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London's urban heat island: Impact on current and future energy consumption in office buildings

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ABSTRACT

This paper presents the results of a computational study on the energy consumption and related CO_2 emissions for heating and cooling of an office building within the Urban Heat Island of London, currently and in the future. The study developed twenty weather files in an East-West axis through London; the weather files were constructed according to future climate change scenario for 2050 suitable for the UK which have been modified to represent specific locations within the London UHI based on measurements and predictions from a program developed for this purpose (LSSAT). The study simulated an office with typical construction, heat gains and operational patterns with an advanced thermal simulation program (IESVE). The predictions confirm that heating load decreases, cooling load and overheating hours increase as the office location moves from rural to urban sites and from present to future years. It is shown that internal heat gains are an important factor affecting energy performance and that night cooling using natural ventilation will have a beneficial effect at rural and city locations. As overheating will increase in the future, more buildings will use cooling; it is shown that this might lead to a five-fold increase of CO_2 emission for city centre offices in London in 2050. The paper presents detailed results of the typical office placed on the East-West axis of the city, arguing the necessity to consider using weather files based on climate projections and urban heat island for the design of current buildings to safeguard their efficiency in the future.

1. Introduction

Urban warming, commonly referred to as the 'Urban Heat Island' phenomenon (UHI), is a well-established effect. The magnitude of the UHI has been studied mostly in terms of the temperature differences between rural and urban locations. There are many studies on the quantification of UHI in large cities and reviews on research in Europe and other areas have been published.

UHI studies conducted in London indicate that urban population could be affected severely in terms of energy consumption and health, especially in summer if the current urbanisation trend continues [1,2]. One of the main factors affecting UHI in London has been identified as distance from the centre, with temperatures increasing towards the centre [3,4]. Indications of the additional effects of urban physical characteristics such as urban canyon geometry, albedo and vegetation has been identified in published articles [5]. A model for predicting UHI temperature within London has been proposed [6]. This model will be used to generate weather files in the present study and this is discussed in more detail in Section 2.2.

As a consequence of increased temperature, the UHI has an effect on energy consumption for heating and cooling urban buildings. This has been studied internationally including Europe, Japan and US (for example [7–9]) and specifically for the UK [2]. As expected, the London UHI was shown to have a positive effect on heating-dominated buildings due to the lower heating demands during winter. On the other hand, the increased temperatures in the city centre had a negative effect on cooling-dominated buildings in London. It is clear that increased temperatures in urban centres can have a significant effect on the energy required to heat and cool buildings, therefore it was concluded that site location should be taken into consideration by designers when making design estimates for energy consumption both for commercial and domestic buildings.

In addition to the UHI effect, climate change is projected to increase the probability of overheating in London [10]. In recent years, global temperature has increased significantly and it is probable that the average annual temperature will increase by several degrees during this century. In the UK, work on climate change projections are carried out under the umbrella of UKCP (UK Climate Projections) [11].

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Literature review has revealed that there exist significant recent work on the effect on climate change on energy consumption by building; for example [12–14] which examine the impact of temperature changes on the building energy consumption for heating and cooling in the US, [15] which examines the case in the UK, [16] for Hong Kong, [17] in Australia and in the UK for office buildings [18,19].

As mentioned before, studies have been carried out on the effect on UHI on energy consumption by urban buildings in comparison to rural counterparts. In addition, work has started in many countries to construct weather files suitable for building energy consumption simulation taking into consideration future climate change scenarios.

However, literature did not reveal any particular studies that focus on the impact of climate change on buildings within the UHI and the consequent effect on heating and cooling these buildings; although significant work exist on the impact of climate change on cities. Such work is urgently needed according to [20] where London is presented as an example and key risks by climate change are listed, including 'risk of overheating' in buildings and 'designing new and adapting existing buildings and infrastructure to minimise the need for cooling'.

