Achieving Suitable Thermal Performance In Residential Buildings In Wuhan, China

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ABSTRACT: The purpose of this research is to propose a reasonable residential building model with special consideration to a subtropical climate region in summer scenario, which will reduce the unnecessary environmental load on buildings. Underpinning the research project will be a case study, which will identify current problems within the residential buildings and with an overall aim of identifying positive strategies for improvement within the recommendations. Furthermore, the cooling reduction of air conditioning and the environmental load are estimated. The report concludes that serious consideration should be given to the implementation of energy saving strategies in current Chinese residential buildings, which have significant scope for reducing energy consumption and enhancing thermal comfort.

Keywords: comfort, residential, energy saving.

1. INTRODUCTION

It is generally accepted that China is now the world's fastest growing economy, and on a global scale, it accounts for 11% of the world carbon dioxide emissions [1]. As the country has to house a population over 1.3 billion, buildings are responsible for almost 30% of the total energy consumption, and one key feature of the recent residential building is homogenous, as most of them have been constructed within the last decade. However, due to the late awareness of the environmental issues, compared to the developed countries, the energy consumption by residential buildings is 200% ~ 300% higher than those that are consumed in other parts of the world with the same climate region. Specifically, the crucial fact is the electricity crisis experienced every summer [2]. Moreover, due to inadequate consideration to thermal behaviour at the planning stage, the building blocks give an inefficient thermal performance and have failed to provide indoor comfort unless extra support is given. This research will endeavour to investigate the residential building blocks with a starting point being the 'summer crisis' phenomenon.

2. CONTEXT

The chosen site - WuHan, is located in central China, it is within the subtropical humid climate zone (114.2ºE, 30.4ºN), with a population of 8 million. The city area is 8,500km² and 21% of which is covered by water. In summer (July and August) the mean average monthly temperature is 28.7º and the relative humidity is 80%. The prevailing wind is from the south (1.5m/s) and the sunshine duration is 7.4 hours per day. The apartment is located in a typical residential community, which has been occupied since 2000 by a family of 3. It is generally north-south facing and comprises of three bedrooms. The apartment is on the first floor and the whole area is 120m² with an average window to floor ratio of 21%. In summer conditions, air conditioners are used to achieve indoor comfort and the occupants always close all the windows and only ventilate the apartment in the early morning (5AM ~ 10AM) according to interviews.

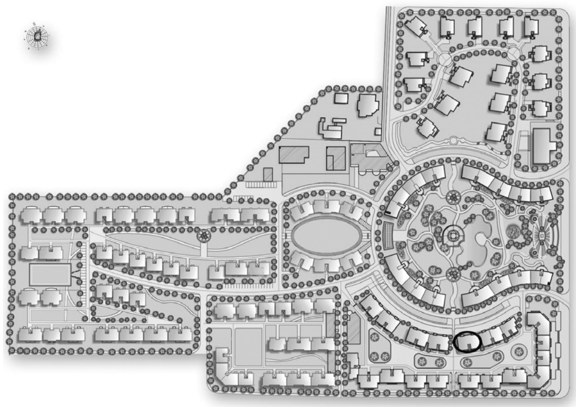


Figure 1: After Master Plan of The Univerland. [3]

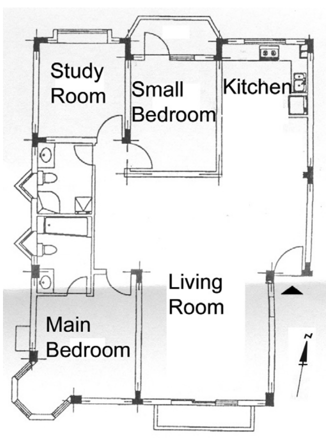


Figure 2: Apartment Internal Plan (After Occupant's Bulletin)

3. FIELDWORKS

Fieldworks have taken place on two days in different rooms to measure air temperature and relative humidity from 24th – 25th May and 2nd – 3rd July respectively. In the first measurement, the result does not indicate severe uncomfortable conditions. Generally, the indoor temperature remains flat around 23ºC compared to the outdoor level (20ºC- 28ºC), but the indoor night time temperature is higher than the outdoors (3ºC gap). As the first measurements took place during a mild season, the results from second time showed some differences. The indoor temperatures are stable at 32ºC - 34ºC, no matter how the outdoor temperature varied from 25ºC - 35ºC. And the only time when the indoor temperature drops is when the occupants open the windows from 5AM – 10AM. Only with the additional use of the air conditioner, can the indoor comfort be achieved to a desirable level. In normal conditions, all the rooms have an uncomfortable indoor environment due to the high level of temperature: 30ºC at least.

