Shortcomings in the UK's Current 'Fabric' First Approach towards Building Energy Targets

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Abstract

Buildings consume between 40 - 50% of the world's energy, and as a result have become a prime focus towards achieving net-target energy and greenhouse gas reductions. Within the UK, building policy sets minimum standards for building regulated loads (demands associated with building fabric and energy demanding systems), which has resulted in policy driven 'generic' fabric first approach to building energy management. However, concerns are increasingly being raised that this 'fabric' approach can result in an increased energy demand. The work presented in this study investigates the appropriateness of a 'fabric' first approach and evaluates the effectiveness building fabric (U-values) in the urban context. The case study area is Central London, an area populated with prestigious office buildings that can be considered representative of many central Europe cities.

Keywords; *'Fabric' first approach, mean Height to Width ratio, overheating risks*

1. INTRODUCTION

Within the UK building energy management considers three key efficiency measures; the delivery of energy via renewable technologies, optimising building fabric and energy demanding systems (regulated), alongside managing loads associated with occupant activity (operational). However whilst operational loads are managed through guidelines and recommendation, minimum targets for both renewables and regulated loads are set by legislative policy. This approach has not only resulted in building energy management being policy driven, where a generic 'fabric' first methodology prevails, but focuses attention on the energy performance of individual buildings. And whilst building energy performance studies recognise that the performance of each subsystem has an influence on the other, they often overlook that in an urban setting, the thermal performance of a single structure is significantly influenced by the myriad of surfaces that surround it; which in turn, influences the thermal performance of surrounding system (Futcher et al 2013). It should be noted this lack of integration is in part due to an underestimation by building designers of the significance of micro-climatic formation on building performance, but also as a result of urban climate research (with a few notable exceptions) focusing on the resultant external thermal comfort conditions.

The basic premise behind a 'fabric' first approach is that the building fabric itself is considered inherently efficient before any additional measures are taken. However research is increasingly finding that lower building fabric U-values results in an increasing overheating risk and higher cooling loads (Al-Homoud, 1997; Korolija et al., 2009); however these examples consider the building in a standalone setting, overlooking the implications of dynamic urban shading at the building surface, which can significantly change performance patterns.

The first section of this paper briefly outlines the influence of urban geometry on micro-climate formation. The second section reports on an observation when a comparison is made between the output performances of typical open-plan UK office buildings and an identical building simulated in the context of a surrounding urban setting. Here the effects of over-shadowing and building U-values are examined using a commercially available computer simulation tool.

2. MICRO-CLIMATE FORMATION

In an urban area the cumulative effects of the local surface energy exchanges (micro-scale), the accumulation of these surface energy exchanges (local–scale), alongside those of the surrounding non-urban area (meso-scale) often result in higher surface, air and near surface air temperatures when compared to the surrounding non-urban area. This urban/non-urban temperature difference is commonly referred to as the urban heat island (UHI) effect (Oke, 1987). The intensity of these temperature differences (which are both spatial and temporal in nature), are found to be dependent on a combination of the background climate, plus modifications brought about by the particular topography of a site, alongside the accumulated thermal effects that result from the myriad of activities and morphologies found within an urban area (Arnfield, 2003). The point where these effects are most profound is at and below the building roof level, referred to in the climate literature as the urban canopy layer (UCL) (Oke, 1987). The canopy layer is distinguished by the unique energy exchanges that occur at the surfaces of buildings and streets. The most obvious example of this is that of the geometric forms that directly impact shortwave (solar) radiation receipt at the urban surface. The prime parameter in determining these daytime dynamic effects is the ratio between the averaged building height (H), to the width (W) of the street that separates them. This daytime urban climate parameter (mean H/W ratio) determines the radiation exchanges with the sky and the surface, and is shown to influence both the thermal conditions for pedestrians (Emanuel, 2003; Toudert, 2006; Tzu-Ping Lin et al., 2008) and the energy required maintaining thermal equilibrium for the buildings' occupants (Rajagopalan, 2007). It is the significance of this daytime urban climate parameter mean H/W ratio as an energy management parameter which is the focus of this study.

