658 - ICE TEA CITY

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Abstract

Although research into the implications of how climate change will impact on our urban environments has long been established, it is only in recent years that research has examined the feasibility and cost implications of reducing the CO_2 emissions originating from urbanised areas. However, much of the attention on the built environment has focused on the energy performance of individual buildings, with little research into how the form of the urban environment, as a whole, influences energy use. In terms of the urban environment, the interactions between urban morphology and the consequential localised climatic conditions that are influential in forming the Urban Heat Island, can impact significantly on the performance of individual buildings. However this relationship is not always recognised when examining the performance of individual building in terms of energy demand and CO_2 reduction. This paper describes an investigation into the link between urban morphology and energy demand in a temperate climate. Using part of London as a case-study, a simulation model is employed to explore how energy demand for cooling partially depends upon the form of the urban environment.

Keywords - Urban Morphology, Urban Heat Island, Radiation exchanges.

1.0 INTRODUCTION

The renowned building services engineer Max Fordham, suggests a similarity between commercial office developments and making a cup of iced tea:

'To make the tea you need energy to boil water for the tea, and then you add further energy to cool the tea'.

This, he argues, is similar to the way we design buildings. Design decisions often result in overheating so, to compensate for this, we install cooling devices to lower internal temperatures.

This analogy could be taken one step further. Urban environments are usually found to be warmer than the surrounding rural area – this is commonly referred to as the Urban Heat Island (UHI) phenomenon. Warmer external urban environments result in an increase in energy demand needed to cool the internal urban environment [1], which in turn further increases the external temperature, resulting in more energy needed to cool the internal environment.

The built environment is responsible for an estimated 50% of the total UK national Carbon Dioxide (CO_2) emissions, with large cities such as London using 75% of its energy on buildings [2]. However, despite intensified energy conservation measures energy demand has risen at an annual average (for EU countries) of 1.1% since 1971 [3]. This is a consequence of both an increase urban population and increased demand for cooling [4]. Internal cooling systems dispose of heat to the external environment, contributing to the UHI. Moreover, these systems are often dependent on the burning of fossil fuels to produce electricity, increasing CO_2 emissions, which is linked to global warming. New directives and research initiatives set by the government are generally concerned with the operational efficiency of individual buildings. However, buildings in urban areas exhibit strong interactions with other buildings that can significantly alter the performance of individual structures.

The warmer air temperatures found in urban areas show similarities in terms of the rates and magnitude to the observed global air temperatures rise [5]. Urban areas now occupied by the majority of the global population, are both a cause of, and recipient of, climate change at all scales. Therefore a study into the link between energy use and urban form is worthy of research.

The first section of this paper outlines the causes of increased urban temperatures. The second part reports on research into the relationship between urban morphology and the demand for energy used for cooling. Using Moorgate, in the City of London as a case-study, where the effects of over-shadowing and loss of sunlight are examined using a computer simulation model.

2.0 ICED TEA CITY

The near-surface air temperature in urban areas is usually warmer (particularly at night) than that over the surrounding rural area. This urban heat island (UHI) phenomenon has been recorded in nearly every urban environment and has been found to be strongest at night under clear skies and calm conditions. The intensity of the UHI depends on the thermal and radiative properties of the surface materials, anthropogenic heat production and on urban geometry. The latter refers to the variety of building configurations in urban areas that create a myriad of open spaces. The layer of urban atmosphere, at and below the building roof-level is referred to in climate literature as the urban canopy layer. It is in this layer that the micro-scale exchanges between buildings give rise to distinctive micro-climates, the most discernible feature of which is the UHI.

The outdoor spaces within the canopy layer are distinguished by the unique energy exchanges that occur at the surfaces of buildings and streets. The most obvious example of this are the shadow patterns of buildings that directly impact shortwave (solar) radiation receipt at other nearby buildings. In addition, the restricted ‘sky view’ from within the canopy reduces radiation exchanges with the sky and increases exchanges with the surrounding urban surfaces. For example, at night, the effect of reducing the sky view is to increase longwave (terrestrial) radiation with the surrounding warmer urban surfaces, or the re-radiation of longwave radiation between surfaces. Thus, the heat remains ‘trapped’. The net effect is to reduce the rate of night-time cooling, a critical factor in the formation of the UHI.