The objective of this paper is to present results of the effect of UHI on energy consumption for heating and cooling office buildings in London, at present and in the future, taking into account climate change projections. In a parallel study [21] using similar methods, the effect of climate change on summer overheating in urban London offices has concluded that overheating in London offices will make them very uncomfortable, internal comfort is related to distance from the city centre and that very local, microclimatic effects at individual sites also have a significant effect. There is a considerable difference between the overheating performance of a standard building at different sites. This paper extends this study and focuses on energy consumption of air-conditioned offices and their environmental impact arising from the need to install cooling due to unavoidable overheating in future summers.

2. Methodology

2.1. Office building model

A geometrical model of the office building was defined; it includes a cell 10 m wide, 6 m deep and 3 m high based and it is based on previous models of office buildings used for simulation in the UK [22]. This cell is repeated to form a 3-storey building, 30 m × 15 m with a total floor area of 1350 m^2.

The building model is based on a typical, air-conditioned office (type 3), as described in ECON 19 [23], as this was considered to be representative of small AC office buildings in UK cities. A typical wall construction was used and windows were double glazed with 50% glazing ratio on the two long facades.

The office building orientated with the longer sides (with external glazing) facing north-south. This layout of the building can provide maximum solar gain in winter and easier shading in summer. In addition, with this orientation, the most efficient use of daylighting can be achieved.

Thermal mass: One important consideration in the parametric analysis was the thermal mass of construction. This is because night ventilation is one of the passive cooling strategies considered. Conventionally, buildings are classified as slow or fast response to heat transfer. The response to the changes in the environmental temperature is defined by the thermal response factor [24], f_r, given by:

$$f_r = \frac{\Sigma(AY) + \text{Cv}}{\Sigma(Au) + \text{Cv}} \tag{3.1}$$

$$C_V = \frac{1}{3}NV \tag{3.2}$$

where f_r is the response factor, dimensionless, A is the surface areas (m^2), Y is the thermal admittance ($\text{W/m}^2\text{K}$), U is the thermal transmittance ($\text{W/m}^2\text{K}$), Cv is the ventilation conductance (W/K), V is the volume of the room (m^3), N is the room air change rate, air changes per hour (ach).

Buildings with a high thermal response factors ($f_r > 4$) are referred to as heavy weight buildings, and those with a low thermal response factor ($f_r < 4$) are referred to as light weight buildings [24].

Two different thermal mass of building are considered, one heavy weight and the other light weight; details on the construction properties with building fabric U-values (thermal transmittance) and Y-values (admittance) are shown in Tables 1 and 2 and based on these data, the building response factors are calculated.

For the construction elements of the building, U-values were set within the limiting values of current building regulation 2000 L2A (2010 edition) [25].

Heating and cooling strategies: Two service strategies were simulated, mechanical ventilation and comfort cooling. Comfort cooling is the strategy that maintains the room temperature at heating and cooling set point in winter and summer, respectively, without considering humidity. In the meantime, a certain amount of fresh air is cooled or heated by the air conditioning system to meet the ventilation requirement. In this project, simulation heating setpoint is 21 °C; cooling setpoint is 24 °C. In the mechanical ventilation strategy no cooling is provided. During winter, air supplied to the room is heated to offset the heating load of the building like comfort cooling, but in summer, fresh air is directly supplied to the room without cooling but need to be heated when the temperature below the heating setpoint, this strategy is termed summer free cooling or night cooling (NC).

Internal heat gain: The internal heat gains were defined using data from CIBSE Guide A [26]. Two levels of internal heat gain were simulated; high and medium. High is 57 W/m^2 sensible heat gain and 15 W/m^2 latent heat gain while medium is 42 W/m^2 sensible heat gain and 7.5 W/m^2 latent heat gain.

Solar gains: The method outlined in CIBSE TM37 [27] has been used to classify the solar gains to the test room in terms of solar gain per unit floor area (m^2) over the period 6:30 AM to 16:30 PM Solar Time (GMT). By exploring different glazing areas and shading coefficients, three levels of solar gains have been determined: low 10 W/m^2, medium 20 W/m^2 and high 30 W/m^2. A glazing area of 50% has been used for all of the solar gains. The shading coefficients of the glazing have been adjusted to achieve medium solar heat gains for the selected orientation (south and north).