At the scale of the city street, the arrangement of the buildings within the street defined by their mean H/W ratio determines the amount of visible sky or 'sky view' from any given point, which in turn determines both the incoming and outgoing radiation exchanges. Whilst a lower sky view will decrease daytime surface heating it will also increases exchanges with the surrounding surfaces. The net effect is a reduced rate of night-time cooling, a critical factor in the formation of the UHI, but whilst important for nocturnal heating or cooling strategies is of minimal significance for buildings with a daytime function such as office buildings. Unlike night time radiant loss daytime radiant gain is dynamic; the solar (direct and diffuse including reflected) receipt at a surface is dependent not only on the surrounding morphology, but latitude and orientation (Futcher et al, 2013). At this scale, a higher H/W ratio will increase overshadowing, resulting in lower radiant temperatures (Pearlmutter et al, 1990) and daytime urban air temperatures often found to be equal or lower than those of the surrounding non-urban environment (Grimmond et al, 2010). The level of solar receipt along with emitted and reflected longwave radiation is significant in influencing the internal temperature of a building, which in turn will determine building conditioning load.

This paper sets out to investigate the localised effects of urbanisation on building performance by comparing cooling and heating loads of identical office type building simulated in various urban configurations. Here various climate files for the same region are used to identify the role of urban form as a building energy management parameter, and the shortcomings in the UKs current fabric first approach, when buildings are considered in their urban setting.

3. METHODOLOGY

Within the UK, dynamic thermal modelling techniques are increasingly used to demonstrate compliance with building regulations. However there is no requirement to represent the complexities of the surrounding urban terrain. This omission is due in part to the complexity involved in the parameterisation of the UCL, where (although undergoing significant research) not one commercially available tool or methodology has been found that has successfully couples the dynamic external conditions to the buildings thermal performance, and in part due to the under estimation of the significance of the urban setting on building performance. The aim of this study is to highlight the significant influences of the urban effect on building performance.

In this study the performance of a typical 'office' type buildings (placed in a standalone setting alongside 2 different urban configurations) are compared using a commercial available thermal dynamic building energy simulation software tool. The tool determines annual heating and cooling loads based on input data such as building fabric, location and climate, whilst allowing daily, weekly and annually timed controls for the energy demanding systems. Note, that aside from the occupation schedule associated with the daytime activities commonly carried out in commercial districts of urban areas, occupant behaviour and comfort are not considered here.

The software was chosen for its ability to analyse the geometrical relationship that exists between direct solar receipt (insolation) and the placement of an individual buildings within an urban street or urban street canyon. The software used here cannot calculate the effect of urban morphology on changes to external air temperatures or give external surface temperatures, but allows the rate of transmission gains and losses resulting from surface temperature differences to be analysed. In addition the software cannot account for anthropogenic heat and pollution, evaporative processes or turbulent transport, other than those provided by the tools boundary conditions. These limitations restrict this study to modified short and longwave exchange on internal temperatures only. The tool used here has been validated in accordance with both CIBSE AM11 standards alongside ANSI/ASHRAE Standard 140-2001.

The results presented will be used to make qualitative comparisons of building performance so that trends and insights into early design decisions can be made.

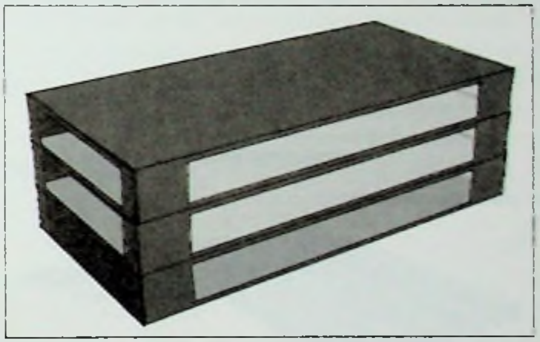


Figure 01. *Office-01*

Building Model

For this study a typical UK air-conditioned open plan office building has been used (**Office-01**). This building type is represented in the Energy Consumption Guide 19 (ECG01) building 'type 3', and has been used in numerous performance studies that relate to energy management