4. SIMULATIONS

The thermal performance will be mainly assessed by TAS [4] and the weather data used is generated from MeteoNorm [5]. Figure 3 is one-week (6th – 12th August) temperature profile from TAS simulation, which can represent the average real case in summer. The main findings from this simulation are:

1) The indoor Temperature is around 32ºC~34ºC according to the varied outdoor temperature level, and only dropped when the occupants opened the windows. This illustrates the huge reliance and use of air conditioning.
2) During the daytime, the indoor temperature is lower than the outdoor temperature but during the night the situation is reversed, the indoor temperature is much higher than outside.
3) Once the building has been ventilated, the indoor temperature drops to around outdoor level.
4) The indoor temperature varies in each room, especially between 2-7pm in the late afternoon and early evening.

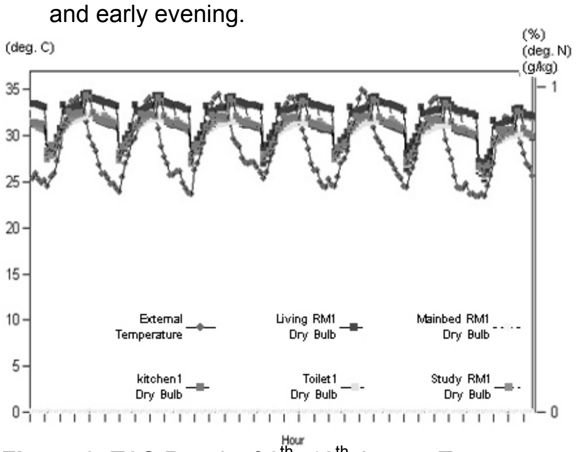


Figure 3: TAS Result of 6th -12th August Temperature Profile

As the calculation steps for each hour's result are the same in TAS, figure 4 is one-day (9th August) thermal performance profile, which indicates all aspects that contribute to the result. (Following all the simulations and analysis are to be considered, are on the same day - 9th August) In general, there are four main aspects (figure 5): Building Heat Transfer (Envelope Properties) and Solar Gain take the major proportion, with 30% each, while Ventilation contributes to 21% of the whole performance. Finally, the Internal Gains occupies 19%, and varies due to different lighting, occupancy and equipment levels. In this situation, the internal gains of a small family are relatively fixed compared to the other three aspects. For a clear illustration of the thermal performance of the building nature itself, the next paragraphs will focus on these other three aspects respectively.