Air flow rate: According to current guidelines, for the office building, 10 L/s per person fresh air is recommended. Based on the estimation of internal heat gain, the maximum occupant density is 4 m^2/person, take the one of the cell offices for example, the size of one cell office is 6 × 3 × 10, area = 60 m^2, volume = 180 m^3. For the maximum people density, 60/4 = 15 people, the fresh air demand is 150 L/s, hence the air change rate is 150 × 3.6/180 = 3 ach. Therefore in this study, air change rate of 3 ach is selected as a fixed parameter. Less fresh air would be required for lower occupancy but the 3 ach is not unreasonable to assume for consistency and to cater for cooling.

Air infiltration: Air infiltration is a parameter depending on weather conditions and building conditions such as air permeability; hence it is hard to estimate. In this project, 0.2 ach for air infiltration is selected as a fixed parameter.

Night cooling: The efficiency of the night cooling is mainly based on the difference between the outdoor and indoor temperatures during the night period and it is a passive cooling strategy utilised in many UK office buildings during the last decade. Mechanical

Table 1
Light weight building construction properties.

	Light weight				
	Area/m^2	U/W/m^{2}K	Y/W/m^{2}K	AU	AY
External wall	594	0.3495	2.7300	207.60	1621.62
Internal partition	756		2.6500		2003.40
Internal floor	900		2.8608		2574.72
Roof	450	0.2363	2.8527	106.34	1283.72
Glazing	216	2.1580	2.1580	466.13	466.13
Ground floor	450		2.5750		1158.75
Sum				780.07	9108.33
f_r			2.72		

Table 2
Heavy weight building construction properties.

	Heavy weight				
	Area/m^2	U/W/m^{2}K	Y/W/m^{2}K	AU	AY
External wall	594	0.3500	5.5300	207.90	3284.82
Internal partition	756		4.1248		3118.35
Internal floor	900		6.0899		5480.91
Roof	450	0.2483	6.0000	111.74	2700.00
Glazing	216	2.1580	2.1580	466.13	466.13
Ground floor	450		2.7200		1224.00
Sum				785.76	16274.21
f_r			4.20		

ventilation or natural ventilation can both be used as a night cooling strategy. For urban buildings stack night ventilation is preferred as the strategy avoids reliance on wind. Mechanical night ventilation is the strategy uses the fans to draw in the fresh cooler air and extract the indoor higher temperature air. The disadvantage of mechanical ventilation is the extra energy penalty due to the fans. The disadvantage of stack ventilation is the decreased potential contribution of night cooling due to the UHI [28]. It is obvious that utilising stack night cooling strategy will consume less energy, but the varied weather condition lead to the interference of the night cooling effect. To investigate the actual impact of UHI on cooling, heating load and the actual effect of the optimum method, stack night ventilation is used in this project to avoid additional energy penalty. A set-point of 18 °C is applied to control the night ventilation system to avoid overcooling, only when the indoor temperature exceeds 18 °C, night cooling can be operated. For the same reason, the night cooling is only switched on when outside air temperature exceeds 12 °C. These two conditions must need to be met at the same time. Night ventilation is designed to start at 21.00 PM, continue all night and switched off at 7.00 AM during the summer period of May to September.

In summary, 16 combinations of building parameters were simulated each with 20 weather files, representing locations in the west-east axis of London, see Fig. 1. The choice of these locations is explained in the following section.

2.2. Weather files

The study used a series of customized local weather files relating to both current and projected future urban climates.

Heat island effect: Local hourly temperature data for the period September 1999–August 2000 for 20 different sites across an East-West transect of the Greater London Area was provided via use of the London Site Specific Air Temperature (LSSAT) model developed by [3,6]. The sites were selected in such a way so as to achieve a wide variety of urban morphologies and resulting local climatic conditions [5], ranging from the densely built area around the British Museum (FW00 and FE00) to the reference rural site in Langley Country Park (WW11). The approximate locations of the temperature measurement sites on the London map are shown in Fig. 1. The site-specific temperature values were input to the EnergyPlus Weather Converter tool [29] to generate epw format local weather files for each site; these files can be used in a variety of thermal performance models such as EnergyPlus and IESVE-the later was used for this study. Measurements from the Met Office London Heathrow weather station were used for the rest of the environmental variables needed to construct the weather files (relative humidity, wind, atmospheric pressure, cloud cover), whereas global and diffuse solar radiation data was provided from the London Weather Centre for the same time period via the British Atmospheric Data Centre [30]. As is demonstrated in Table 3, the temperature values recorded during the monitoring period (September 1999–August 2000) compare well with the synthetic CIBSE Test Reference Year (TRY) for Heathrow which was created for the period of 1983–2005. We assumed, therefore, that it may be considered to be a reasonable representation of a 'typical' year of the 1980s–2000s (i.e. the 'baseline current climate').

