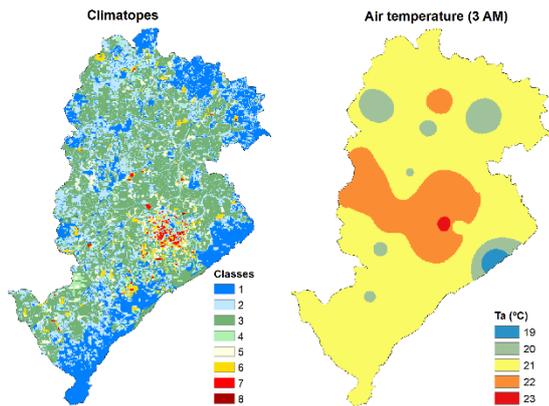


Figure 1: Classes of climatopes and air temperature distribution at night.

### 3. RESULTS

The thematic map representing the relationship between urban structure types, air temperature and thermal comfort is showed in Fig. 2. At night, air temperatures are between 19 and 23°C. In this range of  $T_a$ , the thermal sensation is considered neutral, which roughly corresponds to the comfort class of the thermal comfort evaluation scale. However, the climatopes classes indicate areas where the thermal load is high, and the dynamic potential is low. They correspond to the city regions which have the highest temperatures, concentrated in the center of Belo Horizonte. Although the perception of thermal sensation is neutral, considering the PET index calibration, it is possible that the type of urban structure contributes to a sensation of slight warming, differently than to other areas of the city with the same air temperature but other urban structure type. Otherwise, in the east is concentrated the lowest  $T_a$  values and the class of climatope which indicates moderate cooling (class 1). In this area, the thermal sensation could be colder than in other areas with the same air temperature.

### 4. CONCLUSION

The human thermal comfort is strongly influenced by urban structure types. It is important to represent this influence in the city to support decisions in urban planning. The methodology described here allows mapping the distribution of urban structure types, their influence on climate and the relationship with thermal comfort in open spaces. The case study represented only the impact on thermal comfort at night. It must be tested during the day to see conditions of hot sensation, which has worse consequences in human perception than at night. Despite this, the method was satisfactory for the spatialization of information for urban planning applications (as in urban design and land use proposals aligned with thermal comfort) and could be applied in other cities.

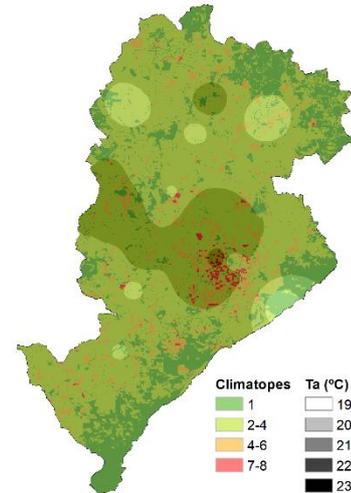


Figure 2: Climatopes classes regrouped and combined with air temperature.

### ACKNOWLEDGEMENTS

This research was supported by FAPEMIG (Fundação de Amparo à Pesquisa do Estado de Minas Gerais - HBD-00036-17), CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico), and INMET (Instituto Nacional de Meteorologia).

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## Energy Efficient Buildings for Uganda: Accessibility, Reliability and Equal Opportunity.

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*ABSTRACT: Design of contemporary glass-box office buildings is unsuitable for the tropical climate of Uganda. Overheating is commonplace in indoor spaces because glazed façades are exposed to beam radiation from all directions everyday, through the year. As a result high-energy loads are associated with space cooling. These energy loads are significant for the context where only 15% of the population has access to electricity accompanied by regular load shedding and black outs. This research posits that shading to reduce cooling energy loads coupled with PV generation can improve overall energy availability for the country.*

*KEYWORDS: Energy, Design, Optimisation*

### 1. INTRODUCTION

A vibrant energy sector is critical a nation's economic development. In Uganda, like most of Africa, energy companies are troubled by unreliable supply, inefficient clientele to support generation capacity, deficient maintenance, erratic procurement procedures, and inability to prevent transmission or distribution losses (Mbabazi and Sansa-Otim, 2015). As a result, Grid Electricity for the end user is unreliable, delivered at high tariffs and in many parts of the country still widely inaccessible. Only about 15% of the national population has access to electricity, and as low as 7% in rural areas where 84% of the population lives. Regular power outages and load shedding can continue more than 3 days for 72% of those connected to the grid (Mbabazi and Sansa-Otim, 2015).

Uganda meets more than 93% of its energy demand with wood fuel, 5% with petroleum combustion and only 1.5% with electricity from hydro or thermal power plants. (Tumwesigye et al, 2011). The high demand for wood fuel continues to deplete forests and exacerbate land degradation. Despite the quickly rising electricity demand, national generation capacities have shrunk. Further, electricity transmission is inefficient, and the country suffers a lack of power import channels.

In this context, electricity demand is increasing at a rate of 8.2% each year, with expanding rural access as a key factor driving this demand. Around 35 million Ugandans, 97% of the population, rely on traditional and relatively inefficient energy sources such as wood, kerosene, fuel, and charcoal to cook their meals and light their homes. Despite this evident need to assess all possible alternatives, commercial construction has not been considered for conservation or on-site generation to feed this power needed. It is estimated, for instance, that urban buildings in cities alone consume on average

56% of the total generated electricity (Blanco and Muzee, 2016).

This research posits that reducing cooling energy loads by shading commercial buildings from solar gain as well as adopting PV for on site generation can improve overall energy availability in Uganda.

Energy efficiency and energy access are sometimes viewed as competing priorities for funding rather than elements that can work together to achieve the goal of providing improved access to energy services. Moreover, energy efficiency is often perceived as a short-term solution to power outages or load shedding without examining its potential as an energy buffer for future electricity planning. In 2006 for example, a compact fluorescent light (CFL) distribution program reduced power demand by 32 MW at an investment of US\$0.05M per MW, which is more than 50 times cheaper than investing in new baseload hydropower plants. Rue du Can et al (2017) estimated that energy efficiency improvements could save 341 MW of on-grid meter-level peak demand.

At an average of \$2.1 Million USD per MW, generation power plants though highly beneficial, are quite expensive for domestic revenue mobilization. Therefore, they are contingent on foreign generosity and require additional infrastructural support both of which are challenging to procure. The long 5-to 10-year durations render hydro generation project funding susceptible to various institutional or fiscal setbacks, like inflation, misappropriation and in the worst cases corruption. Further, delays on mass construction projects are commonplace and bear high financial implications. Bujagali Falls Hydro power dam funding needed considerable revision and refinancing from \$530 Million USD to \$902 Million USD after a four-year delay. (Power Technology, 2017)

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Despite of all this, the escalating demand for urban infrastructure which is currently aggravating energy demand, could instead be re-engineered to achieve immediate energy benefits and possibly stimulate energy conservation in urban housing developments.

## 2. ENERGY IN BUILDINGS

### 2.1 Solar Shading

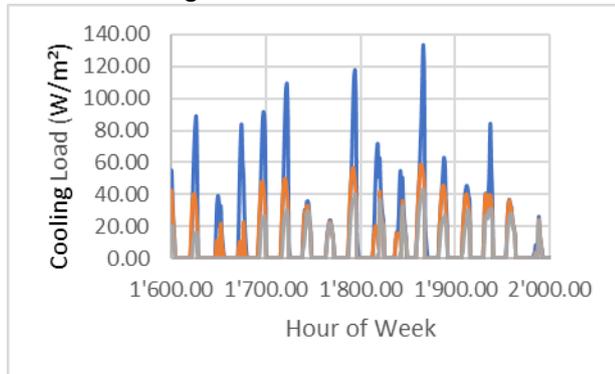


Figure 1: Cooling load simulation results

Simulation results in Figure 1 also in show that cooling peak loads reduce by 26% when window is tuned towards a South as opposed to West orientation. However, a 63% reduction in cooling energy is noticed when the window in its new South orientation is also shaded. Analysis of recorded data from actual buildings on a project in Uganda found that solar shading had improved the percentage of time within the user comfort zone by a factor of 3 and even 5 in some cases (Vandermeulen, 2018).

Solar shading can offer significant energy savings for buildings in Uganda, since like most tropical countries AC consumers more than 55% of typical building energy (Katili, Boukhanouf, & Wilson, 2015).

### 2.2 PV potential

Mukwaya and Okidi-Lating (2014) survey reveals that the average EUI for office building in Kampala is 156 kWh/m<sup>2</sup>/year.

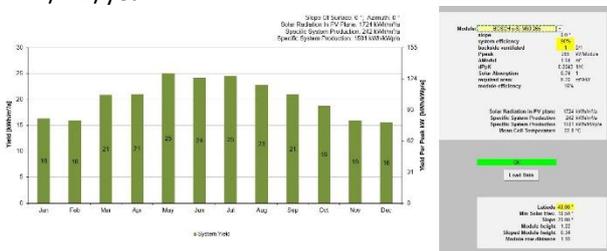


Figure 2: Monthly yield of PV system in Kampala.

The PV potential in the region suggests that from each square meter, a 16% efficiency PV panel can supply 242 kWh/m<sup>2</sup>/year as shown in Figure 2; almost double the required energy. Further, most office building reach peak energy demand during the day when PV supply is most reliable. PV systems are considerably more cost

effective than they were 10 years ago and more efficient, which makes them quite ideal for a context where power outages can continue for an entire week.

When additional measures like solar shading and lighting energy efficiency are in place, installing just 10m<sup>2</sup> of PV can significantly improve work efficiency for most offices in the country.

According to MEMD and UBOS (2014), diesel generators supply over 50% of the energy demand for Commercial and Institutional buildings in Uganda, and Knight (2012) posits that depending on load factor (BEFC) and cost of fuel, a diesel generator will make power in the range of USD \$1 to \$40 per kWh. Therefore, at the current UMEME peak tariff of USD 0.22\$/kWh for commercial customers, and an additional annually increasing generator running costs of USD 0.90\$/litre; investment in 10m<sup>2</sup> of a 16% efficiency PV system installed with battery bank at a cost per Watt of USD 1.05\$/W, can be recovered in under 3 years.

If each of 1000 submitted plans for commercial development approval would each install 5m<sup>2</sup> of PV an additional supply of 1.8 MW would be available for every 9-hour workday from city rooftops. This shared investment cost that can be accommodated by building developers would otherwise cost the government up to USD \$ 3M per MW for hydro dam construction.

## 3. CONCLUSION

Efficient buildings can play a vital role in the development of sustainable cities for a growing economy like Uganda's where access to electricity is low and the available electricity is unreliable. This paper showed that minimising solar exposure through glazed façades significantly reduces indoor thermal loads; the paper then discussed the PV potential for commercial buildings in this context.

Further, the discussion acknowledges that a national sensitisation exercise of this scale would require a strategic implementation plan. Initially, policy adjustments would offer guidance for action and enforcement on shading and energy requirements at building approval level. Then a purposeful forward looking strategy would coordinated priorities, options and measures of implementation regarding incentives for developers to acquire the latest PV systems and associated installation equipment. A schedule of commitments under the national Energy sector would have to be revised and checked for compliance periodically. Research projects and survey programs to develop and implement energy benchmarks for commercial buildings would aid the future expansions of the entire project.

## ACKNOWLEDGEMENTS

This section of the paper acknowledges the collaborative potential of academic fellowships in their

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effort to improve the relevance of life skill-education. Transsolar fellowship is an enabling yet empowering experience that fosters a philosophy to maximise impact by connecting ideas, an ideal that is likely to remain with each fellow even when they return to home countries to apply their knowledge. Guidance from creative and expert engineers; enables the design collaboration necessary to improve people's lives.

## Post Occupancy Analysis of Nzeb Implementation via the PH Standard

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**ABSTRACT:** Building regulations are currently under development across Europe in advance of the implementation of the nearly Zero Energy Buildings (nZEB) standard at national member state level. However, when revising the national building regulations to improve energy efficiency, few examples exist of the monitored performance of such dwellings, making informed decision-making difficult. This paper reports on the monitored performance of nZEB compliant dwellings which were built to the Passive House (PH) Standard. It finds that the PH bedroom CO<sub>2</sub> concentrations are significantly better than in houses built to the current building regulations which use natural ventilation.

**KEYWORDS:** IAQ, CO<sub>2</sub>, Passive House, nZEB, Carbon Dioxide

### 1. INTRODUCTION

In the Republic of Ireland, regulations are being prepared to define nearly Zero Energy Buildings (nZEB) (1,2,3) which will come into effect for all dwellings completed after 31st Dec 2020.

An ongoing project provides monitoring data gathered from both low-energy Passive House (PH) dwellings (seven of which are nZEB compliant) and from dwellings complying with the current building regulations from both Northern Ireland (NI) and the Republic of Ireland (ROI) (fig 1).



Figure 1: Location of Monitored Dwellings on the island of Ireland, Europe

Given the similarities in the nZEB and Passive House (PH) standards (4) and the cost effectiveness of the PH methodology in meeting the nZEB standard (5), it is likely that the PH standard is a viable route to meet the nZEB standard. Therefore this study affords an opportunity to compare the recorded performance of the potential future nZEB building stock with that which is currently being constructed, facilitating evidence-based policy-making.

Data is presented on the Indoor Air Quality (IAQ) by considering the proxy of carbon dioxide (CO<sub>2</sub>) concentrations for 19 dwellings (Ireland – 11 of which are Passive Houses, and 8 of which are built to the prevailing minimum building regulations) which are being monitored over a full year as part of the study of 27 dwellings on the island of (see Figure 1).

### 2. METHOD

Data was analysed for the living rooms, kitchens and master bedrooms for the period September 2016 to September 2017 in Irish homes and supplements an analysis which has previously been carried out in Northern Irish homes e.g. (6).

Metrics gathered at five-minute intervals for the dwellings by the “Netatmo” monitoring equipment include: occupancy profile; indoor air temperature; indoor relative humidity; indoor carbon dioxide concentrations; outdoor temperature; outdoor relative humidity; barometric pressure and energy consumption, similar to studies which have been carried out in the UK (7,8). An analysis of the CO<sub>2</sub> concentrations indicated higher concentrations in bedrooms. Therefore further analysis was carried out to assess CO<sub>2</sub> concentrations during occupied periods in bedrooms for one day for all monitored dwellings. This bedroom data is the focus of this short paper.

The PH dwellings all use Mechanical Heat Recovery and Ventilation (MVHR), while all the dwellings constructed to the minimum building regulations use natural ventilation (apart from OWBR3 which uses positive input ventilation). All but two PH bedrooms (OWPA3, OWPA 6) and 2 houses constructed to the minimum building regulations (OWBR 7, 9) had dual occupancy.

## 3. RESULTS

### 3.1 Indoor Air Quality

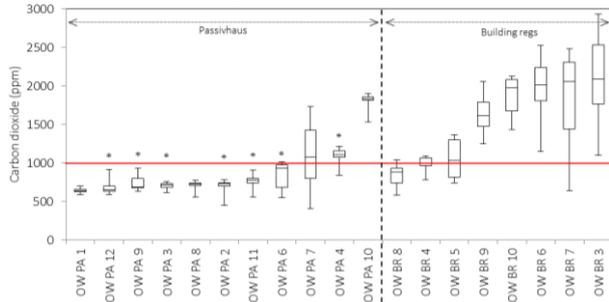


Figure 2: Midsummers day Bedroom night time CO<sub>2</sub> levels

Figure 2 above shows the minimum, first quartile, median, interquartile range, third quartile and maximum CO<sub>2</sub> levels in the bedrooms of 11 of the PH and eight of the houses constructed to the minimum building regulations over a seven-hour period from 00:00 to 7 AM, 21/06/17 (or if 2017 data was not available, 21/06/16). Both the values and range of the CO<sub>2</sub> concentrations are generally lower in the houses constructed to the PH Standard.

Figure 3 compares the bedroom CO<sub>2</sub> levels from 00:00 to 07:00 averaged over all dwellings in the PH group and the minimum Building Regulations group. For the passive houses, the average CO<sub>2</sub> concentration increases from 720 ppm at midnight to 930 ppm at 7 AM. The average CO<sub>2</sub> concentrations in the dwellings with natural ventilation increase from 1170 ppm at midnight to 1750 ppm at 5 AM, and remain above 1700 PPM for the remainder of the monitoring period.

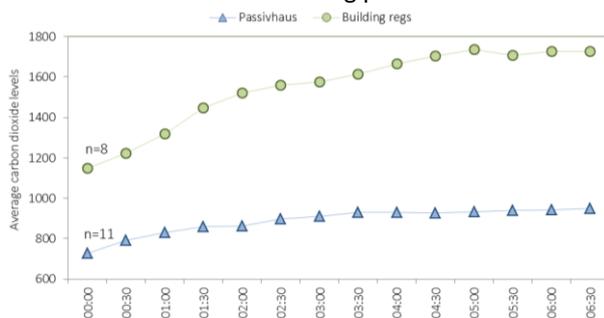


Figure 3: Midsummers day average night time bedroom CO<sub>2</sub>

## 4. CONCLUSION

The results demonstrate that the average CO<sub>2</sub> concentrations in the bedrooms of the dwellings constructed to the PH standard were significantly lower than that of bedrooms constructed to the minimum building regulations. This may be explained by the presence of MVHR systems in PH homes, particularly in light of previous research indicating poor performance of natural ventilation strategies in contemporary housing (9). As demonstrated by closer analysis of individual case study homes (e.g. OWPA10), care must be taken to ensure ventilation systems are performing as designed in

airtight homes to ensure adequate air change rates, and the provision of healthy indoor environments.

This study emphasises the need to consider indoor air and environmental quality, especially in bedrooms, where people spend a considerable portion of each day in an enclosed space. Moreover, air quality in bedrooms should receive particular attention when reviewing national building regulations.

## ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of the Interdisciplinary Centre for Storage, Transformation and Upgrading of Thermal Energy (i-STUTE) under EP/K011847/1 and Invest NI for this research.

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# Monitoring Tool for Urban Brownfield Regeneration Projects: Interaction with Stakeholders

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**ABSTRACT:** Urban brownfield regeneration projects are complex operations that are not automatically sustainable. To facilitate the integration of sustainability issues in these projects, a recent research project led to the creation of an operational monitoring tool tested on case studies. Following this, we undertook interactions with the stakeholders of the case studies to confront the potential of the tool with the future end user's point of view and the reality of the practice. This paper presents the method and results of these interactions. Essentially, it has been recognized that the tool could provide a valuable decision-making support throughout the transformation of urban brownfields into new sustainable neighborhoods. The inclusion of a monitoring tool into the management of these projects appears not only feasible, but realistic and desired.

**KEYWORDS:** Urban brownfields, Sustainable urban regeneration, Monitoring tool, Decision-making

## 1. INTRODUCTION

Within the post-industrial European context, urban brownfield regeneration projects (UBRP) represent an important potential to limit urban sprawl by increasing the density of the already built fabric and to revitalize cities at the neighborhood scale [1]. However, because of their complex nature, most of these operations are not automatically sustainable [2]. To foster a proactive, structured, and continuous integration of sustainability issues into the dynamics of UBRP, a specifically adapted operational monitoring tool was created as an outcome of a recent research project undertaken at Ecole Polytechnique Fédérale de Lausanne (EPFL) (Fig. 1).

Entitled SIPRIUS+, this hybrid tool combines approaches from different fields: a sustainability indicator system adapted to brownfield regenerations and a user-friendly, web-based monitoring software [3]. This way, SIPRIUS+ provides a new, efficient support for stakeholders involved in the decision-making of UBRP. It is designed to meet three requirements [4] : 1. a search for global quality; 2. an adequacy with the specificities of UBRP; 3. an integration into the project dynamics.



Figure 1: Screenshot of the Homepage of SIPRIUS+.

In a first verification stage of the tool, test-applications were conducted on case studies in Belgium, Switzerland, and France to check its general performance and to improve its functioning. It gave positive insights about the potential of SIPRIUS+ to answer the three requirements [5]. However, some aspects inherent to the notion of monitoring could not be completely verified. This is explained by the fact that the test-applications were performed once only while UBRP are long-term projects. Actually, sustainability monitoring implies a continuous and structured follow-up of several environmental, social, and economic criteria. For this reason, a complementary verification stage involved interaction with stakeholders of UBRP. Consisting of round tables, it confronts the tool with the future end users' point of view and the reality of the practice. This paper presents the method and the results of this second verification stage.

## 2. METHOD

To interact with the stakeholders, an interactive round table is organized for each case study: The Val Benoit UBRP in Liège (Belgium), the Gare-Lac UBRP in Yverdon-les-Bains (Switzerland) and the Pôle Viotte UBRP in Besançon (France). The focus of these round tables is made on the monitoring features of SIPRIUS+, which are essential for the tool to meet the three requirements.

### 2.1 Definition of the topics

It is suggested to establish a range of topics to guide the discussion during round table sessions [6]. The topics addressed are the potential of SIPRIUS+ to foster:

- The In itinere and ex-post follow-up of the sustainability objectives of the UBRP;

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- The communication of the sustainability objectives of the UBRP;
- The improvement and optimization of the sustainability objectives of the UBRP.

## 2.2 Structure of the round tables

Before opening the round tables discussions, maximum information is given about SIPRIUS+. First, the research team makes an online presentation of SIPRIUS+. This presentation is personalized for each case study as it shows the test-application made during the first verification stage. Therefore, stakeholders are not only able to see the diverse functionalities of the monitoring tool, but also a dynamic overview of the performance of their UBRP.

Next, an evaluation report is given to each participant of the three case studies. Directly extracted from SIPRIUS+, the evaluation report gives detailed information about over 50 sustainability indicators. As such, it is a major output of the monitoring tool.

Finally, the research team moderates the discussion, according to the topics previously defined.

## 3. RESULTS

In total, 15 participants from different discipline (architecture, urbanism, engineering, and politics) have taken part in the three round tables (Fig. 2). It is important to underline that these round tables are not a foolproof demonstration of the tool neither claim to bring statistical outputs, but are rather a complementary verification of the test-applications. The discussions, reported here under each topic, highlight in a qualitative way trends and perception about SIPRIUS+, its potential to answer the three requirements, and, more specifically, the performance of its monitoring features. Globally speaking, what emerges from these interactions is that, whereas the use of such a tool implies a change in the management of these projects, the evolutions to adopt in order to include this practice appear not only feasible, but also realistic and desired.



Figure 2: Interaction with the stakeholders of the Val Benoit UBRP in Liège (Belgium)

### 3.1 In itinere and ex-post follow-up

The stakeholders agreed on the fact that SIPRIUS+ could contribute maintaining sustainability objectives over the long term of UBRP. In that respect, the word

“dashboard” has been associated with SIPRIUS+ several times, showing the perception of the potential users regarding the support the tool can bring.

### 3.2 Communication

The majority of the stakeholders agreed on the fact that SIPRIUS+ could be a relevant tool to build a shared vision of the sustainability of their UBRP. In that order, it could facilitate the communication about this vision within the internal and external teams of the project, which are usually multidisciplinary. It could also facilitate the communication with a broader audience, such as the population. However, divergences appeared among stakeholders about the level of information to communicate to the public.

### 3.3 Improvement and optimization

Stakeholders agreed on the fact that the monitoring provided by SIPRIUS+ could stimulate an iterative process, that is to say, a willingness to improve and optimize sustainability parameters of their project.

## 4. CONCLUSION

Urban brownfield regeneration projects (UBRP) are not inherently sustainable. A research project proposes an operational monitoring tool, SIPRIUS+, facilitating the integration of sustainability issues during the transformation of urban brownfields into new sustainable neighborhoods. This paper presents interactions with stakeholders in order to gather their point of view about the potential of SIPRIUS+. Even though limited by the small number of participants, it was recognized that the tool could provide a valuable decision-making support throughout the UBRP. Further investigation implies the implementation of SIPRIUS+ within the project teams of the case studies.

## ACKNOWLEDGEMENTS

We would like to acknowledge financial support from the Swiss National Science Foundation (SNSF), Project No 100013\_143376.

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# The Future of Vernacular Architecture in China: Redefining Vernacular Architecture through Contemporary Design and Emerging Technology

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**ABSTRACT:** This research aims to provide an insight into the existing research and practices on vernacular architecture, serving as a basis for further research on vernacular architecture in China and the relevant design research both locally and internationally. It also attempts to identify approaches that can improve the overall sustainability of vernacular architecture from a retrospective perspective, using emerging technologies in contemporary architecture. It looks at the concept of vernacular architecture in contemporary contexts and provide methods for further sustainable practices.

**KEYWORDS:** Vernacular architecture, contemporary design, emerging technology, adaptable architecture, sustainability

## 1. INTRODUCTION

Vernacular architecture accounts for around 90 percent of the world's buildings. It consists of approximately 800 million dwellings [1]. Previous research in the field was mainly focused on how lessons drawn from vernacular architecture (e.g. passive low energy design strategies, performance of materials) can be used to inform the design of contemporary architecture. With the incremental debate on global warming (2-degree limit) and emerging technology, vernacular architecture may still be in a state of confusion, affected by diverse ideas, which should be redefined within future sustainable architectural development.

This research aims to provide an insight into the existing research and practices on vernacular architecture, serving as a basis for further research on vernacular architecture in China and the relevant design research both locally and internationally. It also attempts to identify approaches that can improve the overall sustainability of vernacular architecture from a retrospective perspective, using emerging technologies in contemporary architecture. It looks at the concept of vernacular architecture in contemporary contexts and provide methods for further sustainable practices.

## 2. UNDERSTANDING OF VERNACULAR ARCHITECTURE

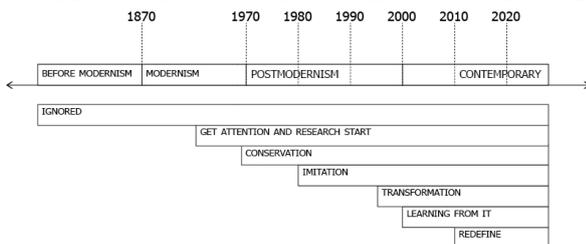


Figure 1: Appreciation of vernacular architecture timeline

As shown in Fig 1, from a longitudinal perspective, the appreciation of “vernacular architecture” has been changed over time. Typically vernacular architecture is regarded as low-tech, passive architecture. However, nowadays architects and researchers try to redefine it in relation to diverse perspectives within contemporary developments.

### 2.1 TANGIBLE AND INTANGIBLE PARTS OF VERNACULAR ARCHITECTURE



Figure 2: Building layers diagram [2]

The concept of vernacular architecture is based on tangible and intangible components. As shown in Fig 2, the surroundings, site, skin, structure, service, and space plan are the main tangible features of vernacular architecture. To achieve sustainability, all layers should be carefully designed since they are highly related to each other.

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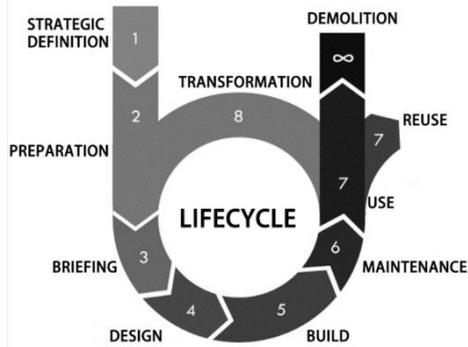


Figure 3: Lifecycle of vernacular

The intangible part of vernacular architecture includes many things. This paper will only focus on issues arising in the lifecycle of a vernacular building. In Fig 3, the lifecycle can be divided into separate stages: from preparation to design, design to building, construction to use and maintenance, and from use to transformation or demolition. With reference to Green Building, it is possible for evident-based design to achieve sustainability at each stage [3]. This method can apply to optimize lifecycle of vernacular architecture as well.

## 2.2 VERNACULAR ARCHITECTURE AS A DYNAMICALLY CHANGING PROCESS/PRODUCTS THAT CAN SUSTAIN

Existing research has revealed that the functions of vernacular architecture may change over time. For most buildings, the functional changes are based on a bottom-up approach [4]. Vernacular architecture cannot be regarded only as an architectural category composed of static buildings that should be carefully protected, but also as a dynamic concept whereby building continuously changes with the inherited tradition from a specific region [5]. Vernacular buildings, on one hand, absorbed new concepts and technologies [6] and, on the other, remained traditional. This procedure has evolved and been sustained over decades through adjustment in forms and details. It has already proved its sustainability in terms of low-tech strategies and vernacular knowledge. However, it will continue evolving at present and in the future.

## 3. Review of projects that redefine vernacular architecture



Figure 4: Review of projects [7] [8] [9]

Though the field of vernacular architecture studies has undeniably grown in recent years, practical projects that explicitly address the application and use of contemporary design and emerging technologies in

vernacular architectural practice are still rare. Taking into account the dynamic balance of aspects of vernacular architecture, architects incorporate various approaches and methods to redefine it. The discussion of those approaches is based on case studies of Guangming Village reconstruction project, Museum of Handcraft paper and Haiti Reconstruction project (Fig 4).

## 4. ADAPTABLE STRATEGIES THAT RESPOND TO CHANGE

Once vernacular architecture is regarded as a process that is constantly evolving, it can respond to change [4]. In the contemporary context, it should change according to living patterns to satisfy basic needs that fit with the wishes and values of the community. Some adaptable design strategies should be established to satisfy evolution. With regard to the meaning of change, the appropriate acceptance of contemporary design and building technologies by vernacular architecture is necessary. It is important to note that such discussion is not new in architectural practice because vernacular buildings are always dynamic.

## 5. CONCLUSION

Rather than discussing low-tech and traditional knowledge, the research emphasizes the dynamism of vernacular architecture; continuously changing and evolving, and open to accepting innovation, and finally accommodating sustainability and advancement with the times. Through the review and analysis of experiential projects, it is possible to identify a number of sustainable approaches (such as collaborative design, implementation of local resources and emerging technologies) of good practice on how to redefine vernacular architecture based on contemporary design strategies and new building technologies. The arguments from precedents embody diverse ways in which development and innovation may proceed.

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# The Environmental Potential of Sky Gardens in a Hot Climate: Low Energy Strategies for Office Towers in Dubai

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*ABSTRACT: This paper tackles the challenge of lowering the energy consumption of office towers in Dubai. The idea of "Sky Gardens" is used as an alternative design concept to base on it. These spaces are defined as transitional zones between indoor and outdoor environments, which provide a smooth transition between otherwise contrasting climatic conditions. The research explores the multiple possibilities of the Sky Gardens; not least as an incentive for users to spend more time away from mechanically conditioned spaces while providing a better climatic interface for the conventional offices. The concept can be traced back to the vernacular courtyards of the region, which were typically equipped with systems that ameliorated the harsh outdoor conditions. The idea is translated and sophisticated so that the Sky Gardens can be adapted during mild, warm and hot periods to improve the building's performance by coupling and decoupling it with the outdoor environment.*

*KEYWORDS: Skyscrapers, Sky gardens, Adaptive Approach, Energy Consumption, Hot Climate.*

## 1. INTRODUCTION

In the last decades, Dubai has emerged as a global city due to its strategic location and the oil-based economic growth of its region. Following trends from other global cities, Dubai embarked on an intense urbanization process fueling vertical development with a complete disregard for the local climatic context. The new townscape is characterized by glossy skyscrapers that compete in an ever-changing skyline. Global actors have chosen Dubai as their preferred Middle East location and therefore office buildings have proliferated. The dependence on air conditioning within those buildings is absolute, resulting in high energy consumption and artificial internal environments. This research will focus on climate based design solutions to reduce the cooling demand and to reintroduce nature in office buildings in Dubai.

## 2. RESEARCH CONTEXT

### 2.1 Dubai's energy context

The cooling demand from buildings represents up to 60% of the total electric consumption in the United Arab Emirates (UAE) [1]. Furthermore, the energy consumed in air-conditioning has sharply increased ten times (5 to 50 Billion KWh) over the last 20 years [2]. The proliferation of fully glazed office towers seeks prestige and projection but they also involve a continuous increase of the electric demand as the typical cooling demand in those spaces is above 300kWh/m<sup>2</sup> [3].

### 2.2 The problem of office towers

After the 90's construction boom, Dubai experienced an exceptional evolution of tall buildings. Currently, Dubai is the home of 911 completed high-rises and it hosts 20 of the top 100 tall buildings in the world [4]. This

trend has had multifold environmental consequences. At the urban scale, the heat island effect has been intensified while wind flow patterns are obstructed. At the building level, deep floor plans and sealed environments make access to daylight and natural ventilation a difficult task. In addition, the lack of solar control and adaptive possibilities enhance the detachment of the user to the natural environment.

## 3. DESIGN CONCEPT

The main goal of this research was to analyze the alternative passive strategies to find potential solutions for Dubai's office buildings. An occupant based approach was taken to eventually provide a design concept that led to a substantial reduction of energy consumption. The introduction of "Sky Gardens" as social break rooms that act as adaptable buffers between the office and the outdoors is the key environmental design hypothesis.

The "Sky Garden" concept is intended as a transitional space, which is not air-conditioned and separates the office from the external environment when this is too harsh. Although its arrangement in the building can vary, the prototype Sky Garden in this study takes 3-office floors. Therefore there is a Sky Garden every three floors and, instead of being vertically aligned, each Sky Garden is slightly displaced respect to the one below, so that they follow a diagonal arrangement. This allows visual connectivity and prevents the generation of strong buoyancy driven draughts.

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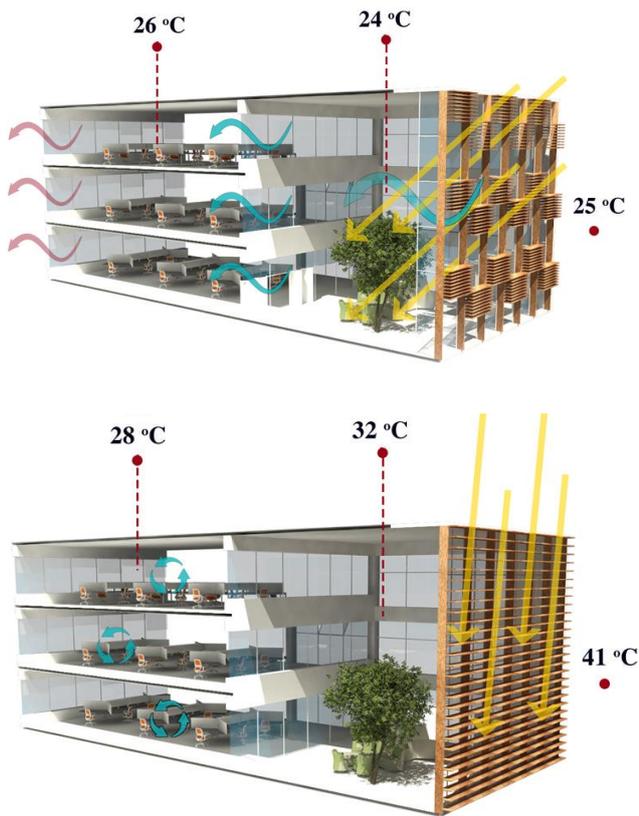


Figure 1: Sky garden concept and performance during mild (top) and hot (bottom) periods.

## 4. PERFORMANCE AND ADAPTIVE OPERATION

Since Sky Gardens' envelope is designed to correspond to different climatic circumstances, openable glazing panels and movable louvers will allow for different adaptive strategies in the different seasons (Fig. 1).

**Mild Period:** The external skin is open in a percentage that is associated to wind speed in order to allow natural ventilation. The external louvers are closed up to let more daylight in the working areas (Fig.1 top).

**Warm Period:** The operation is similar to the mild period, except for the movable louvers, which are deployed to adapt to the higher sun angle. The temperature in the Sky Gardens is still within comfort due to the protection that louvers provide against the direct solar radiation.

**Hot Period:** Since the outdoor temperatures in hot periods are extremely high, the Sky Gardens are decoupled from the outside environment (Fig.1, bottom) and coupled with the air-conditioned offices. In this way and due to the presence of airflow, the Sky Gardens' temperature is kept at 32°C, when the outdoors is at 41°C. This is a tolerable value for activities in a break out space such as circulation, resting, or attending short meetings.

Table 1: Potential savings in cooling loads (CL) for the analysed strategies.

Scenario	CL(kWh/m <sup>2</sup> )
1 Base Case	322
2 1+ Thermostat set to adaptive comfort	219
3 2+Shading devices	174
4 3+Wall insulation	164
5 4+Hybrid ventilation mode	85

## 5. RESULTS

The cooling load of a typical tall office building in Dubai is above 300kWh/m<sup>2</sup> [3]. According to thermodynamic simulations in OpenStudio/Energyplus, the introduction of the Sky Garden together with various passive strategies can decrease the annual cooling load down to 85kWh/m<sup>2</sup>, which means a 70% reduction (Table 1). The first measure consisted in the increase of the thermostat's setpoint from 23°C to 28°C, based on adaptive comfort theories. The second strategy was the implementation of shading devices on the Sky Garden. The third was the addition of insulation in the wall between the Sky Garden and the office, which had a modest effect. Finally, the adaptation of the building management system to a hybrid mode was allowed by the Sky Garden. With the proposed design, mechanical cooling is mainly required from May to October, with a reduced demand during April and November, the rest of the year the building can perform in a free running mode. In economic terms, around 30US\$ per square meter can be saved in the electricity bill.

## 6. CONCLUSION

Starting from the main region's problem of high-energy consumption, this research proves the possibility of having energy efficient tall buildings with a better response to Dubai's harsh climate. This was accomplished by incorporating passive design strategies and a buffer zone between the office and the outdoors.

## ACKNOWLEDGEMENTS

This paper is based on research undertaken at the MSc/March Programme of the Architectural Association School of Architecture, London.

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# Design Process Cultures as Drivers and Obstacles to Sustainable Architecture

## - Identifying the Knowledge Involved in Design Decisions at Architectural Offices in the Nordic Countries.

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*ABSTRACT: The past decades of focus on sustainability and the decrease of energy consumption in the built environment has led to higher demand for integrated design and implementation of technical scientific knowledge in the design process. This paper aims to investigate the state of the art for the implementation of technical knowledge in architectural offices in the Nordic countries and the degree to which integrated design is performed. This paper reflects a larger survey-based study among architectural offices in Scandinavia that have a focus on sustainability. The paper underlines the diversity of each architectural office through a work profile developed based on the surveys. Although the offices' workflows differ, microclimate comfort, daylight, and energy performance tend to be well-integrated topics in building design processes today. However, life cycle costing and life cycle assessment are new topics in the building industry and are still not included in design processes in practice. There is a discrepancy between how important architects evaluate certain kinds of information and how they include it. Much information is still based on 'experience' and 'intuition' rather than derived from the inclusion of technical scientific methods.*

*KEYWORDS: Integrated Energy Design, Informing architecture, Technical knowledge, Sustainability, Work profiles*

### 1. INTRODUCTION

The built environment accounts for around 40% of the energy consumption and approximately 36% of the CO<sub>2</sub> emissions in the EU [1]. Thus, for decades it has been a goal to reduce the energy consumption of operating buildings. In recent years, the quantifications of environmental impact categories have been broadened to include the entire life cycle and emissions from material use [2]. Research has shown that the majority of a given building's sustainability level is derived from early phase design decisions such as its orientation, window façade ratio, and geometry [3]. Thus, an important step to accommodate more stringent building energy requirements in practice was the introduction of the Integrated Energy Design (IED) method [4]. In today's building industry, sustainability certification systems such as the German DGNB have become the drivers for Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) [2]. These systems address Brundtland's definitions of sustainability [5]. However, they also increase complexity, which has led to an increased need for communication among different professions and a more systematic and holistic design team approach addressed by integrated design. Holistic, in this context, means an inclusion of both aesthetics and technical scientific information in the design process in order to address sustainability. One way to enhance the holistic approach in practice is to inform the design process with more technical scientific knowledge in architectural offices through integrated design [6]. This paper investigates

how technical knowledge is involved in making design decisions in order to outline levels of holistic and integrated design in the architectural offices and thus identify design process culture. The underlying hypothesis is that design process cultures can enhance or hinder the Integrated Design Process (IDP) needed to achieve sustainable architecture.

### 2. METHODS

This work is based on surveys conducted in architectural offices in the Nordic countries that are either based in Denmark or have a smaller section in Denmark. These companies are all private and have a reputation for sustainable projects. The surveys were distributed to architects who are also sustainability experts through a central contact person at each architectural office. Response rates were at least 30%, (Table 1). The level of feedback is considered acceptable and representative.

Table 1: Survey responses from all offices.

Profiles	Respondents	Sent
Office A	11	21
Office B	12	20
Office C	10	17
Office D	3	9
Office E	9	31
Office F	8	23
Office G	6	14

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The survey consisted of 37 questions divided into three main topics: (1) technical knowledge in the design phases (related to microclimate comfort, daylight, energy performance, LCC, and LCA), (2) interdisciplinary collaboration in the architectural office, and (3) inputs about the constellation in the office. The survey included only closed-ended questions to ensure that the responses could be quantified afterwards. Closed-ended questions are commonly used for surveys, as they ensure uniformity and reduce the time to answer and process [5].

## 3. RESULTS AND ANALYSIS

The graphical output of the survey is represented by the results from Office A, as seen in Figure 1.

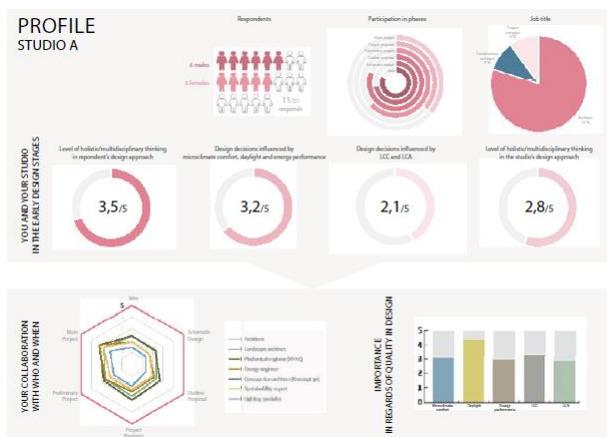


Figure 1: Profile of Office A based on the surveys.

The respondents tended to evaluate their own design processes as being more holistic and more interdisciplinary than the general approaches in their offices. This indicates that individual pioneers are the main drivers for integrated design and that it is not (usually) a top down directive from the offices' partners.

The integration of technical scientific knowledge in the early design phases was uneven; some offices do this and others do not. All offices involve technical scientific information in the later design phases, as defined by the Danish Description of Services [7]. The surveys show that the respondents include knowledge about microclimatic comfort, daylight, and energy performance in the design process equally; however, they mostly work with the topics using rules of thumb and without interdisciplinary collaboration. Very few respondents involve information related to LCC and LCA in their design decisions despite the fact that many find it highly relevant. This limited use can be caused by the lack of national requirements, which persists despite the increased focus from building certification systems. This also corresponds with previous research on the DGNB certification system as a driver for LCC and LCA in design projects in practice [2].

## 4. CONCLUSIONS

Each architectural office has its own overall design process culture, which is defined by how they involve technical knowledge in their design decisions and by how interdisciplinary their design processes are. The surveys show that there can be a large variation in design practices within an office. In some offices, however, design practices are generally consistent and the overall design process culture corresponds to the individual ones. How and to which degree professions are mixed in the office varies; some have explicit strategies of integration and some do not. There is a tendency for microclimate comfort, daylight, and energy performance to be well implemented in the design process cultures. This may be an effect of strict national building energy requirements and the focus on Integrated Energy Design. It is also clear from this study that LCC and LCA are new fields of knowledge in the building industry, which are discussed more than they are actually addressed in design processes today. From this study, it is clear that more focus is needed on LCC and LCA to better address sustainability in practice. Finally, there is a tendency for interdisciplinary approaches to be applied by the individual experts and not by the offices as a whole, which can limit implementation in practice.

## ACKNOWLEDGEMENTS

The authors would like to express their appreciation to the architectural offices who participated in the survey.

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# A Real-Time Carbon Equivalence Modelling Calculator for Computer Aided Design: Using Standardized Life Cycle Assessment Techniques and Locally Sourced Emission Factors

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*ABSTRACT: In complex processes of building design, any feature not directly related to the construction purpose may be deemed superfluous and including new steps relies therefore on usefulness and ease-of-adoption. In this paper, we aim to prove that LCA data undergoes the aforementioned consideration and that decreasing the entry barrier in the application maximizes penetration. This research and its companion tool leverage the moment when architectural decisions are most influential, empowering architects to impact the building's sustainability throughout its full life cycle by visualizing carbon footprint projections in a very customizable and nimble way.*

*KEYWORDS: Carbon Footprint, Life-Cycle Assessment, Embodied Carbon, Software Tool, GEI Emissions*

## 1. INTRODUCTION

According to the Global Alliance for Buildings and Construction in their Global Status Report 2017, buildings and construction together account for 36% of global final energy use and 39% of energy-related carbon dioxide (CO<sub>2</sub>) emissions when upstream power generation is included [1]. It is mandatory for experts in the field to develop technology, strategies, and policies mitigating this impact [2]. Although most of the efforts focus on the building's operative phase, energy, emissions and impact reduction have a great potential in the energy sector. The life cycle of any building consists of seven phases, being one of them "design". [3], [4]. Decisions made in the design phase and the way a building operates are strongly related causing early decision making to have a significant impact in a building's life-cycle [5], [6].