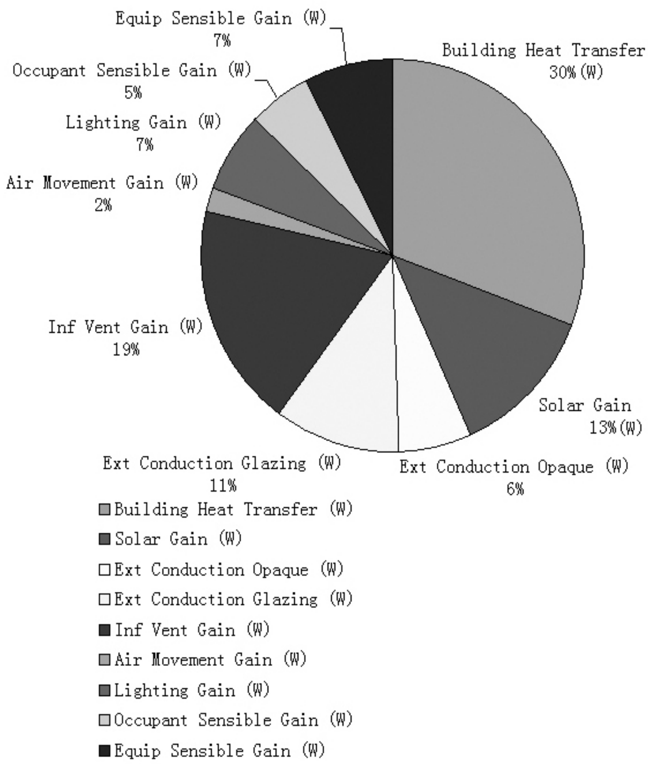


Figure 4 TAS Result of 9th August Thermal Performance Profile

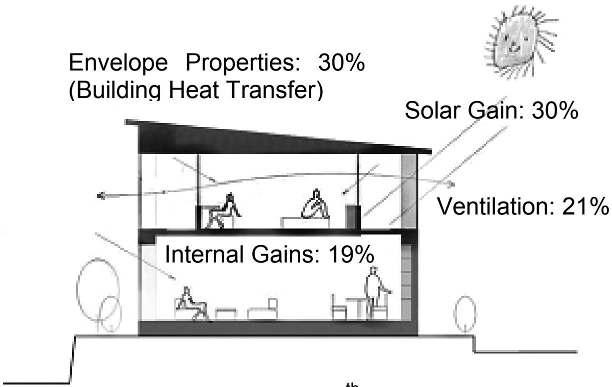


Figure 5 Illustration of 9th August Thermal Performance Profile

4.1 Envelope Properties

The current building envelope materials are: 200mm aerated concrete of the external walls (conductance: 3.6w/m²k) and 10mm single glazing clear glass with plastic frames (conductance: 100w/m²k). The two other substituted materials that have been used for comparison in this study are: 335mm brick and block external wall (conductance: 0.4w/m²k) and 33mm Clear 6-12-6 DG with mid pane blind (conductance: 2.5w/m²k)

For the opaque element – external wall, the thermal performance from the simulation of these two materials is nearly the same, with the current material slightly higher during the night time (around 0.1ºC). Whilst comparing the glazing element – windows, the result is quite different. The present material leads to an indoor temperature around 31ºC~32ºC, however, when it has been changed to a better thermal property material – double glazing low-e with middle blind, the indoor temperature in the same situation and on the same day, gave a reading of 30ºC~31ºC.

The envelope analysis indicates that the glazing elements account for a higher proportion of the building heat transfer, than those of the opaque elements, at the same time, being the main source of the heat gain to the indoor environment. Therefore, by improving the nature of the glazing elements, the indoor temperature can be decreased by 2ºC as an average level in the same circumstances.

4.2 Solar Gains

From TAS observation, two main factors: exposure and shading, affect the thermal performance most. For example, the external walls, which are facing west, have gained double the heat of those of the north or south facings especially in the late afternoon and early evening, after 5pm. However, when the current material has been substituted to a well insulated material (335mm brick and block external wall), this undesirable phenomenon can be avoided effectively. In a climate like this, shading is always desirable in summer, because it can prevent from the incident of solar radiation. Furthermore, shading is essential for all glazed surfaces as the glazing part is usually the most vulnerable part of the whole building. For a latitude of 30.4ºN, the appropriate shading required would be: external overhang plus right/left fins together. The result from the simulation indicates that by introducing a correctly designed shading device, the average indoor temperature can decline by 1ºC compared to the present situation. Thus, when the building envelope has a large exposure to the direct solar radiation, it needs to be well insulated, or well shaded.

4.3 Ventilation

From the weather data, the cooler night time air temperature can be the ideal sink for passive cooling. However, this strategy has not been put into practice by the local residents due to two dominant constrains: outdoor environment and the wind conditions. Such as noise, dust, smell of laystall and mosquitoes, made the occupants reluctant to open windows. On the other hand, the prevailing wind at night time between 10pm - 5am is from east, whilst most of the residential building blocks are north-south facing. In order to avoid the confrontation of these two confines and meanwhile to harness the cooler night time air for passive cooling, an additional ventilation layer has been introduced here based on the principal of ventilating every floor. Since to open the usual windows will not achieve adequate ventilation, the opening layer is designed to be 300mm wide and just below the upper floor/ceiling level, with maximum west, east facing, and also north, south facing, because most of the residential building blocks possess a length of 30m at least. Furthermore, the ventilation layer needs to be well insulated during day time, as discussed before. And this has been tested in TAS, which indicates a desirable result.

4.4 Recommendations

As discussed, the key recommendations for the present apartment are:

1) Double-glazing low-e with middle blind instead of the single glazing.
2) Well insulated external wall (335mm brick and block external wall) instead of the 200mm aerated concrete on west and east façade.
3) Appropriate shading devices for each window.
4) Additional ventilation layer beneath every upper floor/ceiling.