Surface material also has a role to play in the creation of urban microclimates. For example, urban parks, which are usually characterised by a ‘natural’ grass surface, can create local zones of cool temperatures within the UHI as energy is used to evaporate water and cool the overlying air.

Reduced air movement and elevated external urban temperatures impact on internal building temperatures by increasing the amount of overheating days whereby mechanical ventilation and cooling is often used. In addition the use of natural ventilation methods (which rely on pressure variations on building facades) are also restricted by reduced air movement. It should be noted that maximum UHI occurs on days with little or no air movement [6]. The lesson from this is that the energy management of our cities is more complex than simply adding the demands on individual buildings. The energy exchanges that take place in an urban environment in themselves are not complex but occur at different scales and on an infinite number of levels, for both, individual buildings and for the urban system as a whole. It is important to note that these energy exchanges are both dependant on and exert an influence on each other, which in turn influences further energy use. We must recognise that, in an urban setting, the buildings themselves interact to create a distinct environment that has an affect on individual building performance.

The future planning of our urban environments faces several challenges in order to adapt in preparation for predicted future climate change alongside the need to reduce CO_2 emissions. One of the problems faced by urban planning is that the urban layout is often predetermined making street patterns difficult to change without huge modification to the infrastructure that already exists. Therefore it is important to work within the existing parameters of the urban framework. However within this framework there may be a possible solution to the problems of rising urban temperatures.

The research presented here will examine the role of geometry and its effect on building solar gain and energy use.

3.0 THE URBAN GEOMETRY EFFECT

One of the obstacles to studying the effect of urban geometry is the great variety which exists. Thus, simpler configurations, such as urban canyons (representing city streets), have been employed to examine the affect of urban terrain on energy exchanges. These simple forms can be employed to examine links between measures of urban form (such as the building height to street width ratio, H:W) and of energy exchange. It is hoped that these links, once established for this configurations can be applied more generally. This is the approach adopted here.

The IES Virtual Environment Modelling Package (IES) was chosen for the modelling due to its ability to analyse the geometrical relationship that exists between direct solar receipt (insolation) and the placement of an individual building or of groups of buildings. The software calculates the thermal transfer through the building skin as a function of solar receipt and allows it to determine the energy load required to keep individual buildings at a constant internal temperature. Over the course of a year, it determines both heating and cooling loads. The software does not calculate the benefits of diffuse solar radiation. Nor does it assess heat loss at building surfaces as a result of turbulent transport.

To examine the effects of geometry on overshadowing and on the energy needs of individual buildings, a city street as the fundamental component of the urban area has been employed. Although the software can examine street orientation, here the results are present for streets that are oriented north to south. Thus, geometry is explored in terms of the H:W of the streets.

In addition, the case study is based on Moorgate a major throughway in the City of London, where many of the city’s most prestigious buildings are situated. For this purpose, the IES Heathrow weather file was employed.

3.1 LONDON

London is a city of an estimated population of 7.5 million, and is located at 51º32’N. London’s climate can be characterised as a mild midlatitude, but is already experiencing elevated urban temperatures as a result of global warming. The intensity of the London Heat Island has been assessed using a radial grid of 68 stations recording simultaneous hourly air temperatures. The urban heat island was found to be a nocturnal phenomenon with intensity reaching 7ºC on occasion. It was found that the thermal centre is in the City of London, which is characterized by tall buildings and high anthropogenic heat emissions. [7]

This investigation to try to find if an optimum ratio between building height to street width (H:W) exists that will reduce energy required for cooling as a result of overshadowing, for a climate similar of that of London.

The results of energy loads from internal and external sources are important, as they will form the basis of the conclusion. The energy use is set at 85kW/m^2 as a baseline, against which to compare results. This value is in line with the *Action Energy ECON 19* Energy consumption guide [8] over the course of a year.