Office-01 represents the base line building and will be first simulated in a standalone setting, and then in various urban configurations. However the software boundary conditions for an urban environment are set as;

- Ground reflectance - 0.15
- Terrain type – City
- Wind exposure (CIBSE heating loads) – Sheltered

Office-01 is a narrow, 3 storey, open plan layout, 10.5 m high, 32 m long and 16 m wide, 60% glazing to all façades, orientated with the longer façade east to west (Figure 01). The model uses clear double glazing with no shading devices. Walls are insulated and of brick and block construction, with a flat concrete insulated roof and insulated concrete ground floor. The intermediate floors are of concrete with false ceilings. The default thermal properties of the materials have been kept, as these represent global standards alongside limiting variables.

Energy loads

The heating and cooling set point temperatures are 19°C and 23°C respectively, with setback temperature 28°C and 12°C (CIBSE 2006). The heating season runs from October 1st to April 1st whilst cooling operates all year. Fresh air requirements are 10 l/s per person (Building Reg. App. Doc. F, 2006). Whilst infiltration rates 0.3 air changes per hour. Internal gains are shown in Table-01. Operational times are between 7:30 am and 7:30 pm with a 10% continuous load (Econ19 guide), using benchmark values.

***Table 01**- internal gains*

Internal Gains	W/m^2
Occupants - 10m^2/person at 100 W/person – The Metric Handbook	10
Office equipment - CIBSE, 2005	15
Artificial lighting - ECG019, 2003	12

Height to width ratio

To compare results between identical buildings simulated in isolation and in context, two further configurations are considered; Office-01A and Office-1B; both are identical to Office-01. Office-01A is represented by Configuration-A, a street width of 12m in both an east/west and north/south direction, heights to width (H/W) ratio 0.88, whilst Office-1B - Configuration-B has a street width of 9m east/west but remains at 12m in the north/south direction, H/W ratio 1.17 [Figure 02]. All buildings in the surrounding system are of equal height to avoid over shadowing at roof level.

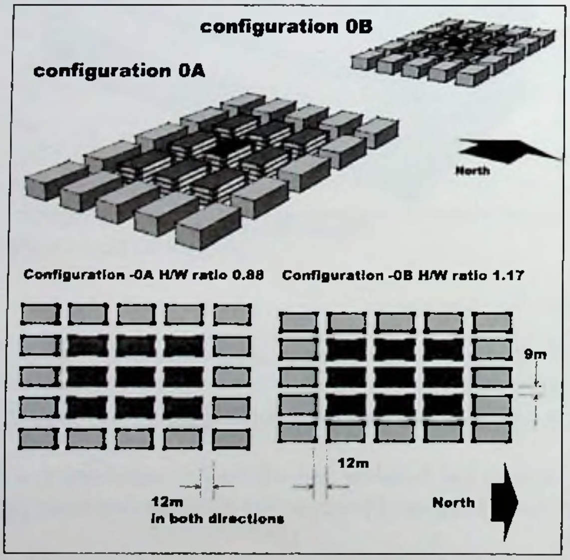


***Figure 02.** Office-01A & Office-01B (shown in red) in context – surrounded by identical buildings – the outer buildings represent the extent of the boundary (pale blue)*

U-Values

Office-01 represents a typical UK construction method, the brick and block wall, with an internal plaster finish and an admittance of around 6 W/m²K. This type of construction can be found in most towns throughout the UK, and is considered a high thermal mass building type.

As before the tool cannot calculate the influence of thermal mass on external surface or near surface air temperatures, therefore for the purpose of this study, different U-values are evaluated in terms of H/W ratio. *Office – 01, 1A & 1B have been given 3 sets of U-values* [see table 02], to allow a comparison of building fabric on performance in the context of urban setting against different weather files. It is also worth noting that the glazing U-value for the both the 2006 building regulations and Best Practice are identical as a way of understanding transmission through the opaque surfaces in context of urban fabric.