Fig. 1. Local temperature measurement sites (sites WW12, WW03, WW02, WW01 and EE12 were not used in this study because data were limited for the construction of weather files).

Table 3
Comparison between temperature values recorded during the monitored period (September 1999–August 2000) and CIBSE TRY for Heathrow.

	Met Office London Heathrow (September 1999–August2000) temperature (°C)	CIBSE TRY Heathrow (1983–2005) temperature (°C)
Average	11.5	11.4
Median	11.3	11.3
Mode	10.5	8.5
Minimum	–4.6	–4.6
Maximum	31.0	31.8
Standard deviation	5.7	5.8
Variance	32.1	33.9

Climate change scenarios: The site-specific weather files were subsequently 'morphed' according to the 2050s medium-high emissions UKCIP02 climate change scenario [31]. Among the different climate change scenarios, only one was used as it was considered sufficient for the scope of this study. The 2050s Medium-High emissions scenario was considered to be the most appropriate for two main reasons: firstly, a high proportion of existing London dwellings will still be in place in the 2050s (the average UK building life span is 60–80 years) [32]; secondly, the specific emissions scenario has been used in previous similar impact assessment studies and represents a medium/worst-case scenario [33].

The morphing process was carried out using the CCWeatherGen tool [34] and is based on the methodology for constructing future weather files developed by [35] and implemented by [36]. As is pointed out by the authors of the tool, the output of the morphing procedure should be treated with caution: The relative changes in the various environmental variables quoted in the UKCIP02 scenarios compare to the baseline timeframe from 1961 to 1990. However, for the purposes of this study the data used as the baseline current climate is the year 1999–2000. It is expected, thus, that the resulting 'Medium-High 2050s' weather files will overestimate the climate change impact somewhat.

The weather generator engine that was publicly available at the time of the study was only compatible with the UKCIP02 weather files. Thus, even though the more detailed and probabilistic-based UKCP09 climate projections were already made available [37], they could not be used to build future weather files for the LSSAT model. Importantly however, Eames et al. [38] indicate consistency between results obtained by thermal simulations of the same dwelling using UKCIP02 and UKCP09 weather files.

3. Modelling results

Thermal modelling results of the typical office building, positioned in 20 locations across the West East axis of London and using weather files adapted for (a) position within the London Urban Heat Island and (b) climate change scenario UKCIP02 high medium 2050 are presented in this section.

3.1. Cooling load

Fig. 2 presents the predicted normalised annual sensible cooling load. As expected this rises in the 2050s in all examined cases. In 2000, annual cooling load ranges from 6.5 kWh/m^2 in heavy weight, medium internal heat gains, night cooled office in the reference site (WW11) to 39 kWh/m^2 in heavy weight, high internal gains office in the centre of London. In 2050, the range is 16.5 kWh/m^2 in heavy weight, medium internal heat gains, night cooled office in the reference site (WW11) and 59 kWh/m^2 heavy weight, high internal gains office in the centre of London. Table 4 presents a comparison of cooling load for the office variations examined between 2000 and 2050 for the reference and city centre location using the high heat gains case as an example. High heat gains was chosen because occupancy densities in city office buildings will result in high heat gains regardless the efficiency of lighting and equipment.

Table 4 shows that sensible cooling load is increased from 46% (city centre, lightweight structure with no night cooling) to 90% (reference site, heavyweight structure with night cooling) in 2050. Also, these two cases have a reduction in city to reference ratio in 2050. In terms of actual increase (rather than percentage values) in cooling load, heavyweight structure with night cooling has the lowest cooling demand in 2000 and 2050.