Understanding the designer's process is a determinant to achieve this goal. Design is a knowledge-based activity [7] since it involves multiple variables such as aesthetic goals, local regulation, budgeting, and material optimization. As a result, the ability to include new information in the process requires the architect to work with multiple criteria, which may be difficult to handle in early stages [7], [8].

The use of tools to estimate the environmental performance of a building is a growing resource within the design community [6],[8],[9],[11]–[22]. However, in most examples, results are included in independent data sheets not displayed in the model, preventing real time architectural practice from adopting a carbon oriented design culture.

This research and its accompanying tool leverage the moment in which architectural decisions become most influential, empowering architects to impact the building's sustainability by visualizing embodied carbon projections.

## 2. METHODOLOGY

This methodology is comprised of two stages. The first stage defines the emission factor in CO<sub>2</sub> of the main construction materials in Costa Rica. The second develops a plug-in tool to visualize this data in real-time in an early design.

### 2.1 Emission Factor Generation (IPCC, PAS 2050)

The concept of constructional unit was developed to establish a relationship between the architectural design process and the project's embodied carbon calculation (CO<sub>2</sub> equivalent). Constructional unit can be understood as the smallest element in a building system composed of one or more building materials, e.g.1m lineal of fiber cement panel with aluminum framing. Note that the composition of the aforementioned unit may vary depending on the region. The emission factor used in the designing process can be calculated by:

$$F_{CU} = \sum_i F_{M_i} \cdot w_{M_i}$$

Where  $F_{CU}$ : Emission factor of a constructional unit;  $kgCO_{2e}/kg_{CU}$ .  $F_{M_i}$ : Emission factor of each building material embodied in the constructional unit;  $kgCO_{2e}/kg_{M_i}$ .  $w_{M_i}$ : Fraction weight of each building material embodied in the constructional unit;

$kg_{M_i}/kg_{CV}$ . For  $F_{M_i}$  estimation, the principles of Life Cycle Assessment are applied.

Different considerations described in ISO 14044 or other standard methodologies are used to determine  $CO_{2e}$  of  $F_{M_i}$ . Data from the Inventory of Carbon & Energy (ICE) Version 2.0, University of Bath Database, was used when raw material data was not available.

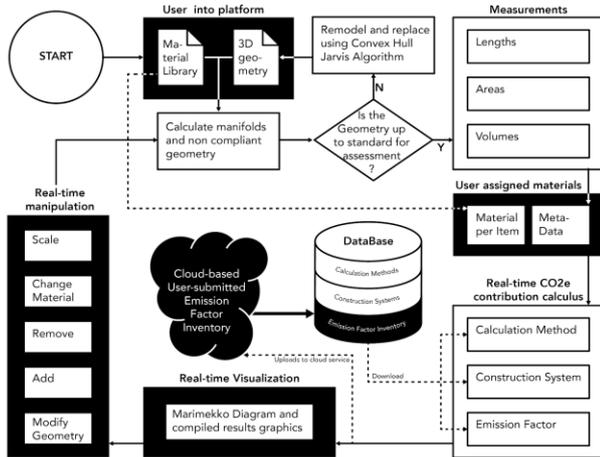


Figure 1: Proposed architecture for embodied energy assessment (black corresponds to user line of sight)

## 2.2 Building a Carbon Oriented Design Tool using visual programming and user research

A 3D tool was created to set an iterative rapid prototyping cycle and maintain the high level of nimbleness necessary to include the findings of the user research into a solution. This visual programming software named Grasshopper was hosted in Rhinoceros 3D.

User research was conducted using think-aloud testing protocols devised by LUMA institute [4]. Results were compiled and analyzed using an affinity clustering method to be leveraged as part of the iterative development process of the prototype.

## 3. ARCHITECTURE

The tool developed includes revision redundancies and uses a decentralized externally submitted database of emission factors, effectively treating the most complex areas of calculation as externalities from the standpoint of the user. Figure 1 shows that the user's "line of sight" only accounts for actions already within the purview of an inexperienced 3D modeler. All other calculations happen at the back end and are independently sourced. Similarly, the calculation method and customization of construction elements are automatically decided without any user input [Fig.1], greatly speeding the iteration process. Users can choose which elements are for calculation and quickly modify their attributes until reaching their desired level of optimization. This feedback loop mechanism is supported by a real-time visualization framework in the

form of a CO<sub>2e</sub> contribution diagram broken down per material using a Marimekko Graph and a net sum of emissions from all sources. An example of the 3D output Carbon relationship is shown in Figure 2.

## 4. CONCLUSIONS

– The implementation of technical standards as the ISO 14-044, PAS 2050 and other methodological tools in a 3D visualization software is greatly valuable since its incorporation enables technical traceability to be associated with design decision-making.

–The developed integrated tool allows the designer to analyze the impact (in CO<sub>2e</sub> emissions) of his real-time decisions on materials and infrastructure without further calculations. Data is presented clearly and easily to read for any designer (even if not familiar with the topic).

–This prototype consists of a useful and powerful tool enabled to enhance the environmental awareness in the design community since early design stages and with future development, it could be integrated in the circular economy for the building sector. There is an opportunity to develop this real-time visualization tool in countries like Costa Rica where most of the mitigation efforts are applied in late design stages, usually implying a greater cost. Early adoption of environmental strategies can be a key point to reach sustainability benchmarks.

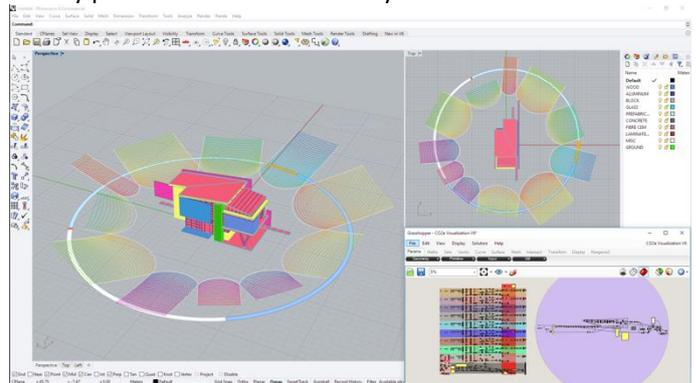


Figure 2. Prototype Calculus and Visualization Tool

## ACKNOWLEDGEMENTS

This study was possible due to the work of the research team of the Laboratory for Tropical Architecture of the University of Costa Rica, its director, PhD José Alí Porras Salazar, and local industry liaisons.

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# Passive Cooling Strategies of Tulou in Fujian, China

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**ABSTRACT:** *Tulou is a traditional Hakka building form in Fujian, southeast China, mostly built between the 12th and 20th centuries. Usually occupied by clans, it has circular or square configuration built with thick rammed earth walls surrounding a central shrine. They have been praised for their thermal comfort, defensibility and communality. While the climate in Fujian is humid subtropical climate with long, hot and humid summers, Tulou responds to this climate, creating a mild microclimate inside. This paper presents a study based on fieldwork carried to investigate the impact of passive cooling strategies of Tulou. The main findings of the study highlight the importance of the courtyard configuration, the roof design, materiality and the benefits of thermal inertia as well as solar control strategies, all of which with great potential to be applied in modern buildings in this area.*

**KEYWORDS:** *passive cooling strategies, Tulou, Hakka buildings, vernacular architecture, hot and humid climate*

## 1. INTRODUCTION

A Tulou, also known as an "earthen building", is a traditional communal Hakka people residence in Fujian, China. It is, usually built in mountainous areas, with a circular or square configuration surrounding a central shrine. Clan groups occupied these vernacular structures, Fig.1. The layout uses the concept of "closed outside, open inside": an enclosure wall with living area and defence function around the periphery, and common courtyard are at the centre [1]. They have been praised for their thermal comfort, defensibility and communality [2].

Yuqing Lou (Fig. 2) is one of the buildings in Chuxi Tulou Cluster, a UNESCO World Heritage site located in Yongding County, Fujian at 24.5°N, 116.9°E. It has a monsoon-influenced humid subtropical climate, with long, hot and humid summers and short, mild winters. The annual average temperature is 20.4 °C with the coldest monthly average temperature of 12.3°C in January and the highest monthly average temperature of 27.7°C in July. The monthly average relative humidity (RH) ranges from 69% to 79% [3].

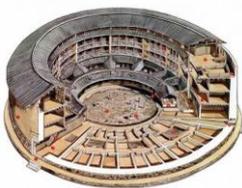


Figure 1: A Tulou (Source: [4])



Figure 2: Yuqing Lou

## 2. FIELD STUDIES IN TULOU

Field studies including measurements, observations and a resident's survey were carried out inside Yuqing Lou over a period of four days in July 2015 to investigate occupant's behaviour and the effectiveness of passive cooling strategies adopted in Tulou. Spot measurements of air movement at the entrance of Tulou and of air

temperature were recorded at specific points across the section of the buildings, and continuous monitoring of the temperature and relative humidity was undertaken in various places. The results were part of a research aimed at developing design guidelines for the subtropical climate [5].

### 2.1 Air movement spot measurements

The occupant's survey indicated that residents stay at the entrance for most of their leisure time, Fig.3. Spot measurement of air velocity at the entrance of Tulou was taken in two days (Fig. 4) with the door kept open. Except for 17:00 on the 26th July, when the highest value of 1.4 m/s was recorded, air velocity remained in average at around 0.5 m/s, which creates a comfortable wind environment for residents to stay.



Figure 3: Entrance of Tulou

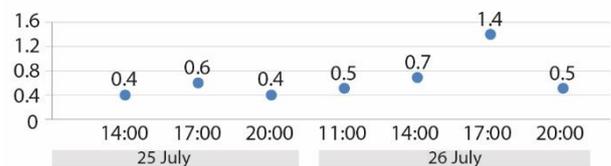


Figure 4: Air velocity at the entrance

### 2.2 Short-term monitoring

The on-site monitoring was carried out to investigate the indoor and semi-outdoor thermal environment. Fig. 5 indicates data loggers' locations: outside the Tulou, in the courtyard and in the bedroom. Fig. 7 shows that the air temperature in the courtyard follows the daily

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fluctuations of the outside temperature closely. The air temperature in the bedroom remains stable, possibly due to the thermal mass of the rammed earth wall. The relative humidity in the bedroom remained stable at 80%.

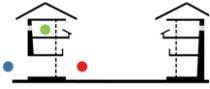


Figure 5: Data logger locations.



Figure 6: Corridor

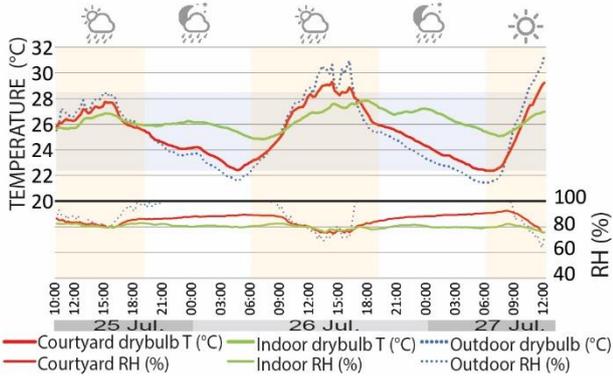


Figure 7: Data logger results

### 2.3 Air temperature spot measurements

Spot measurements of air temperature were recorded at four times (11:00, 14:00, 17:00 and 20:00) on the 26<sup>th</sup> July 2015, Fig. 8. In the courtyard, the temperature rises rapidly once an area is exposed to direct sunlight. The corridor was protected from direct sunlight by the overhang above and the timber handrail, impacting on the air temperature recorded, Fig.6. The top floor bedroom, which is protected from solar radiation by a ventilated roof and overhang, shows lower temperatures than other rooms.

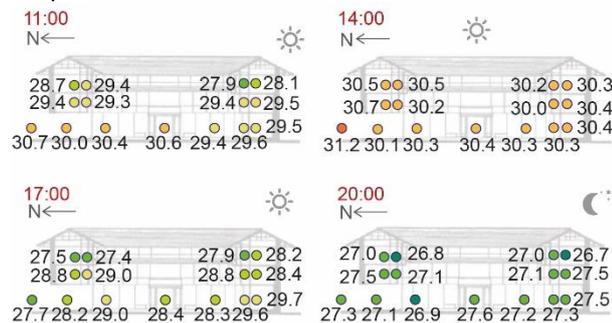


Figure 8: air temperature at 11:00, 14:00, 17:00, and 20:00.

### 3. FINDINGS AND DISCUSSIONS

The fieldwork provided valuable information on thermal comfort and illustrates the significant environmental features of Tulou (Fig.9), specifically:

- Courtyard configuration: The opening facing the prevailing wind in the form of building entrance allows air flow into the courtyard creating a wide range of opportunities available for natural ventilation. The

entrance itself offers an average wind speed of 0.5m/s providing thermal comfort without any mechanical aid.

- Thermal mass: the thickness of the rammed earth wall of Tulou is 2-4m at the bottom and 0.7m at the top. Even though the rammed earth is less dense compared with concrete, it can absorb more heat than concrete [6]. The significantly low temperature fluctuations recorded in the upper floor bedroom ranging from 25°C to 28°C, confirms the effect of the thermal inertia provided by the thick rammed earth wall. It also takes advantage of low air temperature during the night.

- Ventilated roof: The roof extension in the form of eaves provides shading over the walls, openings and corridors in the summer. In addition, the heat generated by solar radiation and moisture is removed by air flow through the roof, protecting the indoor environment from heat generated by solar radiation. The low conductivity and heat storage capacity of the roof and the roof structure which, combined with the large surface area, affect heat exchanges, reducing heat gains during the day and increasing heat loss at night.

- Transitional space and shading: The corridors serve as a transitional space protecting windows and walls from direct sunlight, while the screen on windows obstructs diffuse sunlight, further reducing solar gains.

### 4. CONCLUSION

The traditional Tulou in Southeast China provides valuable lessons of architectural design. In particular, the passive cooling strategies respond well to the climate and have been demonstrated to be effective through the fieldwork. These provide great potential to be applied in modern architecture design in this area.

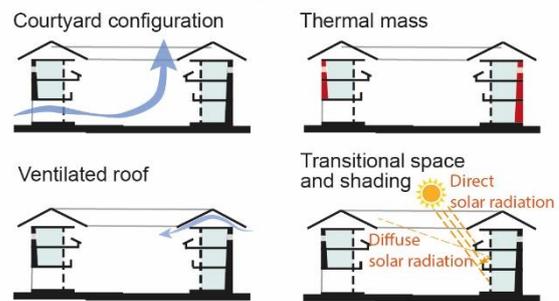


Figure 9: passive cooling strategies

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## Integrated Ecological Systems for Urban Futures

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*ABSTRACT: Climate change is one of the major challenges affecting cities. Extreme natural events continues to hit our cities harder and more frequently with extreme weather conditions. The reality of climate change is also one of the causes of the shift in city agenda that also include the general decline of infrastructure, conspicuous resource depletion, and the emergence of ecology as a new paradigm in urban studies.*

*This paper reviews the outcome of an Australian Government funded project implemented in the City of Geelong. The project provides an example of how to integrate ecological principles with engineering solutions in order not only to regenerate a city centre of a large coastal city but also to redefine Geelong's approach to resilience. Johnstone Park integrated water Master Plan aims to rebuild the green infrastructure in the Geelong, making use of floodwater to irrigate a proposed urban green spine. The project, part of a larger master plan for the city (VISION II) becomes a catalyst for an ecological approach to urban development in the region, setting up a successful example of integrated approach to a number of environmental challenges in the region. The paper reviews the project, identifies the ecological principles, and set out a number of lessons learnt.*

*KEYWORDS: Urban Ecology, Climate change, Urban development, Ecological infrastructure.*

### 1. INTRODUCTION

Climate change is one of the two major challenges that are identified to influence future cities; the other being governance. Al Gore, former Vice President of the United States (1993–2001), described the Australian federal election of 2007 as the first ever to be held in which climate change was the main topic. Climate change realities have already altered the balance in many cities, particularly in coastal cities. The reality of climate change is also one of the causes of the shift in city agenda that also include the general decline of infrastructure, conspicuous resource depletion, and the emergence of ecology as a new paradigm in urban studies. Future cities should be prepared to expect and accept disruption including flooding. There is a need for a step change in our thoughts and ideas to mitigate against the adverse impact of climate change. Kron [3] identified the different social, economic and environmental losses associated with flooding to be incomparable to all other natural disasters. Management and mitigation of flooding in affected cities varies according to the level of flood risks, the history of flood damage, as well as their economic advancement [4].

With the increasing extreme climatic events, the traditional flood management policies and engineering solutions are found to be unreliable; leading to more uncertainties with vulnerable assets and infrastructure. The engineering approach disturbs the riverine ecosystems in both urban and rural zones leading to amplifying the future flood risks. The conventional thoughts of resilient cities that bounce back to their initial states after climate events have proven to be unmanageable. Hurricane Katrina in 2005 is one of those events, by which the area is still disturbed by reduced

long-term population as well as low economic activities [5]; a situation that has not been altered by the vast investments in levees.

While all these measures are plausible to certain degrees, we have not been able to distinguish or develop meaningful applications for 'resilience in cities' as the term becomes diluted and unclear [1]. Resilience in nature is the ability to adapt and absorb shocks rather than the return to an original status. Davoudi [2] defined resilience as the magnitude to absorb disturbances to ecological systems.

Urban resilience refers to living and adapting with turbulences and conflicts [6]. Adaptive management has proven to be effective in natural resources management [7]. Similarly, adaptive resilient communities to turbulences are more tolerant in longer terms [8]. New approaches are required to link urban physical systems with human communities, supporting the information and communication needs of infrastructure organisations, and directly addressing infrastructure decision-making on both urban and regional scales [9]. A shift from the resistant to an adaptive resilient approach is needed in managing and mitigating floods [10]. A more innovative and integrated approach of both engineering and ecological resilience is required to support ecological systems in cities to overcome and absorb turbulence [2]. The Neo Ekistics approach proposed by Elkadi [11] suggests a step change in the resilience approach; combining the ecological principles with the social dimensions of human experience.

Floods are considered one of the most extensive natural disasters in Australia, costing the continent an average annual cost of more than US\$400 million [12]. The economic cost of floods are mainly across South

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Wales, Queensland and Victoria [13]. The two main floods' types are identified by the Australian Bureau of Meteorology are the riverine and the flash floods. Both types are connected with land management strategies and urban infrastructure as rapid urbanisation is correlated with flooding risks and their associated damages [14]. This paper discusses an integrated project to mitigate against cycles of flood and drought in Geelong. The scheme is funded by the Victoria State as part of larger Vision 2 regeneration project.

## 2. METHODS

Vision II project Design studio report was the outcome of the participatory project aiming to regenerate the Geelong Central Business District (CBD) to reach a more vital, productive and sustainable context. Having a main green Spine throughout the City Centre is one of six themes, is considered the main catalyst of regenerating the city. Fig. 1. Shows the integration between the Green Spine theme and other project principles.

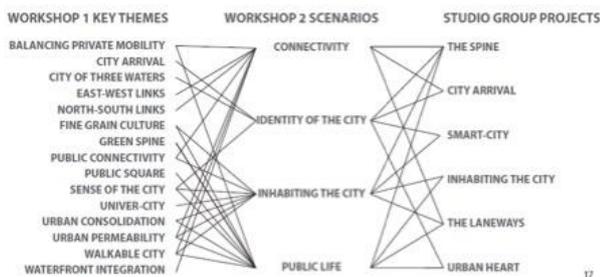


Figure 1: Integration between the Green Spine theme and other project principles

Johnstone Park integrated Water Master Plan (JPIWLMP) demonstrate the feasibility of this theme (Fig. 2). This green ecological spine uses integrated systems to manage storm-water. The project aims to restore the retention basin for retaining, treating and reusing storm-water within the precinct and catchment area.



Figure 2: Johnstone Park integrated Water Master Plan

The partnership project engaged relevant key stakeholders' agencies including the City of Greater Geelong, Barwon Water, the Office of Living Victoria, and Deakin University. Relevant stakeholders were involved in defining design options for this Integrated Water Cycle Management (IWCM) and public infrastructure based on different performed analysis.

A number of participatory workshops were conducted to inform the empirical water management

data in Geelong. The paper analyses the different scenarios and justifies the adopted preferred integrated solution.

## 3. CONCLUSION

There is an increasing recognition that Australian cities are in competition to attract sustainable wealth generating companies and entrepreneurial individuals. Setting and managing a strategy to make a city attractive, user-friendly and distinctive is crucially important. Vision 2 Project sets and manages a strategy to make the city attractive, user-friendly and distinctive. This paper focus on the implementation of Vision2 in the Johnstone Park integrated Water Master Plan (JPIWLMP). The paper examines the ecological principles that defined the project. A number of lessons learnt are also identified.

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## Post Occupancy Evaluation of Indoor Environment Quality in Office Buildings in Mumbai

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**ABSTRACT:** Under this study, office buildings spread across Mumbai were chosen for Post Occupancy Evaluation of indoor environment quality. Parameters evaluated were - Temperature, Humidity, PM<sub>2.5</sub>, VOC, CO<sub>2</sub> and illumination. While rest of the parameters were found to be compliant to ISHRAE 10001:2016. - the two most important office indoor environment quality problems in Mumbai were PM<sub>2.5</sub> and CO<sub>2</sub> levels -Both these parameters were found to be in excess of the benchmarks specified in standards. Indoor CO<sub>2</sub> concentration often exceeded 1000 ppm during working hours, indicating inadequate supply of fresh air. PM<sub>2.5</sub> levels were 2-3 times of the benchmark value of 0.1-25 µg/m<sup>3</sup>.

**KEYWORDS:** Post Occupancy Evaluation, Indoor Environment Quality, Office Buildings, Mumbai

### 1. INTRODUCTION

People spend 90 percent of the time indoor (Haglesan, April 2013) majority at workplaces. India's top eight cities are expecting around 194 million Sq. Ft of Grade "A" offices by 2018 and Mumbai is one of them. Moreover, Mumbai being commercial hub of India, such evaluation of the office buildings be undertaken becomes imperative. All Grade A commercial buildings are air conditioned with high cooling demand and specific type of envelope & humid climate. Occupants' density too is very high owing to the high property rates in the city. High occupant density needs to be complemented with commensurate Indoor Air Quality, Acoustic Conditions, Thermal comfort and lighting quality – to drive better productivity.

#### 1.1. Aim & Objective

The research focused on two issues

1. The indoor environment quality in offices
2. IEQ Improving strategies

The aim of the research was to assess Indoor Environment Quality in office Buildings in Mumbai using Post Occupancy Evaluation Technique. The research encompassed study of IEQ standards, analysis of different POE methods for assessing Indoor Environment Quality in offices. The research also focused on recommendations for improvement in indoor environment.

### 2. METHODOLOGY

For this research, approached number of office buildings across Mumbai region from South Mumbai to Western suburbs. Eight buildings were shortlisted for further assessment, two buildings from each zone of Mumbai. Criteria for selection of buildings were – Age, Area in Sq Ft, Location, Working Hours and nature of occupancy – single or multiple tenanted. Information on building characteristics was collected from building

plans, interviews of building representatives, facility management team and field observations.

Table 1: Details for sample buildings

Sr. No	Location	No. of floors	Area (Sq. ft.)	Occupancy (Nos)	Age (Years)
1	Fort	G+3	9600	250	125
2	Fort	G+3	10200	350	96
3	Andheri	G+7	10500 0	2000	8
4	Prabhadevi	G+6	80000	300	10
5	Vikhroli	G+18	13500 0	4000	12
6	Chembur	G+14	72000	1350	15
7	Thane	G+5	20000	200	9
8	Lower Parel	G+14	10000 0	1000	10

The evaluation was done by using ISHRAE 10001:2016 & NBC 2016 as benchmark. To understand the working and maintenance practices in the building interviews were conducted with facility team. Occupants' survey was conducted to study the occupants' satisfaction and able to get 458 survey completed responses for analysis.

#### 2.1 Measurements

The measurements were taken during working hours from 10.00 a.m. to 6 p. m. The location for testing space was selected within the office for measurements of the selected parameters.

AWAIR's Active Air platform was used for measurement of Temperature, Humidity, PM<sub>2.5</sub>, VOC and CO<sub>2</sub>. Lux meter was used for measurement of illumination levels and Anemometer was used for measurement of air flow rate within the sample office spaces.

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### 3. FINDINGS

The results show that CO<sub>2</sub> concentration was higher than the benchmarks specified in ISHRAE 10001:2016. However in Building B, CO<sub>2</sub> levels are complying with ISHRAE 10001:2016 because of installation of CO<sub>2</sub> sensors it helps them in monitoring and controlling CO<sub>2</sub> concentration. CO<sub>2</sub> sensors were not available in remaining seven buildings. The results clearly show the difference between the building with sensors and without sensors. High CO<sub>2</sub> level indicates high occupants' density & lack of fresh air supply.

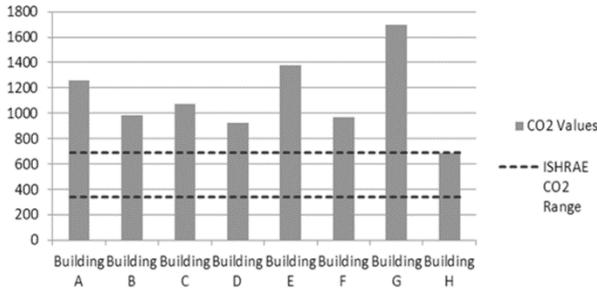


Figure 1: CO<sub>2</sub> Concentration inside the building

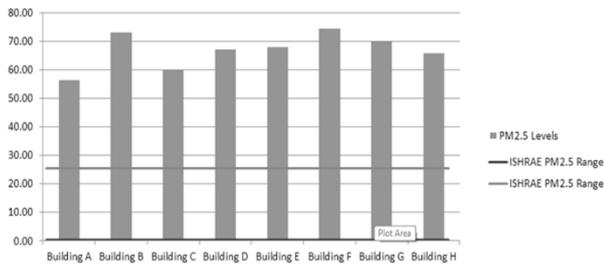


Figure 2: PM<sub>2.5</sub> level inside the building

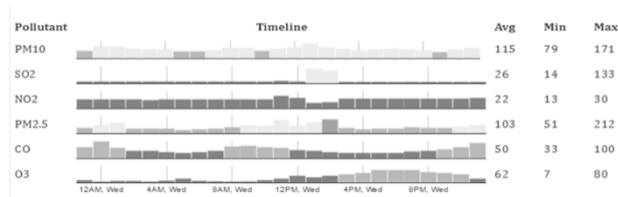


Figure 3: Ambient pollution levels (MPCB website)

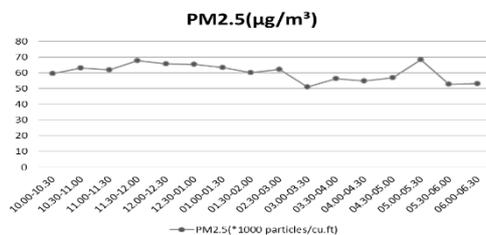


Figure 4: Indoor PM<sub>2.5</sub> moving in tandem with ambient PM<sub>2.5</sub>

PM<sub>2.5</sub> levels in these building were found to be above 70 µg/m<sup>3</sup> vis a vis the benchmark values of 0.1 to 25 µg/m<sup>3</sup>. The ambient PM<sub>2.5</sub> values in all the areas are moving in tandem with the indoor values indicating the issues with the filtering system.

The VOC limits are within the prescribed values as per ISHRAE 10001:2016.

The correlation between occupants' survey and site measurements is low. This shows the dynamic nature of interaction between the building occupants and building.

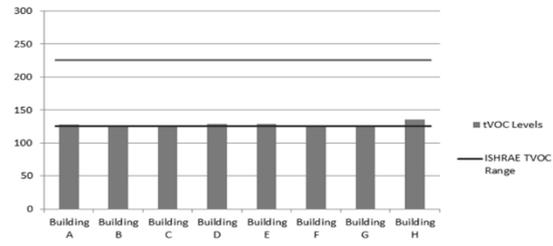


Figure 5: VOC level inside the buildings

The results clearly indicates that on an average, the pollution levels are quite high in the areas of Andheri as they have vehicular as well as industrial emersions while in the other areas of Mumbai there is only vehicular emissions which is less as compared to the combination of vehicular and industrial emissions. But, Chembur found to have the pollution levels much higher and even exceeding National ambient Air Quality Levels as well as WHO guidelines, because it is housing major fertilizer industries, petro chemical industries, petroleum refineries and a thermal plant by which it is reading maximum pollution levels.

### 4. CONCLUSION

The readings indicate that the concentration of PM<sub>2.5</sub> and CO<sub>2</sub> were very high as compared to the benchmark values. A significant co-relation has been observed with ambient CO<sub>2</sub> and PM<sub>2.5</sub> values and the ones observed at indoors. This strongly indicates inefficient filtering of fresh air. In couple of buildings which were studied, they have a practice of shutting off the AHUs during lunch hours. Consequently in post lunch period it was observed that the concentration of PM<sub>2.5</sub> & CO<sub>2</sub> would shoot up. This problem can be resolved by Installation of efficient air filters in AHU to take care of PM<sub>2.5</sub>. And instead of shutting the AHU in lunch hours it is advisable to increase the set point (to say 280C) which would be helpful in maintaining the CO<sub>2</sub> while conserving energy.

### ACKNOWLEDGEMENTS

My sincere thanks to all the offices and their staff, for voluntarily participating in the process and allow me to conduct my research.

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# Impact of External Shading Devices on Daylight Quality in Open-Plan Offices in the United Kingdom

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**ABSTRACT:** Glazed façades of open-plan offices may result in excessive heat gains and visual discomfort. Appropriate shading of the glazed façade helps by reducing high intensity radiation, avoiding glare and allowing daylight penetration throughout the year. Through parametric analytical study, this research assesses the effect of form as a driving factor for the performance of external shading systems, within the context of open-plan office design. The potential benefit to a large glazed facade is reviewed, with external shading systems tested as a mitigating feature, against excessive exposure to sunlight. Subsequently one office design project is presented, which describes the proposed shading device and the applied results.

**KEYWORDS:** Office buildings, Shading devices, daylighting, glare, louvres

## 1. INTRODUCTION

Natural daylight is increasingly viewed as a universal requirement within an office workplace. Most people prefer working in a naturally lit environment with an external view outward from glazed apertures, such as windows [1]. However, excessive daylighting often leads to disturbing glare and increased solar heat gain, thus increasing the use of mechanical cooling systems. Appropriate shading of the glazed facade area of an office building serves as an effective strategy, by reducing high intensity radiation, avoiding glare and allowing daylight penetration throughout the year.

The form of external shading systems should be designed using various responsive techniques. This paper investigates the impact of a specific shading system on daylight qualities of open-plan offices in the United Kingdom. Technical analytic work was performed using DIVA for Rhino and Honeybee for Grasshopper, to optimize the building envelope by improving daylighting performance and visual comfort for a base case. Relating the base case to an applied design shows the proposed model provides high quality daylight for occupants. This paper discusses the main findings of this study.

## 2. ANALYTIC STUDIES

Analytic work was carried out to assess the impact of various design solutions. The computer model was evaluated using the climate of Birmingham (52°N 1°W), England, United Kingdom. Parameters included roof overhang and louvre system.

### 2.1 Roof overhang

Overhangs shield the window from high bright sky areas, thus protecting the office from direct summer sunlight. Jakubiec and Reinhart [2] indicate that direct sunlight is usually associated with discomfort and glare. To decrease the probability of glare, various roof

overhangs with different depths have been tested using Honeybee for Grasshopper (Fig. 1). The result shows a large overhang of 12.5 m on the west allows the facade to remain glazed, receiving four hours of direct sunlight over half of the façade area in winter. For the south elevation, a 2m overhang protects the most exposed areas in summer. However, more shading would be needed to protect the ground floor and the first floor.

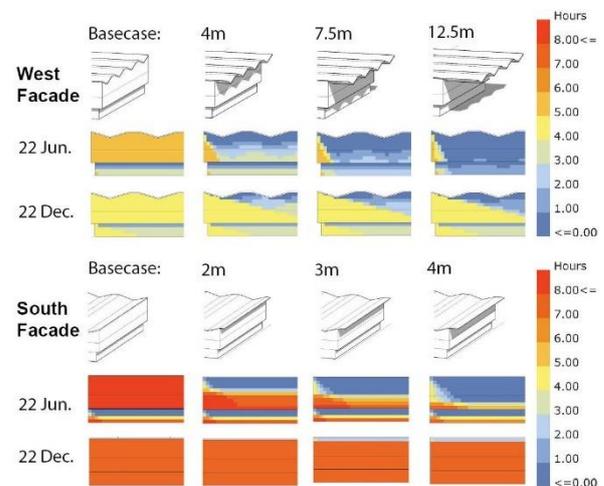


Figure 1: overhang studies

### 2.2 Louvre system

An external louvre shading system has been applied to the south facade and reviewed against the daylight factor (DF) requirement for the office interiors, with both cases designed to allow views outside. Figure 2 shows the results of two prototype systems based on the following scenarios:

Prototype 1: Building with 2m overhanging.

Prototype 2: Building without any overhanging.

Daylight simulations, using DIVA for Rhino, were performed to compare the DF of offices with and without

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the use of shading systems (Fig.2). As recorded in the graph the louvre shading system acts to reduce the highest DF figures beside windows, whilst keeping overall daylight factor results within a reasonable range. The light shelves reflect diffuse light further inside the building and improve daylight penetration throughout the year.

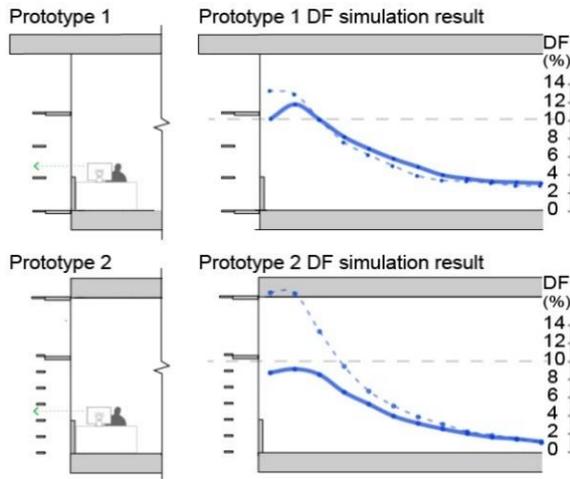


Figure 2: The louvre system and simulation result (DF)

The shading system also helps to reduce the probability of glare by obstructing direct sunlight. Fig. 3 shows the glare reduction by comparing the possible glare hours of the base case, without a shading strategy, against the combined base case and attached shading system. The shading system protects solar exposure most efficiently in summer months, when exposure causes most overheating issues. While in spring, autumn and winter, the office still receives a reasonable probability of direct sunlight.

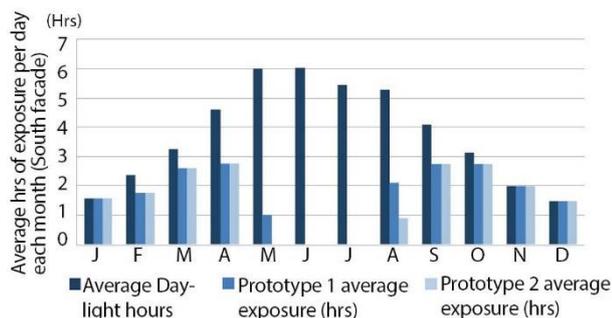


Figure 3: DIVA simulation result - daylight factor

### 3. DESIGN APPLICATION

The proposed model has been shown to provide a high quality of daylight for occupants, applied to an office design in Derby, England, United Kingdom.

Working environments with good natural light are a key requirement within this project. One of the strategies to achieve this focuses on creating apertures for daylight. The integration of rooflights, floor voids and high-level

translucent cladding enhances natural daylight received through the glazed facade. Excessive glare and direct sunlight poses a challenge, due to a desire within the design concept to achieve a lightweight glazed impression for all facades. The proposed model has been applied to this condition. External louvres are fitted to the south facade to offer protection against over-exposure and glare. A large east overhang offers sunlight protection to low morning sun. Fig. 4 and Fig.5 illustrate these principal strategies.

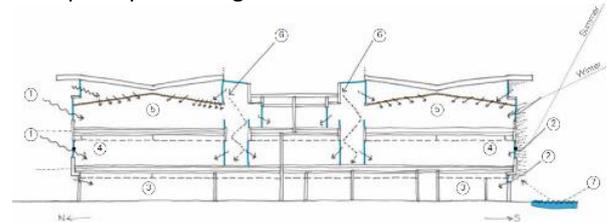


Figure 4: Building section - daylight strategy



Figure 5: South facade with louvres and east overhang

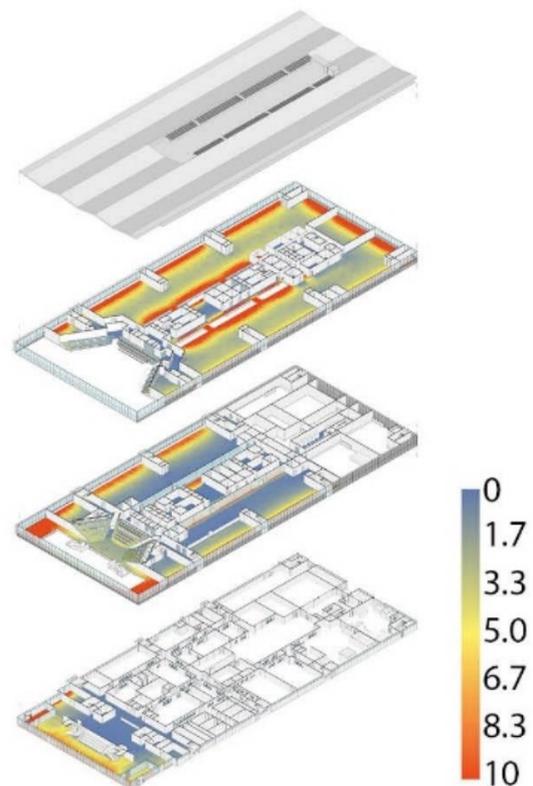


Figure 6: DF simulation

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Daylight simulations at each floor level were performed via DIVA for Rhino. Open plan offices reach a distance of 54m from external facades, with a minimum project requirement to achieve an average 2% daylight factor from CIBSE guide [3]. This was achieved for all the office areas.

## **4. CONCLUSION**

The ability of glazed open-plan office façades to control exposure to sunlight is measured by balancing daylighting penetration distribution, glare and solar heat gain reduction. The results of the analytic study and design application show that the form of roof overhangs, combined with horizontal louvre systems can provide acceptable work plane daylight levels and uniformity, thus providing flexibility for an open-plan office.

## **ACKNOWLEDGEMENTS**

Thanks to Ridge & Partners LLP and all Design Teams involved in this project.

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# Integrated Design Process for Energy Optimization of Office Buildings in Chile

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**ABSTRACT:** This paper refers to a project research of an office building in a cold climate, which objective is to achieve optimized energy standards by applying integrated design strategies. A theoretical model is proposed, and the formulation begins with a morphological analysis. Subsequently, thermal, light and ventilation criteria are integrated; analysing the energy demand throughout the design process. The model is compared with a reference case. As a result, the optimized model achieves a significant reduction in energy demand, and better thermal / visual performance. It concluded that the application of the integrated design, with the support of assisted simulation tools, allows to optimize the energy performance of a building in the design stage.

**KEYWORDS:** Office Buildings, Integrated Design Strategies, Energy Optimization, Passive Strategies.

## 1. INTRODUCTION

Climate change remains challenging due to its impact on cities and the quality of life of their population. In response, the building sector has incorporated sustainability criteria in the design processes. However, there's still a high dependency on active energy systems for cooling, heating and lighting systems that demand energy and influence on climate change. Multiple environmental factors must be evaluated in the design stage. To achieve the energy optimization of a building it is necessary to conceive it as an entire system from the beginning of the process [1], considering the relationship between the building and the environment, in both ways.

The present work refers to a research project of an office building in Osorno city in Chile, located in the south hemisphere. It is characterized by a cold climate and overcast sky predominance, limiting the solar potential for thermal and daylight use. Also, it is a saturated air quality zone in winter periods, due to the high firewood combustion. This situation also restricts natural ventilation systems, without a pre-treatment to eliminate pollution. Therefore, it is challenging to reach reduced energy-demand and environmental impact. The objective is to conceive the building as an integrated system from the early stages of design, to achieve a healthy symbiotic relationship with the environment. Thermal and lighting strategies are taken as the central theme of integrated design, as they are mainly responsible for the high energy demand in office buildings. The application of thermal, lighting and ventilation strategies achieves a reduction in energy demand of 73.9% compared to reference model, according to *Appendix 9 - Certification of Sustainable Buildings (CES)* of Chile [2]. It shows better energy performance and indoor environmental quality.

## 2. METHODOLOGY

### 2.1 Geometric optimization of the building envelope

Initially, a morphological analysis of the building model is performed. The methodology applied is the calculation procedure of ISO-13790: 2008, "based on iterations of its envelope and form" [3]; which objective is to determinate the most favourable condition for climate. The relations are analysed with *Design Builder Software*. First establishing the fixed parameters such as: weather with an EPW file; the edge conditions according to *Terms of reference for non-residential buildings in Chile* (TDR standard), for the corresponding climatic zone [4]; and operation profile, according to the operation of a typical office building in Chile. (refer to Table 1). The model is parameterized, combining the variable parameters: shape (length of the facades, with relation of 0.20, 0.39, 1.0, 2.45, 5.0); orientation (45° rotation) and its percentage of openings per facade (from 20% to 60%). The results provide the lower energy-demand combination, realizing 3 measures: capture of solar gains, avoid of losses and containment of internal gains.

Table 1: Border conditions and schedules simulation

Thermal transm.	Roof	Wall	Floor	Wdw.
U (w/m <sup>2</sup> k)	0.30	0.50	0.50	2.90
Infiltration (ACH <sub>50</sub> )	2.50			
Hours of use (Mon-Fri)	9hs (8:00 -17:00)			

### 2.2 Integrated Design Strategies

The best result of optimization is evaluated with bioclimatic criteria that address the quality of interiors, the thermal environment, lighting, ventilation and acoustics. Thermal design strategies are analysed according to the psychometric chart. The strategies listed below where applied for passive design:

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- Resizing of openings, to adjust energy balance by facade: north 32%, east 20%, west 15%, south 10%.
- Wind protection of north facade, to limit air infiltrations from predominant wind direction (NE).
- Programme zoning according use requirements for thermal and visual comfort.
- High thermal mass building envelope. Windows with thermal and acoustic performance  $U=1.7 \text{ W/m}^2\text{K}$ .
- Passive solar direct gain from north facade in winter and sun shading in summer. Light shelf in north facade to increase light reflections in work places.
- Interior diffuser screens, as a glare protection to north facade in middle seasons.
- Solar shading west facade, vertical and adaptable to afternoon sun path.
- Integration of a central atrium, to provide diffuse skylight distribution in common areas
- Convective ventilation through the atrium with pre-heating and air-filter before injection in workplaces (Osorno temperatures are below  $20^\circ\text{C}$ , 96% of time).

## 2.3 Energy and visual performance evaluation

The thermal performance is analysed according to the UNE-EN 15251 standard and the energy demand of the building in cooling, heating and lighting systems, through dynamic simulation with *IES VE Software*. And is compared with a reference building model, defined by the *Appendix 9 of CES Certification Manual* [2]. Visual comfort performance is analysed by dynamic simulation with *Velux and Radiance*. This determines the Daylight Factor (DF) overcast sky predominance, Illuminance and Daylight Glare Probability (DGP), according to guideline of visual comfort and values by *TDR standards* [4]. The simulation values are in Table 2.

Table 2: Charge, Temperatures and Reflectance coefficients.

Loading equipment	4.5	$\text{W/m}^2$
Ventilation	0.5	$\text{l/s.m}^2$
Lighting load	4.0	$\text{W/m}^2$
Occupancy load	6.0	$\text{W/m}^2$
Cooling setpoint	25.0	$^\circ\text{C}$
Heating setpoint	20.0	$^\circ\text{C}$
Reflection r (%)	R: 70	W:50 F:20 W:0.75

## 3. DISCUSSION OF RESULTS

About geometrical optimization, the building achieves its maximum energy optimization with an interval shape of 0.39 (118ft x 49ft), north orientation and 30% of openings per facade. However, the applied method does not consider visual comfort, and in a first evaluation presents areas of low daylight range. Also, it does not consider environmental quality conditions and ventilation systems with pre-treatment. The application of integrated design strategies is a requirement to improve the building performance, as shown by results. In terms of thermal comfort, the optimized case achieves

an indoor comfort over 45%, compared to 20% of reference case. About visual comfort, the strategies applied determine better daylight conditions than the first case simulated, achieving the values in *TDR standard*: Daylight Factor of 5% over minimum 2%, work-plane Illuminance from 300-500 lux and Daylight Glare Probability-free. In terms of active systems, the baseline building has an energy demand of  $178\text{kWh/m}^2$  per year. However, the proposed solutions provide a significant reduction in energy demands set at  $36\text{kWh/m}^2$  per year, mainly due to ventilation strategy of central atrium, which reduces the heating requirements (refer Figure 1). The energy-demand is reduced in 73.9% with this optimized case.