Table 02 U-Values

(UK part L) U-Value W/m²·K	1990	2006	Best Practice
standard wall construction	0.53	0.35	0.25
flat roof	0.45	0.25	0.13
standard floor construction	0.84	0.25	0.15
low-e double glazing	3.21	**1.98**	**1.98**

Weather files

The consequence of using historic out-of-town weather files to determine urban energy load has undergone significant research (Oke, 1987; Watkins et al., 2002; Kolokotroni et al., 2012, Futcher et al., 2013); this research points to the dissimilarities between 'ideal' meteorological sites and those actually found in urban systems, at both the urban scale and at the localised microscale. Most commercial available dynamic thermal simulation tools use climate data frequently collected from these idealised meteorological sites, but allow for the insertion on new and future climate scenarios. However regardless of climate file these tools are unable to report on the full extent to which the localised urban configuration within the UCL modifies local climate as a result of the modified shortwave and longwave radiation exchanges, anthropogenic gains alongside changes in latent and turbulent transport.

The case area for this study is London (51°32'N), a temperate marine climate with average high summer temperatures fall between 21°C – 28°C. For this study 4 London weather files (LondonDSY05, HeathrowEWY, Hrow9697 and Kew) are used. These files were chosen as to some extent they represent the different accumulative effects of urbanisation on climate whilst under the same synoptic conditions, allowing the influence of variables such as solar radiation and temperature on building performance to be examined.

4. RESULTS

The methodology used here highlights the limitations of the generic 'fabric first' approach to building energy management through a series of dynamic thermal simulation. This approach is evaluated in the context of the urban environment by comparing different scenarios against an identical office type building placed in isolation.

Energy balance

An initial investigation was carried out to establish the energy balance for an office building **Office-01**, in a standalone setting against two identical offices **01A & 01B**, in context. Table 03 summarises the annual loads for the three buildings. Table 03 highlights the overall difference in space conditioning, solar gains and external conduction gains, as a result of the surrounding urban configuration; and show that Office-01A & 01B require 70 and 63% of the annual space conditioning load, whilst receiving 72 and 63% of the solar gains and a 10 and 12% decrease in external conduction gain, respectively against Office-01. The results point to the mutual relationship between space conditioning, internal load, solar receipt and the density of the surrounding urban fabric. These early results indicate the importance of simulating in the context of the surrounding urban system.

Table 03- *Energy Balance for all configurations - 2006 UK U-values – London DSY05weather file*

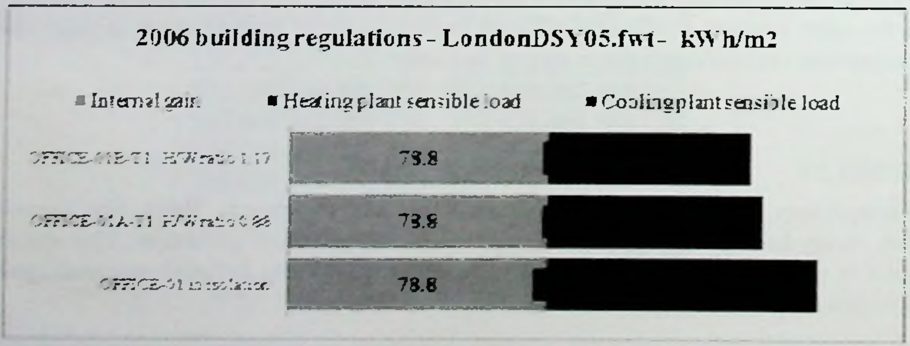
LondonDSY05.	**OFFICE-01**	**OFFICE-1A**	**OFFICE-1B**
Space conditioning sensible (MWh)	-99	-69	-62
Internal gain (MWh)	115	115	115
Solar gain (MWh)	166	119	109
External conduction gain (MWh)	-142	-128	-125
Internal conduction gain (MWh)	0	0	0
Infiltration gain (MWh)	-40	-37	-36