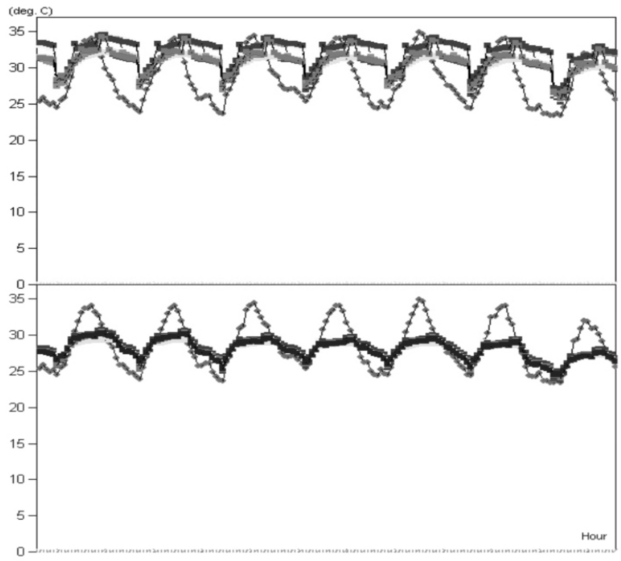


Figure 6: TAS Result of 6th-12th August Temperature Profile Comparison

The recommendations, gained from TAS results are a significant improvement compared to the current situation. Figure 6 clearly demonstrates the dramatic difference. The upper part indicates the present indoor temperature, which is around 32ºC ~34ºC and this demonstrates that a large amount of the air conditioner use is required to reduce temperatures thus, to ensure indoor comfort. The bottom of the table is the simulation result of the recommendation, which gives a reasonable indoor temperature, with 29ºC as the top temperature during the day time, and drops to near outdoor level during the night time so as to eliminate the use of air conditioning.

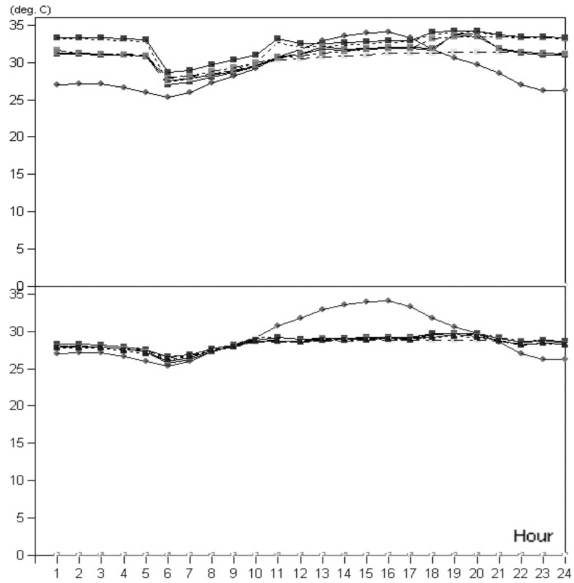


Figure 7: TAS Results of 9th August Temperature Profile Comparison

Figure 7 is the same day – 9th August temperature profile, the main observation from this comparison is that the day time temperature has fallen generally from 33ºC to 28ºC, and this five degree fall has been accomplished by improving envelope properties plus appropriate shading devices. There is an even larger drop of 6 degree, which has been achieved during the night time by introducing night ventilation.

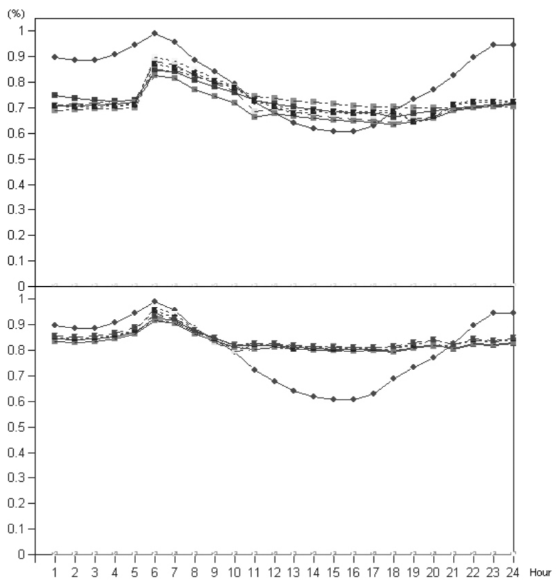


Figure 8: TAS Result of 9th August Humidity Profile Comparison

However, as introduced before, due to the outdoor higher relative humidity at night, the time when the cooler night time air has been introduced into indoor, the higher relative humidity has been allowed into the indoor environment as well. This is demonstrated by figure 8, that the relative humidity has been increased from 70% (present level) to 80% (recommended level) at night. There are different strategies, which can be adopted to avoid this rise if undesirable: adding a sponge material to absorb the moisture at night, which can then be dried by the outdoor environment during the day time self-acting.