3.2. Heating demand

Fig. 3 presents the predicted normalised annual sensible heating load. As expected this reduces in the 2050s in all examined cases and there is little difference between the night cooled and no night cooled offices because during heating season night cooling is not activated. Table 5 presents a comparison of heating load for the office variations examined between 2000 and 2050 for the reference and city centre location. It can be seen that heating demand reduces between 45% and 35% in 2050 while city/reference ratios are similar in 2000 and 2050. In this case, it appears that light weight and heavy weight actual heating demand are in the same order of magnitude.

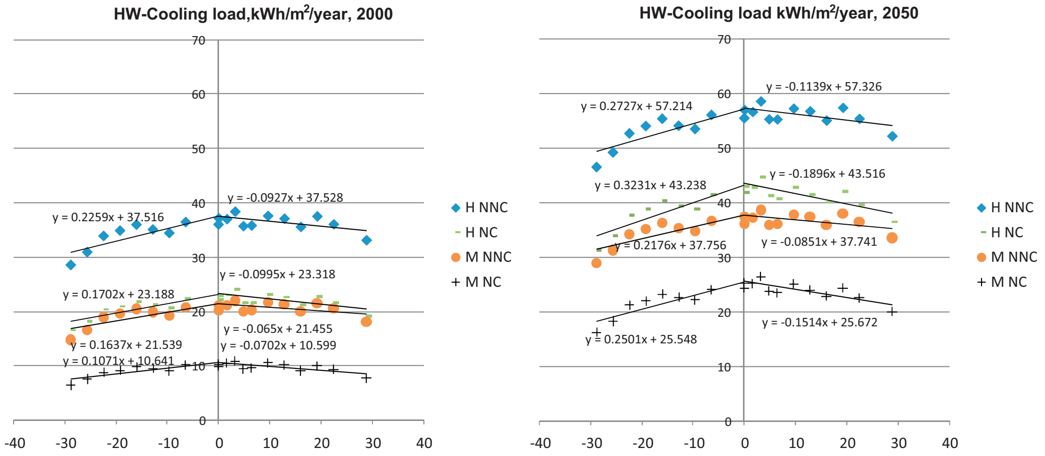

Fig. 2. Predicted normalised annual cooling load using modified weather files for urban location and climate change for a typical office in 20 locations on the West-East axis of London (HW, heavy weight construction; H, high heat gains; M, medium heat gains; NC, night cooling; NNC, no night cooling).

Table 4

Comparison of cooling load for the office variations examined between 2000 and 2050 for the reference and city centre location.

	Sensible cooling load (kWh/m²/year)							
	Reference location			City centre location			City/ref ratio	
	2000	2050	2050/2000	2000	2050	2050/2000	2000	2050
H-H-NNC	28.5	46.5	1.63	38.4	58.6	1.52	1.34	1.52
L-H-NNC	33.7	51.8	1.54	43.6	63.9	1.46	1.3	1.23
H-H-NC	16.6	31.4	1.9	24.1	43	1.8	1.45	1.37
L-H-NC	25.9	41.8	1.6	32.9	54.5	1.65	1.27	1.3