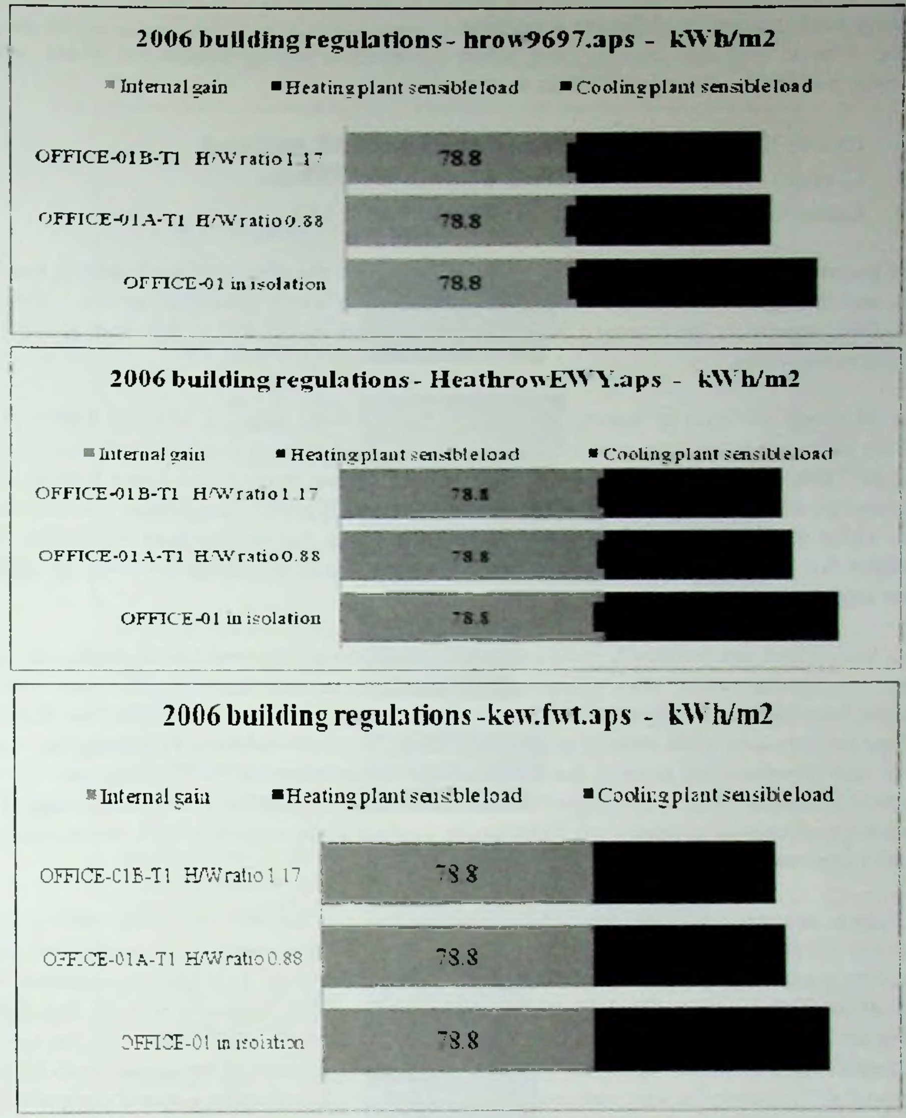
The breakdowns of the space conditioning loads are presented in Graph-01. Here we see the comparative heating and cooling loads alongside internal gains for all three configurations (2006 U-values - all weather files). The results highlight 3 significant points; firstly that the denser the immediate environment the lower the cooling load (overshadowing). Secondly the more rural the location 'Kew' the higher the heating loads (lower ambient air temperatures) and finally the dominance of internal gains (energy demanding activities). High internal gains, common in buildings of this type, place a strong emphasis on cooling over heating strategies (Jenkins et al., 2008).

Internal gains

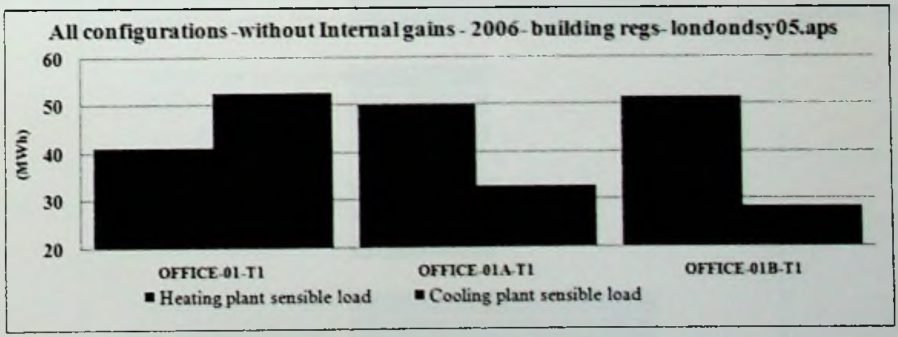
In an effort to isolate the urban effect on heating and cooling loads, the internal gains were removed [Graph 02]. This allows a comparison of the climate conditions on space conditioning loads to be evaluated.