According to statistic from TAS, among the whole period of July and August, most of the daily hourly temperature in the apartment stays within the comfort zone (Temperature22^{0}C-29^{0}C; humidity 30%- 80%) and only 3% of them is when the temperature rise is above 29ºC level, compared with the present situation, 18% of which is over 29ºC. Overall, having been assessed the same period (6th-12th August) indoor environment, the recommendation can ensure 70% of the indoor comfort, during July and August without using air conditioners. This situation is more desirable and effective to the present situation, which can only provide 13% of indoor comfort and fully relies on the use of air conditioning. The results here indicate that the majority of current air conditioner use can be significantly reduced by improving the thermal performances of the building itself.

5. ENERGY CONSUMPTION

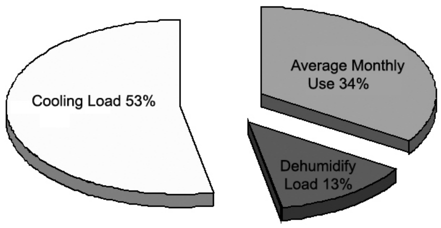
In order to gain a clear observation of the original thermal performance of the building itself, the use of air conditioning hasn't been simulated among all the previous stages until this point, here it has been introduced to help to build up scenarios of the energy consumption. The settings of the air conditioning are basically for full night time use in two bedrooms from 10pm to 5am, while the study room has also been set from 5pm till middle night 12pm. Specifically, the air conditioner only operates when the room temperature is above 29ºC (calculated as cooling load) within the periods that have been set.

The analysis compiled from TAS results of July and August indicate that the solar gain and cooling load have been reduced significantly from 650.66kWt to 63.89kWt and 635.43kWt to 217.65kWt respectively while the internal gains remains at the same level - 883kWt, whilst with a slight increase in the dehumidify load 146kWt – 387kWt.

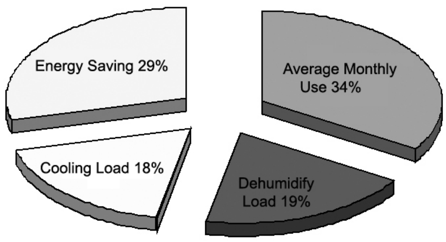
Table 1: Specifications of Recommendation Profile in July & August

	Temperature Reducing (ºC)	Cooling Load Reducing (kWt)	Saving Percentage
Double Glazing	0.6	12.4	3.0
Well Insulation	0.6	53.1	12.7
Proper Shading	1.0	96.6	23.1
Night Ventilation	2.5	255.7	61.2
In Total	5	417.8	100

Precisely, table 1 is the saving list specifications by every strategy. Among the totaling saving, the priority is night ventilation, which is able to reduce the indoor temperature by 2.5ºC, and accounts for 61.2% of the entire saving load.



Present Monthly Electricity Distribution



Proposed Monthly Electricity Distribution

Figure 9: Monthly Energy Distribution Comparison

As the average monthly use of electricity is the same, the above two pie charts Figure 9 represent the differences on the monthly electricity distribution, which shows a significant savings on electricity. Although the dehumidify load has been increased from 13% to19%, the cooling load changed sharply, with a drop from 53% to 18%, and this gives 29% electricity saving in total.

However, this 29% saving is just a general estimate and remains uncovered points. For example, the schedule of air conditioner use is different from the real case. Here it has been considered only in night time from 10pm to 5am, while there must be reducible daytime use in certain level. And the dehumidify load can be also reduced by several means, which have been mentioned before, but haven't been calculated here. Moreover, the efficiency of the air conditioners and certain engineering techniques can be also applied in case of this.

6. CONCLUSION

The whole research confirms the following conclusions:

1) The energy consumption in residential buildings in China has a large inefficient phenomenon during the summer.
2) The present residential building construction has failed to provide suitable indoor comfort.
3) By implementing the recommendations, significant amounts of the current residential energy consumption could be saved. Among all the recommendations, the priority is night ventilation, which contributes to 61% of the total saving.

This preliminary research is a conservative evaluation drawn from summer scope only. There are many further crucial steps, including further research and analysis, which need to be taken urgently. And the overall energy saving in China has a significant potential.

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