3.2 METHODOLOGY

The research reported here, is based on simulations of two types of office buildings (Types A and B) arranged along streets. Type A corresponds with the typical London office building with a height of seven stories, an average gross floor area of approx. 15,000m^2 and a high percentage of glazing. Type B retains the same floor area but is 14 stories high (Table 1).

***Table 1**. Schedule of accommodation for type A and type B.*

BUILDING TYPE	A	B
Floors above ground	7	14
Total floor area (m^2)	14700	14700
Floor plate (m^2)	2100	1050
Volume (m^3)	52500	51450
Total height (m)	25	49
Width (m)	35	35
Length (m)	60	30
Surface area front face(m^2)	1500	1470
Surface area roof (m^2)	2100	1050
Surface area total (m^2)	6250	7840
Fenestration (70% front face only)	1470	1209

Each building in the group has identical properties: constructed of the same materials with only one façade (that facing into the canyon) glazed; occupation density is one person for every 10m² for 10 hours per day, 5 days per week; internal cooling season temperature is set at 23°C. It should be noted that although Type A has an increase of glazing of around 17% when compared to Type B, calculations showed that this did not affect the cooling loads for both building types when exposed to full sun.

These building types are arranged in parallel to create six streets with three different H/W ratios (Fig. 2):

- Type A opposite Type A H:W = 1.1
- Type B opposite Type B H:W = 2.2

The final H/W ratio is associated with the asymmetric city streets formed by Type A(B) opposite Type B(A). The average H/W here is 1.7.

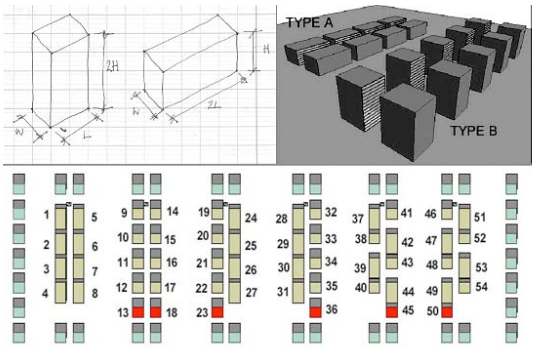

***Fig. 2.** Plan view of the six streets. Each of the individual building units is numbered from 1 to 54. Building Type A is represented by those numbered 1-8 and Type B by those numbered 9-18.*

4.0 RESULTS

The purpose of this exercise is to determine how overshadowing affects the energy loads of the buildings on either side of a street. IES is capable of generating data and images (Fig. 3 shows the shadow patterns generated in the early afternoon in May). In this section the results associated with two selected buildings from the array above (15 and 36) are discussed. Thereafter, the results will be present on the general relationship between H/W and energy use.

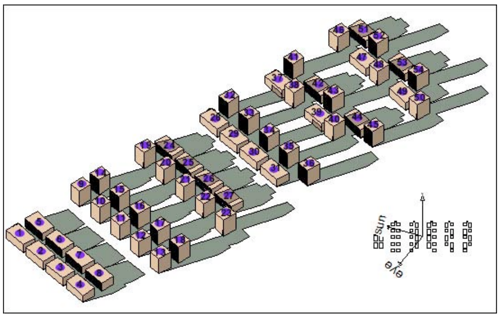

***Fig. 3** Axonometric diagram showing shadow patterns generated by the experimental array.*

4.1 INDIVIDUAL BUILDINGS

An initial investigation was carried out to establish the percentage of direct solar gains that impinges on the west face of the canyon.

It was found that building numbers 14 to 18 **(Type B opposite Type B)** received the lowest percentage of external insolation during the late afternoon during the peak demand months, May and June (as indicated by the Heathrow weather file). It is therefore expected that Type B opposite Type B will result in the lowest energy use for cooling; this will be investigated in the following sections where the results from IES SunCast simulation are used to calculate the amount of energy required for cooling as a direct result of over shadowing.