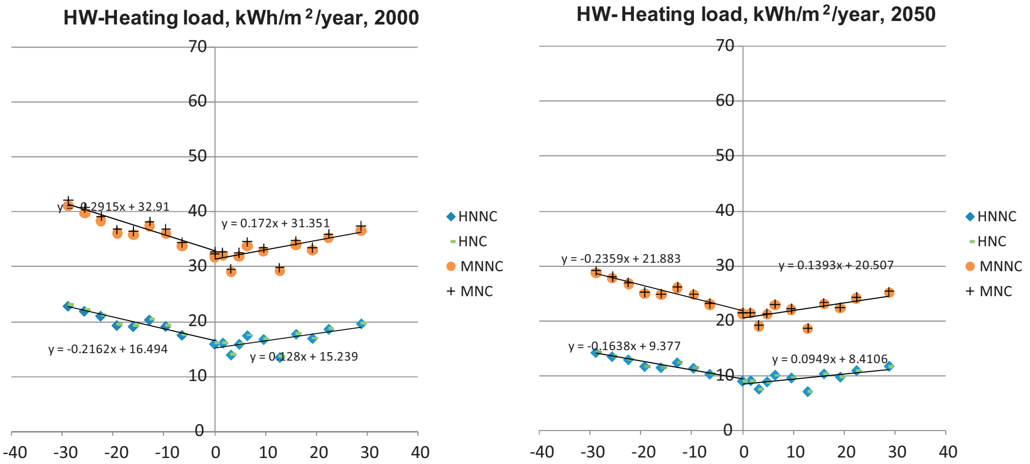

Fig. 3. Predicted normalised annual heating load using modified weather files for urban location and climate change for a typical office in 20 locations on the West-East axis of London. (HW, heavy weight construction; H, high heat gains; M, medium heat gains; NC, night cooling; NNC, no night cooling).

3.3. *Electric cooling energy consumption*

Cooling is usually provided by electricity. The electric consumption for cooling was calculated and presented in Fig. 4. A coefficient of performance (COP) of 2.8 was used for the calculations assuming an all air distribution system. In addition 15.8 kWh/m²/year was added for electric energy required for cooling transport (fans, pumps and controls) for the simulated ventilation rate of 3 ach. This value is based on previous work and assumes 80% efficiency of the fans and a specific fan power (SFP) of 1.8 W/ls, [38]. Fig. 4 shows the variation in electrical energy consumption for cooling while Table 6 shows comparisons between city and reference locations in 2000 and 2050. Table 6 shows that electric energy consumption for cooling is between 23% and 30% more in 2050 while the city to reference ratio is increased in 2050 in comparison to 2000. This implies that more energy will be required for cooling in city buildings than rural buildings but the difference is in the order of 5%.

3.4. *Gas heating energy consumption*

In the UK heating is usually provided by gas. Fig. 5 and Table 7 shows gas energy consumption for heating; a boiler efficiency of 85% was assumed for the calculations; this incorporates the small losses for heat transport. As expected, gas consumption is reduced

Table 5

Comparison of heating load for the office variations examined between 2000 and 2050 for the reference and city centre location.

	Sensible heating load (kWh/m²/year)							
	Reference location			City centre location			City/ref ratio	
	2000	2050	2050/2000	2000	2050	2050/2000	2000	2050
H-H-NNC	22.8	14.2	0.62	13.9	7.5	0.54	0.61	0.53
L-H-NNC	21.0	13.2	0.63	12.8	8.4	0.65	0.61	0.63
H-H-NC	23.1	14.3	0.62	14.0	7.6	0.54	0.61	0.53
L-H-NC	21.3	13.4	0.63	13.0	8.5	0.65	0.61	0.63

Table 6

Comparison of electricity consumption for cooling of the office variations examined between 2000 and 2050 for the reference and city centre location.

	Electricity consumption for cooling (kWh/m²/year)							
	Reference location			City centre location			City/ref ratio	
	2000	2050	2050/2000	2000	2050	2050/2000	2000	2050
H-H-NNC	25.8	32.2	1.25	29.3	36.5	1.26	1.13	1.13
L-H-NNC	27.6	34.1	1.26	31.1	38.4	1.23	1.12	1.13
H-H-NC	21.5	26.8	1.25	24.2	31.6	1.30	1.12	1.18
L-H-NC	24.8	30.5	1.23	27.7	35.1	1.26	1.11	1.15