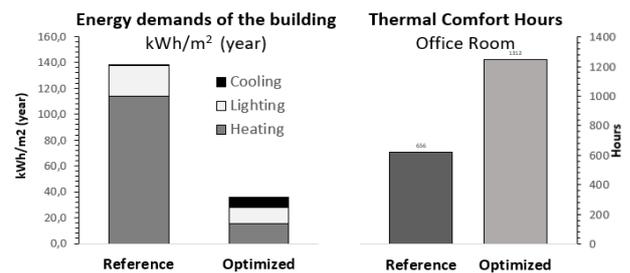


Figure 1: Energy demand distribution and thermal comfort.

## 4. CONCLUSION

The application of an integrated design process and the assisted simulation tools, enable to measure the building performance in terms of energy-demand, relating the variables of indoor environment comfort and building energy requirements for its operation. The presented methodology unlocks the possibility of creating buildings with optimized energy results that ensure a better environmental performance according to the reduction of their emissions to environment, applicable to different climates whenever the local thermal regulation is considered for its evaluation.

## ACKNOWLEDGEMENTS

The authors express their sincere gratitude to Eng. R. Escobar for his valuable support in this research. The authors also extend their sincere gratitude to the academics of the MHSEE program, PhD. A. Pérez, PhD. J. Pulido, PhD P. Wegertseder of the Universidad del Bío-Bío, for motivating the development of this research.

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# Zero Energy Buildings in the Mediterranean: Typological Feasibility Analysis towards an Israeli Adaptation

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**ABSTRACT:** Despite the recent pursuit towards Zero Energy Buildings (ZEB), their global adaptation is far from complete, mostly in cooling dominated climates which are still poorly prepared for their integration. This paper reports on a research project aiming to build a road map for the local adaptation of the ZEB concept in Israel. The methodology of this research was based on a statistical top-down feasibility analysis which explored the possibility of 10 different urban typologies to achieve zero energy balance using the Load Match Index as the performance metric. Results demonstrated large potential variations between residential and office uses as well as between different typologies to deliver zero energy balance in the Israeli context. Findings helped generate detailed criteria and four different models for Zero Energy Buildings in Israel towards new policy.

**KEYWORDS:** Energy Balance, Building Typologies, Zero Energy Buildings, Load Match, Mediterranean Climate

## 1. INTRODUCTION

In 2010, the European Energy Performance of Building Directive (EPBD) recast [1], ignited a pursuit towards nearly Zero Energy Buildings (ZEB). A new goal was set for new and existing buildings to autonomously balance either their primary energy consumption or their carbon emissions using renewable energy, preferably self-generated on-site. Since then, individual national EU policies were joined by many other frameworks globally as the 'zero energy' trend quickly became internationalized; either voluntarily or as part of binding building standards [2].

Despite the generic definition, many variations to the application of ZEB emerged, mostly due to numerous criteria and sub-criteria which should be addressed in their realization. Although many studies were dedicated to the topic, the challenge to define a harmonized framework for ZEBs still stands, frequently leaving the application of this standard at a commercial declaration level. Moreover, many countries, mostly in cooling dominated climates are still poorly prepared for their integration [3].

Within the Mediterranean region, Israel's built environment is a clear example of an unfulfilled energetic potential; despite high solar availability, highly technological building industry and ambitious environmental goals, Israel's built environment is characterized by low energy efficiency and low renewable energy generation levels in both building and urban scales.

This paper reports on a two-year research project initiated by the Israeli Ministry of Environmental Protection and conducted by this author, aiming to build a road map for the local adaptation of the ZEB concept in Israel. Results from this research project were gathered into an adaptation road map, composed of policy

guidelines, local ZEB definition proposals and future research outlooks. Through the following sections, this paper briefly introduces the feasibility analysis methodology which was used for this research and discusses its main findings and implications.

## 2. METHOD

The feasibility analysis explored the possibility of 10 typical Israeli urban typologies, to balance between PV energy supply and energy demand in both offices and residential uses. The yearly Load Match Index was used as the performance metric, signifying the annual coverage ratio between energy generation and demand [4]. The analysis which was based on a statistical top down approach consisted of four main parts (Fig. 1).

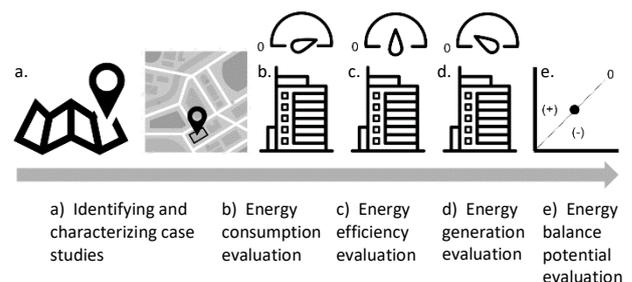


Figure 1: Feasibility analysis milestones

The first phase was dedicated to identifying both urban and building case studies – The city of Petah Tikva was chosen along with five residential and five public and commercial building typologies within it (Fig. 2). The second phase included a quantitative assessment of the total operational energy demand in each of the 10 typologies, based on actual consumption data (where available), or statistical data validated by experts. Average energy consumption data per household was extracted from published statistical reports, and used to

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estimate each building's total energy demand according to its geometrical properties and floor area.

The next phases included a quantitative evaluation of energy efficiency and PV generation, mostly relying on the evaluation methods presented by Dolev et al. [5]. The energy balance evaluation was performed for two scenarios: *moderate*, reflecting existing technologies (20% energy consumption reduction, 15% PV efficiency) and *ambitious*, reflecting emerging technologies yielding higher efficacies (40% energy consumption reduction, 25% PV efficiency). For PV generation evaluation, 30-40% of rooftop areas and 10-15% of south facing facade areas were considered for both of the above evaluation scenarios respectively. The concluding part of the feasibility study summarized the Load Match results graphically according to the method offered by Hermelink et al. in [2], for both *operational energy* (excluding user dependent energy consumption) and *total Energy Usage Intensity* (EUI). Due to the absence of primary energy factors for Israel, the feasibility calculations relied on Site Energy.

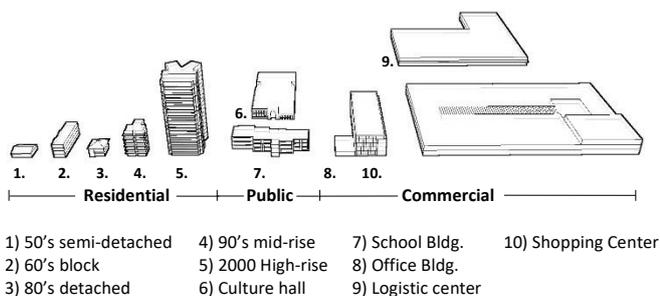


Figure 2: 10 different building typologies evaluated in the feasibility analysis

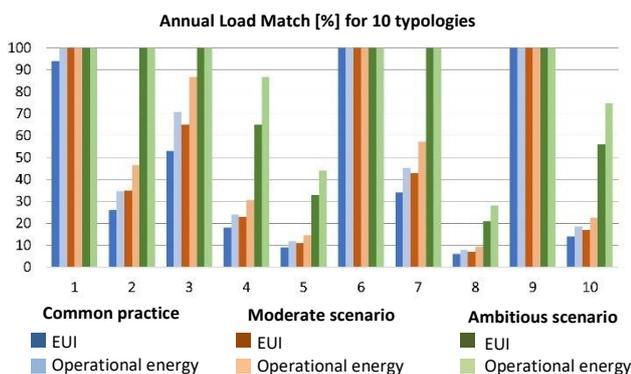


Figure 3: Load Match evaluation for 10 building typologies for 3 scenarios and 2 energy consumption boundaries.

### 3. DISCUSSION

Results from the feasibility analysis (Fig. 3) demonstrate large variations in the potential of different typologies to deliver zero energy balance in the Israeli context. In the residential sector, beyond the effect of building compactness on the energy balance, Load Match variations also correlate with social aspects; lower income sectors, despite lower energy consumption, are

restricted in their ability to finance renewable energy infrastructures without any external funding or subsidy. The correlation between building typology, socioeconomic status and energy balance (both efficiency and production abilities), hence calls for a differential energy and financial strategies tailored for different target populations.

Results for the public and commercial sectors showed that energy intensive buildings (shopping centers and office buildings), will not be able to reach a ZEB balance, even in a spread-out configuration (vast envelope areas), not even in an ambitious energy efficiency scenario. In contrast, buildings with low occupancy and energy demand patterns, such as schools or logistic centres, can relatively easily reach a zero-energy balance, even under today's consumption patterns. These results indicate the potential for an energetic synergy between building typologies, a synergy which should be further explored on different occupancy and energy demand and supply case studies at the district scale.

### 4. CONCLUSION

The feasibility analysis proved as an effective preliminary indicator to evaluate the potential of integrating zero energy strategy within the diverse Israeli urban built environment. It turn, findings from this evaluation helped generate detailed criteria and four different models for Zero Energy Buildings in Israel. A future bottom up parametric study is expected to compliment this analysis with detailed energetic evaluation of district scale typologies and scenarios.

### ACKNOWLEDGEMENTS

This research was funded by the Israeli Ministry of Environmental Protection (Ref. 145-6-3) and was conducted under Bezalel Academy for Art and Design.

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# The Conflicts between the Simplification of Building Regulations and the Challenge of Building Cities for a Changing Climate: The Case of Sao Paulo City

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*ABSTRACT: The application of studies of environmental quality of buildings and public spaces into practice and the way the planning of cities will face the climate changing challenge depends strongly on political will and governmental capacity to create appropriate management tools. While countries as Australia, the United Kingdom, and Canada adopted continuous updated performance-based Building Codes, Sao Paulo city laws have lost over the last century, almost all the prescriptive construction requirements, which influence the environmental quality of buildings, such as the orientation of facades and the minimum sun hours on the openings. In the Code in effect, parameters as the minimum size of windows or the need to provide openings facing the exterior of buildings, or even the adequate room dimensions according to use were excluded. This paper aims to be critical and to make an alert to Sao Paulo's planners about the risk of building such a complex city not regarding the quality of constructions.*

*KEYWORDS: Building regulations, comfort, environmental quality*

## 1. INTRODUCTION

The control of the urban expansion in Sao Paulo, city, Brazil, and the way it has been built is one of the enormous challenges for the local government. Problems such as disorderly urban growth and buildings without environmental quality could be minimized by broadening the technical knowledge provided by specific regulations for the city's climatic characteristics and a set of legislation that leads to more efficient buildings. Despite this, the urban and building regulations of Sao Paulo, recently updated, has opened gaps in the construction requirements, which may result in a chaotic and unhealthy place to live. Therefore, this paper intends to criticize and point out an alert to city planners, through the comparison between the building laws in force in Sao Paulo with the international context, concerning parameters related to the performance of buildings.

## 2. THE CONTEXT FOR ADAPTATION TO CLIMATE CHANGE AND ENERGY DEMAND

Sao Paulo has sprawled uncontrolled towards the periphery implying a significant demand for primary infrastructure. The inability of the public authorities to attend the urban demand resulted in places more sensitive to disasters due to extreme climate events. According to the Climate Change and Cities Report [1], cities account for 40% of greenhouse gas emissions, becoming the main agents of climate change on the microscale. Those changes also represent an increase in the occurrence of severe weather events. A study conducted by Stone, Hess y Frumkin [2] found that between the years 1956 and 2005, in large cities on the

U.S., the increase of weather events was more than double the rate in sprawling metropolitan regions than the observed in the most compact cities.

According to data from the Brazilian Energy Research Company, energy consumption in buildings is responsible for a significant portion of the energy generated in Brazil: approximately 14% of total energy consumption and 47% of electricity consumption [3]. In the global scenario, buildings account for about 32% of global energy demand from a variety of sources, which has motivated cities worldwide to adopt more rigorous urban and building regulations and more efficient energy consumption policies. In Australia, for example, the guidelines adopted throughout the country are listed in the NCC (National Construction Code), a performance-based code containing all kind of construction requirements [4]. Besides that, the NCC provides the map with the Australian bioclimatic zones and determines which are the methods for testing and proving the required performance results. In the UK, in addition to establishing criteria in the Building Regulations with the minimum parameters necessary for comfort, the text is complemented by the London Plan which addresses the challenges for a future embedded in the context of climate change. The Chartered Institution of Building Services Engineers website, another complement to the British regulations, provides the "The CIBSE Design Compass", an online tool for designers to incorporate climate information into a framework, to get relevant information about adaptive thermal comfort and overheating risk [5].

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## 3. SAO PAULO CITY URBAN AND BUILDING REGULATIONS

The city of Sao Paulo has in force three laws for its urban planning and development: The Master Plan (2014), the Zoning Law (2016) and the Building Code (2017) [6]. As recently updated texts, it was expected that they could express the integration of its contents pointing at contemporary urban issues such as managing energy efficiency and providing buildings with quality and comfort to the users. What happens instead are several mismatches between their contents. The Master Plan, for example, besides encouraging the densification of the city, points that the Zoning Law should establish parameters regarding the "comfort conditions"; however, the zoning text even does not mention 'comfort' once. The same article delegates to the Zoning Law the responsibility to regulate the land uses and volumetry compatible with the objectives of urban development policy. Neither the Zoning Law or the Building Code specifies more than the height limit of the buildings, what is not always sufficient to prevent the impact on environmental quality of immediate surroundings on neighbouring.

Regarding climate, according to the Brazilian Association of Technical Standards (ABNT) [7], the city of Sao Paulo is located in a bioclimatic zone where the strategy of passive thermal conditioning of buildings demands the use of building components for thermal inertia and passive solar heating in winter, combined with cross ventilation for cooling, in summer. None of the laws in force, however, mentions or encourages the use of the climate strategies mentioned.

The update of building codes also often indicates improvements in building components and processes. In Canada, for instance, there is a permanent committee to improve the normative text of the National Building Code, which involves extensive society participation [8]. Sao Paulo's Building Code, in contrast, suppressed almost all the few building requirements, such as the minimum dimensions of the rooms and window openings on the current version. The few topics that represented some impact on environmental performance were replaced by an administrative and bureaucratic text, besides leaving several gaps without a precise definition.

### 3.1 The impact of the law on building practice

The outcomes of urban and building laws which are not adequately interconnected and that do not set up important limits can contribute to unforeseen situations and for unhealthy and energy-inefficient buildings.

The Sao Paulo Building Code, on the grounds of the need to simplify the project approval process, exempted the requirement of the layout plan in the approval processes of any project, delegating all the responsibility for quality and performance to designers. There are no recommendations for the use of Brazilian technical

norms or any type of specific base literature to determine what is understood as environmental quality. None of the three existing laws takes into account or mentions the impacts of new buildings on neighbouring sites, which has implications in the urban scale.

Another consequence of the lack of technical parameterization in the laws is the replication of construction models that are not always adequate to the city climate, e.g., the same typology is applied in any site, regardless of the building orientation of façades and openings and the neighbouring constraints. Sao Paulo City has many examples of fully-glazed commercial, without any solar protection and completely dependent on air-conditioning. Besides the commercial sector, in the last years, following a real-estate market growth between 2005 and 2014, residential building cooling demand increased. Glass façades, less thermal mass and poor natural ventilation design reached wealthy and fancy high-rise residential buildings, followed by middle-class buildings, which are spreading very fast.

## 4. CONCLUSION

Comfort and adaptation to a changing climate in the built environment begin with the well-planned urban design. The degradation of the urban environment ignoring the climate-sensitive design in land occupation points to the growing need of the legal instruments for urban management. Some cities, such as London, are demonstrating an advance to the concern of a long-term climate change scenario by anticipating tools and regulations integrated to provide environmental quality to the users of both public and private spaces. The current legislation of Sao Paulo City, however, is silent and creates weaknesses for building an unhealthy and unsustainable city.

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# Climate Change as Game Changer in Passive Architecture: Divergent IPCC Scenarios and Their Impact on Design Strategies

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*ABSTRACT: The purpose of this research is to evaluate future impacts of different emission scenarios on architecture design strategies according to a notable thermal comfort model, the methodological procedure employed in this study is intended to provide quantifiable elements to weight the impact of climate change on passive architecture effectiveness according B1, A1B and B2 IPCC scenarios in terms of design strategies applied to achieve thermal comfort, in compliance with the ASHRAE comfort model. Results showed affectations about 10-25% on comfort effectiveness, causing affectations on the way we conceive and build the future passive architecture morphology.*

*KEYWORDS: Climate Change, IPCC Scenarios, Passive Architecture, Bioclimatic Design.*

## 1. INTRODUCTION

There is a growing concern about future supply of energy and its inherence on climate change in coming years. In this respect, paleoclimatic reconstructions developed by the Intergovernmental Panel on Climate Change (IPCC), have shown that there is unequivocal evidence to couple biogeochemical cycles with global warming due to anthropogenic emissions of Greenhouse Gases (GHG). IPCC specialists and policymakers have modelled reliable scenarios of climate change in order to structure plans to face future challenges. These scenarios divergent narrative storylines and evolution paths to cover a wide range of demographic, economic and technological driving forces on climate change and their impacts [1].

In words of the IEA, the buildings sector is the largest energy-consuming sector, accounting for over one-third of final energy consumption globally and an equally important source of carbon dioxide (CO<sub>2</sub>) emissions dedicated to heat and cool living spaces. In this regard, energy efficiency to provide thermal comfort has been one of the main purposes of passive architecture and bioclimatic design since their inceptions; the same that have been fixed with active technologies since the Industrial Revolution [2].

Based upon the foregoing, the purpose of this research is to evaluate future impacts of different emission scenarios on architecture passive design strategies according to the ASHRAE comfort model.

## 2. ANTECEDENTS

Different bioclimatic design methods involves knowledge of climatology, heat transfer, fluid mechanics and human physiology, amongst others in addition to architectural design principles for the efficient consumption and saving of energy in buildings.

Worldwide, countless studies have evaluated the performance of different set of strategies in different types of climates, involving studies of buildings with various geometric shapes, orientations, constructions or materials or reviews of bioclimatic design strategies focused on achieving thermal comfort [3].

Wang et al. [4] analyzed climate adaptation strategies of modern vernacular architecture such as the cooling effect due to shading of the building, the use of a patio for ventilation and lighting in hot areas in China. The authors emphasize the importance of considering the solutions that are given in the constructive tradition in these localities.

Chandel et al. [5] studied the emergent vernacular architecture of Himachal Pradesh, India; with the aim of identifying design strategies that achieve greater energy efficiency. The parameters that favored the energy efficiency were the incorporation of thermal mass in walls and ceilings, the orientation and the spatial planning. Gou et al. [6] evaluated the performance of departmental buildings in a warm climate in Shanghai, China. Among the passive design strategies that stand out to achieve better comfort conditions were the orientation, a high degree of hermeticity, solar protections and adequate thermal insulation.

Whang and Kim [7] analysed passive design elements in 31 housing projects focused on energy saving built for different countries in America, Asia and America. In addition, Chen and Yang [8] developed a model for passive design optimization, with the aim of being used as an evaluation tool for sustainable construction projects while others develop a Passive Performance Optimization Framework (PPOF) to improve the performance of natural lighting strategies, solar control and natural ventilation, considering the climate of various cities around the world.

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## 3. METHOD

The methodological procedure employed in this study is intended to provide quantifiable elements to measure the impact of climate change on passive architecture according B1, A1B and B2 IPCC scenarios in terms of design strategies applied to achieve thermal comfort in compliance with the ASHRAE comfort model. In order to do this, weather conditions were modelled through a spatial interpolation software to conform a Typical Meteorological Year (TMY) and its future behaviour, with this is possible to measure the impact on different design strategies based on thermal comfort limits confined by the structure shown in figure 1:

- Site weather diagnostics
- Definition of time Intervals of climate change.
- Selection of IPCC scenarios.
- Selection of thermal comfort model of study.
- Analysis of the weighted hourly impact on design strategies effectiveness, estimated on psychometry as shown in figure 2.

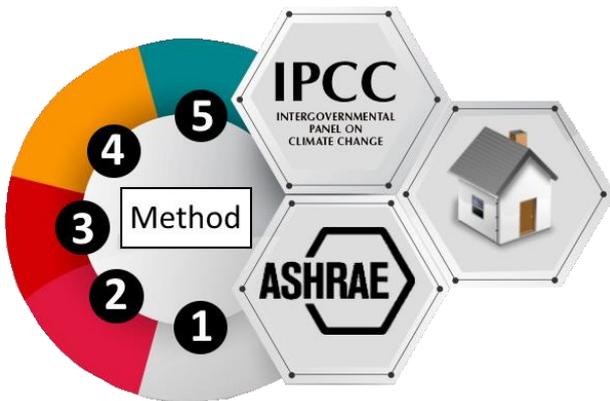


Figure 1: Methodological procedure.

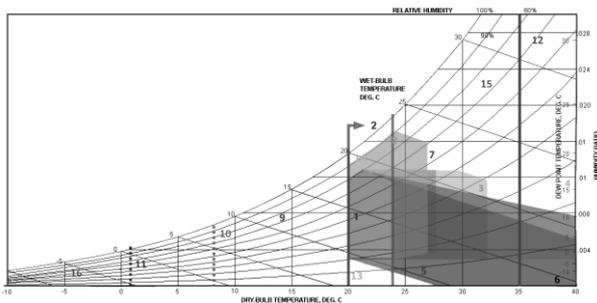


Figure 2: Psychrometric chart and design strategies in compliance with ASHRAE thermal comfort model.

## 4. RESULTS

According to this study, developed in decade intervals from the current climatic condition, the IPCC scenarios have a distinct impact on some of the passive design strategies most commonly used in bioclimatic architecture. Table 1 shows how the annual hourly percentages of comfort extension range linked to the

above-mentioned strategies are modified in the different scenarios.

It is possible to appreciate that the shading of windows in scenario B1 suffers a particular decrease in effectiveness in 2050 decade.

Table 1: Impact projection of different IPCC climate scenarios on passive design strategies effectiveness for the year 2050.

Strategy	B1 <sub>2050</sub> (%)	A1B <sub>2050</sub> (%)	A2 <sub>2050</sub> (%)
Comfort	6.47	6.14	6.71
Sun shading	8.76	13.44	13.96
High Thermal mass	5.52	5.15	1.69
Internal gains	10.61	9.91	10.36
Natural Ventilation	5.72	5.32	5.55
Passive solar gains	2.32	1.92	2.07

## 4. CONCLUSION

This abstract version shows only partial results that indicate the favoring of a brief set of design strategies in 2050; however, it is fundamental to note that it is necessary to observe the total chronological sequence (2030, 2040 & 2050) in order to correlate graphic pattern and conclude with certainty that the divergence in the behaviour of the climatic variables like global radiation or radiant temperature will affect specific architectural design elements in about 10-20% of their comfort effectiveness, causing affectations on the way we conceive and build not only the passive architecture morphology, but the form we validate its vernacular expressions towards the global warming future.

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## Closing the Loop: Revisiting Built Projects through Post-Occupancy Analysis

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**ABSTRACT:** Post-occupancy evaluation is easily one of the most effective tools in completing the full-circle of learning from practice in architecture. The impact of the design strategies envisioned during a project can truly be understood by the experiences and satisfaction of the actual occupants of that space. The paper outlines the results from post-occupancy evaluations of open and transitional spaces in different project typologies located in India's prevalent composite and hot-dry climate. The projects were envisaged using passive design principles and vernacular examples without the support of computer aided simulations. The learnings have been evaluated in the form of quantifiable metrics like energy consumption, spot measurements as well as feedback on users' spatial experiences and satisfaction. The projects demonstrate that comfortable open and transitional spaces can be successfully treated as an extension to the indoors, leading to the potential elimination of built spaces for interactive functions.

**KEYWORDS:** Microclimate, Post-Occupancy Evaluation, Thermal Comfort, Passive Design, Tropical Climate

### 1. INTRODUCTION

Majority of commercial architecture projects today like offices, institutes, malls, group housings etc. are products of the interaction between a developer and the architect/professionals, making educated evaluations of the end-user's needs. Consequently, the actual occupants of these spaces are left out of the design process altogether. This raises serious concerns on the 'Livability' of the project i.e. the way user's interact with these spaces to achieve the most comfortable way to carry out their tasks.

The paper presents the results from field studies like spot-measurements, user-surveys and actual energy bills facilitating the quantification of occupant comfort. The importance of microclimate management and its impact on the resource consumption of the projects proved to be the most significant and accessible strategy applicable to all the prevalent project typologies (Table-1). Modern-day adaptations of vernacular precedents like shaded courtyards, *baolis*, *jaalis* and verandahs were integrated with thermal mass, solar shading and natural ventilation resulting in an average 75% user satisfaction. Overall, the studies establish the potential of using passively designed open-spaces to practically replace the need for built-form.

### 2. CASE-STUDIES

#### 2.1. Institutional Building in Hot-Dry Climate:

*Location : Jaipur, Rajasthan*

*Methodology : Spot-Measurements, Energy Bills, User surveys*

Given the nature of an educational institution, budgetary constraints on the project necessitated the use of cost effective design solutions to achieve desired functionality and spatial quality. Vernacular passive design strategies like 'baolis' (step-wells), courtyards and 'jaalis' (screens) form an integral part of the design and aid in reducing the dependence on resource-hungry

mechanical environmental control measures (Fig.-1). The institute was finally designed under \$30/sft while achieving an overall annual energy consumption as low as 25kWh/m<sup>2</sup>/year calculated on the actual energy bills.

#### 2.2. Office Building in Composite Climate:

*Location : NOIDA, Uttar Pradesh*

*Methodology : Spot Measurements, Energy Bills, User surveys*

The primary concept that guided the office development was an energy-responsive design corresponding to the requirements of the modern workplace and the development of building techniques using modern materials within the Indian construction format. The microclimate created using passive strategies depicted in Fig.2, proved to have a much deeper impact on the energy consumption of the building, which was demonstrated through the actual energy bill of 59.6kWh/sq.m./yr. Post-occupancy surveys further highlighted that people enjoyed using the courtyards even during the peak summer months. "We don't know how the building works, but one thing we can tell you is we don't feel tired when we go home."

#### 2.3. Residential Project in Composite Climate:

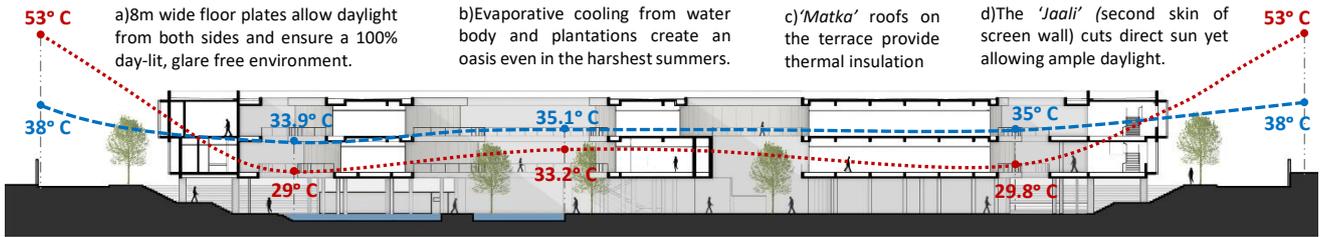
*Location : Chandigarh, Punjab/Haryana*

*Methodology : Spot measurements and User surveys*

The design intent for this housing complex was a commitment to rely as much as possible on nature's resources such as day light, natural ventilation and

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A series of interconnected courtyards form a shaded 'thermal-sink' serving as an interactive multi-functional space and achieving 1/3rd of the building requirement without actually building.

Figure 1: Spot Measurements of an institute in Jaipur on a peak summer day (20<sup>th</sup> May 2011, 2pm)

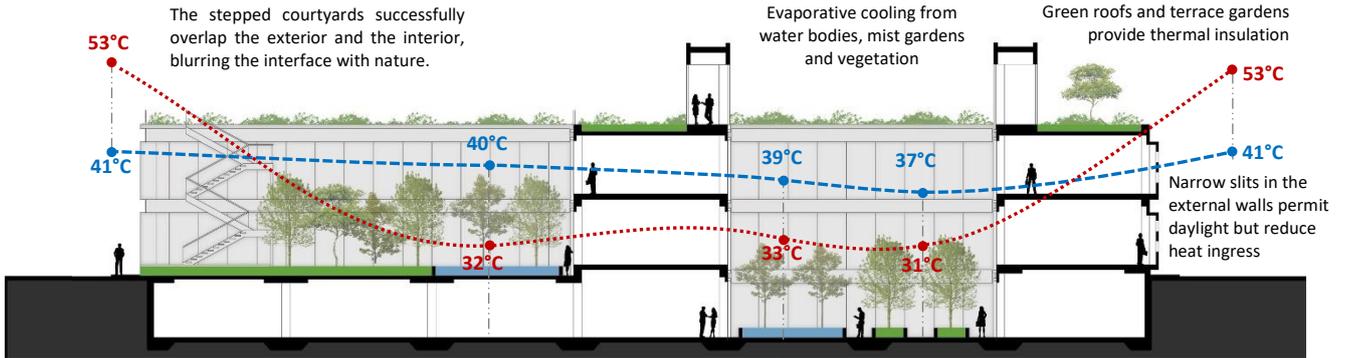


Figure 2: Spot Measurements of an office building in Delhi on 23<sup>rd</sup> May 2012, 1pm

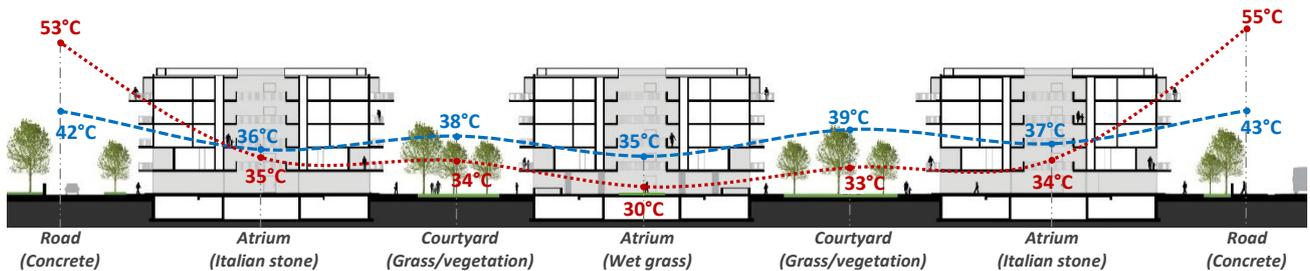


Figure 3: Spot Measurements of a residential complex in Chandigarh (19<sup>th</sup> May 2012, 1pm) ---Air Temperature .....Surface Temperature

passive cooling techniques. The studies on a peak summer day demonstrated that when the outside air temperature was 43°C, the air temperature inside the landscaped courtyards was at 38°C (Fig.3). The surface temperatures dropped by 25K between external road and internal landscape.

### 3. ACKNOWLEDGEMENT

The studies would not have been possible without the cooperation of the project clients and occupants who took the time to help with interviews and surveys.

### 4. DECLARATION

The projects presented are a product of the authors' original and independent professional architectural practice, carried out over a span of almost 2 decades as a part of Morphogenesis architectural studio in New Delhi.

Table 1: Results from User-Surveys for the use of passively designed open-spaces in India's prevalent tropical climate.

Parameters	A	B	C	D	Avg.
<b>Office</b>					
Courtyards	74%	69%	77%	79%	<b>75%</b>
Open landscape	69%	75%	60%	63%	<b>67%</b>
Verandahs	76%	71%	73%	73%	<b>73%</b>
<b>Institutional</b>					
Sunken court	84%	81%	79%	80%	<b>81%</b>
Open landscape	65%	68%	65%	60%	<b>65%</b>
Verandahs	81%	78%	79%	77%	<b>79%</b>
<b>Residential</b>					
Courtyards	85%	81%	75%	75%	<b>79%</b>
Open Atrium	65%	65%	69%	68%	<b>67%</b>
Verandahs	74%	79%	80%	79%	<b>78%</b>
<b>Avg.</b>	<b>75%</b>	<b>74%</b>	<b>73%</b>	<b>73%</b>	

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## Openness, Interaction and Nature:

### Case Study on the Regeneration Design of the Cold Region Architecture Department Building in the Informatization Context

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**ABSTRACT:** With the upgrading of education mode and the architecture discipline development in the informatization context, modern architecture education has gradually shifted from top-down elitism education to bottom-up humanism education, the contradiction between the traditional enclosed space and the growing demand of the Architecture Department Building's environment is the key to the development of architecture education. For cities in cold region, the quality of the architecture education space is threatened by severe cold climate. In the informatization context, optimizing spatial environments is facing severe challenges. Based on the theory of interaction demand and bioclimatology, this paper takes the School of Architecture of Harbin Institute of Technology (HIT) as an example, proposes regeneration strategies and conducts CFD simulation to verify the effectiveness of the design which provides reference to the traditional Architecture Department Building's redevelopment in the cold region.

**KEYWORDS:** Informatization; Architecture Department Building; Shared Space; Passive energy saving; CFD

#### 1. INTRODUCTION

Based on the architectural education concept exploration and transition, the space evolution of the architecture department building is constantly updated. Martijn de Geus holds that the strategy of "box-in-box" and sustainable "hybrid" regeneration is the mainstream trend of contemporary architecture department hall[1]. Gan Ning sums up the law of the evolution of the architectural space: the classical centripetal space -- the decomposition of the centripetal space -- the homogenous space -- the anti-homogenization -- the digestion of the main space[2]. Zhu Wenyi believes that the development of the Architectural Department Building is towards complexity, specialization and diversification[3]. Nader Tehrani deems that the alliance, separation and correspondence of architectural form and content have the characteristics of empirical inheritance[4]. Herman Hertzberger argues that space should always be connected to create public places generating information exchange[5]. Based on the behavioural pattern and functional requirements of the Department of Architecture, Liu Xueqing proposes a design strategy for the functional space renovation of the Department of Architecture of South China University of Technology[6]. However, based on the cold regional climate to create an interactive-shared spaces is still a gap in regeneration of the traditional Architecture Department Building. In Harbin, the cold winter lasts up to 2.8 months and the average daily high temperature is below -5°C. Moreover, the lower the temperature is, the more sensitive of the wind chill index to the fluctuate of wind speed is[7]. Therefore, how to improve the cold region architecture education space comfort in the

informatization context is an urgent problem for architects.

#### 2. METHODOLOGY

The research methods adopted in this paper are data research, questionnaire survey and software simulation.

Data research: By studying world-wide cases of regeneration and educational philosophy, this paper collects the investigation data and analyzes the development status and trends of traditional Architecture Department Building's regeneration.

Questionnaire survey: From the perspective of public space behavioural model and winter outdoor environment comfort experience, a questionnaire survey is conducted on the behavioural needs of students and teachers who are living in severe cold region in Harbin Institute of Technology, School of Architecture (Fig. 1).

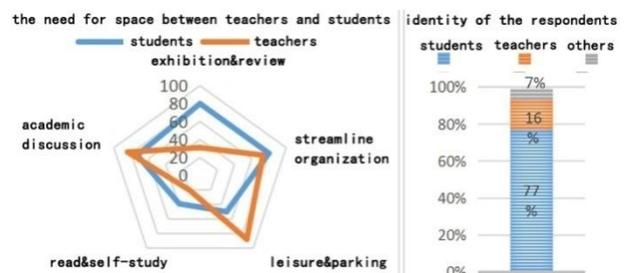


Figure 1: Questionnaire survey and analysis

Software simulation: CFD simulation method is selected to determine Fluent17.0 as an experimental platform. The outdoor natural ventilation simulation experiments are conducted to compared for the School

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of Architecture, HIT before and after the regeneration (Fig. 2).

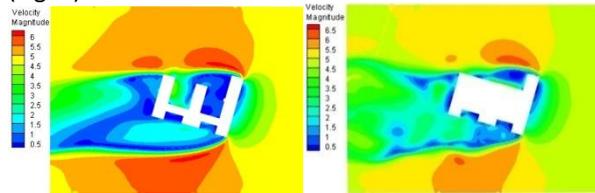


Figure 2: Outdoor wind velocity in 1.5m level before (left) and after(right) the regeneration

### 3. OBJECTIVES

(1) From the supply and demand aspects, this paper probes into the influence factors of the regeneration of the Architecture Department Building and explores the regeneration contradictions in the School of Architecture of HIT. (2) Based on teachers' and students' demands for open space, this paper explores different modes of informal communication between teachers and students in Architecture Department Building and creates diversified informal learning space. (3) Taking the original structure of the Architecture Department Building as a prerequisite, this paper puts forwards design strategies to expand and enhance the public space quality.

### 4. CONCLUSION

#### 4.1 Inter-changeability design in the informatization context

(1) Courtyard space interior sharing: turning the outdoor courtyard into the indoor open space to buffer the climate; (2) Improvement of transfer flow gridding mode: changing the original E-shaped end-corridor into circular traffic stream with accessibility and interest; (3) Interactive integration of information media technologies: providing interactive media technology and display the characteristics of the times.

#### 4.2 Regional deduction of passive energy-saving design

In response to the severe climate in cold region, the paper puts forward technical design strategies of the interior space: (1) Developing underground space, adding underground parking spaces, table tennis-badminton rooms, aerobics rooms and other leisure spaces etc. (2) Adopting atrium epidermis as improve thermal insulation properties; (3) The expansion atrium roof canopy is a movable stair stand with flexible shading seasonally. At the same time, the roof platform can be used as an outdoor gathering place to increase the space utilization rate of the building. (Fig. 3)

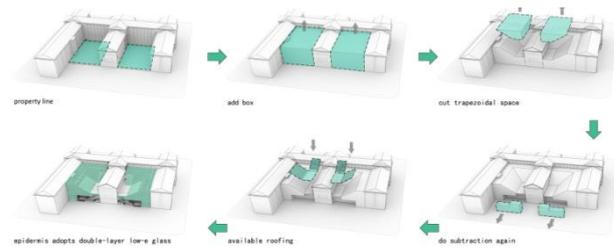


Figure 3: Block analysis

Therefore, it is necessary to design a comprehensive architectural space and microclimate environment to improve the spatial quality of the Architecture Department Building in cold region and meet the needs of the informatization context.

### 5. DISCUSSION

With the upgrading of educational philosophy and the influence of regional natural conditions and architectural culture backgrounds, the regeneration of the Architecture Department Building will continue to developing dynamically. The renovation of the Architecture Department Building should focus on embodying open education spirits and the requirements of the times and encouraging interdisciplinary development to provide opportunities for multi-level talents. Moreover, the building structure has become the primary factor limiting the reorganization, much less a case study has its limitations. Therefore focusing on the outdoor space's interior sharing and the utilization of underground space is effective to optimize the education space pattern and achieve sustainable development of the Architecture Department Building in cold region.

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# Energy Savings from Roof and Wall with High Solar Reflectance Paints in Different Building Types under Tropical Climate

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**ABSTRACT:** This paper investigated the effectiveness of high solar reflectance paints in three building types—houses, medium rise residential buildings, and factories—in the tropical climate of Bangkok, Thailand. It was found that high reflective paint, when applied to the walls and/or roofs of buildings, could reduce electricity used in air conditioning systems up to 21.6-49.8% for a house, 7.6-15.8% for a medium rise residential building, and 7.6-61.7% for a factory. Results also showed that the total solar reflectance or TSR property had a higher impact on reducing energy demand than the thermal emittance property of the paints. When the heat resistance property of construction materials increases, the effectiveness of high reflective paint decreases.

**KEYWORDS:** High solar reflectance paint, Cool roof, Building energy demand, Tropical climate

## 1. INTRODUCTION

Cool roofs are mandatory for climate zone 1-3 according to ASHRAE 90.1 and the International Energy Conservation Code [1, 2]. They have proven to be effective in reducing energy use in buildings [3-7]. However, this effectiveness varies according to climates and building types. This research sought to evaluate the energy performance of different building types—houses, middle rise residential buildings, and factories—when applying high reflective paints in Bangkok, Thailand's climate. The experiments were carried out using dynamic simulation software, OpenStudio.

## 2. METHODOLOGY

### 2.1 Building types

Three types of buildings (house, medium rise residential building and factory) of typical sizes (Fig. 1-3) were selected as representatives of building stocks.

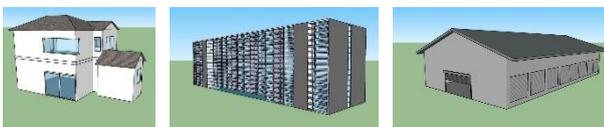


Figure 1: House, medium rise residential building, and factory models.

### 2.2 Constructions

Construction configurations for each building type were as follows.

- House: AAC wall, Roman tile roof.
- Medium rise residential building: Precast wall, concrete roof deck.
- Factory: Steel wall, metal sheet roof.

The effect of construction materials was tested by changing the wall and roof constructions follows:

- Wall: Precast wall, AAC wall, concrete block

- Roof: Roman tile, metal sheet roof, metal sheet roof with 1" fiberglass insulation, metal sheet roof with 2" fiberglass insulation, and concrete roof deck.

### 2.3 Building systems and schedules

Buildings in Thailand normally use only electricity except some building types such as hospitals might use natural gas for hot water. Very few buildings use solar energy. Also, heating systems are normally not installed in buildings because winter temperatures in Thailand typically range from 10-20°C and last very briefly. Therefore, the simulation results focused on electricity use for air conditioning systems which is the largest portion of energy used in buildings in tropical climate.

The house had a split type air conditioning system for the living room and bed room, and assumed there were 4 occupants with 3 bedrooms. The house was occupied during the night from Monday to Friday and occupied 24 hours during weekends. The medium rise residential building had a similar schedule to the house as well as the same air conditioning system type. However, there was an office schedule part for building management and central facilities. The factory had a typical daytime schedule for 7 days a week and assumed it was all air conditioned with package air conditioning systems.

### 2.4 Simulation software

OpenStudio software was used for energy simulation. OpenStudio is a plugin for the SketchUp program which enabled easy 3D modelling and utilized EnergyPlus as an energy simulation engine for research level simulation outputs. OpenStudio was released as a freeware by National Renewable Energy Laboratory (NREL), an organization under the U.S. Department of Energy.

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## 2.5 High reflective paints

Nine high reflective paints (Wall A-D, Roof A-E) were tested in this research. Their reflectivity and emittance values were tested in laboratories and used in the simulations comparing to normal color where typical values were used. The solar reflectance and emittance of each paint used in this research are listed in Table 1.

Table 1: Solar reflectance and thermal emittance values of paints used for the modelling.

Type of paint	Product	Total Solar Reflectance: TSR	Thermal Emittance
Wall	Normal light color	70.0*	0.90*
	Normal white	90.0*	0.90*
	Wall A	95.4	0.86
	Wall B	94.6	0.90
	Wall C	94.6	0.85
	Wall D	93.8	0.89
Roof	Normal red	50.0*	0.90*
	Normal white	90.0*	0.90*
	Roof A	95.0	0.88
	Roof B	92.2	0.84
	Roof C	94.6	0.90
	Roof D	95.4	0.86
	Roof E (high reflective black)	4.6	0.90*

\* Typical value, not from laboratory test.

Each building type was simulated for 13 cases as shown in Table 2.

Table 2: Case study descriptions.

Case	Wall	Roof
1	Normal light color	Normal red
2	Wall A	Normal red
3	Wall B	Normal red
4	Wall C	Normal red
5	Wall D	Normal red
6	Normal light color	Roof A
7	Normal light color	Roof B
8	Normal light color	Roof C
9	Normal light color	Roof D
10	Wall D	Roof B
11	Normal light color	Roof E (high reflective black)
12	Normal white	Normal white
13	Normal light color	Normal black

## 3. RESULTS

It was found that high reflective paint, when applied to walls and/or roofs of buildings, can reduce electricity used in air conditioning system up to 21.6-49.8% for

houses, 7.6-15.8% for medium rise residential buildings, and 7.6-61.7% for factories (Table 3).

Table 3: Energy reduction from applying high reflective paints to selected building types.