***Table 2** – building 15 showing external insolation as a percentage on the west face between 15:00 and 19:00*

Month	15:00	16:00	17:00	18:00	19:00
May	62.9	40.3	21.4	27.2	30.4
Jun	62.6	40.3	30.6	34.4	43.1

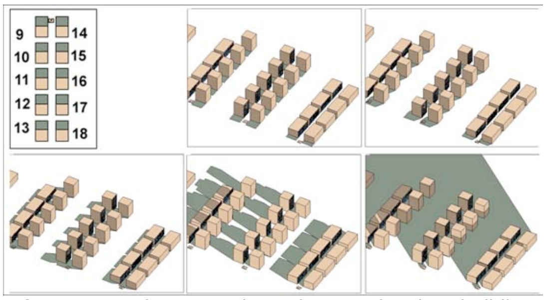

***Fig. 4** – Reference Plan View: Showing building numbers 9 –18 type B opposite type B shadow formation between 12:00 to 20:00*

Building 36 **[Type B opposite Type A]** received the highest percentage of external insolation during the afternoon therefore shall be considered the worst-case scenario. This will allow a comparison of over shading and energy use to be calculated later in this study.

***Table 3** – building 36 showing external insolation as a percentage on the west face between 15:00 and 19:00*

Month	15:00	16:00	17:00	18:00	19:00
May	100	100	100	97.4	58.2
Jun	100	100	100	96.6	78.8

It has been shown that different urban street canyon configurations receive different levels of direct solar radiation as a result of overshadowing, orientation and height to width ratios [9]. The SunCast results (see fig. 4) confirm this, however before any energy calculations can be preformed it is important to ensure that the system is in equilibrium. Building 15 is used as an example to show that the sum of both internal and solar gain is equal to the external conduction and cooling energy [as shown in table 4]. All buildings were found to be in equilibrium in terms of energy transfers. Once this is verified, studies on the thermal behaviour of buildings were then carried out to examine the role of direct radiation received at the glazed face of the canyon impacts on the energy use and CO_2 emissions of buildings.

Building 15 Type B received the lowest percentage of external insolation and is opposite Type B buildings, 49 meters high. However Building 36 also Type B only receives overshadowing in the late afternoon (from 18:00 onwards) therefore received the highest percentage of external insolation for the most part of the day.

Table 4 –The sum of solar gain, external conduction and cooling energy and internal gain

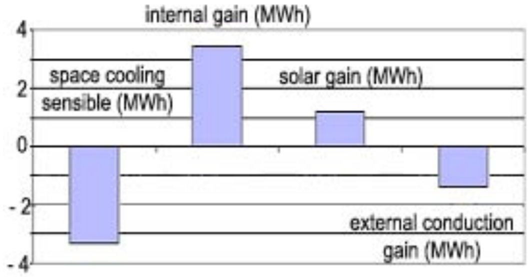

Fig. 5 shows a comparison between the Building 15 and Building 36. This demonstrates the effect of overshadowing on external conduction and solar gains and in turn energy use. The results show that Building 36 (identified by the dashed lines) not only received higher solar gain but that conduction to the outside was also lower. Conduction to the outside only increases in the late afternoon when building 36 begins to experience over-shadowing.

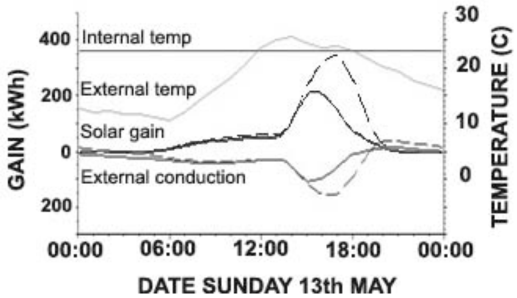

***Fig. 5** – The sum of solar gain [black], external conduction [mid gray], internal [straight line] and external temperatures [light grey]; 13th May Internal temperature set at 23°Celcius. For Building no's 15 and 36 (36 is identified by the dashed line)*

Building 15 receives a less direct solar radiation, which is clearly reflected in the higher rate of conduction to the outside. External temperature also has to be taken into account; as temperatures start to rise, conduction to the outside is reduced. The thermal resistance of the materials causes a time lag between changed external conditions and building response.