From this we can see that the heating load (heating season only) is significantly greater than the cooling load for both Configurations-A and -B. However when modelled in isolation the cooling load dominates; It is worth noting that as we move towards lower operational loads the dominants of internal gains as a driving force for conditioning loads will become less significant placing higher emphasis on designing in context of the external environment. (Internal gains are included for the rest of this study)





***Graph 01**- comparative energy load for all office-01,01A&01B (kWh/m²)*



***Graph 02** - comparative cooling & heating loads–without internal gains*

Building loads under the different scenarios

Having defined both the building and urban parameters, annual simulations where run to determine building loads under different scenarios;

- Climate files - LondonDSY, Harrow, Heathrow and Kew
- U-values -1990, 2006 & Best Practice
- Context – in isolation alongside H/W ratios 0.88 & 1.17

These parameters have been defined as a way to determine the effects of local climate, building fabric and the significance of the surrounding setting. It is worth remembering that Office-01-DSY–2006, represents the current UK building benchmark model and is used here as the 'base case' for comparison.

Table 04 shows the ratio of heating and cooling loads for the identical buildings Office-01,1A &1B for all scenarios as a percentage difference against the base case building (examined in more detail in Table 05). All buildings are shown to have higher heating and lower cooling loads compared to the base case building, with the exception of Office-01 Best Practise - in isolation – DSY; whilst the heating load was found to be 16% lower the cooling load 5% higher. This highlights that when overshadowing is not represented in the model, lower U-values can result in higher cooling loads.

From Table 05 we can see how U-values determine the ratio of the conditioning loads, over both climate and configuration when compared against the base case scenario. This was done to highlight how climate, the form of the surrounding setting (H/W ratio) and U-values influence building performance when internal gains and building form are identical. Presenting the results in this way demonstrates cooling loads has a high dependence on H/W ratio, and that the reduction in cooling loads is not proportional to increase in heating loads. The results suggest the significance of canyon geometry on determining cooling loads regardless of U-value and local climate variations.

The largest comparative load ratio differences occur for the heating loads 1990 U-value scenarios; the most thermally transparent buildings. They show a significantly greater percentage of heating loads over the base case building with a dependence on local climate variations. The 'semi-urban' Kew weather file (01B-1990 - H/W 1.17 – Kew), experiences both the highest heating and the lowest cooling load. But when looked at in more detail (Table 05), we can see that despite the large percentage difference in the load ratio, the sum of the annual loads is lower by around 35% against the base case building. These two buildings make a biased comparison as a result of their different U-values, climate conditions and surrounding surfaces, but they do highlight (despite high internal gains), the importance of simulating in context and using an appropriate climate file to allow suitable levels of insulation to be applied alongside conditioning system sizing. These results go against the current UK generic form first approach to building energy management.

Table 04 –percentage comparison of annual cooling & heating loads for all configurations against 'base case' building Office 01-DSY-2006regs- in isolation (a standalone setting)