Case	1 Base Case	25	69	10	11	12	13
		High reflective paint				Normal paint	
House							
% Energy reduction	100%	-21.6% to -22.8%	-30.1% to -32.3%	-49.8%	+41.6%	-15.6%	-68.6%
Residential Building							
% Energy reduction	100%	-7.9% to -7.9%	-7.2% to -7.9%	-15.8%	+10.9%	-3.4%	+13.4%
Factory							
% Energy reduction	100%	-7.6% to -8.1%	-49.8% to -53.4%	-61.7%	+41.7%	-25.1%	-67.0%

Results also showed that the total solar reflectance or TSR property had a higher impact on reducing energy demand than the thermal emittance property of the paints. When the heat resistance property of construction material increases, i.e. roof versus roof with 1" insulations, the effectiveness of high reflective paint decreases.

## 4. CONCLUSIONS

In recent years, some buildings in Thailand started to use dark colors for building exteriors, not realizing that, consequently, a building's electricity consumption might be unnecessarily higher. The results from this research could help persuading the use of high reflective color both for walls and roofs of buildings with a small added cost and a fast payback period.

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# Optimizing Multi-storey Residential Building Based on Sunlight Performance

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**ABSTRACT:** As the most widely applied residential building type in China, the form of residential areas composed of multi-storey residential building are strictly restricted by the sunlight standard in the design code. However, sunlight can still be inadequate in open spaces and overshadowed buildings in a compacted layout. Using a theoretical model, this paper identified the problem of sunlight and seeks to improve the sunlight performance in the type multi-storey residential building through formal modification of the building. The results showed the efficiency of the modification, which represented both in the open space and overshadowed building.

**KEYWORDS:** Multi-storey Residential Building, Sunlight Performance, Sunlight Duration Time, Building Form

## 1. INTRODUCTION

The multi-storey residential building was the most widely applied residential building type in China in the last decades. They were built in slab form and arranged in rows, which was considered the most efficient way to arrange the buildings into residential areas to meet the sunlight requirement of the design code.

The design code applied sunlight duration time on buildings as the indicator to determine the interval, but neglected the open spaces between buildings, which is thus seriously inadequate in the compacted layouts. Furthermore, the current design code has lowered the sunlight standard. In the case of Nanjing, it was changed from no less than 1 hour on the day of winter solstice (applied efficient sunlight period 9:00-15:00) to 2 hours on January 20 (8:00-16:00), and thus caused sunlight inadequacy on buildings in the middle of winter.

This paper seeks to propose an alternative scheme for the multi-storey residential building, to improve the sunlight performance of this type of residential building and residential areas composed of it through modifying the building form.

## 2. METHODOLOGY

### 2.1 Theoretical model definition

According to the previous research on the multi storey building type, the theoretical model applied 2 types of living units named U1 (11.5m×12m×2.8m) and U2 (15m×12m×2.8m). Every dwelling unit contains 12 living units (6 floors, 2 per floor) and a staircase, and the whole building is composed of 3 dwelling units, size of 76m×12m×18m. Three buildings were then rowed along south-north direction, named Rs, Rm and Rn. Rs was set as the obstructive building, Rn as the boundary, and Rm as the object of formal modification. The interval of the buildings was set according to current design code as 22m (Figure 1).

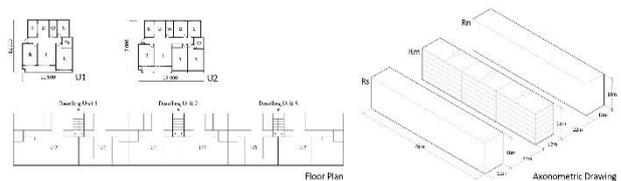


Figure 1: Definition of theoretical model

### 2.2 Sunlight performance simulation

For sunlight performance was measured by sunlight duration time in the design code, TArch software, which was widely used in China, was applied as the tool in this paper to generate sunlight isochronous lines on both plan and elevation as the indicator.

Sunlight performance of the open space between Rm and Rn, and the sunlight performance of the south elevation of Rn, are determined by the upper edge on the north elevation of Rm, so it can be improved by changing the spatial position of the edge by moving it southward (Figure 2). Though the sunlight performance of the Rn can be reduced in the modification without reducing the area of the building, but as shown in Figure 3 by sunlight isochronous lines (generated according to the design code), redundancy of sunlight is plenty on the south elevation of Rm, which allowed us to conduct the modification through volume jetting-out.

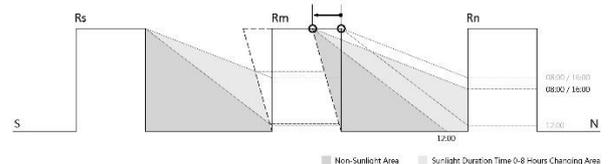


Figure 2: Determinative formal factor of sunlight performance

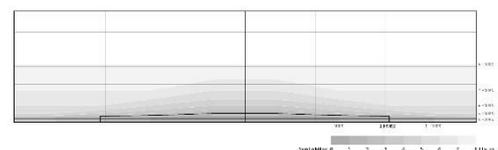


Figure 3: The sunlight isochronous lines of original Rm

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## 2.3 Effect of jetting-out on sunlight performance

The jetted-out volume can cause additional shadow on the volumes beneath. By the analysis on building section and solar elevation angles at different hours, the relationship between the distance of jetting-out and area shaded are clarified (Figure 4, Table 1). As the aperture of sunlight, the area of windows was defined to determine the distance of jetting-out in modification (Figure 4). Sunlight received by no less than 2/3 area of the windows can be accepted.



Figure 4: Influence of volume jetting-out and window setting

Table 1: Influence of volume jetting-out on volume beneath

Time	Obstruction	Full Window	2/3 Window
08:00/16:00	7 hours	1.2m	1.9m
08:30/15:30	6 hours	0.9m	1.6m
09:00/15:00	5 hours	0.8m	1.4m
09:30/14:30	4 hours		
10:00/14:00	3 hours	0.7m	1.3m
10:30/13:30	2 hours		
11:00/13:00	1 hours		
11:30/12:30	0 hours	0.6m	1.2m

## 3. RESULT

Formal modification was conducted on building Rm according to the performance of sunlight on its south elevation to meet the requirement of the design code. A whole level of the building was taken as the basic unit to modify. Sunlight isochronous line on the elevation of modified Rm showed that the sunlight duration time can still meet the request of the design code (Figure 5).

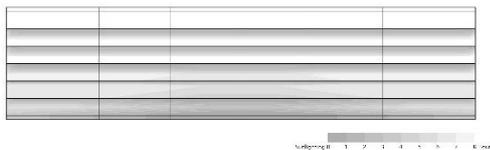


Figure 5: The modified model of Rm

### 3.1 Sunlight performance in the open space

Sunlight isochronous line on the ground level plan (0m) was generated according to the code (Nanjing, Jan. 20, 8:00-16:00) (Figure 6), and the area of the open space between Rm and Rn receiving sunlight for more than 1 hour was calculated and compared with the original one. The sunlight performance was improved by 36.44% in the modified model comparing to the original one (Table 2).

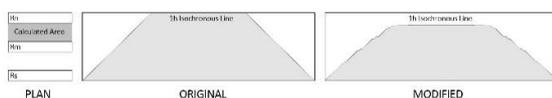


Figure 6: The sunlight performance of open space

Table 2: Comparison on sunlight performance of open space

Scheme	Area > 1h (m <sup>2</sup> )	Increment
Original	497.01	-
Modified	678.10	36.44%

### 3.2 Sunlight performance on the building

Sunlight isochronous line on the south elevation of Rn was generated according to the former design code (Nanjing, Dec.22, 9:00-15:00) (Figure 7), and the area of the elevation which receives sunlight for 6 hours in the time period of the modified model was calculated and compared with the original one. The modified one can still meet the former standard without reducing the building interval, and thus the density of the residential area can be remained. The modification caused a 30% of improvement of sunlight performance (Table 3).

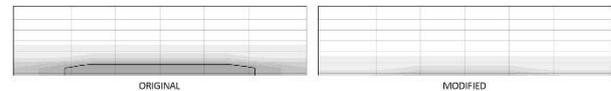


Figure 7: The sunlight performance on Rn

Table 3: Comparison on sunlight performance of Rn

Scheme	Area ≥ 6h (m <sup>2</sup> )	Increment
Original	760.00	-
Modified	988.00	30.00%

## 4. CONCLUSION

It is proved in this paper that simple modification of building form can cause effective improvement on the sunlight performance, both on open spaces and building elevations. And under the lowered standard of sunlight, the modified building form can still meet the higher request of sunlight in the former design code.

Meanwhile, more detailed research is necessary to take different sunlight requests of different rooms into consideration. More design schemes can be developed basing on it, and different performance of the schemes can also be interpreted.

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## Environmental Design for an Educational Building: Reconciling Transparency and Energy Efficiency

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**ABSTRACT:** *The paper presents a proposal for a Student Centre in Northern Greece. The proposed building is located at an existing educational unit in a densely vegetated environment and includes a high level of transparency to increase contact with its surroundings. Environmental strategies focusing on energy efficiency and natural resources preservation aim to balance the effects of extensive glazing through minimising winter heat loss and summer overheating while enhancing the benefits from natural daylight and natural ventilation. The preliminary estimation of the building's environmental performance through simulations revealed almost 47% reduction on heating and cooling loads by implementing sustainable design strategies, and more than 20KWh energy production by pv cells integrated on the building envelope, as well as appropriate daylight conditions. Further simulations demonstrate in detail energy consumption requirements, pollutant emissions, daylight levels and occupants' comfort.*

**KEYWORDS:** *Sustainable building design, energy efficiency, building performance simulation*

### 1. INTRODUCTION

A proposal for a new Student Centre was prepared in the framework of an invited entries architectural competition for the American College of Thessaloniki, Greece (lat. 40.5N). The initial concept of the building called for a high level of transparency to enhance social interaction among the educational community and contact with the surrounding densely vegetated site. Aiming to an integrated environmentally responsive approach, sustainable design strategies focusing on energy efficiency and natural resources preservation were incorporated in the proposal in order to offset the effects of extensive glazing through minimising winter heat loss and summer overheating while enhancing the benefits from natural daylight and natural ventilation [1,2]. A preliminary estimation of the building's energy performance through simulations in early design stages revealed almost 47% reduction on heating and cooling loads by implementing selected strategies, and more than 20KWh energy production by pv cells integrated on the building envelope. The preliminary simulations also showed adequate natural daylight on working level height. Further detailed simulations demonstrate more thoroughly energy requirements, pollutant emissions, daylight levels and occupants' comfort.

### 2. PROJECT BRIEF AND DESIGN CONCEPT

The site is the campus of a large educational unit, in the outskirts of the city, in a low-density highly vegetated area. The temperate climate in the larger area of the city is characterised by high temperature and intense insolation in the summer and cold and humid conditions in winter. The project brief required a building to

complement the existing educational facilities and to host offices, cafeteria, multipurpose hall, amphitheatre, a gym and guest studios.

The design concept is based on promoting interaction between all spaces, students and staff and integration in the natural environment within and around the campus. The interaction is enhanced by the location, the form and the transparency of the proposed building, which is situated between the two existing ones, expands with wings in three directions of the campus and allows unlimited view through glazed facades and common spaces at the central core (Fig. 1).



Figure 1. Images of the proposed building digital model.

### 3. THE ENVIRONMENTAL DESIGN STRATEGIES

Sustainable environmental performance of the building is considered in terms of reducing requirements

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for consumption of natural resources. The energy efficiency strategies focus particularly on passive cooling as well as passive heating and natural daylighting of interior spaces. Moreover, provisions are made for spaces for water management and for energy production by solar panels. Special consideration has been given to outdoor microclimate conditions by preserving and enhancing all existing vegetation at the site. Building location is selected to benefit from existing concentration of cypresses at the NW of the site for protection from cold NW winds which prevail at the area in winter. Moreover, the core areas of the building are oriented SE to the current open space configurations and pathways, at adequate distance to avoid overshadowing by the existing buildings.

To avoid summer overheating through the extensive glazing, large overhangs cover all the facades and vertical movable louvers extend in front of east and west façade windows for solar protection (fig. 2). To minimize winter heat loss from the glazed surfaces high levels of insulation are proposed for frames and panes, including thermal breaks, low emissivity coatings and noble gas layers. Thick external insulation layers are also proposed for all walls, floors and roofs.

The extensive external windows were also combined with large amounts of exposed thermal mass at the concrete floors, walls and ceilings in the interior spaces to allow for effective night ventilation cooling in the warm period. Openings on the internal walls were also proposed to allow for adequate cross ventilation and increase airflow and heat dissipation efficiency.

South facing skylights on the second-floor roof are proposed for allowing buoyancy driven airflow and increase natural daylight and winter solar gain potential.

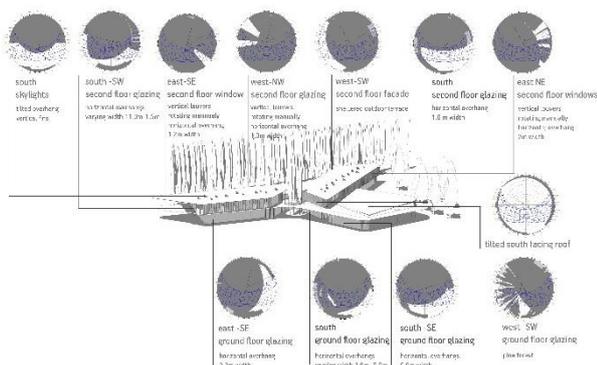


Figure 2: Annual shading diagrams for representative windows show the effectiveness of solar protection elements

### 4. ENERGY EFFICIENCY ASSESSMENT AND RESULTS

A preliminary assessment of the environmental strategies is based on simulations of the building thermal performance with Ecotect Analysis software, and further simulations performed with Design Builder include more detailed input (HVAC systems, operation schedules, building properties etc) and demonstrate energy

consumption requirements, pollutant emissions, natural daylight distribution and thermal comfort. The thermal analysis indicates the potential energy savings. Consecutive simulations, in which design strategies are added successively, demonstrate the reduction of energy requirements achieved by shading elements, envelope insulation, south oriented skylights and summer nocturnal ventilation leading to estimated savings in heating and cooling loads up to 47% (fig. 3). Natural daylight simulations show high daylight levels and even distribution in offices and common areas, with most values between 300 lux and 500 lux at winter overcast sky conditions of 6Klux illuminance (likely to be exceeded in 80% of the year in the specific location [3]). Moreover, microclimate simulations with Envi-met software show thermal comfort conditions for occupants at the outdoor spaces, wind field and ambient temperatures around the building.

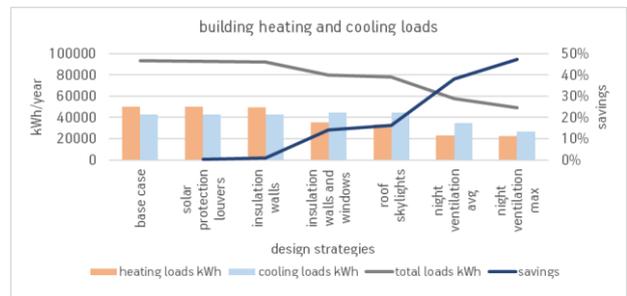


Figure 3: Annual heating and cooling loads estimation with successive scenarios of environmental design strategies integration: (a) solar protection elements, (b,c) reduction of thermal transmittance coefficients from regulation thresholds to 0.25W/m<sup>2</sup>K and 1.5W/m<sup>2</sup>K for walls and windows respectively, (d) integration of skylights and (e,f) two summer nocturnal ventilation scenarios of 5 and 10 ach respectively.

### 5. CONCLUSIONS

The initial assessment of the environmental design strategies on a new highly glazed educational building has shown how appropriate shading, adequate insulation, effective night ventilation cooling and natural daylight efficiency can compensate for large glazing surfaces and result in energy savings for heating and cooling. Passive design strategies in combination with energy production potential and resources preservation considerations, may result in an overall energy efficient building which interacts, complements, and highlights the natural environment.

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# A Systematic Approach for the Environment Performance in Residential Areas Design

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**ABSTRACT:** The design of residential area is a complex urban design process involving multiple dimensions and shaping the physical form of the cities. The question of how the form meets the needs of all other dimensions while satisfying environmental performance requirements is discussed in this paper from the methodological point of view. A Factors System (FS) is built to organize the factors in different dimensions of the complex urban system to discover, demonstrate and describe the relevance between the formal & spatial factors and other ones. Based on the FS, the Width/Height ratio is found as an operational factor to relate the space characteristic with the environmental performance and also with economic, social, visual factors. Also a real case, a residential area in Nanjing City, China is chosen to verify the feasibility of the system and the operability of the Width/Height factor.

**KEYWORDS:** urban design, complex system, Width/Height ratio

As same as urban design, the residential district design could be seen as a complex design process, which is facing problem solving and including all dimensions of the urban entity: morphological, perceptual, social, visual, functional and health as well as physical performance [1], which is the most important dimension recently. When we start to think of how design decisions are made with environmental performance and all other dimensions behind, the questions of systemic and scientific methodology of doing corresponding research for the discovery of new urban design knowledge is put forward.

## 1. SYSTEM THINKING AND SETTING

The paper builds a Factors System (FS) to organize the factors in different dimensions of the complex urban system to discover, demonstrate and describe the relevance between the factors of each dimensions (Figure1), which is suggested as the essence of understanding a complex system [2]. The FS includes some subsystems, each including several factors which are considered in the residential district design process:

**Morphologic aspect:** The factors of urban form include the character of building(s), such as building size, height, shape, volume, materials, etc.

**Openness Aspect:** The factors of open space consist of the general characteristics of space between buildings, such as size, shape, visual fields [3], the paths width and building height [4] and the typical characters of street space and open space, such as street wall (frontage) continuity [5], open space distribution/ratio, green space ratio/property, water network, etc.

**Activity aspect:** The social factors include diversity, safety [5], life style, dwelling density, crime statistics, sanitation rating, building conditions, environmental data, public realm [1], people's activity [4,7]. The

perceptual factors include sense of place [8], historical identity, culture, accessibility, sociability, comfort, etc.

**Economic aspect:** The economic factors comprise land use, land use intensity, density (FAR), property values, rent levels retail sales, etc.

**Climate and Energy aspects:** As an increasingly important dimension, urban climate factors consist of evaluation of air-flow [9], solar performance, energy balance, heat island, thermal performance, etc.

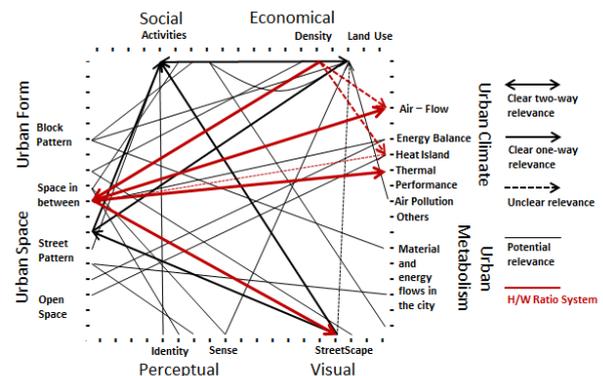


Figure 1: Factors system diagram

## 2. THE MEANING OF THE FACTORS RELATED TO PERFORMANCE IN DESIGNING SYSTEMS

In the FS, all of the factors are incorporated into a system of residential district design considerations. By connecting the relevant factors of the system, we can obtain an internal diagram of the system, which shows the complex relationships of factors. Then two steps are carried out in the system:

Firstly, the evaluation factors and the operational factors are distinguished and related. There are lots of scientific evaluation factors but they cannot be directly operated in the design process. For example, the sky view factor (SVF) describes the surface geometry, but it

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cannot correspond to the specific urban form, so SVF is not an operational factor. But in the system, SVF may be connected to other operational factors, such as the Width/Height ratio. This kind of relationships is easy to find in the system. Secondly, the operational factors that may be most associated with other factors are selected out, the detailed relevance between the operational factors and optimization factors could be demonstrated and described with formulas and graphs, and the corresponding operational indicators which can be used in urban design could be raised finally. Related to the environment performance in the design of residential areas design, based on FS we find that Width/Height may be an operational factor to define the urban space of the areas and also to relate to the economic, social, visual and microclimate factors.

### 3. EXPERIMENT AND ANALYSIS

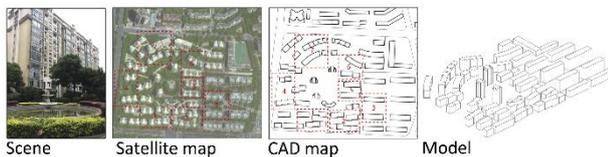


Figure 2: Case: A real residential area in Nanjing, China



Figure 3: W/H value results

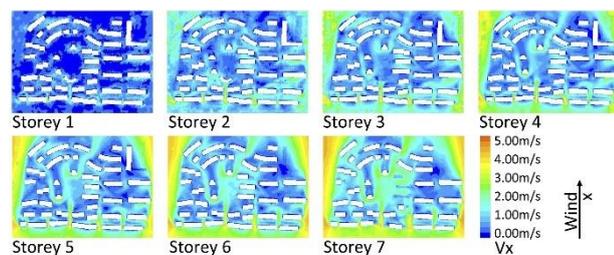


Figure 4: Ventilation evaluation results

Then the paper chooses a real case, representing the most common residential area in Nanjing city, China (Figure2), to verify the feasibility of the system and the operability of the Width/Height factor. The existing area could be regarded as a comprehensive result of considering most of the factors, so the case can be used to verify whether and how W/H is related with other factors. In addition, because the existing design has not yet taken into account the ventilation performance, which is more and more important, its specific relationship with the W/H is calculated in particular.

To do this, firstly a series H/W value of the area is calculated in MATLAB(Figure3). By analysing the types

and variations of these H/W values, specific spaces are described and classified. Secondly, the ventilation efficiency (*i.e.* wind velocity vector on wind direction,  $V_x$ ) of the area is evaluated in Fluent by the CFD approach and the simulation results data are also extracted post-processing by MATLAB(Figure4). A series of correlation analysis shows that the W/H ratio is positively correlated with  $V_x$ . The range of the W/H values is similar under the specific FAR, Coverage condition, and it can correspond to the ventilation.

### 4. CONCLUSION

As a result, the paper not only puts forward a series of parameters based on the Width/Height which are related to the environment performance as well as to the multiple factors of different necessary aspects, but also shows the methodological conclusion of transformation from systematic thinking into scientific urban design method, which proves that: urban design in science is possible.

### ACKNOWLEDGEMENTS

The study was financially supported by the National Natural Science Foundation of China (51538005 and 51708274) and China Post-Doctoral Science Foundation (2016M591823). The authors would like to thank Yihui Yang for his help in the illustrations.

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# Investigations on the Application of Nanomaterials to Improve the Environmental Performance of Buildings

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**ABSTRACT:** Nanotechnology is commonly regarded as a crucial step ahead in technology advancement to tackle some of the environmental problems of our contemporary building construction industry. The main characteristic that distinguishes nanomaterials is size, being defined as materials whose parts are smaller than 100 nanometres. This change in size of the material's structure, enables the generation of new material interactions with energy, opening new possibilities for performance improvement, which in turn leads to a reduction of energy consumption and greenhouse gasses emissions. Nanotechnology appears to be one of the alternatives to pursue the desired impact minimisation, while meeting the required comfort standards to provide good living conditions to the building's occupants. But, how reliable is this statement?

**KEYWORDS:** Nanotechnology, Nanomaterials, Thermal performance, Environmental performance, Energy Consumption

## 1. INTRODUCTION

There is currently a good range of commercialised nanomaterials designed to improve the environmental performance of buildings. Their performance is designed to respond to different priorities defined by the building construction industry's sustainability agenda, in which thermal control plays a major role. This research is focused on assessing the thermal performance of some of these nanomaterials. We understand that performance comes as a result of combining material properties and design. Departing from equal design solutions, can we rely on material properties alone to meet a targeted performance? In this regard, can nanomaterials outperform traditional materials?

To answer this question, we have designed a methodology to analyse and assess the thermal performance of a selection of nanomaterials. Some nanomaterials claim to have a positive input in the sustainable performance of buildings, but this performance has been only assessed as isolated individual materials by their manufacturers, and not as architectural solutions (assemblies/components) that form part of an applied design strategy. This research aims to investigate this gap in current knowledge in relation to the environmental performance of nanomaterials for their application in contemporary architecture. The research objectives of this study are: to analyse and assess the energy and environmental performance (thermal performance, energy consumption and CO<sub>2</sub> emissions) and ecological profile (embodied energy and carbon) of a selection of nanomaterials for architecture. This short paper focuses on presenting our research methodology.

## 2. METHODOLOGY

As a first step, it was important to classify the collected information in an organized and efficient way, for which a database was developed (Figure1). This database would also allow us to classify all technical data related to nanomaterials and case studies, compare the different aspects of the environmental performance of these materials, and efficiently select a combination of materials to be used in our analysis, which would involve computer simulations and life cycle analysis.

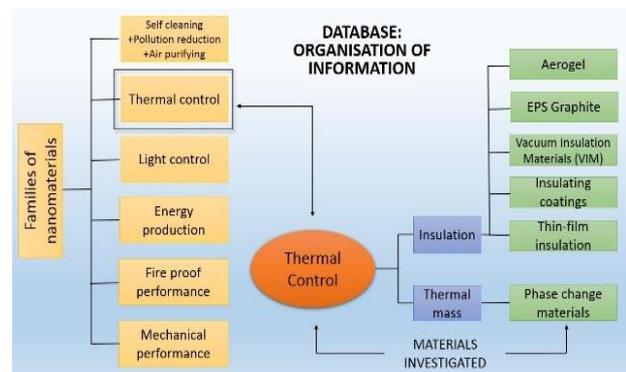


Figure 1: Nanomaterials Families in Architecture

For our analysis we chose a Zero Carbon House for which we could get sufficient data, and change their material solutions using nanomaterials, simulate them, compare them, and extract conclusions. The Zero Carbon House (ZCH) in Birmingham (Figure2), has been thoroughly analysed and monitored, showing excellent energy performance and retrofitting design qualities. The main goal is to use this house as a departing model, changing its material assemblies using new ones that include as many nanomaterials as possible to convert it into a Nano house, then simulate the house in all its new material configurations, compare the results to its

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current real solutions, and lastly extract conclusions. For evaluating performance, we are using the environmental simulation software Design Builder.



Figure 2: Zero Carbon House in Birmingham, Street view

Firstly, the house's thermal performance was simulated in its current state with the aim of validating our model, which effectively obtained the same results claimed by the designer. Secondly, it has been simulated with different nanomaterial assemblies, using either insulating nanomaterials or nanomaterials with high thermal mass capacity: Aerogel, Phase Change Materials (PCMs), Thin-film Insulation, Vacuum Insulation Materials (VIM), and Insulating Coating and Expanded Polystyrene Products (EPS Graphite) (Figure3). Critical factors in this analysis were: thickness, conductivity, specific heat, and density.

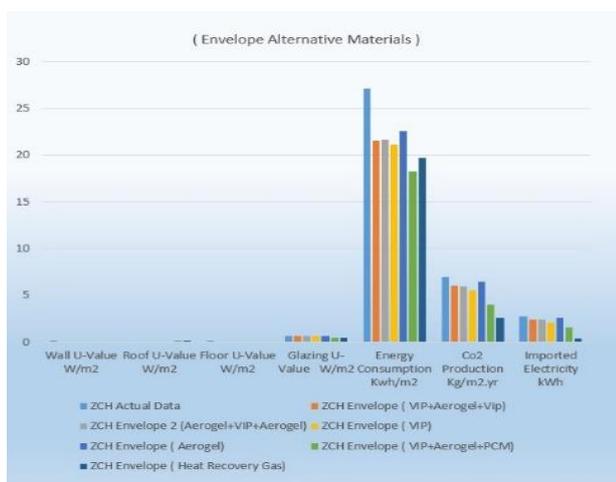


Figure 3: Simulation results

Performance assessment considered heat loss and variations in internal temperature, energy efficiency, CO2 emissions, and cost. Walls, roof, floors and windows were separately simulated for different construction

details, the ones offering the best results were combined to generate the Nano house version, which was holistically simulated.

### 3. CONCLUSION

This paper focuses on assessing the use of nanomaterials in comparison to conventional sustainable solutions in architecture. Preliminary results show that the use of these emergent materials can effectively optimise the building's thermal performance in different aspects, getting the best results from Vacuum Insulation Panels. The use of nanomaterials improved the thermal and environmental performance of the analysed ZCH House, by reducing its energy consumption by 25% and its CO2 emissions by 45%. The use of these materials opens new alternative routes for sustainable design strategies and a new array of specialised functions. We are currently working on the next phase in the study, which looks into developing the ecological profile of these materials (LCA), to assess their performance in connection with their environmental impact.

### ACKNOWLEDGEMENTS

The authors would like to acknowledge the Iraqi Ministry of Higher Education and Scientific Research and the Middle Technical University in Baghdad for the scholarship given to the first author, and Iraqi Cultural Attaché in London for their effort in managing the scholarship. In addition, they acknowledge the University of Liverpool for their support.

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# Learning Ecological Knowledge from Traditional Japanese Villages and Architecture Using Simulation

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*ABSTRACT: This paper demonstrates research and local practices in Japan to learn ecological knowledge from traditional Japanese villages and conventional architectural typologies through environmental analysis using computational simulation, and showed that we can experience and learn the traditional knowledge, which our ancestors established over a long period of time, in a short period of time using computational simulation.*

*KEYWORDS: Traditional Village, Architectural Typology, Ecological Knowledge, Environmental Simulation*

## 1. INTRODUCTION

Traditional villages and conventional architectural typologies are decreasing in number, because what was rational at the time is no longer practical in today's industrialized society. They are often treated as objects for preservation from a historical and cultural point of view and sometimes referred for semiotic purposes. This study tries to reinterpret them as "ecological knowledge" using simulation.

## 2. TRADITIONAL VILLAGE IN NISHI-AWA

Nishi-Awa is an area located in Tokushima, Shikoku, Japan. There are over 200 villages located on the steep valleys. There also exists traditional agricultural system that utilizes natural processes effectively. This topography was created by the natural movement of the plates and is very complicated; where each village in valleys faces different directions. A slope facing South is called "Hinoji (Sun-Place)" and a slope facing North is called "Kageji(Shadow-Place)", however this word "Kageji" is not necessarily seen negative in this context. To support this, Keka Village, one of the biggest villages, is facing north. Then, we analysed the cumulative amount of solar radiation that falls onto the surface of the village using Radiance. The amount of solar radiation that falls on Keka (facing North) was about 50% of Akamatsu (facing south) in winter but, annually, it was 80%. This implies that even a slope facing North can get enough solar radiation, if the angle of inclination is gentle. However villages that face north and are located on steeper slope get smaller amount of radiation and consequently the size of the villages are also smaller than Keka. It is interesting to see how villages were extended seems to have been determined by the amount of solar radiation the villages receive. We can also learn a lot of things from the houses. Good locations (in terms of environmental conditions) were first given to agricultural land, and the houses were then placed on unused area. First, stone walls were built on

the slope then houses were allocated so that they face the valley. The houses are also placed away from the walls and are half-buried on the slopes. By simulating with CFD, it was found that the wind environment of the front yard of the house is always gentle, as the strong wind from the valley is blocked by the stone wall and the wind from the mountain is blocked by the roof. The houses were built in order to protect themselves from the severe environment.

## 3. SAW-TOOTH ROOF IN ICHINOMIYA

Ichinomiya, Aichi Prefecture, Japan, is an area historically famous for its textile industry. The city also has a unique streetscape where many factories are covered with a saw-tooth roof. The saw-tooth roofs are north-oriented to ensure stable lighting throughout the whole year. First, we analysed the performance of solar gain, daylighting and natural ventilation using simulation and then reconstructed it for a new house of a young family; North-South inversion, extension of eaves and turning one unit into an outside terrace, in order to make the environment fit into modern lifestyle. This was done after performing simulation to ensure that the house gains enough solar radiation during winter, enough shading during summer, and sufficient natural ventilation. It is impacted by the daily changes in the sky, however they can live without artificial lighting in daytime. In addition, high performance envelope and HVAC system were also integrated. The design demonstrates the possibility of reliving the traditional saw-tooth roof cityscape into the city, in addition to preservation of older factories.

## 4. CONCLUSION

This paper showed that we can experience and learn traditional knowledge, which our ancestors established over a long period of time, in a short time using computational simulation.

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## Traditional Villages in Nishi-Awa, Tokushima



Figure 1 : Bird's-eye view photo of the Villages

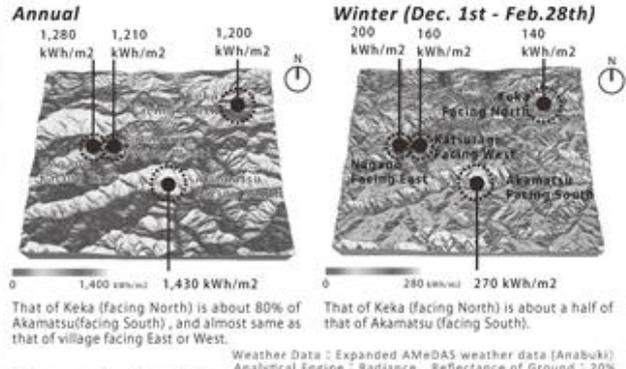


Figure 3 : Analysis of Cumulative Amount of Solar Radiation

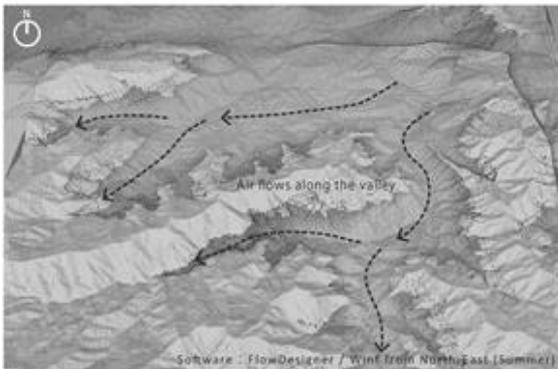


Figure 2 : Air-Flow Analysis in Village Scale

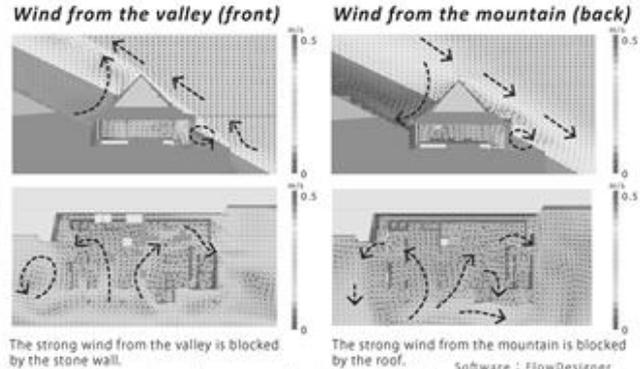


Figure 4 : Air-Flow Analysis in Building Scale

## Saw-tooth Roof in Ichinomiya, Aichi



Figure 5 : Image of Fabric Textile Factory with Saw-tooth Roof (North-Oriented)



Figure 6 : Image of a New House with Saw-tooth Roof (South-Oriented)

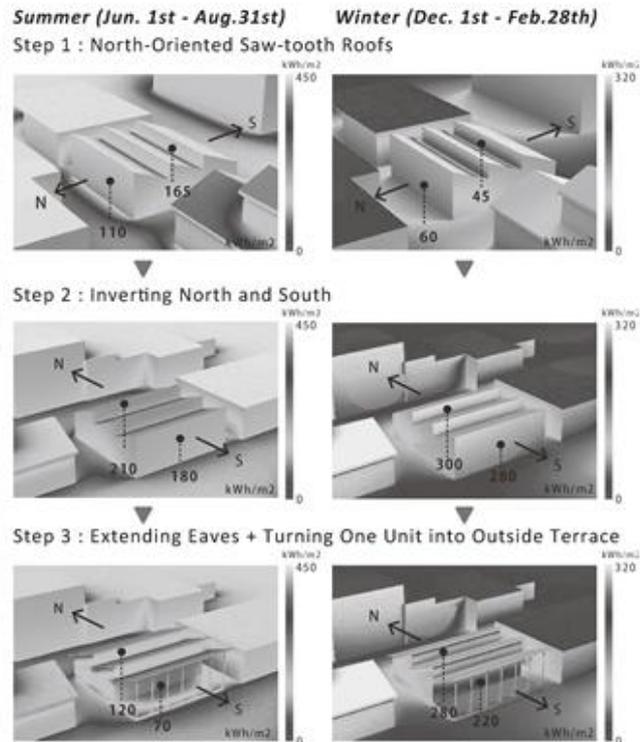


Figure 7 : Analysis of Cumulative Amount of Solar Radiation of reconstructed models

# Cultivating of Human Resources Capable of Utilizing Simulation: Attempt of Design Studio at University

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**ABSTRACT:** At the University of Tokyo, we held a design studio annually, and we train all the students to master various simulation tools and compile their proposals. In addition, we hold design proposals for students who recognize proposals that actively use simulation tools with other educational institutions. Through these attempts, we aim to cultivate human resources superior in simulation utilization.

**KEYWORDS:** Design Studio, Simulation, Education, Design Process

## 1. INTRODUCTION

Expectations for efficiently utilizing simulation at the design stage and proposing energy efficient and comfortable buildings are increasing more and more. In Japan, the shift to new energy code began in 2016 and there is a growing need to use simulation more effectively. Although various simulation tools for daylighting, wind and energy consumption have made remarkable progress, it is necessary to properly establish the design process how and when to use the simulation tools for the study of design. There is a report [1] that it is possible to propose effective energy conservation by using simulation by focusing on the early stage of design such as a programming phase and a schematic design phase. It is important to educate the simulation utilization method and to cultivate the human resources capable of more effectively using the simulation tools at educational institutions such as university.

In this paper, the approach at a design studio using simulation tools which started ten years ago at the University of Tokyo and the design process utilizing simulation and its problems are considered.

## 2. FEATURES OF DESIGN STUDIO

The university of Tokyo holds design studios featuring various themes, not only about design but also about structural and environmental engineering, from April to June, about 2 and half month, every year. Students can choose a studio to join freely by their own interests. As one of these design studios, we started our new design studio in 2008. The biggest feature of our design studio is that all students who join us are required to acquire various simulation tools, for example Climate Consultant or Ladybug for the climate analysis, Radiance for the daylighting simulation, EnergyPlus (Honeybee) for the calculation of energy consumption and FlowDesigner (one of the famous CFD tool in Japan) for the wind analysis (Fig.1). Students

challenge to consider and decide on design of their proposal using these simulation tools.

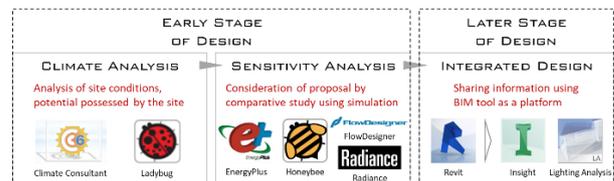


Figure 1: Design Process of using simulation tools.

From 2014, the studio has been entitled "Design with Climate" and sites are set as the land of characteristic weather conditions around the world, so as to grasp the features of climate more objectively by focusing on the climate analysis. Not only architects but also sustainable engineers are joining this design studio as an advisor, and students learn how to summarize one proposal by utilizing simulation in the discussions with them on a daily basis.

## 3. COLLABORATION WITH BIM TOOLS

From 2017, in addition to the previous simulation tools we started to use BIM (Building Information Modelling) tools, Revit for a platform of sharing information and using Insight and Lighting Analysis for simulation tools connecting with BIM. This frees us from the complexity of sharing the input information necessary for simulation such as model and material property value between CAD tools and simulation tools which was one of the problems of utilizing simulation so far. I hope to develop human resources who can use the simulation more positively at design stage by learning the merit of BIM tools in our design studio.

## 4. COLLABORATION WITH OTHER EDUCATIONAL INSTITUTE

The Support Association for Building Environment Design (SABED) [2], which I am a member of the Directors, started a design proposal for students called

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"SABED DESIGN AWARD" from 2016 (Fig.2). This competition is aimed at honouring the design of green buildings with excellent expressiveness by utilizing simulation in the curriculum of the university.

To become a trigger to utilize simulation in daily design assignments, it is widely recruiting proposals in design assignments at each university without setting specific issues. The results of analysis by using simulation tools are posted in all entries, and many students are positively challenging to utilize simulation in their assignments. On the other hand, there are many proposals that conditions which are the prerequisites for analysis by simulation tools and the design decision process based on simulation results are not accurately expressed. It highlights the problem that the way of using the simulation to aim for the realization of reasonable building design with support has not penetrated much in the education curriculum yet. In addition, the shortage of faculty members or tutorials that students can learn when they want to utilize simulation in their design assignments is pointed out as another problem. It is obvious that students' interest in using simulation tools is very high, so it is hoped that the curriculum of utilizing simulation will be developed at each educational institution triggered by holding this proposal.

## 5. CONCLUSION

In our design studio, which began with the purpose of making effective use of simulation tools, many students discovered the possibility of utilizing simulation. In addition, a design proposal for students which are collaborating with other educational institutions are helping cultivate human resources who can use simulation tools effectively. However, the development of faculty members and tutorials teaching to use simulation is still inadequate.

Enriching the curriculum with more educational institutions and actively exchanging information about their curriculum, we should make it possible to propose energy saving and comfortable buildings more easily by utilizing simulation.

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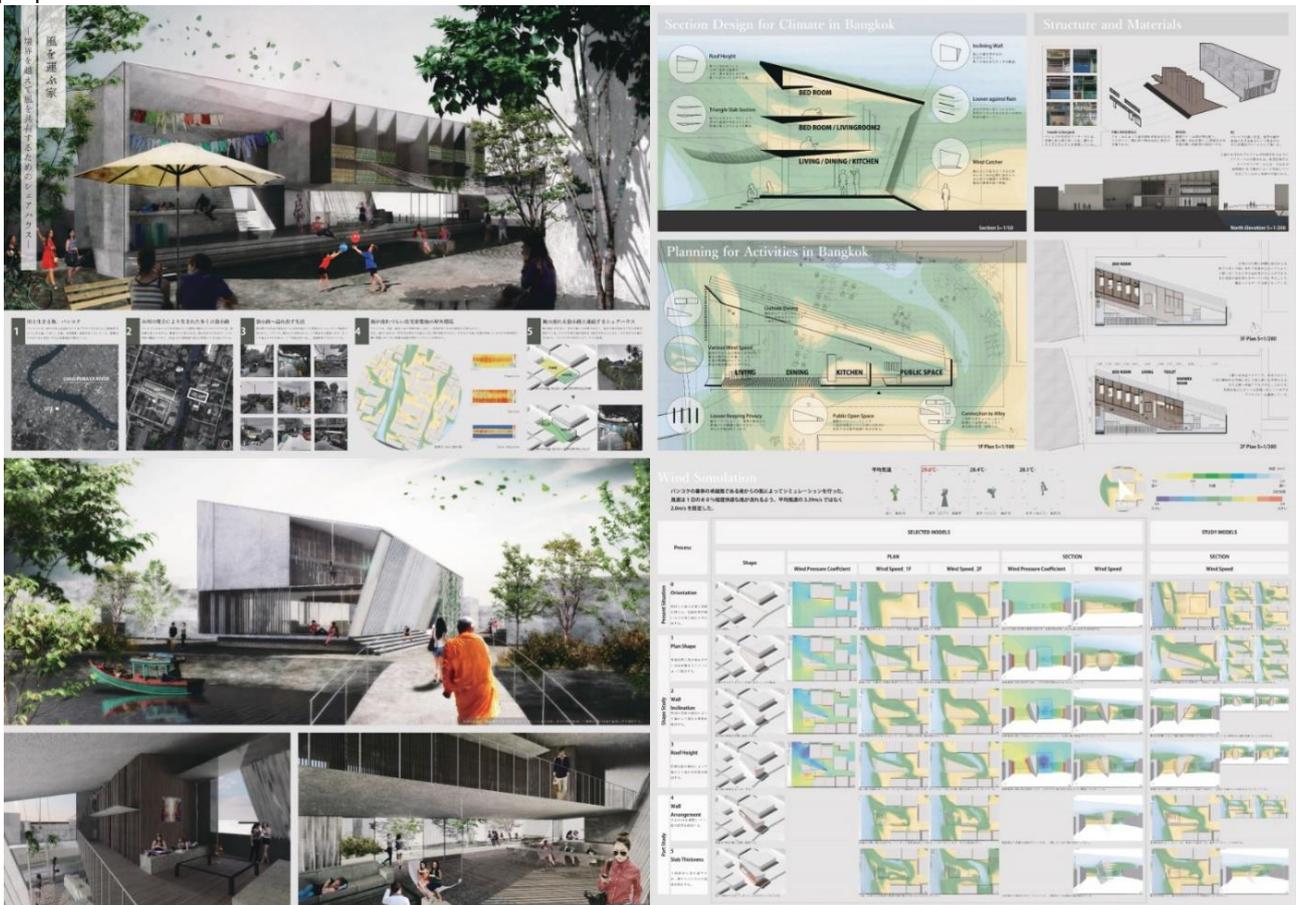


Figure 2: Proposal for Excellence Award in 2016

## Types of Window Glazing for Public Housing Development: Exploring Use of Low-E Glass

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*ABSTRACT: Hong Kong Housing Authority (HA) has been providing affordable public housing in meeting the need of over 30% of the Hong Kong population. Embracing a caring attitude to foster social, economic and environmental sustainability, we adopt passive design to create quality homes for our residents in a green and healthy living environment plus a harmonious community. Since 2012, HA has been conducting study to explore use of different types of window glazing for the public housing flat with a view to optimising a comfortable indoor environment along with the passive design approach. This paper highlights briefly the summary of our findings on the three common types of window glazing (float glass, tinted glass and low-E glass).*

*KEYWORDS: Public Housing, Sustainable, Passive Design, Comfortable, Glazing*

### 1. INTRODUCTION

Established in 1973 under the Housing Ordinance, the Hong Kong Housing Authority (HA) develops and implements one of the largest public housing programme in the World. We provide subsidized public housing through mass production in meeting the housing needs of those who cannot afford private housing in Hong Kong in support of the Government policy on housing. With this mission, we plan, build, manage and maintain different types of public housing. In line with the principle of “functional and cost-effective” design, we have developed a library of Modular Flat Design (MFD) for public housing developments (PHD). This aims to achieve the best value and practice in sustainable housing design and construction, and to strive for greater efficiency and productivity through wider use of mechanized building process promulgated under Quality Housing Initiatives, whilst at the same time maintaining a certain level of design control over standard of provision and maintaining consistency across different projects. We promote passive design to create quality homes for our residents in a green and healthy living environment plus a harmonious community.