The results show higher solar gain results in higher energy use to maintain the desired internal temperature. The energy balance was calculated for both building 15 and 36 with the internal temperature set at 23°C; the results show energy demand for Building 15 is 3.823MWh, and Building 36 4.463MWh. It must be remembered that we are not looking for an exact figure but to make a comparison on the effects overshadowing and elevated temperatures has on cooling loads and the resulting carbon emissions.

Electricity produces 0.52 $kgCO_2/kWh$. Using this value we can calculate that;

- Building 15 produces 1987.96 $kgCO_2$
- Building 36 produces 2320.76 $kgCO_2$

Building 36 produced 14.3% more CO_2 if energy is supplied from carbon based fuels than building 15 as a result of a greater level of insolation. To verify these results the same calculation where made with the internal temperature set at 10°C, the results were similar with building 36 using 11% more than building 15, therefore we can assume that the results are deemed reasonable within the limits of the programme.

Calculations of CO_2 emissions were worked out for every building, to find the lowest and highest levels and their corresponding canyons. This established which configuration has the optimum height to width ratio in terms of energy demand. It is worth remembering that the units used in this simulation are as a point of reference and in no way represent realistic values.

The buildings with the lowest emissions as a result of their orientation and height to width ratio were the three Type B buildings numbers 9, 19 and 46 (see Table 5 and Fig. 6) it should be noted that these are all east facing buildings and at the north end of the canyons.

Table 5 - *Type B east facing buildings on the north end of the canyons - $KgCO_2$ results.*

BUILDING NO.	Space conditioning sensible (mWh)	kWh	$kgCO_2$
9	3.204	3204	1666
46	3.587	3587	1865
19	3.593	3593	1868

This was due to the overshadowing of the east face from the surrounding buildings in the morning plus the minimum solar gains during the afternoon (no windows on the west face).

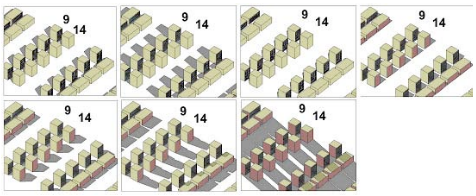

Figure 6 – *development of shadows for buildings 9 and 14*

Calculations were carried out for all five configurations of street canyons to see which height to width ratio performed best in terms of CO_2 emissions. Building numbers 13, 18, 23, 36, 45 and 50 were removed from the calculation to achieve equal gross floor area and equal internal loads. Each canyon consisted of a total of 8 buildings with a total gross floor area of 117600 m^2.

The height to width ration with the lowest CO_2 emissions was found on Buildings number 9 to 17 as expected [table 6]. This street canyon consisted of Type B building opposite Type B buildings and produced an average total of 15726.88 $kgCO_2$ per day.

Table 6- *total $KgCO_2$ for building numbers 9 to 17*

BUILDING NO.	Space conditioning sensible (MWh)	kWh	$kgCO_2$
9	3.158	3158	1642.16
10	3.943	3943	2050.36
11	3.944	3944	2050.88
12	3.944	3944	2050.88
14	3.807	3807	1979.64
15	3.815	3815	1983.8
16	3.817	3817	1984.84
17	3.816	3816	1984.32
			15726.88

The street canyon with the highest CO_2 emissions were Building numbers 37 to 44 [table 7], this urban canyon consisted of a mix of building types, and produced a total of 17339.4 $kgCO_2$

Table 7; *total $KgCO_2$ for building numbers 37 to 44*

BUILDING NO.	Space conditioning sensible (MWh)	kWh	$kgCO_2$
37	4.071	4071	2116.92
38	4.513	4513	2346.76
39	4.076	4076	2119.52
40	4.502	4502	2341.04
41	4.209	4209	2188.68
43	3.881	3881	2018.12
43	4.208	4208	2188.16
44	3.885	3885	2020.2
			17339.4

These results show that street canyons consisting of taller buildings opposite tall buildings can provide savings in terms of carbon emission, reducing emissions by 1612.75 $KgCO_2$ around 10% when compared to a configuration of buildings of different heights, as a result of overshadowing.