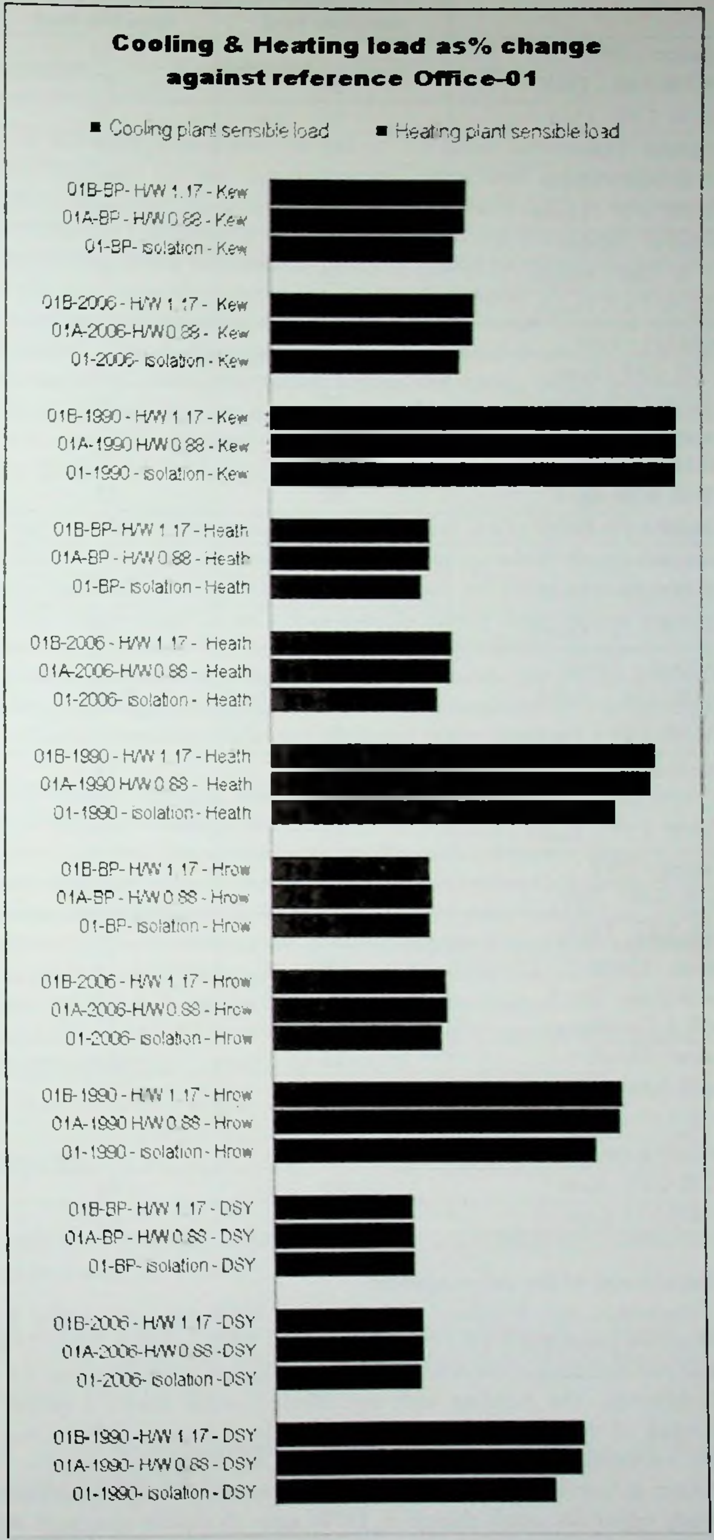


Table 05- *Total Annual Cooling & Heating (MWh)*

	Cooling plant sensible load	Heating plant sensible load	Annual Totals
01-1990- isolation - DSY	75	32	107
01A-1990- H/W 0.88 - DSY	**57**	**37**	**95**
01B-1990 -H/W 1.17 - DSY	53	38	92
01-1990 - isolation - Hrow	65	39	104
01A-1990 H/W 0.88 - Hrow	48	44	92
01B-1990 - H/W 1.17 - Hrow	44	45	89
01-1990 - isolation - Heath	52	43	95
01A-1990 H/W 0.88 - Heath	38	50	87
01B-1990 - H/W 1.17- Heath	34	51	85
01-1990 - isolation - Kew	46	51	98
01A-1990 H/W 0.88 - Kew	33	57	89
01B-1990 - H/W 1.17 - Kew	30	58	87
01-2006- isolation – DSY BASE CASE BUILDING	**109**	**10**	**120**
01A-2006-H/W 0.88 -DSY	**82**	**13**	**95**
01B-2006 - H/W 1.17 -DSY	76	14	90
01-2006- isolation - Hrow	104	14	118
01A-2006-H/W 0.88 - Hrow	78	17	95
01B-2006 - H/W 1.17 - Hrow	72	18	90
01-2006- isolation - Heath	87	15	102
01A-2006-H/W 0.88 - Heath	64	19	83
01B-2006 - H/W 1.17 - Heath	59	19	78
01-2006- isolation - Kew	81	18	99
01A-2006-H/W 0.88 - Kew	59	22	81
01B-2006 - H/W 1.17 - Kew	54	23	77
01-BP- isolation - DSY	**114**	**9**	**123**
01A-BP - H/W 0.88 - DSY	86	11	97
01B-BP- H/W 1.17 - DSY	80	12	91
01-BP- isolation - Hrow	109	12	121
01A-BP - H/W 0.88 - Hrow	82	15	97
01B-BP- H/W 1.17 - Hrow	76	15	92
01-BP- isolation - Heath	93	13	105
01A-BP - H/W 0.88 - Heath	68	16	84
01B-BP- H/W 1.17 - Heath	62	17	79
01-BP- isolation - Kew	82	18	100
01A-BP - H/W 0.88 - Kew	60	22	82
01B-BP- H/W 1.17 - Kew	55	22	77

U-values in the context of the urban system

For a fairer comparison, two buildings with the same H/W ratio and under the same local climate conditions are examined [01A-1990- H/W 0.88 – DSY and 01A-2006-H/W 0.88 –DSY] (table 05). These two buildings coincidentally have equal annual loads; however the ratio of these loads is quite different. The building with the lowest U-value shows a greater tendency to overheat as a result of the significantly higher cooling load (around 30% higher), even in the context of the surrounding system. The importance of an accurate representation of the surrounding system in terms of H/W ratios can be seen in table 05. Here a difference in heating and cooling loads occur for small change in H/W ratio (3 meters east/west direction). This change to the urban configuration adds approximately 1 MWh to the heating load, whilst reducing cooling between 3 and 6 MWh; implying (in terms of cooling load) the significance of dynamic insolation received at the surface in the context of the urban environment, which is missed when simulated in an isolated or standalone setting.

5. CONCLUSION