In September 2014, Buildings Department issued PNAP APP-156 outlining the guidelines controlling Residential Thermal Transfer Values (RTTV) of building envelopes, including visible light transmittance (VLT<sub>Glass</sub>) and external reflectance (ER<sub>Glass</sub>) of the glazed portions. Being one of the pre-requisites for the granting of GFA under APP-156, the RTTVs for a residential block should be (a)  $RTTV_{Wall} \leq 14W/m^2$ ; (b)  $RTTV_{Roof} \leq 4 W/m^2$ . This practice note is included as one of the pre-requisites for the granting of gross floor area concessions. Taking this as a reference, the HA explored, for passive design approach, whether the use of low-E glass in Public Housing Developments

is beneficial and effective or not in reducing the energy absorption in the building envelope and cost-efficient.

### 2. THE STUDY

In the initial stage of the Study, we identified the various glass types and properties which are commonly applied for domestic flats. Following that, we proceeded to (a) Stage 1 - on-site measurements; and (b) Stage 2 – an academic analysis on the thermal performance when using different glass types in our flats.

#### 2.1 Stage 1 - On site measurements

We set up measurements for domestic flats of a public housing development (PHD) site under construction, and measured the average indoor room temperature for facades facing south and west and with different glass types:

- Clear float glass (6mm) – currently applied in PHD standard
- Tinted glass (6mm)
- Laminated low-E glass (5mm+0.38mm PVB\*+5mm) – \*Laminated glass is manufactured by permanently bonding one or more polyvinyl butyral (PVB) interlayer between sheets of clear, coated or tinted glass under heat and pressure. The 10.38mm thick low-e glass is fitted to the 50mm window frame extrusion.

The results of the measurements taken in two different construction sites are identical. The average indoor room temperature when comparing to clear float glass are:

- Tinted glass – lowered by 1.5C
- Low-E glass – lowered by 0.5C

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## 2.2 Stage 2 – Computer Simulation and Analysis

At Stage 2, we engaged an academic study to analyse the thermal properties of the three different glass types with computer simulation on the temperature response with different window glazing in a PHD flat. The whole flat is regarded as a thermal zone in the study, and 3 different scenarios (i.e. an air-tight space without air-conditioned, naturally ventilated space, and an air-conditioned space) are tested and investigated. From the computer simulation, the difference in heat gain between tinted and low-E glass is insignificant (Fig. 1). The performance pattern between the three different glass types is consistent.

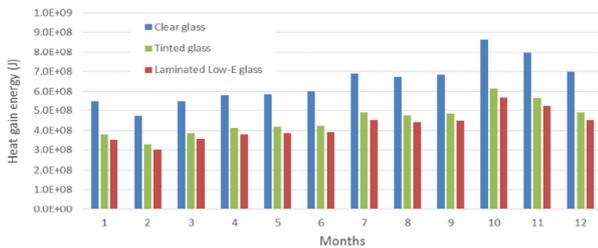


Figure 1: Difference in heat gain between clear glass, tinted and low-E glass.

Based on the results of these computer simulations, it can be concluded that both the low-E glass and the tinted glass can effectively reduce the window’s heat gain energy. The maximum room temperature in a naturally ventilated room for the case of clear glass is about 2.1°C higher than that of low-E glass, or 1.7°C higher than that the temperature of the tinted glass. It can be seen that the difference of room temperature for low-E glass and tinted glass is only about 0.4°C. The thermal performance of tinted glass and low-E glass is comparable. This aligns with the findings at Stage 1.

Table 1: Comparison of overall effects

	Low E	Tinted
Highest room temp (naturally ventilated room)	38.8°C	39.1°C
Highest room temp (air-conditioned room)	34.7°C	34.9°C

## 3. SUMMARY OF FINDINGS AND ANALYSIS

The low-E coating on the glass reduces solar heat transmission to the room. This phenomenon is similar to the THERMO Vase Effect. At a scenario of a heated and closed window room, the low-e coating reflects the heat back inside; whereas in an air-conditioned room, the low-E coating serves to repel the heat from the outside. In this Study, both on-site measurement and computation analysis demonstrate that the temperature inside the room is always higher than the external in all three types of glazing. Heat energy

released into the room from concrete wall/envelope heated up by the western sun in the afternoon cannot escape from the room to the external via the window (for all glass types) and is reflected back into the room creating a thermal vase effect. This explains the fact that the room still maintains at high temperature in regardless of the types of glazing materials.

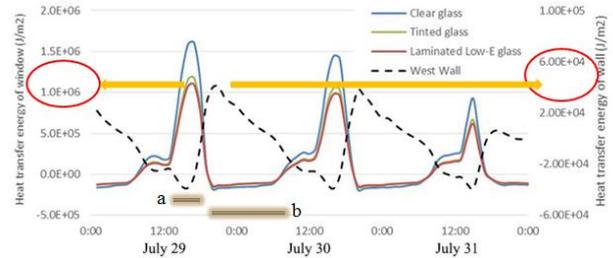


Figure 2: Net heat transfer energy of the west window and wall.

Heat retention capacity is similar for tinted glass and low-E glass; whereas the heat retention for concrete is almost four times higher than that for tinted/low-E glasses (Fig.2). The heat capacity of glass is smaller than concrete wall. Hence, the temperature decreases quickly after the direct sunlight in the window, whereas the concrete wall takes a longer duration to release the energy into the room.

However, under active design approach, the low-E glass is still considered effective for accommodation to be fully air-conditioned and constructed as an integrated glass unit with an internal air gap which affects the low-E’s performance.

## 4. CONCLUSION

Difference scenarios for PHD (6mm clear glass windows) are simulated in the sensitivity check to test the RTTV: (a) domestic block with MFD; and (b) different absorptivity (external wall finishes, colour scheme). Even maintaining the current 6mm clear glass for windows, the resultant RTTV<sub>wall</sub> with lighter colour falls within the prescribed value of 14W/m<sup>2</sup> under PNAP. Given the findings of the Study that the thermal performance of tinted glass is comparable to laminated low-E glass under passive design approach, we would tend to adopt lighter colour in the (west-facing) façade, and might also consider adopting tinted glass for better RTTV performance on project basis.

## ACKNOWLEDGEMENTS

We would like to show our gratitude to Dr. Lu Lin, Vivien, Dr. Wang Deqi, Mr Zhang Weilong of the Renewable Energy Research Group, Hong Kong Polytechnic University for giving us valuable insights to complete this Study.

## Urban Oasis in Industrial Setting: Revitalisation of Industrial Building to Wah Ha Estate

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<sup>1</sup>Hong Kong Housing Authority, HKSAR, China

*ABSTRACT: Hong Kong Housing Authority (HKHA) makes its first attempt to convert a 59-year-old match box building Chai Wan Factory Estate (CWFE) to Public Rental Housing. The biggest challenge of this project is “how to provide a sustainable living environment from a derelict Grade II Historic Building located within an industrial area which is subject to severe noise pollution from nearby industrial buildings and transportation facilities, and at the same time, to maximise the development potential of the site as well as to conserve the historical values of this 59 years old architecture?”*

*KEYWORDS: People, Comfort, Sustainability, Revitalisation, Heritage*

### 1. INTRODUCTION

**Chai Wan Factory Estate (CWFE)** was constructed in 1959 and granted Grade II Historic Building status in 2013. Situated close to the Mass Transit Railway station in Chai Wan and surrounded by industrial buildings, CWFE is the last H-shape factory building remaining in Hong Kong. The conversion was announced in 2012 as a mean to increase the supply of public housing in short-term and to respond to the local community’s strong aspiration to retain the CWFE. This derelict historic building underwent an extremely fast-track 4 years programme transforming into a new identity, Wah Ha Estate, in 2016 accommodating some 600 tenants in 187 flats.



Figure 1: CWFE in 1964 and Wah Ha Estate in 2016

### 2. SUSTAINABLE DESIGN FOR THE PEOPLE

Our approach was to integrate the residential design into the existing industrial environment, as well as to revitalise the neighbourhood. Before starting the building works, we decontaminated the soil to ensure a long-term safe and healthy environment for future residents. The original first to fifth floors in CWFE were converted into domestic units, while the ground floor was reserved for a courtyard, retail shops, car parkings and estate management facilities to serve the daily needs of tenants.

To guarantee structural safety of CWFE, we tested the existing floor slabs to verify that the structure and materials to be retained were sound and would meet the latest fire safety requirements. The test results were positive and encouraging. This enabled us to retain an astonishing 70% of the existing building structure as well as the building appearance, effectively reduce the need to demolish and rebuild floor slabs significantly. To maximise the development potential, an additional domestic storey was added to the North Wing after checking the existing loading capacity. The alteration process involved the use of a remote-controlled demolition robot and saw-cut methods, minimising nuisance to the neighbourhood and reducing vibration to the existing structure.

CWFE is surrounded by severe traffic noise generated by local transport facilities as well as noise by industrial buildings nearby. The domestic flat design was constrained by the existing structure and layout imposed by this listed Grade II building. To minimise the impact of traffic noise on tenants, all domestic flats were designed to overlook the internal courtyards. Acoustic balconies with noise absorptive panels and noise screens were strategically placed to reduce the amount of noise, with a maximum noise reduction of 9db(A), entering each flat.

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Figure 2: Acoustic Balcony

### 3. CONTRIBUTION TO THE ENVIRONMENT

Other than saving a large amount of construction materials by retaining 70% of the building structure, Wah Ha Estate was also modelled to be 46% more energy efficient than the specification in the Electrical and Mechanical Services Department's Performance-based Building Energy Code.

We implemented extensive landscaping, with a greening ratio of over 40%, to create not just a pleasant environment but also a "green-lung" within this built-up urban industrial area.

We conserved precious water resources used in gardening. Rainwater harvesting system, together with the drip irrigation system, is installed to collect rainwater for irrigation. It is projected to save over 50% of irrigation water annually. We also used eco-friendly recycled block pavers at the external areas.

We adopted passive designs in this development by creating new eco-wells to enhance natural ventilation and to capture daylight for domestic flats.

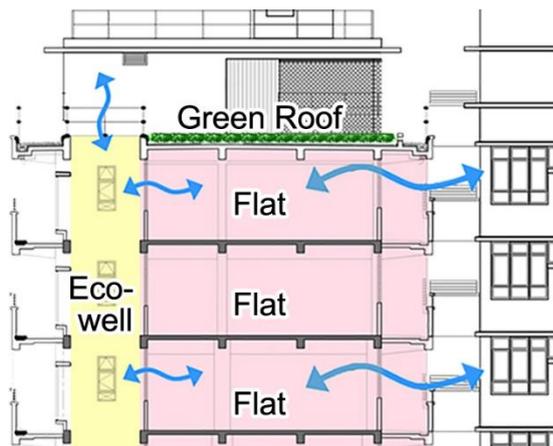


Figure 3: Interaction between Eco-Well and Flats



Figure 4: Green Roof at Wah Ha Estate

### 4. CONSERVING THE HERITAGE

A number of "Character Defining Elements" as identified in the Heritage Impact Assessment were retained in the conversion. These include the block's distinctive "H-shape" form, its strong horizontal lines created by balconies and slabs, painted characters of the building name as well as other notices on walls detailing the floor loading capacities, ramps with concrete grilles, and chimney stacks.

### 5. INTERACTION WITH THE COMMUNITY

As part of the HKHA's people-oriented approach, and in a move to raise public awareness of heritage conservation, we invited ex-tenants and other local stakeholders to take part in a community engagement workshop to collect and incorporate their views and memories into the design process. A Display Area was thus created on the ground floor giving full details not only on the history of CWFE in relation to the general development of Chai Wan district, artifacts salvaged during building clearance, but also the conservation of heritage values, sustainable designs and construction methods adopted, and the entire revitalization process of CWFE.



Figure 5: Display Area

### 6. CONCLUSION

Wah Ha Estate has successfully demonstrated the adaptive re-use of existing building structure to Public Rental Housing. With consideration for the people and community to live smart and healthy within the 2-degree limit, we applied innovative designs and technologies to create a more sustainable urban environment in delivering the public housing production.

## **PEOPLE AND COMMUNITY**

Cities are primarily about people. Smart and healthy cities are nothing but buzzwords without considering the need and wish of the communities within. This track connects science, technology and research with people and their everyday lives, for example:

- human behaviour, design for behaviour change
- user-building interaction and post occupancy evaluation
- passive energy neighbourhood, community and city development
- low energy thermal comfort, public health and wellbeing

## Assessing Sustainable and Healthy Environments. Case Study: A Learning Space in Mexico

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*ABSTRACT: Healthy environments are essential to prevent disease while promoting health and well-being. Healthy people and communities substantially contribute to sustainability. The design of the built environment in an education context is of high priority, providing architecture students with a healthy and comfortable education environment could contribute to a better cognitive experience, less absenteeism, greater students and lecturers' productivity and better social relationships. The methodology proposed here is called Nurturing Environments Assessment Method (NEAM), and focuses on the health and well-being of building users'. It is based on a POE methodology; however, the NEAM applied here includes: A Space Occupancy Survey, a Users' Survey (mood and perception of the building) and physical measurements of the interior environment. 99 students and 19 staff members participated in the surveys. The NEAM proved to be a useful tool to assess the quality of a building. The case study building needs to be fully equipped with furniture for students to relax and work. Solutions must consider improving ventilation, acoustics and lighting levels inside lecture rooms. In addition, strategies to make this building safer during evacuation in case of fires or earthquakes are essential for the wellbeing of occupants.*

*KEYWORDS: Healthy environments, NEAM, POE, Sustainability, Education building.*

### 1. INTRODUCTION

According to the World Health Organisation healthy environments are essential to prevent disease while promoting health and well-being. Healthy people and communities substantially contribute to sustainability, reducing the use of public health services, having longer productivity years and more possibilities of living a healthy and happy life individually, as a family and as a community or country.

Post Occupancy Evaluation (POE) studies have proven to successfully assess the design, occupation and operation of buildings. The main objective of POE is to improve building performance contributing to users' comfort, reducing building's environmental impact while keeping low operation costs [1-2, 4, 6-9].

This paper discusses the influence of the built environment in the well-being of architecture students in a Mexican university, through an innovative POE methodology called Nurturing Environments Assessment Method (NEAM). It was developed for this project. NEAM studies buildings' environment and performance with an emphasis on people's health and wellbeing. The term *nurturing environments* is used by Health Science disciplines to denote Environments that foster successful development of an individual, while preventing the development of psychological and behavioural problems. Nurturing environments teach, promote, and richly reinforce prosocial behaviour, including self-regulatory behaviours and all of the skills needed to become productive adult members of society [3].

The case study is the newest building of the Architecture Faculty of the *Benemérita Universidad Autónoma de Puebla* (BUAP), after 18 months of occupation. The university campus is located in Puebla City, 120 Km SouthEast of Mexico City. The proposed NEAM evaluates an education building performance in terms of its interior environmental quality, functionality, furniture and equipment, landscape, access and security. Moreover, people's psychological and physical health is assessed; together with their perception of the interior environment of the building, and their mood while studying or working there.

### 2. METHODOLOGY

The importance of the built environment in an education context shall be of high priority since users spend long hours in that environment. Architecture education has a great impact on people's lives and environment. In the last two decades there has been a huge development of a new focus of university curricula in Schools of Architecture: educating architects with a sustainable design knowledge.

Providing architecture students with a healthy and comfortable environment could contribute to a better cognitive experience, less absenteeism, greater productivity and better social relationships.

#### 2.1 Building description

The ARQ12 is the newest of the 12 buildings that conform the Faculty of Architecture at the BUAP (Fig. 1). It was finished in January 2016, including: 6 lecture

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rooms, offices, toilets, cleaning room and roof garden. Total construction area is 958 m<sup>2</sup> [5]. The main idea was to provide lecture rooms equipped with the latest education technologies: Wi-Fi, video projectors, smart boards, 3D design boards and 3D printers. Photovoltaics panels provide energy for 12 lamps located on the upper floor ceiling.



Figure 1: Exterior and interior views ARQ12 building (2017).

## 3. RESULTS

### 3.1 Users survey and Space Occupancy Survey (SOS)

A survey was distributed among students and lecturers in the ARQ12 building. The main purpose was to identify people's perception of the building and how the built space contributes to their activities, either to perform better as students or as lecturers, or not. Respondents pointed out that lecture rooms are dark and badly ventilated. Main problems include: users do not open the black out blinds, there are louvers for ventilation but it is not enough to naturally ventilate a room with 40 people in it. Regarding the dimensions of the lecture rooms, users said they feel crowded and hot. Other comments include the lack of common areas and lack of furniture to chill out.

A SOS was carried out during one week in the middle of the academic term. Main findings include: the roof garden is never used; lecture rooms host more students than the designed capacity. The building is highly occupied, from 7 am-9 pm Monday to Thursday; on Fridays occupancy is below 50%.

### 3.2 Interior environmental quality

During the same week of the SOS, interior environment measurements were registered. Humidity and temperature were recorded at different times of the day. Main problems include: high interior temperatures at midday, low temperatures from 7 until 9am and poor acoustics.

### 3.3 Users' mood and health assessment

The Scale for Mood Assessment (EVEA in Spanish) proposed by Sanz (1993) was used. The EVEA contains 16 mood questions, respondents selected according to their feelings while being in the ARQ12 building. Students felt cheerful, happy, optimistic, joyful and tense. Staff felt

optimistic, cheerful, happy, joyful and restless. In both cases the fifth selection was a negative one. Users' health condition is yet to be assessed by members of the Nursing Faculty of the BUAP.

## 4. DISCUSSION AND RECOMMENDATIONS

Healthy people and communities contribute to generate sustainability. Learning environments are crucial for personal and professional development of individuals. Since the built environment greatly influences people's life, educating architects becomes a critical task. Their learning environment must provide a comfortable space where they can develop both professional skills and healthy lifestyles.

The NEAM proved to be a useful tool to assess with a holistic approach the use of an education building. The method still needs validation assessing other type of buildings.

## 5. CONCLUSION

Building assessment after occupation is key to correct problems that occur due to construction errors or modifications, maintenance or use of the building. Rectification strategies are essential for the sustainable use of buildings and users' wellbeing.

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## Low Energy Consumption Cities in the Tropics: A Study of Cities' Compactness in Tropical Climates

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*ABSTRACT: Local climate conditions must be always considered when looking for architectural and urban design. In this paper, as a simplification, "tropical" cities are defined as those that face more problems related to high temperatures than low temperatures. To understand what would be the ideal density in a tropical context, we studied a hypothetical city of 100,000 inhabitants within three scenarios: single-family plots, buildings of 30 floors and an in-between case. Based on this study, high densities seem not to be sustainable solutions regarding the energy consumption necessary for its operation. However, the current construction process of the tropical Brazilian cities is based on compactness and density theories but more commitment to local development is necessary, in order to mitigate urban temperatures, and to affect cities' growth and the inhabitants' quality of life positively.*

*KEYWORDS: Tropical cities, Compact cities, Energy Consumption*

### 1. INTRODUCTION

In the nineteenth century, the United Kingdom experienced overpopulation, poverty and diseases in cities because of industrialisation, making life expectancy in the Victorian era less than 25 years old [1]. In Brazil, the fast growing cities, present similar problems that compromise inhabitants' quality of life. In the past, several authors criticised the growth of cities and proposed connected smaller towns, more integrated to nature [1,2]. Today, in the same way, methodologies are developed with the aim of improving cities' quality of life: walkable cities [3], cities without cars [4], cities for pedestrian [5], self-sufficient cities [6]. We believe that limiting the growth of cities is one of the strategies to reduce urban problems. However, what will be the parameters that would indicate the most convenient city for the tropics? Certainly, one of them will be the area to produce food, ensuring independency from other cities, and another parameter will be the people's density, which should limit the size of the city. As we should explore one thing at time, the objective of this study is to analyse one parameter of a less energy dependent city while ensuring thermal and physical comfort to the inhabitants. The initial analysis verifies three different density situations, to evaluate the advantages and disadvantages related to thermal comfort and energy costs, focusing on sustainability. In this paper, as a simplification, we call "tropical" cities those that present more periods of high temperatures than low temperatures.

### 2. LOW ENERGY TROPICAL CITIES

At present, there is a serious debate about whether the sprawling city or the compact city is more

sustainable, although their definition is unclear [7]. Therefore, to define our "ideal tropical city", we consider that the definition of the compact city is one in which the relation "free area/occupied area" is the minimum possible, whereas for a sprawling city the relation is maximised. These "free spaces" (spaces without construction) will be valuable as urban agriculture areas as well as green and leisure, contributing also to controlling the temperature of the microclimate of the city.

#### 2.1. Low energy consumption cities

While technology is still on its way to provide clean energy for all human activities, the most effective way to achieve energy efficiency and limit dependence on energy production is to limit consumption. Several authors of cold regions argue that compact cities are more sustainable than sprawling cities because the urban infrastructure is cheaper [1,7,8], but the energy cost of water pumping and vertical transportation energy costs are not considered. They compose the highest energy consumption of a building (when there is no air-conditioning).

In addition, it is possible to find four environmental disadvantages of a compact city in the tropical climate: 1) a compact city presents an increase of internal air temperature in dwellings, fact that is good for the cold climates and bad for warm climates; 2) it creates the necessity of mechanical renovation of the internal air; 3) the dwellings have to increase the insulation, rising the cost of construction; 4) there is psychological gain and visual and experiential advantages of being in contact with nature inside the city, which compact cities usually don't offer enough.

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## 2.2. Permeable Cities

Natural ventilation is essential to cooling down warm cities. In Brazil, the way that tall buildings are currently constructed blocks it. This fact limits both heat and humidity dilution, increases urban warming and reduces the pedestrian and indoor thermal comfort, increasing air conditioning demand, which increases global warming. Still, we maintain that the tropical city might have some characteristics of the compact city, such as: having limited growth, providing a mix of uses, encouraging walking or cycling.

## 2.3. Searching for the right density

High densities in warm climate cities increase urban temperature. So, what would be the ideal density in a tropical context? To answer this question, we studied a hypothetical city of 100,000 inhabitants divided into 10 areas of 10,000 inhabitants distributed on a flat surface. We created three hypotheses of urban form provided the neighbourhood within walkable limits [9]: an area of single-family plots (horizontal city); buildings of 30 floors (vertical city) and an intermediate case. It is evident that the third option does not offer the same comfort (physical) as the other options because we suppressed the elevators. That is why we limited its height up to 4 floors (connecting them also with ramps).

We calculated the annual energy costs for urban lighting, water pumping and elevator, as shown in Table 1. It was studied individual batches of 12x30 meters, usual shape in Brazil, as a starting point.

Regarding the lighting calculations, we considered the lamp power of 250W only, at a cost of R\$ 0.527/kWh (Rio de Janeiro charges) [10], ignoring the reactor losses, cables and other equipment of the electric grid. As in this case the energy consumption is proportional to the city's area, one can think of photovoltaic systems to remove light consumption, or even think in a hypothetical case of using intermittent illumination of the streets. To these costs would be added those of electrical cabling, gas, sewage and communications systems, which were not included in the calculations of this study (Same costs/person/area).

In the horizontal and intermediate case cities, a 18 meters high station is needed for water pumping. In vertical areas, the bomb should pump water to 93 meters high for each tower. For vertical transportation in vertical cities, three elevators per tower are usually used [11]. Costs were calculated based on elevators of 12 people capacity running four hours a day [12].

Table 1: Urban lighting, water pumping and elevator annual energy costs.

Energy costs	Horizontal City (R\$)	Vertical City (R\$)	Intermediate City (R\$)
Lighting	5.703.325,70	288.133,00	1.825.064,20
Water pumping	284.685,40	3.385.488,00	284.685,40
Elevator	00,00	1.953.942,09	00,00
<b>Total</b>	<b>5.988.011,10</b>	<b>5.567.523,09</b>	<b>2.109.749,60</b>

It can be observed that horizontal areas presented greater difficulty to maintain themselves within walking distances, and urban lighting presented a high cost. The vertical city, however, obtained low cost in urban lighting, but a water pump and elevator increased its operation costs. The intermediate case achieved lower annual energy costs instead of giving preference to physical comfort.

## 4. CONCLUSION

Although our cities face similar difficulties as the UK faced in the post-industrial era, the climate in Brazil and UK of course are different. So constructive and formal solutions that were developed and applied there cannot be used here as acknowledged solutions. Local climate conditions must be always considered.

Based on this study, high densities are not sustainable solutions regarding the energy consumption necessary for its operation. In the same way, horizontal cities occupy large spaces, increasing public lighting costs. A city of intermediate or low density seems to respond better to the local climate while offering less energy dependence excluding the compact city approach.

Thus, reviewing the construction process of the current tropical Brazilian cities is very important, as they are based on compactness and density theories that mainly respond to the real estate market interests. More commitment to local development is necessary, in order not to contribute to increases in urban temperatures in a tropical zone, but to affect cities' growth and the inhabitants' quality of life positively.

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## Improvement Proposal for the Fabrication of Artisan Brick. Case: San Pedro Cholula, Puebla, México

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*ABSTRACT: Artisan brick fabrication in Mexican communities are known to have social backwardness, this generates human health and environmental issues due to high levels of pollution. This study shows an improvement proposal for the locality of San Diego Cuachayotla, leading brick producer in Mexico. It focuses and highlight the main problems of the chain production, through a participative diagnose methodology. As a result, an integral project was designed, in stages. A first one with the construction of a proposal including an improved productive space, a living area, a family orchard garden, fruit trees, and family farm area to supply and promote a scheme for self-sufficiency. The improvements of the productive chain were developed following the «Best Available Techniques» concept, and an ecologic oven MK2 was chosen due to its high energy efficiency, to its pollutants reduction and fuel savings at low cost and feasible technology. This project shows how utilizing inclusive diagnosis methodology following a selection of best options available can help to improve quality of life as well as a reduction on the environmental impact focused on specific community needs and demands.*

*KEYWORDS: Artisan brick fabrication, local brick industry, comprehensive improvement project.*

### 1. INTRODUCTION

Artisan brick fabrics units in Mexico are settled mostly in communities that have high levels of social backwardness<sup>1</sup>. Figures show that demand of brick as a product is high and represents an important economic activity. However, its production process is responsible of high levels of pollution due to the type of fuel utilized, and to the poor efficiency of the burning process; industrial disposals, and tyres among other harmful materials have been recorded as fuel to burn bricks [1] this causing health issues due to the carcinogenic particles emission and its irreversible illness such as silicosis, and lung fibrosis [1]. According to Blackman and Bannister [2], the brick industry in Ciudad Juarez, Mexico, is one of the mayor causes of atmospheric pollution in the area.

### 2. BACKGROUND

According to the National Council of Statistics Informatics and Geography -for its acronym in Spanish- (INEGI), in 2009 there were 10,251 brick production units national wide in Mexico. In the last census (2014) 9,044 production units were reported, although Mexican brick producers net estimates 16,953 production units [3], these figures show that it is an industry with an important economic and environmental impact. Puebla state, is the main producer of artisan brick, and its mayor

activity is concentrated in the municipality of San Pedro Cholula with 1,035 economic-active artisan brick production units [4], San Diego Chuachayotla is one of the six municipal auxiliary boundaries were this activity outstands.

### 3. METHODOLOGY

Through a participative diagnosis in the community, the conditions and state of the production chain and the main problems that face producers were set and recorded by applying profound structured interviews with key actors. Good practice was also documented in fieldwork emphasizing on identifying the most efficient techniques to achieve significant levels to foster the environment. The design project for improvement was developed through participative design workshops and mental maps were applied as instrument to better know the relevance and level of awareness of the proposal among the users. Finally, results were presented and exposed to local authorities for feedback and in search of funding as a pilot program of two stages; the first stage is the construction of the proposal, and a second stage includes the assessment of the improvements employed.

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<sup>1</sup> According to the Mexican National Council of Evaluation -for its acronym in Spanish- (CONEVAL), the Social Backwardness

Index, of San Diego Cuachayotla auxiliary boundary is established like High (4).

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## 4. FEATURING LOCAL ARTISAN BRICK INDUSTRY: OPERATIONAL CONDITIONS

According to the features of the brick production units defined by the EELA Report [5], the study shows that in San Diego Cuachayotla, there are transformation units that employ artisan processes of fabrication, in the form of small family business scheme. The community reflects a low scholar index, were most of the population is advocated to the informal manufacture and commerce of ceramic clay products working in precarious conditions. In general, in the neighbourhoods mixed used terrains happens, where brick burning ovens are side by side with housing buildings with serious building and spatial backwardness, and thus, with serious impact on human health, to the environment, and to resource depletion. Adding the obsolescence of the ovens and appropriate safety equipment to operate them.

## 5. THE PROPOSAL: A HOLISTIC IMPROVEMENT

Results from participative design workshops [6], was an integral project of improvement, it accounts a productive brick workshop area, housing area, a small orchard garden, fruit trees and a small family farm area that allows families in the first stage to simultaneously take part on working activities and self-sufficiency labour scheme (Fig. 1).

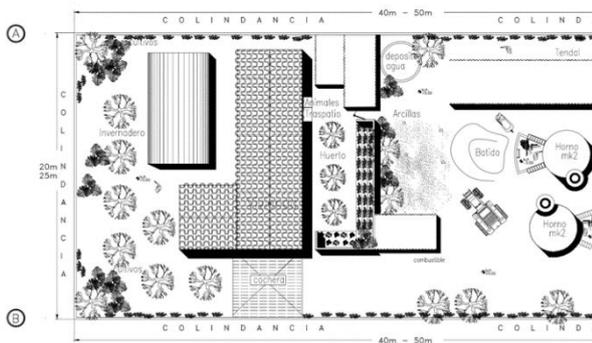


Figure 1: Lay-out Plan. Zone A: Housing, Orchard garden and family farm area

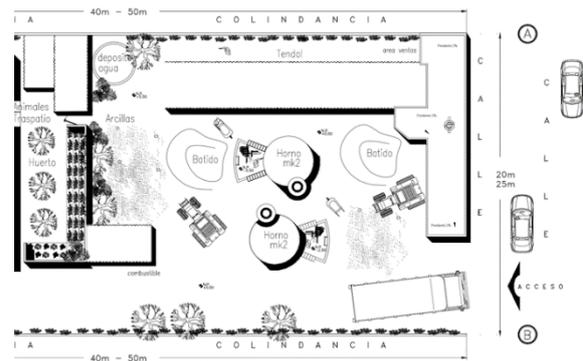


Figure 2: Lay-out plan. Zone B: Artisan brick assembly area

Improvements of the assembly area were based and developed under the «Best Available Techniques» 2 concept [7], applied to the brick manufacture sector lead to the selection of the MK2 ecological oven, which represents the most efficient, low cost and advanced technology available that can be applied to the same brick assembly and burnt process, considering cost-benefit, and a high standards of environment protection and pollution reduction. The proposal shows the recommended space to develop an improved systematic chain for the assembly of artisan burnt brick production (Fig. 2) and the space required to undertake self-consumption food production. Some aspirational and specific needs of users were also included in the lay-out plan.

## 6. CONCLUSION

Since long time ago, it has been pointed out the serious health issues generated by the artisan brick sector in Mexico, arguing that is an activity that lacks of proper technology showing backwardness, nonetheless, very little studies have been carried out in detail focusing on applying proper diagnosis and specific needs and demands of brick producers communities. Development of holistic proposals that responds to the particular conditions and needs, contributes to the reduction of environmental degradation and pollution, and human health. As a second stage it is important to undertake studies that track and assess the improvements and changes made in such proposal to measure social, environmental and economic benefits, as well as to identify problems in order to propose corrective actions.

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entitled 'Ceramic Manufacturing (CER)' for industrial emissions levels.

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# Statistic Data Based Holistic Building Performance Analysis: Method Development through Case Study on Finnish Residential Sector

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*ABSTRACT: This paper describes the study on method development (regression analysis model and genetic algorithm model) and shows the results of the preliminary tests. The proposed holistic building performance analysis allows analysing the transition of energy demand, and understanding the impact of energy efficiency improvement in the building sector driven by nZEB implementation. By applying Finnish statistic data as open data source, the feasibility and potential of analysis was studied. It is clarified that a room for improvement is remained, but both proposed methods have potentials to provide informative outputs for the future energy analysis.*

*KEYWORDS: building performance, statistic data, regression analysis, genetic algorithms*

## 1. INTRODUCTION

### 1.1 Structure of future energy situation

Decentralized energy technology can be the strategic option for future energy supply, which allows minimizing the dependency of fossil oriented fuels and maximizing renewable energy utilization at energy demand points. In addition, the energy efficiency of buildings is a key factor in energy use for heating in building sector. The European Energy Performance of Buildings Directive (EPBD) requires all new buildings to be nearly zero energy buildings (nZEB) by the end of 2020, and two years prior to that for public buildings.

Historically, centralized energy systems, such as electric power grids and district heating networks, develop gradually over many years. The capacity of systems, is generally determined and installed looking ahead to the future growth of energy demand to preserve the quality of secured energy supply. However, both now and future, the situation in energy demand structure will change because decentralized energy technology, such as heat pump (HP), combined heat and power systems (CHP), and photovoltaic system (PV), are being enhanced and installed at the energy end-user's side, especially by promoting nZEB. This change causes that decision makings are getting complicated and required to degrade capacity as well as upgrade for the conventional energy systems.

### 1.2 Energy efficiency action plan by municipalities

Finnish government has the Energy Efficiency Agreement for Municipalities, which is an agreement between the Ministry of Economic Affairs and Employment, the Energy Authority and the Association of Finnish Local and Regional Authorities on the more efficient use of energy in the municipal sector. It formed from 2017 and the municipalities and cities that have signed it can refer to the instructions and tools when they

are drawing up the action plan required by the energy efficiency agreement [1]. To understand status of energy efficiency of the sector within the governance boundary and develop action plan considering the current situation are highly important. However, it is almost impossible to implement energy auditing for all building stocks based on the energy efficiency plan. Thus, the method to estimate building performance of current building stock in the governance boundary is required.

## 2. OBJECTIVES

This paper describes the study on method development and tests of the holistic building performance analysis which allows to analyse the transition of energy demand, and to understand the impact of energy efficiency improvement in the building sector driven by nZEB implementation.

Table 1: Statistic dataset

Category	Data source	ref
Construction	Building and dwelling production	[2]
Buildings Stock	Buildings, Intended use of building	[2]
Electricity use	Electricity consumption by Sector	[2]
Heat use	Heat consumption by Sector	[2]
Energy use in households	Energy consumption in households	[2]
Population	Preliminary population	[2]
GDP	Key indicators per capita	[2]
HDD	Heating Degree Days	[3]

### 2.1 Dataset

To make it possible to apply the developed method to other regions, applied data source for the developed methods is statistic data which are basically available from governmental services. This research applies Finnish statistic data which are available online shown in

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Table 1. This study uses 21 sets of data in total from 1995 to 2015.

## 2.2 Models

This research developed and tested two methods, regression analysis model and genetic algorithm (GA) model. Regression analysis is a method of mathematically sorting out which of those variables have an impact to the objective indicator.

Eq1 shows the building performance (kWh/m<sup>2</sup>) with relevant parameters. Parameters are combined as the indicators.

$$PEC/FLA = K(PEC/GDP)^a (GDP/POP)^b (HDD/HDD_o)^c \cdot POP^d \cdot (1/FLA)^e \quad (eq1)$$

Where *PEC* is primary energy use (both electricity and heat consumption), and *FLA* [m<sup>2</sup>] is the total floor area of building stock. *GDP* [euro] as economic parameter, *POP* [persons] is the total population. *HDD* indicates heating degree days. All parameters are converted as non-dimensional parameters with division by each value in 2010. To apply regression analysis, the eq1 is converted as eq2.

$$\log(PEC/FLA) = a \log(PEC/GDP) + b \log(GDP/POP) + c \log(HDD/HDD_o) + d \log(POP) + e \log(1/FLA) + K \quad (eq2)$$

In terms of GA model, it is applied to estimate average building performance as key performance indicator. The GA is used through a specified loop to minimize the difference between statistical data and estimated data. The GA cost function model is defined as following

$$\min \left( \sum_{i=1995}^{2015} E_i - \sum_{i=1995}^{2015} (w_{att} A_{att_i} + w_{det} A_{det_i} + w_{bl} A_{bl_i}) \right) \quad (eq3)$$

$w_{att}, w_{det}, w_{bl} \in [100 \ 900]$

where  $E_i$  is the total energy consumption,  $w_{att}$  is the average building performance for the attached houses in the year  $i$ ,  $w_{det}$  is the average building performance for the detached houses in the year  $i$ ,  $w_{bl}$  is the average building performance for the detached houses in the year  $i$ ,  $A_{att_i}$ ,  $A_{det_i}$  and  $A_{bl_i}$  are annual constructed area for the attached houses, detached houses and block buildings. The target year is [1995 – 2015]. The advantage of GA model is availability of building performance distribution of each year by looped iteration as well as average building performance.

## 3. RESULTS AND DISCUSSION

Table 2 shows the results of the regression analysis. The model provides the results to support deep analysis. The studied parameters are highly correlated, especially

the parameters about energy intensity (a), economic intensity (b), and population growth (d). By analysing the trends of each parameter, the influences for the trend of energy use and building performance can be described.

Table 2: Results of regression analysis

	Estimate	Std. Error	t value	Pr(> t )
K	-7.874e-17	8.392e-17	-9.380e-01	0.363
a	1.000e+00	1.850e-15	5.405e+14	<2e-16
b	1.000e+00	1.029e-15	9.717e+14	<2e-16
c	-5.474e-17	8.678e-16	-6.300e-02	0.951
d	1.000e+00	4.363e-15	2.292e+14	<2e-16
e	1.000e+00	3.590e-16	2.785e+15	<2e-16

Fig 1. Shows the results of GA model. The results provide the exact values of average building performance of each year. However, the impact of other factors is still involved in the result. To analyse the behaviour of building performance trend, further development is needed.

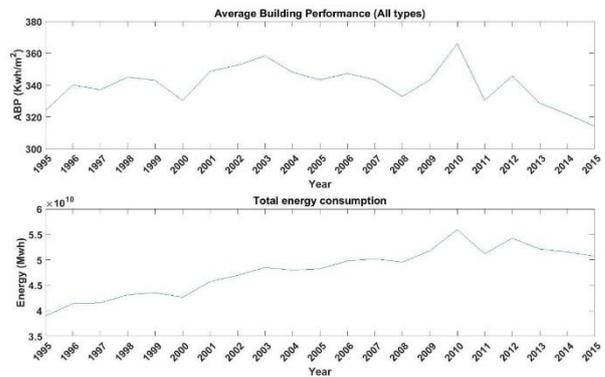


Figure 1: Results of GA approach

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## Smart Housing after the Tsunami: Lessons from Kirinda, Sri Lanka

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*ABSTRACT: The present context of climate change and concomitant water related design challenges necessitate architectural innovations to provide sustainable housing for rural low-income communities, particularly in developing countries that are vulnerable due to economic, political and socio-cultural factors. In the wake of the Tsunami in 2004, the Sri Lankan government faced the paradoxical situation of rebuilding communities devastated by the disaster and the potential to build environmentally resilient settlements. The Kirinda Tsunami Resettlement Project is one such example that served a minority community and attracted international awards for its innovative architectural designs. This paper analyses the Kirinda Project, as a part of a larger PhD research project which employs an archival and empirical research methodology to evaluate planning intentions and the reception of the housing projects in the context of economic liberalisation in Sri Lanka. Thus, this paper considers the synergy between the existing cultural landscape and the new housing designs, with the aim to provide lessons for sustainable architectural design for smart and healthy housing within the 2-degree limit at the scale of the rural village.*

*KEYWORDS: Climate change, Rural low-income communities, Developing countries, Sustainable housing, Cultural Landscape*

### 1. INTRODUCTION

The United Nations has declared that “Water is at the heart of adaptation to climate change, serving as the crucial link between the society and the environment.” [1] Accordingly, the UN champions the need to accelerate efforts towards meeting water related challenges in “The International Decade for Action” commencing on World Water Day in 2018. Water related challenges directly impact housing. While urbanization increases the pressure on domestic water supply, climate change and concomitant disasters continue to threaten established communities. Kazi Ashraf, architect and urbanist, warns “if catastrophes and perils determine design motivations in the 21st century, water is up there...” [2] In this context, the provision of sustainable housing in the context of water related challenges must be prioritised as an ongoing concern for architects.

This paper explores the lessons that can be derived from a case study analysis of a new village design in post Tsunami Sri Lanka to inform sustainable housing design within the 2-degree limit in the Tropics. This study derives from a larger research project which examines village design in the context of Sri Lankan economic liberalisation in the late 20<sup>th</sup> century. The primary research aim is to inform decision makers about sustainable housing design for low-income rural communities. Focusing on the Kirinda village designed by the Pritzker Architecture Prize winner, Shigeru Ban, this paper examines the physical planning intentions and the housing design of the project – acknowledging the life changing horror of this catastrophe – to consider the potential lessons that may be transferred to sustainable

housing design for healthy communities in the context of other water related challenges.

### 2. POST DISASTER RECONSTRUCTION

The statistics of the 2004 Tsunami are staggering. The Tsunami devastated 65% of Sri Lanka’s coastal belt resulting in more than 40,000 deaths, more than 800,000 homeless people, the complete destruction of more than 60,000 housing units, and the partial destruction of another 40,000 homes. Not least, the country’s most important industries of tourism and fishing were decimated. [3] Sri Lanka’s National Housing Development Authority (NHDA) declared that the “lack of proper construction standards to resist tidal waves and negligence on the part of the home-owning public to follow even the available standards added to the severity of destruction.” [3]

As a result of this unprecedented natural disaster, the Sri Lankan government reviewed policies and recommendations for new housing designed for coastal settlements. These initiatives placed emphasis on community mobilisation and informed decision making with a view to the short-term and long-term success of the housing provided. [3] Reflecting on the extent of the damage, the NHDA stated that “On the one hand, the social aspects of re-construction, especially an inclusive and participatory approach has proved to be successful in many contexts. On the other, post-disaster scenarios often provide a golden (if perverse!) opportunity to “design with nature” that not only will withstand future disasters well but are also cost-effective.” [3] In the context of post tsunami Sri Lanka, this response has

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triggered renewed emphasis on passive sustainable architectural design.

### 3. A PASSIVE DESIGN

The village of Kirinda is one such example of new housing to resettle predominantly Muslim families that were affected by the disaster. The village was nominated for the prestigious Aga Khan Award for Architecture in 2013 and the project report offers a wealth of detail about the project. [4] The goal of Shigeru Ban was “to maintain the village’s pre-disaster social and cultural structure by building the homes on the same plots as they were previously located, while delivering structural environments that enhanced the inhabitants’ quality of life.” [5]

#### 3.1 Methodology

As a part of the mixed method qualitative case study, which employs archival research to investigate the planning intentions, and empirical research to investigate the project reception, this post occupancy analysis of the built environment will be complemented by ethnographic findings.