7.0 CONCLUSION

This investigation set out to look into the correlation between urban geometry and energy use for cooling. The results pointed towards a relationship between energy loads and overshadowing. The height to width ratio with the lowest CO_2 emissions was found on buildings number 9 to 17. This street canyon consisted of Type B building opposite Type B. This configuration received the lowest percentage of external insolation during the late afternoon, when temperatures are beginning to rise.

It showed that tall buildings opposite tall buildings, in street canyons with the highest height to width ratio, use less energy when cooler internal temperatures were desired than a street canyon with a variation in height or with low rise buildings. This reduction in energy use was a result of a larger surface area of the building being shaded.

The limits of the test showed the results with verification came within 3.5% within the limits of the simulation software. Therefore it can be concluded that overshadowing can save energy for cooling. The 10% energy saving would go a long way to achieve the reduction in emissions set by the government (to reduce carbon dioxide emissions by 20% by 2010) and is thought would reduce external temperatures.

This paper set out to investigate if energy use could be reduced as a result of overshadowing. The use of a computer simulation programme IES showed that a saving of 10% CO_2 could be achieved by manipulating the urban canyon.

To answer the original question asked in section 2;

Does an optimum height to width ratio exist that permits the internal cooling load to be reduced?

Although subjective the results showed that by manipulating the height to width ratio you can influence energy use, and that greater height to width ratio may have a positive effect on energy by reducing the demand for energy for cooling by overshadowing.

- Wide streets and other open spaces encourages air flow which improves the opportunity to ventilate the inner parts of a city and reduce temperatures, but not on still days or days with very large air mass formations.
- The taller the buildings and the narrower the streets, the less long-wave radiation is received. Building proximity to each other determines the amount of reabsorbed long-wave radiation from their immediate environment. (Johnson and Watson, 1983).
- Dense urban fabric (high height to width ratios) provides solar shading at street level but also traps heat resulting from multiple solar reflections, reduced albedo, and lowered Sky View Factor.
- Height to width ratios, have to be taken as a function of orientation, due to the Intensity and direction of insolation received on a face at any given time.

These results also point towards the premise that energy exchanges between buildings are both dependant on and exert an influence on each other, which in turn influences further energy use. And that we can no longer think of urban structures as if in isolation.

6. Acknowledgements

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7. References

1. Santamouris M. (First edition, 2001) - Energy and Climate in the Urban Environment
2. Summary Report London's Warming: The Impacts of Climate Change On London:, [Online], available: http://www.london.gov.uk/gla/publications/environment/londons_warming_tech_rpt_all.pdf [12 June 2008]
3. Background document A European Strategy for Sustainable, Competitive and Secure Energy What is at stake - [Online], available: http://ec.europa.eu/energy/green-paper-energy/doc/2006_03_08_gp_working_document_en.pdf [12 June 2008]
4. Tall Buildings and Sustainability Report March 2002, Corporation of London [Online] available. http://213.86.34.248/NR/rdonlyres/08A4077B-3199-442E-B4D1 E7F9F2C68E15/0/SUS_tallbuildings.pdf [12 June 2008].
5. Voogt J; *Environment: overpopulation impacts Urban Heat Islands: Hotter Cities* http://www.actionbioscience.org/environment/voogt.html
6. Oke T. (second edition, 1987) – *Boundary Layer Climates* [Online], available: http://weather.msfc.nasa.gov/uhipp/epa_doc.pdf [December 2005]
7. Watkins R; Palmer J; Kolokotroni M; Littlefair P – The London Heat Island: results from summertime monitoring - BUILDING SERV ENG RES TECHNOL 2002; 23; 97 DOI: 10.1191/0143624402bt031oa
8.Action Energy ECON 19 Energy consumption guide [Online], available: *-http://news.bbc.co.uk/1/hi/sci/tech/4140606.stm* [12 June 2008]
9.Givoni B. (First edition, 1998) - *Climate Considerations in Building and Urban Design* [ISBN 0-471-29177-3]