The objectives of this work is to explore the role of the urban setting as an energy management parameter and to highlight that the current generic 'fabric first' approach encouraged by UK building legislation may result in an increased energy demand. This is investigated through a series of studies that are concerned with the difference in regulated loads of modern building types in their standalone setting (as is current practice) against identical buildings in various urban settings. The work reports on the outcome of a series of dynamic thermal simulation studies for various street configurations comprised of generic building forms assigned specific occupation and activity (function) patterns. Here 'mean H/W ratio' is used to identify performance patterns associated with the form of the surrounding setting, the timing of the buildings function and levels of insulation. All buildings are assigned typical building parameters including operational and activity loads associated with the building function. Importantly, these types of buildings are occupied during the daytime and have significant internal energy gains.

In an urban context where neighbouring buildings provide shade, building performance patterns change significantly. In short, for occupied office buildings for which the cooling load dominates, improved energy performance is related to the level of solar masking provided by the surrounding urban morphology. In an urban canyon setting these effects are captured by the ratio of building height (H) to street width (W). The H/W value is an effective measure of the performance of both individual buildings in an urban context. The results demonstrate that the urban setting for a building is a significant factor in determining its energy requirements: the performance of identical buildings varies with different urban settings.

Whilst buildings where identical, building performance was compared in various urban configurations, in addition buildings were assigned 3 different sets U-values and exposed to 4 different weather scenarios. The results highlight 3 significant points: firstly the significance of the urban setting. Secondly identical buildings perform differently as a result of small changes in background micro-climate conditions. And thirdly internal gains significantly dilute the influence background micro-climate conditions on building performance. This challenges the current generic blanket approach to U-values. It is also worth noting that all energy whether delivered from renewables or not ends up as heat energy, adding heat to the external environment, increasing conditioning needs. This results in higher urban temperatures requiring further energy to cool the internal temperature – a catch 22 situation.

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