#### 3.2 Housing design

The Kirinda project consisted of 67 single storey detached housing units, shaped by passive design principles which mediate the conditions of the tropical climate. The slatted gables encourage cross-ventilation. Materials were sourced locally (compressed earth blocks, clay roof tiles, timber from rubber trees) and building elements were assembled using local techniques and labour. [6] The provision of a simple courtyard (partly inspired by the work of the renowned Sri Lankan architect Geoffrey Bawa as well as Sri Lanka’s coastal vernacular architecture) separates living areas from wet areas and increases usable space whilst also protecting the privacy of the women of the house. As a result, the housing design was shaped by passive architectural principles in response to the climate, the need for a cost-effective solution in a short period of time, and the specific cultural needs of the community in a fitting response to the established cultural landscape of the region. [5]

### 4. LESSONS LEARNT: POST DISASTER SUSTAINABILITY

There is a deep connection between water, the natural environment and human settlements, represented by the traditional ‘village model’ in Sri Lanka; a synergy which can be defined as a ‘cultural landscape’. The cultural landscape is defined as “the combined works of nature and of man”, in the 1992 World Heritage Convention, which are unique and diverse, and illustrated as the “evolution of human society and settlement over time, under the influence of the physical constraints and/or opportunities presented

by their natural environment and of successive social, economic and cultural forces, both external and internal.” [7] In their discursive form, cultural landscapes are intimately connected to sustainable development, as they “often reflect specific techniques of sustainable land-use”, which supports biological diversity, and “a specific spiritual relationship to nature”. [7] Recognition of this synergy is critical for sustainable housing design development whereby adherence to passive architectural principles is only part of the solution. Smart and healthy village design must recognise the value of established village models and the implications for the continuity of the sustainable practices of the community, in relation to their livelihoods and the environmental context.

In the context of climate change and the increasing likelihood of unpredictable, extreme natural disasters and the implications for human settlement – exponentially urbanized, coastal, and often poor – the Kirinda example offers valuable lessons for sustainable housing for a minority community in a developing country that responds to a specific cultural landscape. Drawing on archival and empirical source material, this research project considers the lessons for smart and healthy housing design, within the 2-degree limit, at the scale of the rural village.

### ACKNOWLEDGEMENTS

This PhD research project is conducted at the School of Architecture and Built Environment, University of Adelaide, with funding from an Australian Postgraduate Award.

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# Daily Patterns of Occupants' Window-Opening and Air-Conditioning Usage in Hot-Humid Climates of Southeast Asia

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**ABSTRACT:** The aim of this study is to clarify detailed typical daily patterns of occupants' behaviour of window-opening and air-conditioning in hot-humid climates. Face-to-face interviews for 1,570 typical households were carried out in Malaysia and Indonesia. All samples were divided into several groups, based on the city climates and air-conditioner ownership, and subdivided through a principal component analysis and a hierarchical cluster analysis. The result shows the daily patterns of occupants' behaviour in hot-humid cities is clearly different from those in relatively cool city. Windows tend to be opened during daytime even if air-conditioner is installed, while air-conditioners are mainly used during sleep time.

**KEYWORDS:** hot-humid, window-opening, air-conditioning, daily pattern, classification

## 1. INTRODUCTION

There is concern that the spread of air conditioners (AC) among urban residential buildings in hot-humid Southeast Asia will bring about further increases in primary energy consumption and CO<sub>2</sub> emissions [1]. Higher-income occupants tend to use AC more, and further increase in the AC ownership rate is predicted as their household income increases [2]. Natural ventilation is considered an energy-saving strategy to achieve indoor thermal comfort while reducing AC usage, and in particular, window-opening is a key adaptive behaviour in hot-humid climates. Previous studies showed that outdoor/indoor air temperatures are one of the key drivers for opening/closing windows [3], and the duration of opening windows is significantly related with seasonal changes of outdoor temperature [4]. In the tropical cities in which the diurnal range of outdoor temperature is often much larger than that of seasonal change, the diurnal pattern of window-opening and its drivers can be rather important. Therefore, in this study, detailed typical daily patterns of occupants' window-opening, AC and fan usage, and their interrelations were investigated.

## 2. METHODS

Typical daily patterns of window-opening and using cooling appliances during the dry season were surveyed

through face-to-face interviews using a questionnaire form in the following three cities: Johor Bahru, Malaysia (2004, 2006), Surabaya, Indonesia (2013, 2016) and Bandung, Indonesia (2014). Totally 1570 households were interviewed (Table 1). Johor Bahru and Surabaya experience hot-humid climates (the mean daily outdoor temperature is 27-28oC). Meanwhile, Bandung is located on relatively high lands (altitude: approx. 700m) and experiences relatively cool climate (22oC).

## 3. BRIEF PROFILE OF RESPONDENTS

The average household size ranges from 1.9-5.4 people among all samples with an average of 3.8 (Table 1). Household income data were converted into income ratios to standardize currency units among countries and years. As indicated, the income ratio of the respondents is relatively low in Surabaya (7.6-7.9) and high in Johor Bahru and Bandung (8.3-9.4). AC ownership rate is also low in the former city (0%-11%) and high in the latter two cities (35%-61%).

## 4. CLASSIFICATION: DAILY USAGE PATTERNS

All samples (n=1570) were classified into several groups based on the following three hourly usage data: (1)windows/doors, (2)fans and (3)AC. First, we divided them into two groups considering the climates: (i)those in hot-humid climates (i.e. Johor Bahru and Surabaya)

Table 1: Brief profile of respondents.

	Total	Survey 1	Survey 2	Survey 3	Survey 4	Survey 5
Sample Size	1,570	356	303	347	265	299
Survey City / Survey Year	-	Johor Bahru / 2004	Johor Bahru / 2006	Surabaya / 2013	Surabaya / 2016	Bandung / 2014
Mean Daily Air Temperature (Average) (°C)	-	27.1	27.1	28.0	28.0	22.0
House Type / Average Household Size	- / 3.8	Detached / 5.4	Apartment / 4.6	Apartment / 3.4	Apartment / 3.6	Apartment / 1.9
Median Household Income (LCU)	-	4,000 MYR	2,000 MYR	1,800,000 IDR	3,000,000 IDR	4,000,000-8,000,000 IDR
Median Income Ratio*	8.5	9.4	8.8	7.6	7.9	8.3 - 9.0
AC ownership (%)	29.6	61.0	35.3	10.7	0.0	34.8

\*Converted by the exchange rate (Source: The World Bank, Indicators)

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and (ii) those in relatively cool climate (i.e. Bandung). Second, we divided each group whether AC owners or not respectively. Third, a principal component analysis and a hierarchical cluster analysis (squared Euclid's distance, Ward's method) were conducted. As a result, AC owners in hot-humid cities were subdivided into 3 groups (A1-A3), while the non-owners were subdivided into 2 groups (B1-B2) with similar usage patterns of AC, windows/doors and fans respectively (Table 2, Fig. 1).

## 5. WINDOW-OPENING PATTERNS

The daily window-opening patterns are clearly different between hot-humid climates and relatively cool climate. Most of the households open windows during daytime in Groups A-B (14.3 hrs/day), while they open them only morning and evening in Groups C-D (3.8 hrs/day) (Fig. 1b, Table 2). Interestingly, they tend to open windows/doors during daytime even if they have AC in hot-humid climates. This implies they prefer air flow to cool their bodies rather than lower room temperatures. The households of Group B1 tend to open windows/doors during daytime but those of Group B2 close them throughout the day. We asked the reasons not to open windows/doors (multiple-choice answers) and found the proportions of those who answered 'insects', 'privacy' or 'dust' were significantly different between the above two groups (chi-square test,  $P < 0.001$ ,  $P < 0.05$  and  $P < 0.05$ , respectively). In Group B2, more respondents chose 'Dust' as a reason (i.e. during daytime) than those in Group B1. In contrast, in Group B1, more respondents chose 'insects' and 'privacy' than Group B2. There are probably other stronger reasons for opening them in the daytime.

## 6. AC USAGE PATTERNS

Two different patterns can be found in AC usage in the hot-humid climates (Group A1-A3, Fig. 1a). Most of them use AC in sleep time but only households in Group A3 use them from afternoon till evening as well. Thus, the AC usage time of them is approx. twice longer than Groups A1-A2 (Table 2). The average income ratio is significantly different between the AC owners (Groups A1-A3) and the non-owners (Groups B1-B2) (Mann-Whitney U test,  $P < 0.001$ ). This confirms higher-income occupants tend to have AC more. However, the average income ratio is not significantly different between Groups A1-A2 and Group A3. We cannot say higher income is the reason for the longer use of AC.

## 7. FAN USAGE PATTERNS

Overall, fans are used only in hot-humid climates (Fig. 1c). In the hot-humid climates, the fan usage rate of non-AC owners (Groups B1-B2) is higher than that of AC owners (Groups A1-A3) particularly during the sleep time. This is probably because the non-AC owners need to use fans instead of AC to sleep comfortably.

Table 2: Profile of the groups

	Climate	AC	N	Share (%)	AC Usage (hour)	Window-opening (hour)	Fan Usage (hour)	
A1	Hot-humid	Own	47	3.0	6.6	19.9	13.5	
A2			276	17.6	7.3	10.3	11.2	
A3			38	2.4	13.2	11.7	13.9	
B1			-	764	48.7	-	17.0	15.4
B2	Relatively cool	-	146	9.3	-	6.9	11.8	
C			Own	104	6.6	5.5	3.1	0.1
D			-	195	12.4	-	4.2	0.6

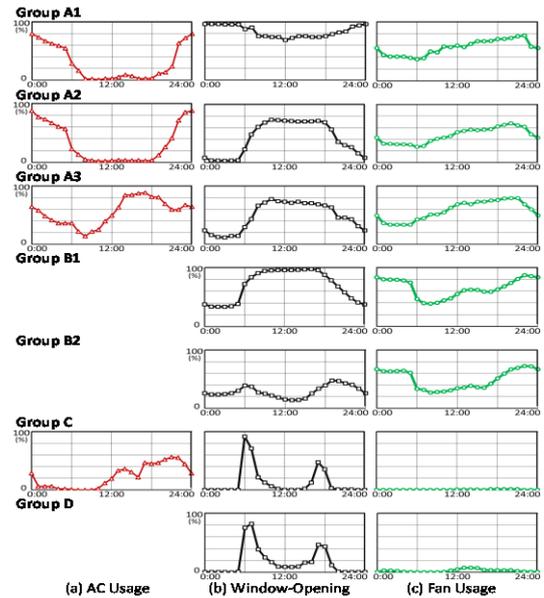


Figure 1: Typical daily patterns of AC usage, window-opening and fan usage by each group.

## 8. CONCLUSION

The typical daily patterns of occupants' window-opening behaviour in hot-humid cities were different from a relatively cool city and could be divided into several patterns. They tend to open windows/doors during daytime even if they have AC. AC was mainly used in sleep time. Non-AC-owners in hot-humid climates tend to use fans in sleep time.

Thermal measurement was also conducted in some housing units, and will be analysed about the relation with daily window-opening patterns in a future study.

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# How Urban Design Can Make Cities Safer for Women?

## A Statistical Analysis of Safetipin

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*ABSTRACT: Safe public spaces that are universally accessible for enjoyment have become important goals for cities around the world. Universal safety is a fundamental requirement for cities to become sustainable and inclusive. Such performance criteria are difficult to measure at the scale of the local neighbourhoods and streets, and this can have life-and-death consequences for vulnerable and marginalised demographics, such as women, children or urban newcomers who are unfamiliar with local dangers and risks. However, technological advances are creating a new landscape for data production, collection and analysis, capable not only to portray routine urban patterns in fine spatial and temporal scales, but also to empower citizens as part of this process. This study analyse the data collected in Bogota and Nairobi through SafetiPin app which was developed in response to the exclusive and unsafe character of neighbourhoods. This mobile app crowd-sources data to identify the factors that lead to lack of safety and insecurity in cities. The findings of this study suggest that lighting, openness, visibility, and public transport could significantly affect the prediction of whether people feel safe. This paper also discusses the extent of this impact.*

*KEYWORDS: Urban Safety, Women, Public Spaces, Crow-sourced data, SafetiPin*

### 1. BACKGROUND

#### 1.1 Urban Safety

Universal access to safe, inclusive and accessible public spaces particularly for the more vulnerable population like women and children is one of the key targets for global initiatives, such as the Sustainable Development Goals (SDGs), specifically SDG 11 which is related to cities. Women's safety in urban environment is not a new topic, and has come to the discourse since 1980s [3]. However, despite all the efforts by international stakeholders to create safer urban environment, women and girls are often exposed to harassment and other forms of violence which limit their access to public spaces. This lingering issue of lack of safety in public spaces is perhaps due to lack of access to the reliable data to reach to a consensus. Despite the significance of this type of data, only coarse statistics are available for cities and urban districts. While the safety and accessibility of cities can differ dramatically from one street to another.

A growing body of evidence shows that women's perception of safety is highly influenced by environmental factors [2], and therefore identifying the parameters that associate with safety in public spaces is of paramount importance.

#### 1.2 Urban safety measurements:

There are some national metrics and statistics reported in the literature that demonstrate that actual conditions of safety in cities, particularly for women, are still far from the set targets by the SDGs. According to UN-Women [5], for example, many countries in the

world do not have legislation against sexual harassment, or do not even have recorded data on the topic. Due to lack of internationally agreed methodology, monitoring urban safety is still very challenging, and results in missing, incomplete and inaccurate data. One factor aggravating this situation is that, even when records exist, sexual harassment, and especially sexual assault, is known to be under-reported by women.

Urban safety, particularly for women, requires more and better data, and frameworks and tools to produce metrics that can be useful at multiple scales, from the local level for urban planning purposes, to more aggregated levels, such as cities or nations, for benchmarking and global comparison purposes. For a study to be successful and impactful in this sensitive area of research, data collection procedure should be designed to include as many vulnerable people as possible. This can be achieved through employing a user friendly method that while generating accurate and large quantity of data, is not identifiable or too complicated for the participants to take part. Also the data should be adaptable and replicable across a wide number of countries, and SafeTipin, as the measurement tool of this study, has well addressed these criteria.

### 2. METHODOLOGY

This study uses SafetiPin [1] to crowd source data related to urban safety. SafetiPin is a mobile app that has been developed in 2013 as a tool to collect data on insecurity in cities. Building on the international methodology of safety audits, SafetiPin collects data with the aim of improving the wellbeing of vulnerable

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population through giving them voice. The two premises of SafetiPin are that 'large-scale data collection can lead to change, and that safety will ensue when more people become engaged with the issue' [4]. This setting and support from UN, led SafetiPin to achieve a global reach, being applied in 30 cities across 10 countries in the world, collecting a large dataset.

SafetiPin rates public spaces using a set of key parameters of safety with a rubric-based method of assessment. The rubric includes the following parameters: (1) light during night; (2) openness of public space; (3) visibility of the space through windows and doors (Visibility of the space to watchers); (4) presence of people; (5) presence of security professionals; (6) quality of walking path; (7) proximity to public transport; (8) balance of gender usage of public space; and (9) feeling/perception of safety. However, this study only analysed the parameters that directly related to urban design and planning. Safety data is collected by voluntary users using the SafetiPin app in their personal mobile phones. In addition to this data from citizens, SafetiPin adds a layer of data through capturing and assessing night time pictures of the city which supplements the user generated data and makes it much more extensive and large scale. This paper analyse the data collected in two case studies: Bogota and Nairobi.

### 3. STATISTICAL ANALYSIS

In order to understand how lighting, openness, visibility, walk path, and public transport correlate with the feeling of safety, a cumulative odds ordinal logistic regression with proportional odds was run.

The final model (Including lighting, openness, visibility, walk path, and public transport as independent variables) statistically significantly predicted the safety feeling over and above the intercept-only model,  $\chi^2(14) = 2326.784$ ,  $p < .001$ . All the independent variables named could significantly effect on prediction of whether people feel safe, except walk path ( $p > .05$ ). Analysis suggests that the state of the walk path- whether there is no walking path available, or it is available but with different qualities- does not have an impact on people's feeling of safety.

### 4. DISCUSSION & CONCLUSION

It is believed "that if spaces are made safe for women, they will be safer for everyone" [4]. Therefore, this study was conducted with the aim of increasing safety for women in public spaces and encouraging urban improvement strategies.

SafetiPin as a safety audit was used to crowd source the data. The methodology involved statistical analysis and regression modelling to identify the indicators of urban safety for women, and the extent of correlation for each indicator. Results indicated that lighting, openness, visibility, and public transport were significantly

correlated with the safety feeling of women in Bogota and Nairobi. Interestingly, women is 29 times more likely to feel safe if the public space is bright compared to when the place is little lit.

Also this study showed that openness, and visibility of the public spaces has a significant correlation with how safe women feel. Women are 15 times less likely to feel safe if the place is not open than if it is completely open, and they feel 500 times less likely to feel safe if there are no eyes in the street than if it is highly visible. This literally means that they don't feel safe if there are no windows, or entrances of shops overlooking the public spaces.

The proximity to public transport was also shown to be significantly correlated with safety feeling. Women were 31 times less likely to feel safe if the public transport was distant than if it was very close.

This study unfolded the relationship between characteristics of public spaces, and feeling of safety for women. The next step will be comparing the two case studies, Bogota and Nairobi, as this can bring some insights on how universal or contextual those relations are. Also, mapping and visualization tools will be developed to better communicate the spatial distribution of urban safety, and their influencing factors. It is hoped that the findings of this paper can assist urban designers in identification of the necessary urban design interventions to improve urban safety for women, and also in developing a good understanding for a better risk management, and developing risk reduction strategies to strengthen the social health and environmental resilience.

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## Perception of Habitability in a Low-income Dwelling in Hot-dry Climate in Mexico: Spatial, Psychosocial and Thermal Habitability

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*ABSTRACT: The purpose of this research was to identify the habitability conditions presented by house for low-income families in an area with extreme hot dry climate such as Mexicali. Field work was carried out, through surveys. Based on the opinion of the occupants of the dwelling, their perception of spatial, psychosocial and thermal conditions of their dwelling were obtained. The results show which the psychosocial aspects, such as perception of security, privacy and pride, are at adequate levels, however, the thermal habitability showed problems throughout the year.*

*KEYWORDS: Perception of habitability, Low-income dwelling, Hot-dry climate*

### 1. INTRODUCTION

In Mexico, public politics follow a trend towards the standardization of housing models, as a way of production that can be available to families whose income reaches up to 3.9 times the minimum salary, which in 2016 represented 65.9% of the beneficiaries of INFONAVIT [1]. The government's priority has been to satisfy the demand for housing, even when the quality of housing affects their own living conditions.

Habitability has different conceptions such as the one that indicates the relation and adequation between man and its environment and refers to each territorial scale (housing complex, immediate environment and dwelling) which in turn are evaluated according to its capacity of satisfying human needs; likewise, this author points out determinants of habitability, including physical-spatial, psychosocial, thermal, light, acoustic, security and maintenance [2]. There are investigations with different approaches to study habitability [3, 4], several of them focused on the conditions of thermal habitability and health risks and others that consider physical and psychological factors related to the internal habitability of the home [5].

The objective of the article is to determine the spatial, psychosocial and thermal habitability conditions of mass-production housing for low income inhabitants in an area of hot-dry climate, such as Mexicali Mexico, with the purpose of knowing how these factors impact the quality of life of the occupants.

### 2. METHOD

Divisions were chosen that had mass construction houses, destined mainly for low-income families. This type of housing has a common space (living room and kitchen), a bathroom and one or two bedrooms. From

the total of 32,901 low income dwellings was estimated the sample. A sample design was made with a confidence level of 95%, margin of error of 5%, probability of occurrence of 30%, which resulted in a sample of 319 homes. A random application design was carried out; however, it found a high amount of abandoned dwellings, users who did not want to answer and security problems in some of the subdivisions. Therefore, it was necessary to redesign the sample to 90% reliability, margin of error of 10% and make a deterministic application.

A questionnaire was prepared, structured according to the type of environmental habitability: spatial, psychosocial, thermal, light, acoustic and olfactory. Spatial and psychosocial habitability are based on the Landázuri and Mercado studies [5]. Respecting spatial habitability, the form, dimensions of the dwelling, spaces for circulation, furniture entry, growth capacity, ease of vehicular and pedestrian access were considered. Psychosocial habitability, understood as security, functionality, vigilance, significance, identity; satisfaction, pleasure. For thermal habitability, questions were asked about thermal sensation, thermal preference, personal tolerance, acceptance of the environment in the warm and cold period [6].

The surveys were captured in Excel format, the consistency of the data was revised and 214 effective records were obtained. A statistical analysis was carried out by means of frequencies.

### 3. RESULTS

#### 3.1. Spatial Habitability

Regarding the size of the house, 44.1% considered it adequate, 34.3% considered fair and 21.2% considered that the size was inadequate. For 48% of the inhabitants

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they mention that spaces for circulation are adequate, 28% say they are regular and 23.7% are bad. However, to move furniture inside the space 51.5% indicate that there are serious problems to move furniture, 25.5% say that moderately and 23% say there are no problems. 44.4% consider that the separation of the home and the street is adequate, which gives them privacy in their home, 36.6% indicate that it is regular and 18.9% that there is no privacy.

### 3.2. Psychosocial habitability

Table 1 shows the main aspects related to psychosocial habitability. The perception of security in the home predominates (68.1%), associated to the 75.2% who said to feel proud to inhabit the house (significance). Regarding to change the aspect of the house (identity), around 50% said they would not like to change it.

*Table 1: Psychosocial perception of the inhabitants of the series construction housing, Mexicali.*

Variables	Percentage (%)				
	Never	Hardly ever	Regular	Almost always	Always
Security	6.3	5.4	19.9	20.5	47.6
Functionality	17.5	12.0	22.9	25.3	22.3
Vigilance	60.2	3.0	4.2	16.9	16.7
Significance	0.0	5.0	19.7	13.4	61.8
Identity	38.0	12.5	16.6	10.9	22.3
Pleasure	15.6	24.0	23.0	30.7	7.2

### 3.3. Thermal habitability

The ambient temperature conditions during summer (May to September) are outside the thermal comfort ranges. 50.9% of the inhabitants feel the environment tolerable, 38% perceive it regular and 11.1% very intolerable. Table 2 shows the degree of acceptance of the environment that the inhabitants of the house have to the impact of the temperature. It is observed that the inhabitants have almost the same degree of non-acceptance of the thermal conditions of their dwelling both in the warm period and in the cold period. Around 40% in both periods manifest regular conditions. Around 20% consider the thermal conditions of their home acceptable in summer and 30.3% consider in winter. This shows that housing presents greater problems of thermal habitability in summer than in winter.

*Table 2: Thermal acceptance perception of the inhabitants of the series construction housing, Mexicali.*

Pe-riod	Percentage (%)				
	Very Unaccep-table	Unaccep-table	Re-gular	Accep-table	Very Accep-table
Warm	12.0	27.8	39.1	20.4	0.6
Cold	7.3	20.6	41.8	27.3	3.0

### 4. CONCLUSION

In general, most of the inhabitants said that the psychosocial aspects, such as perception of security, privacy and pride, are at adequate levels. However, the thermal habitability showed problems throughout the year, with predominance in the warm period. Even when there are critical conditions due to the impact of climate and the size of the dwelling, an adequate psychosocial perception prevails in the inhabitant of mass-production housing in Mexicali.

### ACKNOWLEDGEMENTS

The authors would like to thank the National Council for Housing and the National Council for Science and Technology, for the financial support provided for the "Environmental habitability in housing built in series for cities in Mexico, based on indicators of benefits, social impacts and quality of life", CONAVI-CONACYT 205807.

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# A New Comparative Study of Daylit Area Drawings and Occupant Assessments with Daylight Simulations

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*ABSTRACT: This paper aimed at an approximation of daylight availability metrics and users' perceptions in order to understand if the daylight metrics approach the users' visual experience on the sufficiency of natural light in classroom spaces in the city of Florianopolis / SC, Brazil. The study allowed the comparison of the results by simulations of Daylight Autonomy performed throughout the software DIVA Plug-in Rhinoceros 5.0, with visual perception drawings, conducted by 256 users of three classroom environments. This comparison indicated which simulated parameters correspond more closely to the evaluations of daylit area, partially daylit area and non-daylit area in study spaces. There was a greater proximity between the DA500lux [50%]/ DA 250lux [50%] parameters in the first two rooms studied, and DA 300lux [50%] / DA 150lux [50%] in the third room analysed. The results evidenced the relation of aspects of visual perception not only with illuminance values, but also with the physical measurements of surface brightness, expressed through the visual field luminances. Since it is known that in addition to criteria of horizontal illuminance levels in the work plane, several factors influence the process of visual perception and characterization of the conditions of the light environment.*

*KEYWORDS: Daylighting, Occupant evaluations, Drawings, Daylight autonomy*

## 1. INTRODUCTION

Daylighting is a dynamic process, which presents temporal and spatial alterations, so the most ambitious challenge in natural lighting design is to maintain the balance between maximizing lighting conditions throughout the day and the user satisfaction. In this context, some of the scientific community's authors [1,2,3] raise the question of which the ideal criteria are to evaluate and verify that an environment is satisfactorily illuminated by natural light, once it is the architecture that defines important aspects of the light, but it is the user who perceives and evaluates in their experience in the environment.

What is a well daylit space? And what are the appropriate illuminance levels to consider that an area has sufficient or adequate daylight? Do they effectively respond to user satisfaction? The answers to these questions are complex and subjective. In order to provide information about daylit spaces and the application of daylight metrics, some studies aim to understand how well the results of natural light metrics obtained from computer simulations represent the user's reviews about the sufficiency of natural light in real spaces [3,4,5].

Great part of these studies already accomplished, deal with research produced in the Northern Hemisphere. There is a lack of studies in the Southern Hemisphere, with relevance in subjective evaluation considering local climatic aspects. Thus, the objective of this research is to investigate the association among the user's perception about the natural lighting behavior in classrooms spaces in the city of Florianopolis/SC, Brazil,

and parameters that characterize numerically daylighting conditions obtained in computer simulations.

## 2. METHODS

The methodological process of the research is organized in: experimental research, numeric characterization of the natural lighting conditions through computational simulations, and correlation between the users' perception with simulated daylight results.

### 2.1 Field Study

The field study was conducted in two classrooms (ARQ 201 and ARQ 204) of the department of Architecture and Urbanism at the Federal University of Santa Catarina-Florianopolis/SC, Brazil, and in a third classroom of another building (305 EFI), also at the Federal University of Santa Catarina-Florianopolis/SC, Brazil.

### 2.2 Experimental Setup

The experimental research involved 256 evaluations of students and volunteers about the natural lighting in the study spaces. To evaluate the spaces under different sky conditions, visits were accomplished in days with different sky conditions and in different schedules, synthesized in Table 1. Evaluations were conducted with all electric lights off and any movable shading systems fully retracted (opened).

To survey information about the perception of natural light, users experienced the study space for a period in order to experience the multiple points of view of the space. Then, the user was instructed to

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independently evaluate the behavior of natural lighting in the environment through drawings representations.

Table 1: Experimental study visits

	Day	Schedule	Sky conditions	Nº of users
ARQ 201	10/11/17	05:00 pm	Very Overcast	11
	16/11/17	12:50 pm	Clear Sky	10
	23/11/17	09:30 am	Variable	10
	30/11/17	04:00 pm	Variable	11
	08/12/17	08:40 am	Clear Sky	3
	12/04/12	15:30 am	Clear Sky	3
	04/05/12	12:30 am	Clear Sky	1
	07/05/12	10:40 pm	Clear Sky	4
			<b>Total: 53</b>	
ARQ 204	03/11/17	09:40 am	Variable	15
	08/11/17	08:30 am	Overcast	12
	08/11/17	02:50 pm	Overcast	23
	22/11/17	11:25 am	Clear Sky	23
	01/12/17	09:30 am	Overcast	13
	01/12/17	11:10 am	Variable	14
	08/12/17	08:00 am	Clear Sky	3
	23/04/12	12:00 am	Overcast	3
	07/05/12	10:50 am	Clear Sky	2
	17/05/12	01:40 pm	Variable	10
			<b>Total: 118</b>	
EFI 305	17/11/17	01:45 pm	Variable	63
	27/11/17	03:30 pm	Variable	19
	08/12/17	09:30 am	Clear Sky	3
			<b>Total: 85</b>	

## 2.3 Daylit Drawings Evaluation

Users were asked to divide, according to their own perception, the study area into daylit and non-daylit areas. The users' subjective information were compiled, identifying the limit of the areas considered "fully daylit" (>75%), "partially daylit" (>25% <75%) and "non daylit" (<25%), through the "area-based" averaging function [4,5].

## 2.4 Simulation Parameters

Parallel the analyses of the user's perception, was obtained through simulation computational, the Daylight Autonomy (DA) measure. Study spaces were modelled in Rhinoceros 3D 5.0 program and simulated through DIVA-for-Rhino. Were adopted for Daylight Autonomy (DA) the illuminance minimum averages 500lux, 300lux, 250lux and 150lux, with minimum level of 50% of occupied hours.

## 3. RESULTS AND DISCUSSION

Based on the methodology applied in this research, a first approximation of daylight parameters and user perception was generated. This comparison indicates that DA500lux [50%]/ DA 250lux [50%] parameters correspond more closely to the qualitative assessments of daylit areas and non-daylit areas in study spaces in the first two rooms studied (ARQ 201 and ARQ 204), as shown in the figure 01 a) and b). In the third room analysed, there was a greater proximity between users' perception and DA 300lux [50%] / DA 150lux [50%] (Figure 01 c)).

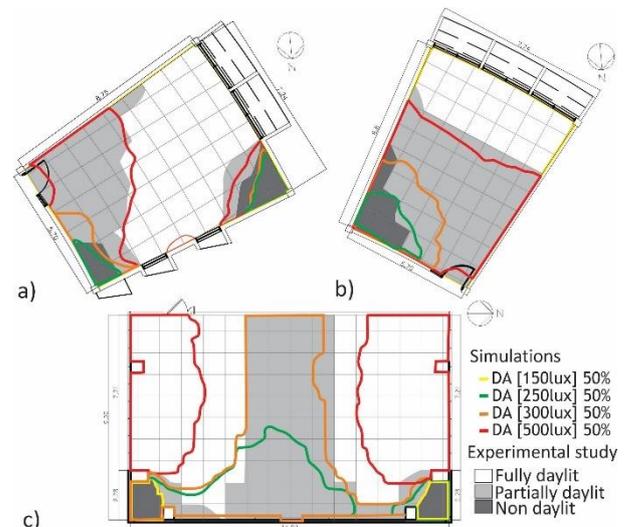


Figure 1: Comparison of user's evaluations with DA 150lx, 250lx, 300lx and 500lx. a) ARQ 201 b) ARQ 204 c) EFI 305

It should be emphasized that the two analysed spaces located in the building of the Department of Architecture and Urbanism, ARQ 204 and ARQ 201, have materials with high reflectance. The results evidenced the relation of aspects of visual perception not only with illuminance values, but also with the physical measurements of surface brightness, expressed through the visual field luminances. It is inferred that the magnitude of average luminance might influences the user's visual perception changing the values of illuminances that will satisfy the user.

## ACKNOWLEDGEMENTS

The authors would like to thank CAPES and CNPq for the financial support.

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# Designing Green Spaces for Elderly Residents in Densely Built Neighbourhoods

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**ABSTRACT:** In World Health Organization's Global Age-Friendly Cities Guide, green spaces have been identified as essential age-friendly features in urban environments. A pilot study had been conducted to study the interrelationship between key design aspects of green spaces, health conditions of elderly residents, and their perception and preference of the green spaces using questionnaire survey. It was also found that perceived safety in green areas is associated with the aesthetic quality and the physical health of elderly residents. The results also reveal individual differences among elderly residents in perception of green spaces and the associated health outcomes. Moreover, this study showed that plant colour and maintenance of green spaces are the key design and management aspects that linked to objective assessment on aesthetic quality. Findings of the study will inform the planning and design of age-friendly urban environments in high-density cities.

**KEYWORDS:** Urban Green Spaces, Ageing Society, High-Density Cities

## 1. INTRODUCTION

Asia will lead the world in population aging. Asia has more than 50% of world population, and rates of demographic aging in Asian countries such as Japan, Korea, China, and India are among the highest in the world [1]. In Hong Kong, the proportion of elderly people aged 65 and above is expected to exceed 30% (approximately 2.6 million) by 2041 (Financial Secretary's Office, HKSAR Government, 2013). Ageing and urbanization are closely related. 80% of elderly population in developed countries are living in cities, and so will be some 25% in developing countries by 2050 [2]. In the Global Age-Friendly Cities: A Guide [3], clean and safe green spaces have been identified as essential age-friendly features. Studies showed that older adults in high-density cities spend a considerable amount of time in urban green spaces [4]. It is of great importance to study the design of urban green spaces and the potential positive role in promoting health and active ageing in cities [5].

## 2. METHODOLOGY

The study focused on two high-density cities with sharp growth in elderly population: Hong Kong and Tainan. In both cities, green fragments along the streets and small parks spread in compact residential districts were selected to conduct the survey, as small-scale green spaces within easy walking distance are often highly valued by elderly people [6]. Cluster sampling is an effective and efficient means to evaluate a large population. Two rounds of questionnaire surveys were conducted between December 2016 to January 2018. With questionnaire designed based on previous studies [7,8] and the SF12v2 Health Survey, the first round of the

survey is to probe older adults' perception towards green spaces in densely built urban areas, and the effects of individual factors such as age and health condition. The second round of the survey is to further investigate the key design aspects identified from the first round, and to study detailed design solutions.

93 persons in Tainan and 118 in Hong Kong participated in the first round of the survey, and another 120 participants in Hong Kong joined the second round of the survey. Correlation coefficient test, moderated regression analyses and associated subgroup analyses, and generalized linear test were conducted for data analysis using SPSS (Version 22.0, IBM SPSS Statistics).

## 3. RESULTS

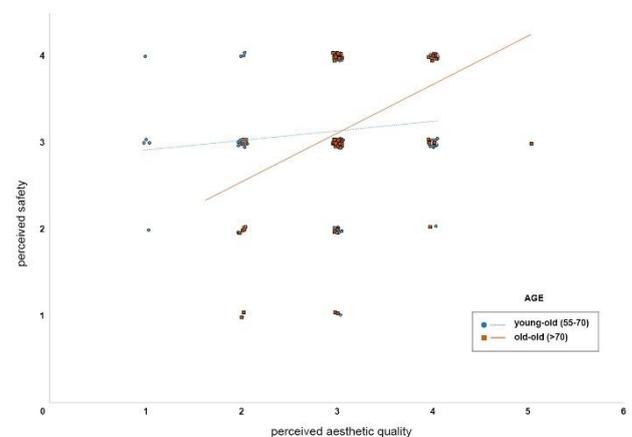


Figure 1: Relationship between aesthetic quality and perceived safety as moderated by age.

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## 3.1 Perceived safety in green spaces

The results of the two cities share common patterns in terms of the perceived safety in UGS. Positive correlations were found between the perceived safety and aesthetical quality of UGS in Tainan ( $r = 0.28, p = 0.007$ ) and Hong Kong ( $r = 0.24, p = 0.011$ ). It indicates that older adults feel safer in UGS with higher aesthetical quality. Furthermore, respondents' perception of safety in UGS of both cities was linked to the physical function of elderly visitors. In Hong Kong, perceived safety presents a strong correlation with Role Physical Score ( $r = 0.25, p = 0.006$ ), indicating role limitations due to physical health, and a positive correlation with the Bodily Pain Score ( $r = 0.20, p = 0.027$ ). On the other hand, results of Tainan showed a significant correlation ( $r = 0.23, p = 0.030$ ) between the perception of safety and Role Physical Score. It indicates that for elderly visitors, physical health conditions would affect the perception of safety in green spaces. Our results agree with Bhalla and Proffitt [9], who stated that people with poor health would perceive the environment as more challenging.

Data collected from the first round of the survey (Hong Kong and Tainan) were analysed with moderated regression. The results showed that age is a powerful moderator in the association between the perception of safety in green spaces and the aesthetical quality ( $F(1,212) = 4.81, p = 0.03$ ). It indicates that the aesthetic quality of UGS is more important to perceived safety for old-old visitors (age above 70), compared to their young-old counterparts (Figure 1). Previous study [10] pointed out that safety concern is a barrier for older adults to visit green spaces. In this aspect of the work, it is necessary to further study the detailed design aspects related to perception in green spaces.

## 3.2 Design aspects related to older adults' perception of green spaces

*Table 1: Coefficients (dependent variable: assessment of overall aesthetic quality)*

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.303	.407		3.203	.002
Plant Colour	.234	.125	.238	1.868	.049
Shape and Geometry	.194	.120	.209	1.609	.111
Diversity	-.047	.093	-.054	-.499	.619
Seasonal Variation	.013	.066	.017	.191	.849
Maintenance	.227	.101	.228	2.250	.027
Proportion of Soft Surf	.066	.108	.065	.609	.544

Multiple regression was run to further investigate detailed design aspects that linked to the objective assessment on aesthetic quality in green spaces. The multiple correlation coefficient R, with a value of 0.57, indicates a well fit of the model and good level of prediction. The test for the statistical significance of each of the independent variables showed that plant colour ( $p = 0.049$ ) and maintenance ( $p = 0.027$ ) are significantly correlated with the evaluation of aesthetic quality of

green space (table 1). The results showed that for every one unit increase in rating of plant colour, the overall aesthetic quality is evaluated 0.234 units more positively on average; and for each one unit increase in rating of maintenance, there is a 0.227 unit increase in the overall aesthetic quality assessment.

## 4. CONCLUSION

This paper showed for older adults, individual health condition affects perception of safety in urban green spaces. A significant relationship between aesthetic quality and perceived safety was found, and age presents strong moderating effect on the relationship. It reveals old-old people are sensitive to aesthetic quality of urban green spaces. Furthermore, this study showed that plant colour and maintenance of green spaces are the key aspects that linked to objective assessment on aesthetic quality. Findings of the study will inform designers in creating age-friendly urban environments in high-density Asian cities.

## ACKNOWLEDGEMENTS

This research is supported by the Hong Kong Research Grants Council General Research Fund under Grant 14603617 and Vice-Chancellor's Discretionary Fund of the Chinese University of Hong Kong.

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## **EDUCATION AND TRAINING**

Inspiration, knowledge, and innovation come with education and training. They empower professionals, practitioners and even laymen to play a part in future city development. Opportunities and issues related to the dissemination of knowledge are discussed in this track, for example:

- architectural education for low energy and sustainable design
- professional development, training and certification for a low energy future
- innovative methods, experiences and teaching techniques on passive low energy design
- lifelong learning and continue education for sustainable architecture and low energy design

## When Buildings Converse with Climate: Can Technology Mediate the Dialogue between Climatic Forces and Building Design?

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*ABSTRACT: It has been argued that buildings have evolved and adapted well in their response to social and economic context but have increasingly become indifferent towards local climate, completely relying on energy-consuming add-on systems to provide for occupant comfort. It doesn't help either that contemporary energy standards encourage a similar idea of first thermally isolating the occupied spaces from the environment and, only then, employing efficient active systems for space conditioning. This paper illustrates a course structure where students and faculty collectively explored and discovered the potential of an integrated configuration of envelope and energy systems that positively interacts with exterior environment and enhances indoor comfort conditions with minimal energy use. The focus of this paper is to present how a critical approach of understanding climatic design principles can be developed through reverse synthesis of exemplary built examples. With a focus on occupant comfort and energy use, the students explored the potential for environmental response to different climates using a deconstructed version of a known existing building as inspiration to reference new designs.*

*KEYWORDS: Passive Strategies, Climate Responsive Design*

### 1. INTRODUCTION

As part of a winter school course at the CEPT University in Ahmedabad, India, students, and faculty collectively explored and discovered the potential of an integrated configuration of envelope and energy systems that positively interacts with exterior environment and enhances indoor comfort conditions with minimal energy use. By first taking onsite measurements and developing a calibrated computer-based simulation model, shown in Fig.1, students assessed the climate responsive strategies incorporated in the iconic Le Corbusier designed Mill Owners building [1]. This understanding acted as inspiration to reference new designs starting from a baseline version of the existing building. The method took a generic cross-section of the building and generated multiple iterations that respond to various climatic conditions. Within the programmatic boundaries of the existing design, students explored the effectiveness of envelope, interior layout, materiality, and conditioning strategies that should vary in response to place. The students were divided into four groups and assigned a unique city in four distinct climate types: Tropical Sao Paulo, Temperate New York, Polar Moscow, and Mediterranean Melbourne. The exercise was designed to heighten the awareness of how a building design can be adapted to the characteristics of the local climate.



Figure 1: Graphic rendering of baseline simulation model

The goal was to develop a climate responsive approach towards high performance design that stems from a rigorous understanding of a building's environmental, physical, and technological context. Day one consisted of climate analysis and identification of critical design strategies responding to the respective climate conditions. On day two, main building sections of the proposed design were developed with passive strategies incorporated in the design. Session on day three identified, through computer simulation, the construction types and material properties suitable for each climate. On day four, students revised the building massing responding to daylighting and natural ventilation.

### 2. BASELINE CHARACTERIZATION

Onsite measurements for interior air and surface temperatures, local air speeds, and daylight levels,

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presented in Fig.2, illustrated that the building in fact achieves indoor thermal and visual comfort conditions entirely passively in line with the design intent described extensively in several publications [e.g. 2, 3]. In addition to the clearly articulated exterior shades that control solar heat gains, the building form is oriented to prevailing winds and facilitates cross ventilation, thermal mass utilizes the diurnal temperature swing and preconditions incoming outside air, and the façade integrated vegetation to cool outside air with evapotranspiration.

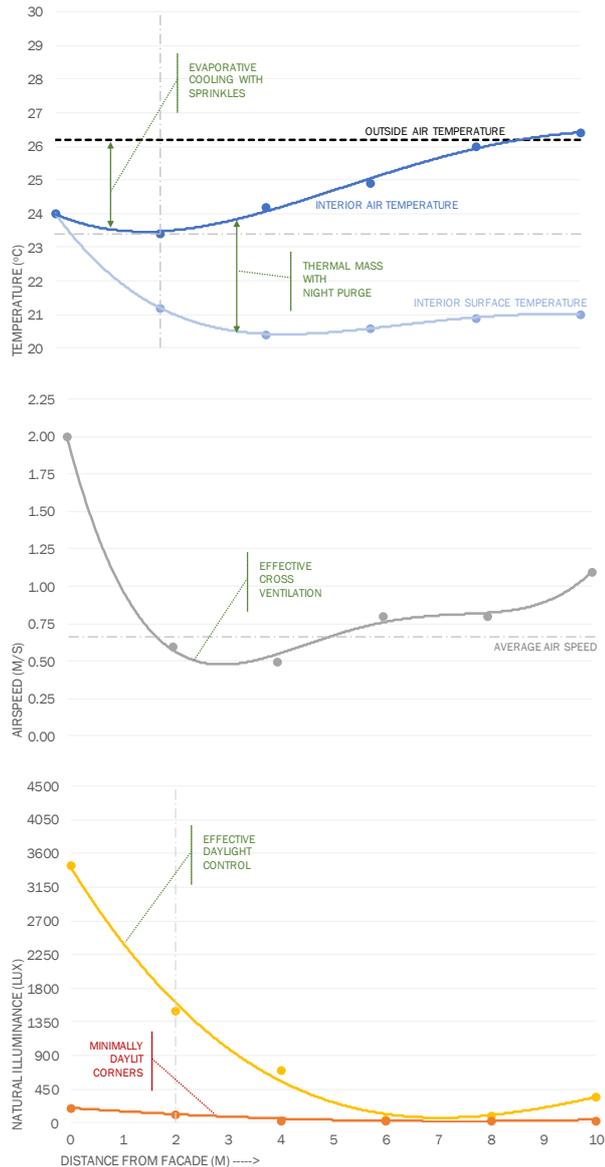


Figure 2: Spatial temperature, air speed, daylight distribution showing thermal and visual comfort conditions achieved passively

### 3. DESIGN PROCESS

Once the students developed an understanding of the bioclimatic principles incorporated in the existing design, and replicated that performance using baseline simulation models; individual groups developed their own interventions to modify the current configuration in response to their respective climatic context. Fig.3 presents energy analysis results showing potential energy reduction with envelope improvements for the different climates. This understanding of the impact of envelope constructions on building energy use informed the building skin configuration for each climate, which was then also studied for daylight effectiveness (Fig.4) via computer simulation models.

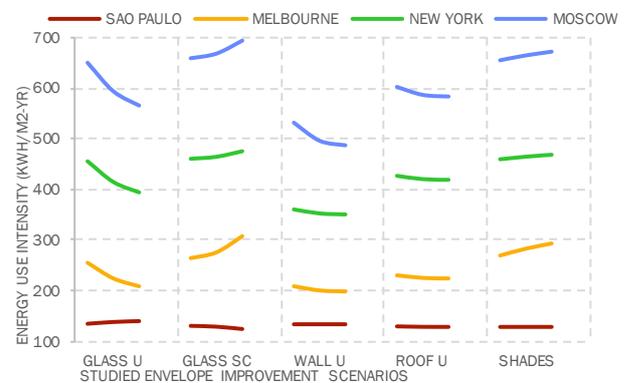


Figure 3: Representative energy analysis results for envelope improvements in different studied climates

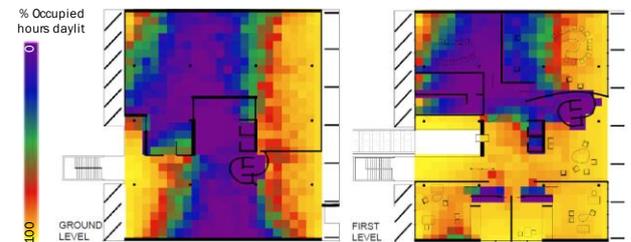


Figure 4: Representative daylight analysis showing natural illuminance distribution with proposed envelope configuration

### ACKNOWLEDGEMENTS

The course was generously supported by the Summer Winter School at CEPT University. The authors further acknowledge the help and guidance from Prasad Vaidya and Sanyogita Manu, and thank the M.Tech in Building Energy Performance program class of 2016 for their enthusiastic participation.

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## Students' Low Energy Luminaire Design Projects

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**ABSTRACT:** Three low energy luminaire projects, in which architecture and design students participated, utilizing LEDs, local materials and/or 3D printing were evaluated in this study: A) temporary luminaire compositions featuring local material assemblies produced in graduate architecture student charrettes in Thailand, illuminated with LEDs, assembled and photographed as part of a Fulbright workshop; B) 3D printed prototypes of luminaires produced by interior design students exploring light and shadow patterns and exploring a new modeling technology and C) U.S. EPA-funded LED desk lamp project by undergraduate students; exhibited at the National Sustainability Expo. The three projects' requirements were different. A and C had an emphasis on available material and sustainability, B had a technology emphasis and used biodegradable material. Researchers found students' luminaire design projects exhibited a great deal of variation across the convenience sample (n= 5, 22 and 18 for A, B and C respectively). Team compositions and disciplines varied. The use of various attributes: 3D printing; sustainable, local, or "found" materials; technology; light sources; and universities' facilities' with workshop availability varied across the projects. For B, 73% of participants reported the use of 3-D printing improved their effectiveness as an Interior Designer. Each project presented a unique learning opportunity.

**KEYWORDS:** Lighting, Technology, Sustainability, Students

### 1. INTRODUCTION

One of the fundamental elements of architectural design is light. Artificial light is required in buildings as a daytime supplement for the completion of some visual tasks and also for building activities transpiring during nighttime hours. It is estimated that artificial lighting consumes about 22 percent of electricity in the United States [1] alone. The demand is growing for low energy buildings. However, there is no global definition for a low-energy building. Because national standards vary considerably, 'low energy' developments in one country may not meet 'normal practice' in another [2]. One definition stated that a low energy building is any type of building that uses less energy than a regular building. It is generally considered to be one that uses from 30 kWh/m<sup>2</sup>a to 20 kWh/m<sup>2</sup>a (9,500 Btu/ft<sup>2</sup>/yr to 6,300 Btu/ft<sup>2</sup>/yr). [3] There is a need for low energy luminaires (lighting fixtures) and efficient lighting strategies [4]. Some use Light Emitting Diodes (LEDs) and it is estimated that by 2020 LEDs will be used in 61% of the lighting market [5]. The U.S. Department of Energy (DOE) reports that "Energy Star"-rated LEDs are expected to use at least 75% less energy when compared to incandescent lighting [6]. LEDs are also long-lived, which reduces light bulb replacement waste [7]. LEDs' color temperature and color quality varies [8]. Other innovations, such as 3D printed luminaires with customization to meet individual lighting needs while being functional, unique and sustainable [9], may also result in less energy consumption when combined with design strategies like the heat-sink design that allows for effective heat transfer from the LED module to the surrounding air [10].

Another low energy strategy is the use of local materials which reduces transportation distance and costs as well as the carbon footprint [11].

### 2. METHODS

Three low energy luminaire projects, in which architecture and design students participated, utilizing LEDs, local materials and/or 3D printing were evaluated in this study: A) temporary luminaire compositions featuring local material assemblies produced by graduate architecture students in Thailand, illuminated with LEDs (refer Figure 1); B) 3D printed prototypes of luminaires produced by interior design students exploring light and shadow patterns, and new modeling technology (refer to Figure 2), and C) U.S. Environmental Protection Agency (EPA)-funded LED desk lamp project by undergraduate students; exhibited at the National Sustainability Expo held on the National Mall in Washington DC (refer to Figure 3).



Figure 1: Project A - Instructor-provided baskets held local Thai materials and artifacts for students' experimentation.

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Figure 2: Project B - 3D printed prototype luminaire design student project in USA.



Figure 3: Project C - Students with instructors presented their luminaire projects at the U.S. Environmental Protection Agency (EPA) National Sustainable Design Expo on the National Mall in Washington D.C., USA. Photo to the right: courtesy of EPA.

The three projects' requirements were different. A and C had more emphasis on available material and sustainability, B had a technology emphasis and used biodegradable material for 3D printing.

### 3. RESULTS AND DISCUSSION

Luminaire projects appear to be a favorite vehicle of instructors, domestic and abroad, seeking to teach their students about light. Researchers found that students' luminaire design projects exhibited a great deal of variation across the convenience sample (n= 5, 22 and 18 for projects A, B and C respectively). The results are summarized in *Table 1*, below. Team compositions and disciplines varied. The use of various attributes: 3D printing; sustainable, local, or "found" materials; technology; light sources; and universities' facilities' with workshop availability varied across the projects.

Table 1: Variables of interest across the three projects

Variable	Project A	Project B	Project C
Team composition (undergrad-U & grad-G)	G	U	U
Sustainable Material	Yes	Yes	No
Local Material	Yes	No	No
Found material	Yes	No	Yes
Computer Aided Design	No	Yes	No
Digital photography	Yes	No	No
3D printing	No	Yes	No
Light source	LED	Energy Efficient*	LED
Workshop availability	Yes	No	No

\* Student options included Compact fluorescent, LED, Organic LED

For Project B, 73% of the participants reported that the use of 3-D printing improves their effectiveness as an

Interior Designer. This could result in the availability of a variety of 3-D printed lighting fixtures for consumers that would not otherwise be available using traditional methods. Each project presented a unique learning opportunity for students.

### 4. CONCLUSION

Each of the projects used for a comparison analysis in this study integrated various elements of sustainability, technology and teamwork. It is recommended that future student luminaire design projects focus on the integration of sustainability with technology while employing team efforts.

### ACKNOWLEDGEMENTS

The authors wish to acknowledge funding received: Fulbright Specialist Project and U.S. EPA P3 program.

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# Do 'Green' Academic Buildings Actually Support Teaching and Learning?

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<sup>2</sup>United Nations 10 Year Framework of Programmes, Sustainable Buildings and Construction Programme

*ABSTRACT: There are pressures to showcase adoption of green buildings in universities for several reasons, including, demonstrating leadership, aligning with sustainability vision of the university and "walking the talk". New generation learning and teaching spaces are moving away from the model of didactic teaching and learning towards two-way teaching and learning models. While university buildings are incorporating such new teaching and learning models into their buildings, there is little or no evidence that green teaching spaces are actually supporting student learning outcomes. In comparison, the literature is rich with post occupancy and thermal comfort studies undertaken in green office spaces. This paper presents a case study of a green building in a Victorian university in Australia. The building was considered to be an example of Australian excellence and has received a number of awards. Using one classroom in the building, the researchers monitored the temperature, relative humidity, and CO<sub>2</sub> levels in this classroom during a two week peak period of a summer intensive program. The findings suggest that this particular classroom did not always provide comfortable conditions for teaching and learning. More research is required to draw definitive conclusions.*

*KEYWORDS: Green buildings, Education, Teaching and learning, Classrooms, Universities*

## 1. INTRODUCTION

This paper documents a single case study to provide some insights into understanding links between thermal comfort and learning outcomes in educational spaces in an university. The project uses a simple approach to understanding the link between indoor environmental quality (IEQ) and anticipated learning outcomes of a learning and teaching space in an Australian university. The approach taken examines how selected readily measurable aspects of IEQ compare to reference standards over a typical teaching period (air temperature (ta), relative humidity (RH%), and carbon dioxide concentration level, CO<sub>2</sub> (ppm)) in the peak of summer in Australia.

## 2. IEQ AND EDUCATIONAL SPACES

IEQ can be considered from a wide range of perspectives, however measurable aspects are commonly described in terms of the domains of acoustic, light, thermal and air quality [1, 2, 3]. Comprehensive evaluation remains challenging so studies typically aim to evaluate individual aspects of IEQ when seeking to establish causal links to comfort as well as to educational outcomes.

The connections between IEQ and educational outcomes can be readily imagined and anecdotally supported, however there remain few studies that draw definitive conclusions regarding comprehensive causal relationships [3]. Mendell and Heath [3] put forward a general hypothesis that the causal connection between learning and IEQ in schools might occur through either health or discomfort. Discomfort affects performance

when occupying the learning space, and health affects attendance and impaired performance.

Limiting the review to the domains of the thermal environment and air quality, standards for performance assessment can be identified. Assessment of thermal aspects of IEQ can be undertaken using the established principles of thermal comfort, well described by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) [4] for air-conditioned buildings. Air quality may be indicated by a wide range of possible measures as described by European standards [5] of which carbon dioxide concentration is one such indicator.

Voluntary standards may be employed by organisations to complement mandatory standards. One such approach involves employing Green Star rating in Australia when undertaking the construction of new learning and teaching spaces [6, 7]. Within the Greenstar assessment framework set up by the Green Building Council of Australia (GBCA), this relates to Thermal Comfort (Credit 12) and Indoor Air Quality (Credit 8) [8]. A subset of these requirements can be readily assessed, as described in the following section.

## 3. METHOD

A learning and teaching space (400 m<sup>3</sup> approx.) was considered within a recently built (4 years old), Greenstar rated, multi-story building at an urban university campus in Melbourne, Australia. Enhanced performance requirements relating to thermal comfort and indoor air quality were assessed during the delivery of a post-

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graduate course over 10 days in the peak period of summer (January).

The building provided minimal opportunity to modify the indoor environment by the 20 students participating in the course. Windows were fixed and the heating, ventilation and air conditioning (HVAC) system was entirely automated (automation incorporates the sensing of indoor pollutants and room usage via a centralised timetable database).

Enhanced performance parameters considered (drawn from of GBCA [8]) were:

- Measured carbon dioxide concentration levels: less than 800ppm under normal operating conditions.
- Thermal comfort: 80% occupant acceptability level in accordance with Section 5.2/5.3 of ASHRAE Standard 55-2013 [4].

Measurement was achieved using a recently purchased Hobo MX1102 data logger, measuring  $t_a$  (accuracy: +/-0.21 °C), RH (accuracy: +/-2%RH) and CO<sub>2</sub> concentration (accuracy: +/-50ppm, ±5% of reading).

For thermal comfort assessment, airspeed and radiant affects in the room were assumed to be minimal ( $t_a$ =operative temperature  $t_o$ ), and students were assumed to have a metabolic rate of 1.1 *met* (sedentary, relaxed typing) and clothing insulation of 0.7 *clo* (typical summer business attire).

## 4. RESULTS AND CONCLUSION

Results of the study showed that the building was achieving enhanced air quality and thermal comfort targets most of the time (Figure 1). The upper temperature limit for thermal comfort was assessed at 26 °C using CBE [9], exceeding at the end of the class, which concluded at 4 PM each day.

As a learning and teaching space this deterioration in thermal comfort toward the end of the class may adversely impact learning outcomes as students are likely to be fatigued when lecturers seek to consolidate the days learning. Often, this is in the form of ensuring key learning outcomes are reiterated as key messages.

The case study assessment undertaken illustrates the potential difference in IEQ specification needed in a learning and teaching space, if it is to be effectively optimised for its purpose. The example highlights that 'Green' building performance settings, based on commercial buildings, are insufficient when it comes to learning and teaching facilities.

More research needs to be undertaken to draw definitive conclusions. One way to achieve this is to monitor teaching and learning spaces during seasonal highs and lows in identified teaching and learning spaces.

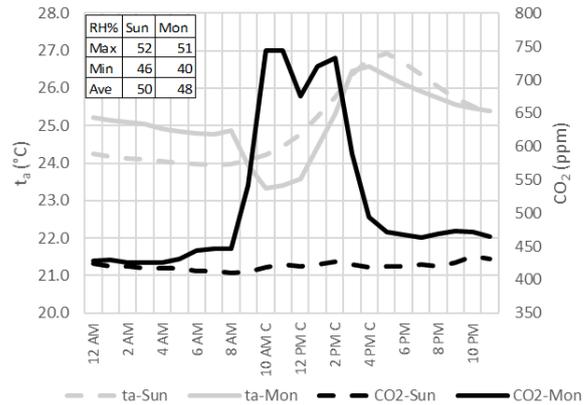


Figure 1:  $t_a$  and carbon dioxide concentration for typical unoccupied (Sunday) and occupied (Monday) periods.

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# Expert in Energy Design and BIM Energy Analysis Tools: A New Core Module for the ABITA Master Postgraduate Training Course

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*ABSTRACT: Building energy performance optimization requires an integrated design approach to explore and evaluate alternative strategies for energy saving and to improve construction process management. Energy efficiency education into architecture and engineering curriculum should address economic, social and environmental issues arising from the technology as well, training professionals and technicians who wish to be able to develop core skills in those subject areas according to a multidisciplinary educational approach. This paper presents the experience of a Postgraduate Master Degree Program at University of Florence, Master ABITA, that includes studies on low energy architecture and energy efficiency measures, integration of renewable energies in buildings, Building Information Modelling and Energy Simulation Analysis tools.*

*KEYWORDS: Buildings Energy Efficiency, Postgraduate Education, Energy Management, BIM, Energy Design Tools.*

## 1. INTRODUCTION

In recent year several education initiatives focusing on buildings energy saving have been carried out to attempt the needs of professionals with specific skills in technology or policy areas, architecture, engineering, economics, management and environmental science to enable them to plan, design, evaluate or research energy supply and design strategies to reduce energy consumption according to an economic sustainable development. [1]

The existing renewable-energy education and university training programs need to overcome many challenges that include first of all the unavailability of well-structured curricula on renewable-energy education [2].

Moreover, several international standards like ISO 14001 (ISO, 2004) or ISO 50001 (ISO, 2011) introduce the role of energy managers both in industrial companies and in the building sector [3]. Well-designed training programs for energy managers and AEC curriculum's customization are also required to meet the growing needs of energy experts from building industry.

The future challenges of the education and training program are related to follow-up activities, the development of interactive tools and the curriculum's customization to meet the constantly growing needs of energy experts from industry. New technologies and tools for a sustainable architecture design have to be included into an integrated process, as well as renewable resources, innovative systems design, industry structures and policies, economic, social and environmental issues.

## 2. MASTER ABITA POSTGRADUATE TRAINING COURSE

### 2.1 Topic and Program

Since 2003 the University of Florence offers a Postgraduate Master Degree Program in Sustainable Architecture and energy efficiency in buildings, the Master ABITA, which aims at educate and train students in the use and development of competitive skills and tools for energy efficiency.

The Master ABITA consists of four modules:

- *M1-Sustainable architecture and building deep renovation*
- *M2-Integrated design process for Nearly Zero-energy buildings\_Energy Manager core module*
- *M3-Building Energy Simulation and Analysis*
- *M4-Build the future: Smart Cities and nZEB*
- *ML- Professional project work*

The course runs over a year, and modules are scheduled based on 6 months with a 2-3 days class per week, mixing both theoretical lessons and workshop sessions. The Master ABITA addresses energy efficiency topics focusing on sustainable architecture and deep renovation, with reference to different Best Practices for Nearly Zero Energy Buildings and to the most innovative solutions for envelope technologies such as adaptive envelope, smart facades, high performance glass facades, integrated PV technologies, innovative shading systems, etc.

Master ABITA has been renewed over the time considering following aspects:

- industry involvement for learning integrated practices;
- project-based learning and on-the-job training experience.

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Figure 1: nZERO-Foundation, Arch. Danilo Rinaldi, Final Thesis Project, Master ABITA 2015/16.

Students learn about products technology innovation directly from partner companies involved into thematic workshops, guided tours to products manufacturing factories, exhibitions and expo dedicated to the Architecture and the Construction sectors. Industries partnership also allows students to establish professional relationships, internships and employment opportunities.

According to UNI EN ISO 50001 and international standardization of professional training, in the last year Master ABITA has introduced a new core module for the qualification of Energy Manager for industrial and civil sector (UNI CEI 11339:2009). Course topics include a technical overview of energy management, building monitoring and targeting, energy auditing, solution development, and regulations and standards. It provides participants with comprehensive knowledge and skills they need to energy saving design, to evaluate financial savings and reduce operational costs, achieving sustainable goals such as carbon emissions reduction.

At the end of the module participants meet the knowledge requirement to attend the exam for Energy Manager qualification, according to EGE TUV and UNI EN ISO 50001.

## 2.1 Methods

Training methods focus on an integrated design methodology throughout the building life cycle including design, operation, management and decommission

phase. Learning activities are designed to enable students to transfer knowledge into their future practice as professionals and building technicians.

Applicative methods and BIM tools are adopted according to European Directive 2014/24/EU that requires the use of BIM procedures and digital processes in public buildings construction.

The Master course includes a series of activities which consist of lectures, computer labs and workshops. Step-by-step coaching, handouts, video tutorials, classroom follow-up and interactive simulations are also implemented as software tutoring methods.

Students will be involved in an education process integrating BIM methodologies with energy simulation tools. By applying BEM methods to a project case study, students are able to perform a Model-Based project evaluation on building energy performance optimization (Fig.1-2), contributing to decision making at the early stages of design process and improving the whole building construction quality into an interdisciplinary perspective [4].

## 3. CONCLUSION

This paper showed a customized postgraduate educational program for training energy experts in the field of energy efficiency to meet the industrial needs for trained energy managers, closing the gap between theory and practice. The highly technological profile of the Master course trains specialists in sustainable strategies and innovative building technologies, who find professional opportunities at public or private institutions, national and international architecture and engineering studios, design companies related to product technology innovation.

## ACKNOWLEDGEMENTS

The authors would like to thank the ABITA Research Centre of the University of Florence and industrial partners involved into the Master ABITA.

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# Teaching CFD as a Pedagogy for Architectural Design: A Qualitative Study Based on Interviews

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*ABSTRACT: The goal of this study is to investigate the academic efforts to apply Computational Fluid Dynamics (CFD) in architectural design. CFD refers to a computational method for predicting the movement of fluid. Since airflow is an important issue in architecture, CFD can be a helpful tool in architectural design. Specifically, the benefit of using CFD can be maximized if it can be used from the beginning of the design process. However, the complexity of CFD has been a barrier to be utilized in the early stages of design. Although the development of new software made CFD more accessible for architectural designers, it caused another problem of blind users who cannot interpret the simulation results. With a qualitative and interview-based research method, this study explores the current position of CFD in architectural design education. Former instructors and students of two CFD courses offered at two design-oriented architecture programs in the US participated in the interviews. Through the interviews, this study questions the future direction of CFD for architectural design education.*

*KEYWORDS: CFD, Architecture, Design, Education, Interview*

## 1. INTRODUCTION

Computational Fluid Dynamics (CFD) refers to computational methods to predict the movement of fluid. Due to its efficiency, CFD has been widely used in the engineering fields since the 1970s. It has a great potential in the architectural field as well since airflow has been an important issue in architectural design. Moreover, the shape and the interior of buildings have become complex these days, thus, it is becoming hard to predict airflow in and around a building. Although CFD can be helpful to predict airflow in relation with architectural design, the CFD users in the building industry tend to be limited to researchers or consultant engineers rather than architectural designers in general. It has been due to the software license cost and the intensive knowledge required for conducting CFD simulations.

Therefore, in the current practice, architecture firms generally outsource CFD experts for the projects having critical safety issues with airflow. In these cases, CFD is a method for evaluating a completed design rather than actively participating in the design process. However, key design decisions are made in the early stages of design, thus, the benefit of using CFD would be maximized through its early application. In response to the current situation, CFD platforms specialized for architectural projects are developed recently. They offer cheaper license cost and user-friendly interfaces providing the features optimized for architectural projects. Although utilizing these platforms is still unfamiliar in the current practice, some architecture schools in the United States offered a course for learning CFD for students in their programs. This study investigates the academic efforts to

explore the application of CFD in architectural design and education.

## 2. METHODOLOGY

Interview-based approach in qualitative research is an efficient way of collecting data since the data comes directly from the person who has the experiences [1]. Due to these advantages, an interview-based approach is chosen for this study. To obtain rich data while maintaining flexibility, the interviews were semi-structured in an open-ended format.

### 2.1 Data Collection

After a thorough search of architectural design school curriculum in the US, two institutions were found, which offered a course for learning CFD. The instructors and former students of the course were interviewed through face-to-face meeting or online meeting platforms.

### 2.2 Data Analysis

The obtained data were analyzed in the following steps:

1. Transcribing the recorded interviews
2. Dividing the transcripts into different excerpts
3. Analyzing the excerpts checking both explicit and implicit meanings
4. Coding in keeping with the findings
5. Clustering codes and developing categories

## 3. RESULTS AND DISCUSSION

The results of the data collection and analysis were summarized with the following categories.

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## 3.1 Contexts

Table 1 shows the summary of the basic information on the investigated courses:

Table 1: Basic information on the investigated courses.

	Time offered	Software	Academic Level	Number of students
Course 1	2006 ~ 2016	FloVENT	Undergrad. 3 <sup>rd</sup> year min.	15 max.
Course 2	2014	ScSTREAM	Graduate	10 max.

## 3.2 Limitation of CFD

The participants pointed out the limitations of CFD as a design tool as described in Table 2.

Table 2: Limitations of CFD.

Simulation Process	<ul style="list-style-type: none"><li>- Difficulty in the simulation of free-form geometry</li><li>- Interoperability (one-way process)</li><li>- Excessive simulation time</li></ul>
Supporting Information	<ul style="list-style-type: none"><li>- Lack of supporting knowledge</li><li>- Uncertainty of the weather in outdoor simulation</li></ul>
External	<ul style="list-style-type: none"><li>- Required computer space</li><li>- License cost</li></ul>

## 3.3 CFD as an overview of building physics

CFD is a compound of various theories in thermodynamics and fluid dynamics, which can provide the students with an overview of building physics. Showcasing how the building physics theories interact with each other, CFD can play a role as a connection point of those theories.

## 3.4 CFD as a virtual lab for building science education

Visualization is one of the key concepts of CFD. Visualization quickly catches the students' attention and show fluid flow and temperature distribution without the equations. Therefore, students could experiment their learnings in this virtual lab and ultimately have a better understanding of building science.

## 3.5 Misleading results caused by the lack of knowledge

CFD results could be easily misleading because the lack of knowledge could lead the users to enter unrealistic inputs. The alterations in the simulation setting could end up with different results. We should constantly question the credibility and the embedded assumptions for the results of CFD.

## 3.6 Improvement of the architect/consultant engineer relationship

The interests in sustainable design are growing in the current practice, but still many projects are designed without evidences. Through learning CFD, students

constantly question about their hypothesis based on the evidence. This approach helps architectural designers to maintain a balanced position, which eventually opens conversations between designers and engineers.

## 3.7 Evolution of CFD

Given the fact that the evolution of CFD has been accelerated in recent 20 years, the future of CFD looks promising. The limitations of CFD are now in the process of being solved. Nonetheless, the users should be aware of the trade between accuracy and user-friendliness and judge what is important to know as an architectural designer.

## 4. CONCLUSION

The interview participants taught CFD in design-oriented architecture schools as they found problems in the current architecture education. The lack of building science education in academia eventually causes the miscommunications and conflicts between architects and consultant engineers in the professional practice. As the implementation of CFD in architectural education seems to be one of the solutions, CFD platforms targeting architectural designers have been emerging recently. However, this phenomenon brought another problem such as a user having difficulties in connecting "simulation input and output" [2]. The problem raises a question: what is necessary to know? To answer this question, we need to determine the "desired knowledge level of architecture students regarding building physics" [3]. Nevertheless, CFD is a "promising area of future research and teaching in architectural education" [4] having a possibility as an architectural design tool. Since there are not many cases of teaching CFD in architecture design schools in the US, a limited number of participants were interviewed. Therefore, this study can be continued to the similar cases in other countries or in the professional practice.

## ACKNOWLEDGEMENTS

This study was funded by Student Initiated Grant (SIG) from College of Architecture & Urban Studies, Virginia Tech. We would like to thank Dr. Mohammed Alshayeb, Dr. Jae D. Chang, and Dr. Jeehwan Lee for their supports.

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# College Education of Green Building Design Based on BIM

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**ABSTRACT:** The energy consumption of construction is huge, and it is necessary to generalize green building. With the maturity of domestic BIM (Building Information Modelling) technology, it will be more efficient to design green building employing BIM, which requires designer to shift their thinking modes to adapt to new architectural design requirements. Architecture education should also fit the change positively, helping students to establish the theory system of green building and learn to design green building by BIM technology. Combined with concrete teaching practice, this paper introduced teaching processes such as preparation before class, prophase, metaphase and anaphase of design. It summarized the encountered problems and the experience in the teaching process, and prospected the future work of establishing green building teaching system.

**KEYWORDS:** BIM, Green Building, Architecture Education, College-enterprise Cooperation, VR

## 1. INTRODUCTION

The energy consumption of construction is huge, and it is necessary to generalize green building. With the maturity of domestic BIM technology, it is more efficient to design green building by BIM, which requires designer to shift their thinking modes to adapt to new architectural design requirements. However, design institutions are facing the contradiction between the growing demand of designers who are proficient in using BIM and the fact that existing designers have few time to learn BIM because of heavy work. Architecture education should also fit the change positively and regard the cultivation of green building design as a core course, easing the short supply of skilful designers in institutions.

## 2. Teaching Practice of Green Building Design Based on BIM

In recent years, we have combined green building education with each links of teaching process. From indoctrinating the students in green building ideals in *Fundamental of Architectural Design*, to teaching courses such as *Building Structure*, *Building Physics*, *Building Construction*, *Building Materials*, and *Digital Architecture Design and Simulation Analysis*, we taught students basic theories of green building design, structural lectotype and material selection, and organized special training of green building, but we still lack practical training of green building design and application of BIM technology. It is the very teaching aim of the course *Technology and Design of Green Building*— let students establish the green building theory system and learn to design green building by BIM technology. The flowchart of teaching design is shown in Figure 1.

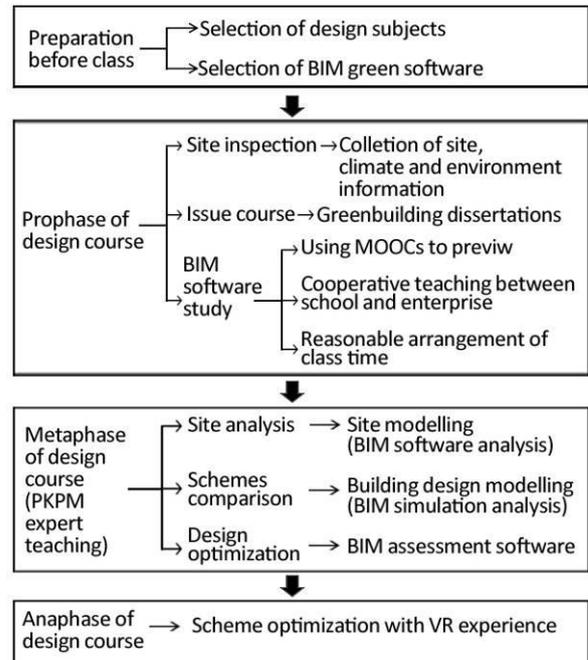


Figure 1: The flowchart of teaching design

### 2.1 Preparation before Class

The design subjects and green building software should be decided before class. The sites in campus were selected as the design subjects, encouraging students to begin with simple buildings and investigate in a familiar climate and environment. In this way, students can spend more time on environment analysis and the factors of green building that should be more considered during building design. We chose the green building software developed by PKPM, which corresponds with the newest standards like Assessment Standard for Green Building GB/T 50378-2014 and combines with BIM technology. By establishing centralized digital model and

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calculating in wind environment, light environment, energy consumption, noise and other different simulation software programs, it is also high-efficient and convenient in practical application.

## 2.2 Prophase of Design Course

Students need to inspect the sites, further acquaint with local climate and environment conditions, and take courses such as thematic lecture of green building, software study and so on.

Teachers will give thematic lecture of whole green building design system, helping students establishing the green building theory system and understanding how to employ basic courses in green building design. When students use BIM software to analyse design, they can understand the principle from resulting data. In this way, students can judge the design whether need to modify design and know how to optimize the design plan.

The software study will be combined with college-enterprise cooperation, and PKPM technicians will give classroom teaching; make full use of MOOC resources (Massive Open On line Course), let students prepare before class independently; arrange the class time reasonably and ensure adequate extracurricular practice time.

## 2.3 Metaphase of Design Course

First, students are required to build site modelling, use software to analyse the available range of site that meets the requirement of sunshine, and prepare for site plan. Second, students adopt the method of scheme comparison to design, use SketchUp or CAD to draw several preliminary schemes, and import them into Sunlight or other software to analyse from sunshine, ventilation and other aspects. Choose the best one to optimize. At the stage of scheme optimization, students employ PKPM assessment software and green building scheme software to optimize architectural design scheme. During the design, PKPM experts will be invited to class again to help students solving problems of using software.

## 2.4 Anaphase of design course

After a series of simulation analysis, the resulting assessment report basically accord with the Assessment Standard for Green Building. Technicians will help students to import their schemes into VR generator, using VR to make students be personally on the scene of their schemes. Students adjust their schemes and complete the design.

## 3. Summary of Teaching Practice

During the teaching process, we summed up some positive experiences of this course:

(1) In the arrangement of courses, the student's practice is mainly and the teacher's professors are

auxiliary, and then their ability of thinking and learning can be improved;

(2) Make full use of MOOVS resources to encourage students to study independently, set up an extracurricular individual course for students;

(3) We must help students to explore green building, let them establish the system of green building knowledge;

(4) Combine college-enterprise cooperation with courses, invite professional experts to answer questions from students, make it easier for them to master software quickly;

(5) Design specifications and assessment standards should be the newest, make the courses very similar to actual projects;

(6) Let students experience their scheme with the help of VR technology, which enhances their ability of design.

Compared with the previous course, the teaching methods which added with BIM platform and VR technology make students more intuitive to master the design method of green building scheme. But the application of whole process of design and coordination among each field are untouched. Hereafter, we will organize more practice and research, let get further training in their graduation design stage. Moreover, we will also strengthen the communication and cooperation with colleges and enterprises at home and abroad, and further complete the green building teaching system based on BIM.

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# Teaching Sustainable Architecture in Large Lecture Courses: Experiences at Cal Poly Pomona University

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*ABSTRACT: This paper discusses with examples, a course that introduces net zero carbon design and energy modelling in large lecture courses. Several strategies were implemented: integrating design in technical courses, reducing the number of variables to consider in the design problem, increasing understanding of the physics of energy and buildings and increasing expertise in the use of analogue and digital tools. The course is conducted in both lecture and seminar/lab formats and it involves theory, practical applications, calculations, hands-on experiments and a main project in which students integrate energy model in the design process of a zero net energy project. All 49 student projects for the 2016 and 2017 courses are collected in two books, "Going to Zero" and "Going to Zero 2017".*

*KEYWORDS: Architectural education, sustainability, energy modelling, lecture courses*

## 1. INTRODUCTION

Future architects must have the knowledge and skills to design the high-performance buildings that we need to keep our impact well below the 2-degree limit. For this to happen architecture schools must provide a more comprehensive sustainable design education to all students. However, at this moment architecture students in the United States are exposed only to basic concepts in sustainable design. They are only introduced to more advanced concepts such as energy modelling or the design of zero net energy, low carbon buildings, in graduate or advanced undergraduate seminars or upper division studios. Because these courses are not required, only a small fraction of architecture students are able to take them. This paper discusses strategies that increase student understanding of sustainable design principles.

## 2. APPROACH

The changing conditions of architectural practice emphasize the importance of research which has now become critical to twenty-first century architectural practice. The more unanswered questions we have regarding the rapidly evolving world around us, the more we need research to help us answer them [1]. It is also important to teach research methods to undergraduate students. This course includes a research/ design based approach that includes several steps to overcome implementation difficulties in large courses with more than 100 students.

### 2.1 Integrate Design in Technical Lecture Courses

Architecture students typically learn by implementing concepts from lecture courses in their design projects, typically in studios. However, this can also occur directly in the lecture course, in which students develop a design project to implement concepts learned in lectures. The author has tested two

approaches: in the first one students design, build, monitor and analyse small shelters which maintain comfort using only passive strategies. In this approach students learn through a haptic approach, by building with their hands, feeling the forces of the sun and nature in contact with their bodies. In the second approach students design a zero-net energy building using energy modelling software. In both approaches the design is informed by the systematic analysis of design options.

### 2.2 Reduce number of variables to consider in a design problem

There is a limit to the number of variables that a designer can consider at the same time to solve a design problem. In their Zero Net Energy (ZNE) project the number of variables which must be considered to find a solution is reduced, allowing the students to develop a deeper understanding of the issues.

### 2.3 Increase student understanding of building physics

Students learn the basics of building physics with a special emphasis on how heat is transferred through the envelope by conduction, convection and radiation.

### 2.4 Increase student understanding of modelling tools

Students are taught to use digital and analogue tools as appropriate. It is important for the students to learn how to use building simulation software correctly to test concepts and ideas. Once the students understand the concepts they can learn tools to evaluate them.

## 3. THE COURSE

This is the first of two required Environmental Control Systems courses at Cal Poly Pomona University. All 3rd year undergraduate students and 2nd year graduate students are required to take this class, which includes six topics: 1. Psychrometrics and thermal comfort; 2. Site,

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climate and architecture; 3. Solar geometry; 4. Energy and buildings: passive heating and cooling, renewable energy and solar active heating; 5. Mechanical heating and cooling; 6. Daylight.

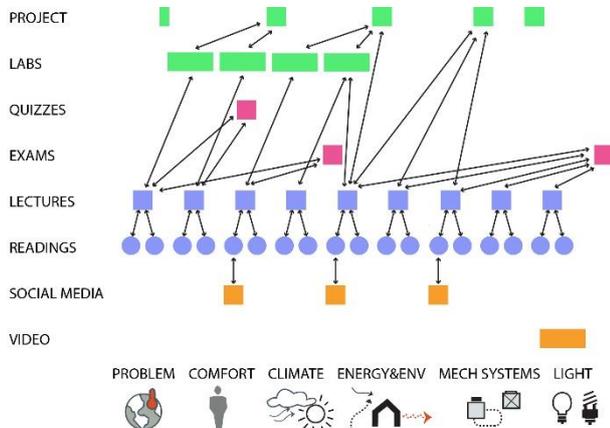


Figure 1: Structure of the Course

The course is conducted in both lecture and seminar/lab formats. It involves theory, practical applications, calculations, and hands-on experiments. Topics are explained in lectures, practiced in the labs and integrated in the design process through the Net Zero Energy Project. Figure 1 shows the course components as described above. The rows indicate the different types of activities in the course, and the columns indicate when the different topics are introduced. The top row shows the project milestones and submittals. The second row shows the four labs. One quiz is given in the beginning of the quarter. Two exams are given, a midterm and a final. Lectures discuss the concepts which are also connected to the readings, in the textbooks or lectures. Social media is used as an asynchronous communication tool and production of a video is an option for extra credit at the end. There is more emphasis in the lectures and hands-on laboratory projects in the first half of the quarter, shifting to implementation of concepts in the project for the second half of the course.

## 4. THE ASSIGNMENT

Los Angeles is home to many emblematic twentieth-century houses, some of which seek to respond to the climate and harmonize with nature. Students in the course selected one of several well-known mid-century homes in Los Angeles, analysed it and implemented design measures to achieve zero net energy ZNE and zero net carbon ZNC. The five houses were: Case Study House 22 by Pierre Koenig; VDL house by Richard Neutra; Eames House by Charles and Ray Eames; Kappe House by Ray Kappe; and King's Road House by Rudolf Schindler. Students also visited the buildings for a first-hand learning experience.

To achieve the learning objectives of the course, the students followed a three-step process. First, they

analysed climate, the bioclimatic guidelines that responded to the climate, and architectural precedents that respond to similar conditions. They used weather files, Climate Consultant and the 2030 Palette. From this analysis, the students acquired a better understanding of the relationship between the buildings and the environment around them. Then they analysed the home they selected as originally designed, using an energy modelling software (HEED), and comparing results with a California Energy Code compliant building (Title 24-2013). This analysis allowed the students to understand climate responsive design strategies that the architects had implemented many years ago. In the final step the students proposed design strategies to achieve net zero energy. These strategies were tested systematically, one at a time and then selected strategies were combined to achieve net zero energy and net zero carbon.



Figure 2: Student Example of Design Project

## 5. RESULTS AND CONCLUSIONS

Course evaluations indicate that students learned through the implementation of sustainable design strategies in their projects. Results demonstrate that it is possible to introduce the design process of ZNE buildings and introductory energy modeling in lecture courses. However, this takes a significant amount of time and effort from the instructor. All 49 student projects for the 2016 and 2017 courses are collected in two books, "Going to Zero" and "Going to Zero 2017" available through online retailers. Students from the course were featured by Architecture 2030 as part of a series of cutting edge courses and the teaching associate for this course was one of ten winners of INNOVATION 2030/COTE Top Ten for Students.

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## Adaptive Reuse Strategies: Passive Design Intervention in Seremban Old Railway Depot, Malaysia

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**ABSTRACT:** The aim of the architectural design thesis is to study the potential benefit of implementing passive design in an adaptive reuse project. From studies, several types of adaptive reuse together with its building elements were identified. Next, the potential of each adaptive reuse type was explored to determine the relevance of implementing each type to a unique project. The potential approaches were applied to an unused naturally-ventilated railway depot in Seremban, Malaysia to find out further improvements that can be added. Finally, several suggestions were made to improve the passive design potential through these various types of adaptive reuse for the aforementioned heritage building.

**KEYWORDS:** Adaptive reuse, Passive design intervention, Railway depot, Heritage building, Tropical climate

### 1. INTRODUCTION

With the increasing number of sustainable developments, more methods of 'going green' have been introduced. While modern day construction focuses more on the sustainability of new buildings, adaptive reuse tries to take advantage of old and derelict buildings. Adaptive reuse of an old building can be seen as a means to preserve the historical values of a building and while at the same time giving positive impact in both society and the environment [1].

One of the strategies to achieve sustainability in a building is passive design strategy. Passive design takes into consideration the local climate and site conditions to enhance the comfort and wellness of building users while keeping the energy use at minimum [2]. To achieve this, several strategies may be considered during the early stage of construction such as building orientation and layout, thermal mass, shading and ventilation [3]. However, for an adaptive reuse project, the passive design strategies can be implemented as a new strategy to improve building performance while at the same time reduce its total energy consumption [4].

Therefore, it is crucial to understand the context and limitations as to what is suitable to be introduced into an adaptive reuse project. This design thesis will demonstrate the potential of adaptive reuse in building elements by identifying the passive design of the building and introducing strategies to further enhance the performance of an old railway depot in Seremban, Malaysia (2°43'05"N, 101°56'23"E).

### 2. ADAPTIVE REUSE

Adaptive reuse can be defined as "a significant change to an existing building function when the former function has become obsolete" [5]. Within the last decade, there is an increasing trend in building reuse and adaptation. One of the reasons for the increasing

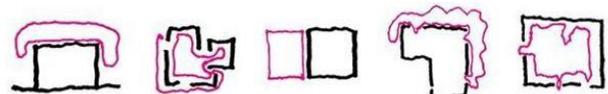
amount of adaptive reuse projects is the growing perception that reusing old building is cheaper than demolishing the old and building a new one [1].

#### 2.1 Adaptive Reuse Function

In modern context, adaptive reuse is seen as a way to preserve the historical values along with other benefits from environmental, social and economic aspects [1]. More buildings received proper renovation works as part of their makeover, increasing the value of adaptive reuse works and making it more appealing to the masses.

#### 2.2 Types of Adaptive Reuse

To date, various adaptive reuse projects have been completed all around the world. In her book *Old Building, New Form*, French architect Françoise Astorg Bollack [6] has categorised adaptive reuse projects into five categories (Figure 1):



1. Wrap 2. Weaving 3. Juxtaposition 4. Parasite 5. Insertion

— Existing Structure — New Structure

Figure 1: Adaptive reuse categories [6].

#### 2.3 Adaptive Reuse by Building Elements

Different adaptive reuse may use different building elements during its renovation and thus, create a unique character of its own. From her example [6], the types can be summarised by building elements as follows (Table 1):

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Table 1: Building elements characterisation of each type

Adaptive reuse type	Building Elements
Wrap	Roof, Facade
Weaving	Wall, Structure
Juxtaposition	Entire building
Parasite	Wall, Roof
Insertion	Building Envelope, Structure

## 2.4 Passive Design Intervention in Adaptive Reuse

The adoption of passive design measures aims at reducing energy consumption of a building [2]. Depending on many factors, passive design strategies in adaptive reuse can vary from one building to another to suit the local needs. Some of the passive design potentials for the proposed adaptive reuse type is shown in Table 2.

Table 2: Passive design potential of each type

Adaptive reuse type	Potential for Passive Design
Wrap	- Diffused lighting through skylight - Double roof
Weaving	- Window system to allow daylighting - Cross ventilation through openings
Juxtaposition	- Provides shading via building mass - Acts as wind breaker/ accelerator
Parasite	- Additional fenestration to allow for daylighting and natural ventilation
Insertion	- Overhangs and canopies for shading - Wind directions control through positioning of new elements

## 3. PROPOSED CENTER FOR ADAPTIVE REUSE STUDY

For the design thesis project, an abandoned railway depot has been selected to showcase the different types of adaptive reuse. The idea is to convert the building into a mixed development building, consisting of commercial and communal spaces as centre for adaptive reuse study. The project aims to determine the environmental benefit potentials of the adaptive reuse project according to the types borrowed from Françoise [6].

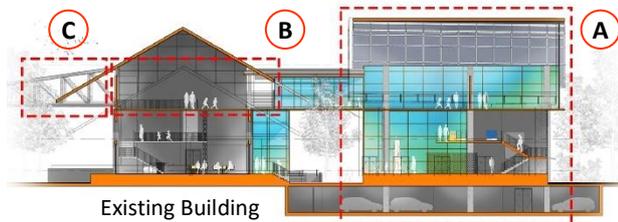


Figure 2: Application of adaptive reuse types in the old railway depot in Seremban, Malaysia.

The design proposal incorporates several types of adaptive reuse as passive design intervention. In Figure 2, juxtaposition of the new building (A) allows for shaded

communal spaces in between the building and courtyard. Insertion of additional floor (B) and link bridge (C) that protrudes the building wall at high level creates additional fenestration for the building that allows more daylighting and natural ventilation. Table 3 suggests other improvements that can be applied to further enhance the passive design in each adaptive reuse type.

Table 3: Suggestion for improvements of passive design

Adaptive Reuse Type	Suggestion for Improvements
Wrap	- Façade and overhang design
Weaving	- Internal partition to control daylighting and ventilation
Juxtaposition	- Building heights to provide shade and redirect prevailing wind for ventilation
Parasite	- New elements: protruded wall, link bridge
Insertion	- Structural elements to be designed in line with the site context

## 4. CONCLUSION

In this study, it can be concluded that different adaptive reuse types gave different benefits to the adaptive reuse project as a whole. However, what may seem suitable for one project does not mean it would be suitable for other projects. The study conducted was to show how an adaptive reuse project was carried out with the environmental aspect as its driving force.

## ACKNOWLEDGEMENTS

We sincerely thank Railway Assets Corporation (RAC), Malaysia, Ar. Dr. Yong Kum Weng and all support.

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## Research Pro-Design in Environmental Architecture, Pedagogical Approaches for Quality and Performance: The Case of the Latitudes Global Studio Project

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*ABSTRACT: Engaging students with research is a prime concern within the current higher education's strategic agenda. In this context, the Latitudes Network (2014) is a global educational network that puts design of buildings and urban spaces at the heart of mitigation and adaptation to global climate change. The network has been set up by the Faculty of Architecture and the Built Environment at University of Westminster. The Latitudes Global Studio (LGS) was created with the objective of promoting environmental design exercises in cities of different climates. As part of it the partnership London - São Paulo brought together students from the Architecture and Environmental Design MSc course at FABE, University of Westminster, London and from the Faculty of Architecture and Urbanism of the University of São Paulo. The feedback from the students involved in the LGS showed an increase from 86% overall satisfaction in the academic year preceding the LGS to 92%.*

*KEYWORDS: Design, Environment, Buildings, Local Knowledge, Pedagogy.*

### 1. INTRODUCTION

Engaging students with research is a prime concern within the current higher education's strategic agenda (Healey and Jenkins 2009). In this context, the Latitudes Network (2014) is a global educational network that puts design of buildings and urban spaces at the heart of mitigation and adaptation to global climate change. Through a series of complementary activities, the Latitudes Network (LN) connects researchers and students in different climatic regions, enabling cross-cultural and inter-disciplinary innovation for design in an age of unpredictable environmental shifts.

The network has been set up by the Faculty of Architecture and the Built Environment (FABE) at University of Westminster to inspire today's young designers to exchange knowledge, ideas and experience. Within the Latitudes Network, the Latitudes Global Studio (LGS) was created with the objective of promoting environmental design exercises in cities of different climates, benefiting from local knowledge. The LGS involved students from FABE and paired them with corresponding Latitudes Network member institutions from around the world. This paper refers to the experience of one of such partnerships.

### 2. RESEARCH AND THEORETICAL BACKGROUND

As a vehicle to teaching and learning of Environmental Design, the use of the Evidence Based Design approach, the Integrated Studio and the Live Projects have been debated by a number of scholars in the last 30 years (Marco *et al.*, 2013; Yannas, 1989,

Szokoloy, 2004). These approaches are recently gaining significant popularity across HE institutions and are discussed in several publications (Harriss, Widder, 2014). In addition to that, the so called Live Projects (whereby students are involved with external communities) embed the principles of experiential learning theories (Kolb, 1984; Morrow 2014), providing real-life experiences and opportunities to learn through direct engagement with fieldwork of buildings and with building occupants.

The Evidence-Based approach, coupled with Life Project Experiments, is intrinsic to the ethos of the Latitudes Global Studio (LGS) project, implemented between the partnerships. The project was based on a methodological path which allows design decisions to be questioned based on the gathering of data substantiating it and justifying the design process with a logical argument underpinned by the climatic, social and analytical studies that students were trained to perform. In the case of the LGS, the support of the LN allowed design ideas to be tested against the local knowledge of experts in the field of environmental design, through video conferences and field trips.

### 3. THE EXPERIMENT: LATITUDES GLOBAL STUDIO LONDON-SÃO PAULO

As part of the LGS Project the partnership London (LAT 52°N) - São Paulo (LAT 23°S) brought together students from the Architecture and Environmental Design MSc course at FABE, University of Westminster, London and from the Faculty of Architecture and Urbanism of the University of São Paulo (FAUUSP). The

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theme of the LGS for two consecutive academic years (2016-18) was the 'Environmental Performance of Brazilian and British Modernist Architecture'. This translated into a common brief where lessons learnt from fieldwork on iconic modernist buildings in São Paulo and London were transferred to studio-based design projects informed by analytic studies. Brazilian students investigated Brazilian buildings and informed results to the UK partners and vice-versa, via video-conferences.

In a second phase, UK students had a design brief for an environmentally responsive architectural proposal in São Paulo (Koppen classification: tropical), whilst the Brazilian students designed for London (Koppen classification: temperate). The design exercise was supported by field trips to São Paulo and London, characterising intense periods of academic exchange including building visits and design workshops. The identification of climatic-responsive attributes of examples of modernist architecture was rendered more effective by the opportunity to compare architectural responses from two different contexts (Figs. 1, 2).



Figure 1: Design project developed by UK students to a site in São Paulo, in Republic Square (LGS 2017-18).



Figure 2: Design project developed by Brazilian students to a site in London, Paddington (LGS 2016-17).

Moreover, the identification of further opportunities for environmental improvement, based on performative shortfalls and advancement in technology, informed the design agenda. This particularly focussed on the contemporary re-interpretation of the Tropical Bioclimatic Modernism in the São Paulo and Brutalist and Pre-Brutalist Architecture in London. The students' final outcomes showed considerable potential for improvement of comfort conditions and energy demand reduction.

## 4. FINAL CONSIDERATIONS

The exposure to a variety of learning methods within the subject area of environmental design experimented in the LGS project London-São Paulo for two consecutive years, was enriched by the exchange between students and local experts as well as the real-life experience provided by the field trips. This widened the context of students experience and improved their outcomes and level of satisfaction. The feedback from the students involved in the LGS showed an increase from 86% to 92% of the overall satisfaction with the learning experience (University of Westminster, 2018). This positive outcome signals the enhanced learning potential of a multilevel pedagogical approach combining, on an international platform, Integrated Studios, Live Projects and Evidence-based methods for improving the teaching, learning and practice of environmental design in the 21st century.

## ACKNOWLEDGEMENTS

Thanks to the Latitudes Network, the University of Westminster and the University of São Paulo for the support given to LGS (2016 – 2018).

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# The Poetics of Light in the Sculpture Gallery of the Castelveccchio Museum by Carlo Scarpa

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*ABSTRACT: Carlo Scarpa is skillful in using components and materials to create, moderate and enhance the light required for exhibiting the sculptures. The aim of this research is to explore his daylighting strategies and try to understand the interplay of light and space in the sculpture gallery of the Castelveccchio. This study started with background research, on-site studies then followed by parametric analysis. Overall, the findings suggest that Scarpa has wisely used key light and side light in the problematic space, creating a fascinating lighting environment.*

*KEYWORDS: Daylighting, Exhibition design, Modelling, Spatial creation*

## 1. INTRODUCTION

Beside of remarkable specific details such as the stairs in the Olivetti Showroom, the convex arches (vesical piscis) in the Brion Tomb and others, Carlo Scarpa was also sophisticated in solving various kinds of problem in exhibition spaces. The Museum of Castelveccchio could be considered as one of the most famous representative renovations of old and new, space and light. The first phase of this restoration began in 1957 and ended in 1964. Most of the building works were accomplished in this period, including the sculpture gallery on the ground floor.

The aim is to understand Scarpa's daylighting strategies, and this paper mainly focuses on the study of space and light in the sculpture gallery, which included the subjective appreciation of the luminous environments in this museum, Daylighting performance analysis and visual perception analyses. The paper started with an in-depth literature review and on-site studies, and the information gathered includes Scarpa's drawings and architects' commentary. An objective understanding of Scarpa's design approach could be built after reorganising these references. The archival research and fieldwork was then supported by quantitative analysis.

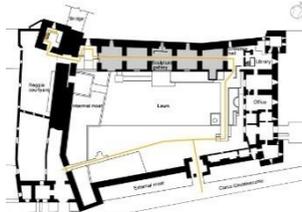


Figure 1: Castelveccchio plan. Grey space is the sculpture Gallery. (Source: Author)

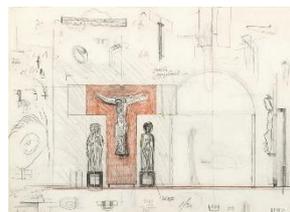


Figure 2: Scarpa's manuscript, showing daylighting strategies. (Source: Museo di Castelveccchio)

## 2. LIGHTING STRATEGIES ANALYSIS

Carlo Scarpa is skillful in using components and materials to create, moderate and enhance the light required for exhibiting the sculptures. In the Castelveccchio renovation, besides of spatial orchestration and the careful organization of the exhibits, he also demonstrated his distinctive way of blending daylight and artificial light to create changeable and fascinating interior lighting conditions.

The sculpture gallery of the Castelveccchio is a long, linear space, consist of five square exhibition rooms (figure 3), Carlo Scarpa's architectural interventions in the sculpture gallery are that he reinstalled the floor and the ceiling, also changed the position and frame of each window and door. The purpose of introducing the various type of window frames is for matching the symmetry of Gothic façade. The frames of the door which placed at the end of the gallery and the frames of the north windows create a unique luminous environment in the galleries: the grids of the frames which were arranged closely together help filter daylight, and this is a way to control the lighting sources. Besides of using artificial light, the more important intervention is the small extension (Sacello) of the first room and the low wall of the third room. The interior surfaces of Sacello are covered by smooth plaster surfaces, and during the daytime, this material helps reflect the daylight, delivering light to deeper interior spaces. This small space which has a skylight are normally brighter than other indoor spaces, and it guides the visitors' spatial journey. Its black plastered walls and dark brown clay-tiled floor are well illuminated by the flood of light that enters through a full-width roof light, creating a strong contrast with the rather calm light of the main gallery (Hawkes, 2008). In terms of the partition in the third room, it seems that his concept of moving the exterior wall into the indoor area has adverse effects on the exhibition because the indoor space is reduced. But, in

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terms of lighting, the large panel which connected the original arches and the interior wall can reflect daylight, and the walls restrict the access of the sunlight and provide a dynamic, yet balanced interior luminous environments.

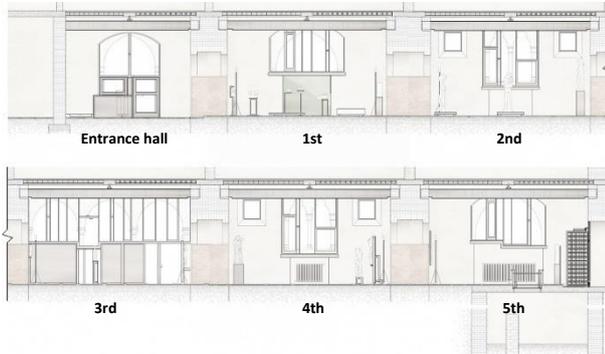


Figure 3: The Section of the gallery, showing window typologies and exhibits' position (Source: Caruso 2015)

### 3. ILLUMINANCE AND DAYLIGHT FACTOR ASSESSMENT

Those analyses were generated by using Radiance IES. The average illuminance level is 184 Lux under the CIE overcast sky condition, and the highest point is in the Sacello which covered by half of the skylight. The average daylight factor is 2.2%, only 27.8% area can archive the target of exceeding 2%, which confirmed the necessity of artificial lighting. According to the below image, gothic windows are the main ingress of daylight and the south area which mainly illuminated by daylight has a changeable illuminance level. New interventions, the Sacello and the partition in the third room are the key portions that breaking the entire brightness balance of the original Castelvecchio space. It is important to note that each sculpture of south area is faced to east or west, and all of them have been placed at the edge of two illuminance level ranges, which guarantying an appropriate and transitional modelling in problematic rooms.

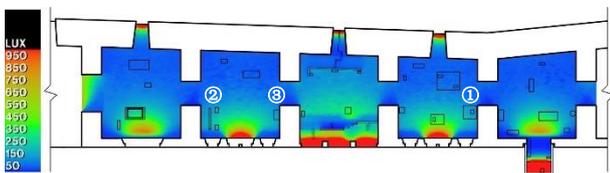


Figure 4: Illuminance assessment under the overcast sky condition without artificial lighting. (Source: Author)

### 4. VISUAL PERCEPTION ANALYSES

This part of the research was based on the on-site mappings. The photo demonstrates that artificial lights have been partly used in corners which display the lowest illuminance level. The new dark floor can reflect part of daylight and the wooden grilles can block a percentage of intense daylight from outside. All strategies show Scarpa's careful consideration and

wisdom, and the below mapping image is the strong evidence which reveals a clear luminous environment. As to the modelling of sculptures, each statue is illuminated vividly; the highlight, medium level area and the shadow are displayed quite clear, and facial expressions are also apparent. It is pleasing for visitors to enjoy the explicit modelling of the exhibits.

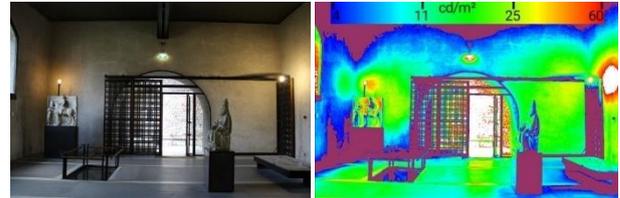


Figure 5: Luminous mapping of the 5th room. (Source: Author)

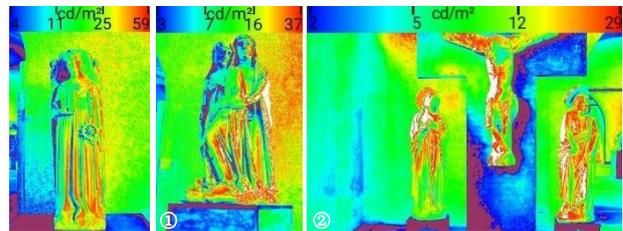


Figure 6: Luminous mapping of sculptures. (Source: Author)

### 5. CONCLUSION

In the restoration of the Castelvecchio Museum, Carlo Scarpa demonstrated his abilities to use different kinds of light, materials and architectural components to create architectural dramas. On the one hand, Scarpa successfully designed a new circulation route which connected all individual galleries, and numbers of transitional spaces between indoor and outdoor, old and new, classical and modern. On the other hand, depending on the different lighting challenges presented to him by the old building, he skillfully used key and side light in this museum to create a charming spatial ambience and luminous dramas in the galleries.

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## VELS: VHDL E-Learning System

### Automatic Generation and Evaluation of Per-Student Customized Tasks for Courses Modelling Low Energy Hardware

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*ABSTRACT: For the complex smart systems of the future, you need highly educated engineers to design systems which not only carry out their needed functionality but also are low power, which in turn benefits all people. Learning hardware modelling with a hardware modelling language like VHDL is an extensive undertaking, which involves practice by solving many assignments independently. Providing an adequate learning experience is a difficult task due to large classes and different types of learners. This paper presents the VHDL E-Learning System, an automated assessment system to give students tasks and automated feedback and therefore provides students the possibility to increasingly build up their proficiency in designing digital systems.*

*KEYWORDS: E-Learning, automated assessment, VHDL, low power hardware*

#### 1. INTRODUCTION

Smart Homes, Smart Buildings, Smart Grids, Smart Energy Systems, Smart Cars etc. all have one thing in common: they use embedded systems which often have to handle extreme power restrictions, are highly connected and communicating, and sometimes even have to serve multiple purposes. These devices don't appear, they have to be creatively and wisely engineered, not only to serve a purpose to replace old devices, but as a system of systems not to work against a higher goal, such as the 2-degree limit. This demands highly skilled, highly educated knowledge-workers, proficient and experienced in the design of low energy hardware but the decreasing teacher-to-student ratios limit the possibilities to offer necessary personalized guidance, based on the students' needs.

A very important instrument electrical engineering students need to learn is the modelling of digital systems using a hardware description language like the Very High Speed Integrated Circuit Hardware Description Language (VHDL). VHDL allows the description of digital hardware with their underlying algorithms and functionalities like low power modes in order to be simulated and converted to real world circuits. The VHDL E-Learning System (VELS) is a tool for students to learn interactively at their own pace and build proficiency in designing efficient digital hardware.

VELS is published on GitHub [1] under the open source license GPLv2, making it freely accessible to teachers at schools and universities around the globe.

#### 2. METHOD

Although VHDL includes standard constructs such as loops, if-case statements, sequential statements, subprograms, etc. for the description of algorithms, it is

different to a conventional programming language as C, C++, or Java. VHDL incorporates language concepts specific to modelling hardware, such as the definition of modules with an interface and behavior, instantiate existing modules (so called "IPs"), communication buses, ports with data directions and the modelling of time. Created designs can be simulated on register transfer level and gate level to investigate their functional correctness as well as estimate factors like power consumption and the impact of related measures such as dynamic frequency scaling.

VELS is designed as a flexible tool that, once configured, fully automatically generates individual VHDL assignments for students and receives VHDL models submitted by students. It simulates and checks these models, approves or gives feedback, and allows multiple submissions such that students can improve their models iteratively. VELS offers the flexibility to create assignments that teach students how different hardware modelling decisions have an impact on power consumption. VELS is implemented as a Python based daemon on a remote server and the interaction with students is performed via email, handling subjects as interpreted system commands.

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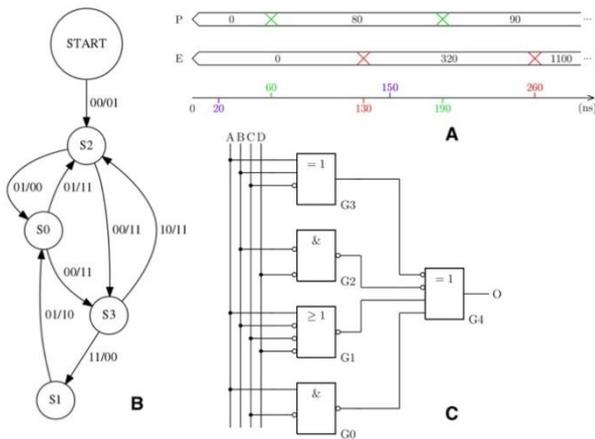


Figure 1: Example of tasks implemented in VELs A) working with timing and delay models [2], B) a finite state machine, and C) modelling a simple logic circuit

### 3. SYSTEM FEATURES

VELs consists of an email submission system, tasks and supporting tools. After configuration VELs interacts fully automatically with students and no tutor intervention is required. This facilitates large classes while each student can still get many assignments, try various solutions and get them checked. Thus, students can work at any place and time of their own choice.

Various features provide flexibility for teachers:

1. a tool that assists in defining new tasks
2. an uniform interface to add support for different simulation backends
3. a web interface to configure courses and monitor students' progress
4. different scheduling modes: free task selection or strict sequence of assignments

20 different tasks have been implemented up to now, from implementing basic boolean functions up to modelling parts of a simple but complete microprocessor. Tasks are parameterized such that every student gets a different variant of the problem. The main work to generate a new task is to formulate the assignment precisely, unambiguously, and to design the testbench that is deployed by VELs to check submitted solutions. Assignments in VELs are sent as generated PDF documents, which consist of a textual description and explanatory graphics (examples can be seen in Figure 1).

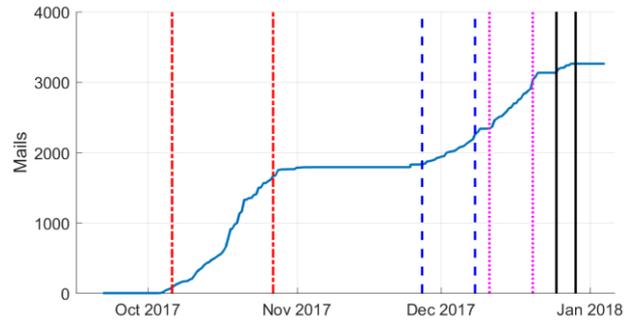


Figure 2: Number of received mail submissions over time for a 2017 graduate course. Each vertical line pair represents the start- and end-date of one task group.

### 4. SYSTEM USE AND CONCLUSIONS

VELs has been used for three years in six courses, three at the undergraduate and three at the graduate level. In total over 1000 students have used the system. Additionally VELs was recently used in a life-long learning application for companies as external education [3].

Evaluation of the system with feedback from students, teachers who used it in courses and statistics collected by the system leads to following conclusions:

1. Students enjoy using the system and the chance and the given freedom to learn.
2. VELs ensures continuous learning, a feat important to learning hardware modelling.
3. VELs has proven itself to be flexible enough to be used with different course types and easily add new tasks.

Figure 2 shows the number of submissions over time for a graduate course held in 2017 and strengthens statements 1 and 2.

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# Influence on Learning Efficiency from Natural Light in Educational Environment: A Pilot Study Using EEG Mind Wave Mapping Research Methodology

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*ABSTRACT: This paper presents preliminary research outcomes from applying EEG Mind Wave Mapping methodology for investigating the impacts of learning environment on students' concentration and learning performance under different lighting conditions. During the learning process, whether students remain attentive generally influences their learning efficacy. Literature shows that classroom lighting may be important for pupils' academic performance. However, most of the time, lighting could not be adequately controlled due to the given building envelope design and the spatial layout. The present study explores the influence of different lighting conditions in a conditioned room on architectural students' mind wave when they were engaging in a learning task. Lighting scenarios included naturally lit, artificially lit and hybrid mode set in this room were experimented and the test scores of the learning tasks under these scenarios were compared against mind wave mapping results. The preliminary findings from this study showed that students' performance in a natural daylight and hybrid lit room shows higher concentration than that in the artificially lit room, as a result, the use of natural light in the learning environment is more desirable and this can have significant benefit for reducing energy demands from artificial lighting in educational spaces.*

*KEYWORDS: Learning Efficacy, Lighting conditions, Electroencephalography (EEG) Mind Wave Mapping, Attention and Relaxation.*

## 1. INTRODUCTION

Nowadays people spend most of their time indoors. In the recent years, a number of studies had been conducted to investigate the relationship between learning efficiency and indoor environmental quality [1]. The findings from these studies indicated the quality of the learning environment has significant impacts on the academic performance.

Many educational spaces experience direct sunlight which normally associated with discomfort glare due to either inappropriate building orientation or solar control, which results in deteriorating visual comfort and in some cases causing health problems. For evaluating the impact of interior environment on learning efficiency, using electroencephalography (EEG) signal sensors to detect electromagnetic mind wave can be used as a more objective metric to corroborate traditional subjective questionnaire-based methods and task-based methods.

This study focuses mainly on develop an alternative and potentially more holistic research methodology which effectively detect, assess and interpret the data collected for the investigation of spatial design and environment comfort for enhancing Learning efficiency in education.

## 2. NATURAL LIGHT AND LEARNING EFFICIENCY

Human beings acquire knowledge in various ways, but mostly from attending school. In the process of learning, attention affects the learning result, and

attention is the basis of learning well [2]. Natural light is known to have positive psychological and biological effects on learners. Daylight helps students to retain attention and learn information; and natural light can improve students' feeling, behavior, and concentration [3-4]. During the learning process, whether students remain attentive throughout instruction generally influences their learning efficiency. For creating a healthy and comfortable space for effective learning, internal environmental quality and its effects on learning is an important research subject deserves much attention.

Literature review shows scholars had used EEG signals to evaluate mental exhaustion [5]. However, there are few previous studies employed EEG mind wave mapping technique to investigate the impacts of lighting conditions in learning space on learning efficiency, this study uses EEG signals as the medium to observe architectural students' attentiveness during learning in a conditioned room.

## 3. METHODOLOGY

Although every individual's attentiveness to the same learning content differs, and their EEG signal fluctuations vary, this study aims to identify the changes in EEG signals during attentive learning under three type of lighting conditions by using convenient and simple methods. In these lit scenes: daylight, artificial lit and hybrid learning environment, the environmental conditions in terms of the luminous and thermal environment and

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EEG Mind Wave-related data generated from students' engagement of learning tasks were recorded and analysed at a similar time period.

This study employed highly portable mobile brainwave sensors to gather the mind wave data. The research data was analyzed by using the descriptive statistic. Subjective questionnaire surveying students' perception of the environmental conditions in the room was also undertaken during the experimental process. The ambient temperature, relative humidity, horizontal and vertical illuminance on the worktop were recorded to substantiate the subjective perception of the environmental quality in the room.

### 3.1 Hypotheses and data analysis

One of the key objectives of this on-going research project is to explore how lighting conditions influence the learning efficiency, attention, and outcomes. The research questions to be addressed are:

- Does interior lighting conditions influence attention?
- Does interior lighting conditions influence learning outcomes?

A group of architectural students from both undergraduate and graduate school participated in this experiment and the Preliminary results is shown in Table 1. The experimental room with different lighting conditions is shown in Figure 1.

Table 1: Data collected from the experiment by using EEG mindwave mapping methodology .

Learning space	Lux Max	Attention Values					Score Average
		0-20	21-40	41-60	61-80	81-100	
Daylighting	476	2%	19%	36%	24%	19%	93
Artificial light	531	3%	17%	32%	37%	11%	77
Combine	765	15%	35%	12%	1%		50



(a)



(b)



(c)

Figure 1: Learning spaces: (a) daylighting, (b) artificial light (c) combine. (photos by the author).

### 4. RESULTS AND DISCUSSION

In all circumstances, the neurons in the human brain are ceaselessly active, emitting small amounts of electromagnetic waves. These electromagnetic waves are used as electroencephalography (EEG) signals. Without training, humans are generally unable to control fluctuations in their EEG signals. Therefore, the use of EEG signals to determine whether students are learning attentively is viable. In the three different learning environments, the mean illuminance ranged from

inadequate to excessive were recorded and research data collected shows significant differences between the three group students' attention conditions.

Table 1 shows that the subject in the daylight room produced higher elevated level of attention brainwave values than the artificial lit and the hybrid scenario, indicating daylight enhances attention in the learning process. This finding echoes the collected data on the intuitive perception of the three scenarios. However, could the same observation be observed from conducting a design task which normally does not involved much intensive reading and writing? This will be the next experiment to be conducted in this pilot study.

### 5. CONCLUSION

This paper presents the preliminary research findings obtained from using electroencephalography (EEG) signal sensors to detect electromagnetic wave patterns which are indicators of learning efficiency in a conditioned room with varied lighting conditions.

The research results indicate natural daylight classrooms can maintain good level of concentration during the learning process without consuming too much energy required for artificial light. The research methodology developed through this pilot project and the findings can help designers and designers gain better understanding of how learning efficiency can be achieved through appropriate classroom design in the future.

### ACKNOWLEDGEMENTS

This study was supported by the School of Architecture in National Taiwan University of Science and Technology, Taiwan and University of Westminster, UK.

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# The Daylighting Benefit of Chinese Traditional Eave Corner Structure-Nen Qiang Fa Qiang: Daylighting Study of Canglang Pavilion in Suzhou

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**ABSTRACT:** Chinese traditional architectural technique is vast and profound. Besides of unique appearance, ancient building's structure, material and form also closely related to the local climate and culture. The aim of this research is to explore the daylighting benefit of a traditional upturned eave structure-Nen qiang fa qiang. This study started with background research, then followed by field work and computer-aided parametric analysis. Overall, the findings suggest that Nen qiang fa qiang eave structure can enhance the illuminance level both in the overcast and sunny sky conditions, also can against part of direct sunlight in the summer months.

**KEYWORDS:** Traditional Structure, Passive Design, Eave Corner, Daylighting Benefit

## 1. INTRODUCTION

In Chinese southern classical gardens, types of roof are diverse. For instants, one roof named gable and hip roof could have two distinct eave structures. One of them called Shui qiang fa qiang (Figure 1 right), its eave is straight, only the decorative diagonal ridges tilt-up. The other is Nen qiang fa qiang (Figure 1 left), its eave structure incline gently upward, making the entire corner eave area warp.



Figure 1: Nen qiang fa qiang (left) and Shui qiang fa qiang (right) (from Hou 2013) (redraw by author)

The aim of this study is to explore the daylighting benefit of Nen qiang fa qiang to the covered space and try to summarise the traditional passive strategy which could be developed and taken as a design reference. To get a realistic result, the following research was focus on the case study of Canglang Pavilion which was built in the early eleventh century. This kind of eave obviously can bring in sunlight in winter and block sunlight in summer, also can reduce horizontal wind pressure of the roof, meanwhile, it can drain off rain and snow, keeping water away from the building base (Needham 1971).

Firstly, the study introduced basic lighting analysis, then follow by comparative studies: illuminance level simulation of two kinds of eaves under the overcast sky condition. Theoretical analyses were undertaken by using software Ecotect and IES VE. Overall, the findings suggest that Nen qiang fa qiang eave structure can enhance the illuminance level both in the overcast and

sunny sky conditions, also can against part of direct sunlight in the summer months.

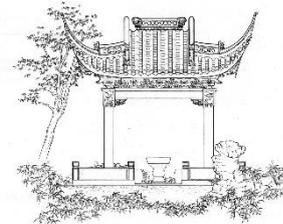


Figure 2: Canglang Pavilion (from He 2014).

## 2. BASIC LIGHTING ANALYSES

Suzhou located at the lower Yangtze region. According to NASA retrospective analysis, overcast sky accounts for around 35% of the time in a year. The highest solar altitude is about 83 degrees at 12:00 on the summer solstice. On the winter solstice, this solar angle is only 37 degrees (Figure 4).

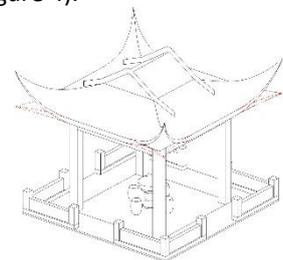
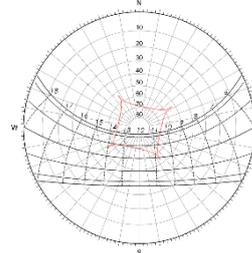


Figure 4: 30°N sunpath diagram. Figure 5: Theoretical models. Red line shows the orientation of Canglang. (Source: Author) Red line represents normal slope roof. (Source: Author)

According to onsite surveys, Canglang's eave corners at an angle of around 44 degrees to horizontal. On the one hand, compared with normal slope roof, four upturned eave corners could be taken as the ingress of top light, allowing reflected light can access from all

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directions. And the enhanced lighting effect is more apparent under the overcast sky, which the horizon luminance is a third of the zenith luminance (LG10 2014). On the other hand, Nen qiang fa qiang can block harmful sunlight in the summer and let in soft sunlight in the winter. More specifically, the tilted angle only allows direct light that below 44 degrees obliquely pass through the pavilion. Analysing from above sun path diagram, this roof could against direct sunlight from morning until around 3 pm on the summer solstice and it would not obstruct low sunlight in the winter. As shown from the section (Figure 6), the southeast upturned eave corner can keep sunlight which solar altitude is about 80 degrees out of the base completely in the summer. However, in the winter, this eave corner can ensure visitors who sitting on the stool exposed to the warm sunlight at noon.

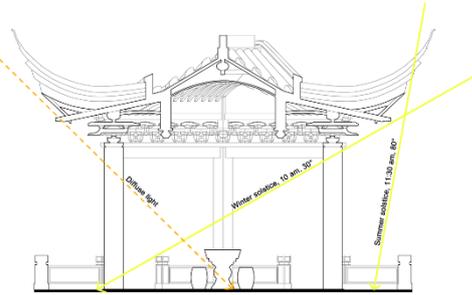


Figure 6: Diagonal section of Canglang. (Source: Author)

### 3. COMPARATIVE ILLUMINANCE ANALYSES

This analysis was generated under the simulated overcast sky condition by using Radiance IES. Overall the average level of Canglang is 3636 Lux, which is about 100 Lux higher than the pavilion with normal slope eave. The contrast is more evident in the below images: the red contour lines (3800 Lux level) show that Canglang's illuminance level (Figure 7 right) at four edges is obviously higher than the ordinary one. Meanwhile, the 3400 Lux level range at the middle area of right is much wider than the left.

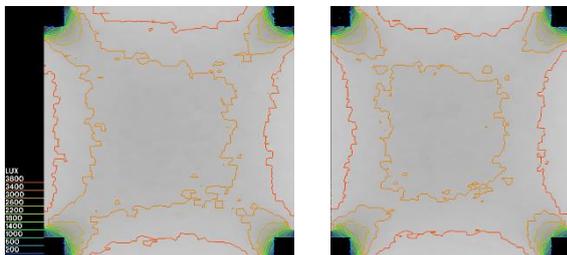


Figure 7: 0.7m height plane illuminance distributions of the normal pavilion (left) and Canglang (right) (Source: Author)

In term of vertical illuminance distribution, it is remarkable to note that two forms of roofs have the almost same daylighting impact on the pavilion's upper space. However, the round stools area of Canglang (figure 9) which has four upturned eave corners is much brighter than the pavilion (figure 8) which has common slope eave, and the floor area of Canglang also can obtain

more solar radiation than the normal one. From another point of view, Canglang's brightness contrast is much more intense and vivid, completely showing wisdom and advancement of traditional passive design strategies.

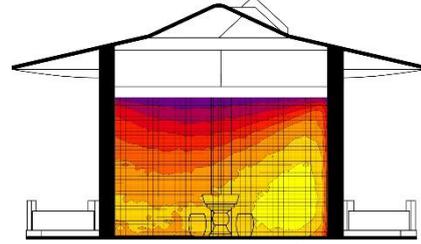


Figure 8: Illuminance distributions of the diagonal section. (pavilion with normal slope eave) (Source: Author)

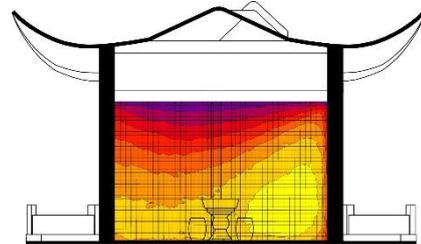


Figure 9: Illuminance distributions of the diagonal section. (Canglang pavilion) (Source: Author)

### 4. CONCLUSION

In conclusion, From the above analyses, the exquisite eave design-Nen qiang fa qiang can passively filter direct sunlight in different time of a year, and at the same time allow diffuse light entering the interior from the top. It is clear that this Traditional modular eave structure shows an appropriate response to the local environment and this uniquely designed eave can provide a useful daylighting roof design reference for the contemporary in the Far East.

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# Zero Degrees of Separation: Changing Architectural Education in East Africa

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*ABSTRACT: It is widely acknowledged that buildings contribute a considerable proportion of global GHG emissions in both their construction and use, making them a key contributor to global climate change. This reality is still absent in architectural education in much of sub-Saharan Africa, where a business-as-usual approach still predominates. Contemplating the responsibility of architects, landscape architects, urban designers and urban planners have in curbing GHG emissions, this paper reflects on how architectural education could respond to the challenges posed, placing architecture students and educators front-and-centre in this challenge, through their actions and outputs. The paper presents on-going dialogue surrounding the need to address climate change as an integral part of architectural discourse, looking at the attendant opportunities and challenges that arise from this process, and what we can learn from this discourse.*

*KEYWORDS: Environmentally Conscious Design, East Africa, Integration, Architectural education, Course Mapping*

## 1. INTRODUCTION

It is often surprising that architectural education seems to prioritise solutions from the past, regarded them as suitable for the changed circumstances of the future, more so for Environmentally Conscious Design (ECD). Architectural education forms an important avenue through which the challenges of the unknown future should be addressed, helping “... students to develop the skills, strategies and attitudes needed for professional practice ... lay[ing] the foundation for continuous learning throughout life” [1]. In the context of East Africa, education is, however, at times perceived as the mere transmission of knowledge from teacher to student, an approach that ensures continuity with the known past, but this raises questions of its appropriateness, given “societal, and thus spatial, constructs [are] emerging with such rapidity that we are (sic) can no longer educate for a fixity; instead we must educate for moving targets” [2], in essence, it becomes an ethical issue [3]. This leads to questions related to contemporary architecture education in the region.

## 2. METHODOLOGICAL APPROACH

A proposition put forward by Hill, Lorenz, Dent, & Lützkendorf [4], states that sustainability is an “overarching moral and ethical framework through which to define the standards and values of all built environment professionals”. This suggests the need for architecture students to be recognise the dilemmas they may face embedded in their chosen profession. Reflecting on the current state of architectural education in East Africa, the need to transform architectural education is brought to the fore, with a need to prepare future professionals to engage with the development of resilient built environments. This presents an

opportunity to redefine architectural education, with the current review looking at the state of architectural education, across the region. An evaluation of the curricula was undertaken, as was a review of course handbooks and validation reports.

## 3. STATE OF ARCHITECTURAL EDUCATION

How far sustainability is incorporated or integrated within architecture programmes in East Africa, was the focus of the mapping exercise, looking at courses in each programme, and mapped these onto generic validation classifications provided by the National Council for Higher Education.

Table 1: Course mapping against validation criteria

Criteria	School A	School B	School C	School D
Design Integration	58.6%	38.5%	47.3%	47.0%
Design / History & Theory / User	13.5%	12.5%	19.6%	32.7%
Environmental / Technical	11.8%	19.8%	14.2%	11.4%
Implementation	6.8%	11.0%	4.7%	9.0%
Skills	9.3%	20.8%	7.9%	11.4%
Electives	1.7%	0.0%	7.5%	2.4%

Feedback received from Commonwealth Association of Architects (CAA) Validation reports, provided an idea of how the integration of knowledge content was being addressed. Three of the programmes showed limited evidence of integration of sustainability into the design studio, with School C the only one to attain a working approach:

“... little evidence of integration of technology, environmental design and sustainability in the design projects.” (School A)

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"... need for a greater level of integration of technology (environmental design, structures, construction and sustainability) in the studio design work." (School B)

"Student work and presentations displayed a good understanding of sustainable design principles and the relationship between people and the built environment ..." (School C)

"There are concerns regarding planning, sustainability issues, and the integration of building construction technology." (School D)

While sustainability issues may have been included in the curriculum, it was clear these were not taken up in the design studio, a failure to appreciate that "... studio integration is very relevant, as architects cannot completely realize their knowledge or technique unless it is realized within the project process" [5]. A challenge that was evident was the nature of the programmes themselves: while School C had an integrated curriculum model, the other schools used a separate subjects model, which appears to be conducive for the uptake of sustainability content in architectural design, in effect, Zero degrees of separation between teaching and learning.

It should be pointed out that an integrated approach is more than bringing content together or teaching knowledge content under a single course name. Staff have also to be available to help students interrogate this knowledge content, and to implement issues within design projects. Changing architectural education thus emerges as a key factor in addressing climate change, more so in the context of sub-Saharan Africa, where its effects are likely to be particularly adverse. This requires going beyond merely introducing new course units, but addressing, how programmes are taught, challenging the notion of 'Curricular Prestige' [6], which neglecting the idea of design as an integrated approach.

## 2. CONCLUSION

As educators, it is imperative that we go beyond merely helping students react to existing phenomenon, but engaging them in recognising and appreciating consequences as well. What is being advocated is a transformation of the educational process, opening opportunities for discourse about future possibilities, and not merely providing dressed up solutions from the past. This adds dispositions such as: carefulness, thoughtfulness, humility, criticality, receptiveness, resilience, courage, and stillness as core to architectural education [6] none of which are actively encouraged in many existing curricula in East Africa, more so as the educator is often regarded as the sole generator of knowledge.

Solving impending challenges is intrinsically linked to challenging long accepted ways of thinking and acting. This is only possible if professional responsibility seeks to

transcend present educational approaches, while looking to the needs of the future. Educating professionals to recognise the ethical dilemmas that are intrinsically linked to their roles as built environment professionals is key, ensuring they seek to make choices acknowledging that architecture itself is complex, and therefore, "architectural education should instil a sense of the complexity and diversity of the cultural, natural, and societal environment" [7].

To be able to implement change in the curriculum would require a change in mind-set, as teaching sustainable architecture requires a new approach, one that acknowledges the wide scope of architecture, beyond just that of building [D]esign. Key to any strategy to incorporate ECD into curricula is to acknowledge the limitations (perceived or otherwise). The one size fits all approach negates a key concern for architects who can act as "... moral citizens ... engaging in an open process of negotiation, criticism and debate ..." [8].

## ACKNOWLEDGEMENTS

Thanks to the architecture schools that participated in this study, and made their information available.

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# Teaching Urban Climatology through Field Observations: The London Urban Climate Walk

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*ABSTRACT: Urban climatology (UC) is fundamentally interdisciplinary as it draws upon the expertise of several distinct fields including: atmospheric sciences, architecture, engineering, geography and urban planning & design [1]. For a student of UC, integrating the contributions of each to an understanding of urban climate is a challenge; each has a focus on different spatial and time scales and uses different terminology to describe the relevant features/processes from their perspectives. As a result, what represents a solution in one field can create a problem for those working in another. For example, building air conditioning that is used to offset uncomfortably hot outdoor temperatures adds waste energy to the outdoors, contributing to warming and creating an energy demand feedback loop. In this paper, we describe the London Urban Climate Walk and how it is used to explore urban microclimates and teach the principles of urban climatology. The walk treats the participants as a mobile 'weather stations' and links their sensory faculties to climate processes. The paper will present the results of atmospheric measurements taken along the route and of interviews with participants.*

*KEYWORDS: Urban climatology, climate experience*

## 1. INTRODUCTION

Urban climatology (UC) is fundamentally interdisciplinary as it draws upon the expertise of several distinct fields including: atmospheric sciences, architecture, engineering, geography and urban planning & design [1]. For a student of UC, integrating the contributions of each to an understanding of urban climate is a challenge; each has a focus on different spatial and time scales and uses different terminology to describe the relevant features/processes from their perspectives. As a result, what represents a solution in one field can create a problem for those working in another. For example, building air conditioning that is used to offset uncomfortably hot outdoor temperatures adds waste energy to the outdoors, contributing to warming and creating an energy demand feedback loop. There are a great many examples of these types of these loops in the urban setting where the juxtaposition of processes and outcomes are proximate in space and time and difficult to disentangle [2].

In this paper, we describe the London Urban Climate Walk and how it is used to explore urban microclimates and teach the principles of urban climatology [3]. The walk treats the participants as a mobile 'weather stations' and links their sensory faculties to climate processes. This abstract describes the design of the walk; the paper will present the results of atmospheric measurements taken along the route and of interviews with participants.

## 2. CLIMATE OF CITIES

The climate impact of cities is a product of its physical form and functions. Form describes: the surface cover (e.g. the fractions of the ground that is vegetated and impermeable); the manufactured materials used for building and paving (e.g. glass, concrete and asphalt) and; the three dimensional geometry created by buildings (and vegetation) and their relative placement. These attributes affect the natural exchanges of energy, mass and momentum at

ground level, creating areas of shadow and sunlight, shelter and exposure and, warmth and cooling. These microclimates change rapidly over the course of minutes and hours. The functions of cities describe the activities of humans that are often bundled into economic sectors such as residential, transport, commercial and so on. Each of these activities is correlated to the resource demands of the population (for heating/cooling buildings, transport, etc.) that results in waste energy and materials that are deposited into the environment, adding heat/water vapour and diminishing air quality. These demands and emissions have distinct temporal and spatial patterns. Together, the net impact of urban form and functions is to generate a myriad of microclimates.

The purpose of the urban climate walk is to select a route so that the participant is exposed to a variety of microclimates. For this reason, the walk is designed through a heterogenous urban environment characterised by variations in:

1. Street widths, building heights and orientation,
2. Traffic flows including vehicles and pedestrians,

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3. Building dimensions, fabrics and uses and,
4. Green surface cover and street plantings.

### 3. LONDON CASE-STUDY

The London Urban Climate Walk (LUCW) was designed in and around the City of London, the historic core of greater London. It occupies an area of 3km<sup>2</sup> and has a resident population of less than 10,000; at the same time it is an international financial and business centre that draws over 300,000 commuters daily. The urban landscape that has developed consists of medieval street patterns, old buildings of limited height, modern buildings with unusual dimensions and fabrics, etc. (Figure 1). The result is a great variations in daytime microclimates that the LUCW is designed to capture.



Figure 1: The City of London has an eclectic urban architecture that includes historic low-density buildings constructed of brick/stone that are juxtaposed with modern tall buildings using steel and glass.

Figure 2 shows the route of the LUCW, which begins at Finsbury Square ① and finishes on the north embankment of the Thames ⑨. At the start the walk outlines the major controls on urban climate, specifically the roles of urban morphology and the Sun's path. At the end, the role of the river as a ventilation corridor is discussed. Between these two points the walk exposes participants to areas of shadow and shelter caused by the interference of buildings on exchanges of energy, momentum and materials.

The LUCW has run more than two dozen times since 2014; people attend by signing up via Eventbrite or as part of an organised event linked to universities and societies. The audience is diverse and includes interested citizens and those with an interest in building and urban disciplines. Over the past year, the impact of the event has been gauged through questionnaires. The results of these be presented at PLEA 2018.

### 4. NEXT STEPS

The route of the LUCW can be used as a transect to evaluate the exposure of pedestrians to varying environmental conditions. Measurements along this route can be used to provide evidence to justify the selection of the particular route. In addition to air temperature and wind recordings, we are currently making measurements of air quality (AQ) along the route using diffusion tubes that are located so as to complement London City's air quality network. These data will be used to evaluate the impact of tall buildings on ventilation at street level.

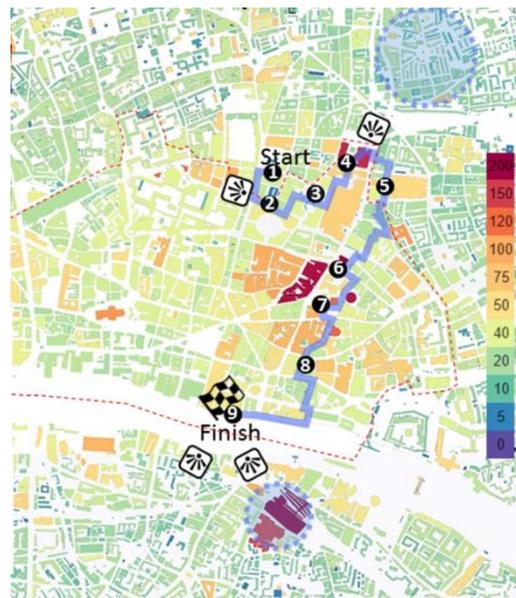


Figure 2: A map of central London showing the path of the walk. Buildings are coloured according to height.

### 5. CONCLUSION

The development and implementation of the urban climate walk has allowed us to: organise the principles of urban climatology around an urban transect and; to communicate urban climate effects to a diverse audience of specialists and citizens. A well designed route can link the substantive interests of the myriad of disciplines with an interest in urban environments and their improvements. The evidence from questionnaires supports our view that this can be an important means of educating on the impacts of urbanisation and architecture on outdoor climates.

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