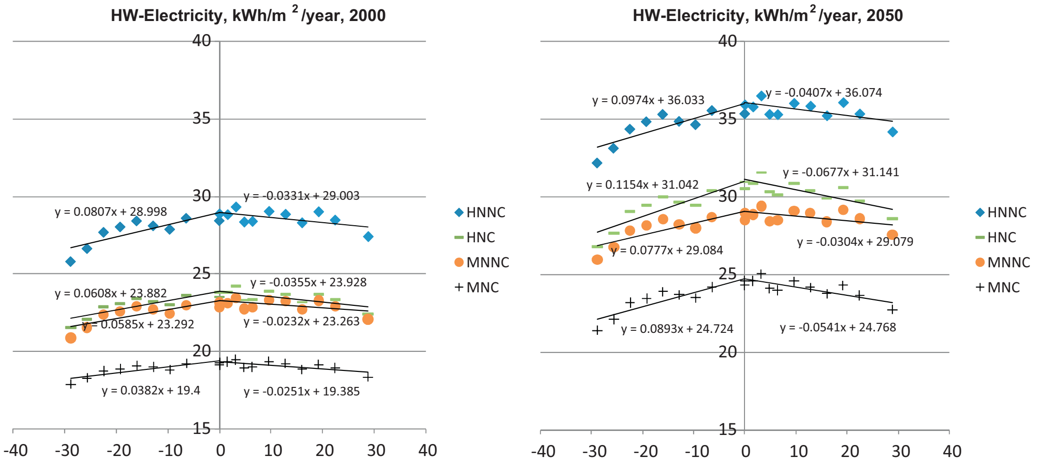

Fig. 4. Predicted Normalised annual electricity consumption for cooling using modified weather files for urban location and climate change for a typical office in 20 locations on the West-East axis of London (HW, heavy weight construction; H, high heat gains; M, medium heat gains; NC, night cooling; NNC, no night cooling).

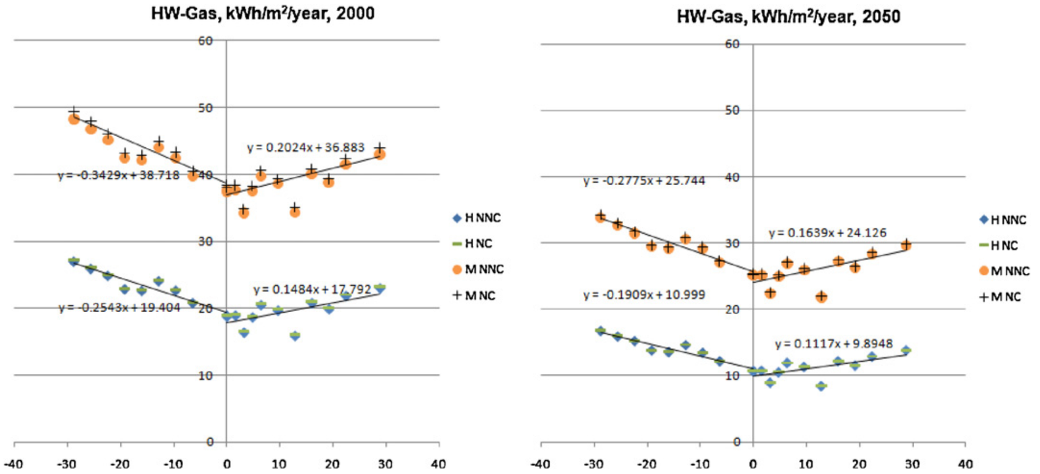

Fig. 5. Predicted Normalised annual gas consumption for heating using modified weather files for urban location and climate change for a typical office in 20 locations on the West-East axis of London (HW, heavy weight construction; H, high heat gains; M, medium heat gains; NC, night cooling; NNC, no night cooling).

in the city location and in 2050. Gas consumption is reduced by almost 40% in 2050 in the reference location and 45% in the city centre location. The city to reference ratio of 0.61 in 2000 and is reduced to 0.53–0.54 in 2050 indicating more reduction in the city in 2050. In this case, heavy weight construction with night cooling has the highest gas consumption while a lightweight construction the lowest; but the differences are not very large.

3.5. Carbon dioxide emissions

This section presents the environmental impact of heating and cooling in terms of CO_2 emissions. The calculations are based on electricity conversion factors of 0.52 $kgCO_2$/kWh and gas of 0.19 $kgCO_2$/kWh; these are the current conversion factors used for compliance to current buildings regulations in England [25]. The results are presented in Fig. 6 and Table 8. Fig. 6 shows that offices with night cooling produce less CO_2 emissions in 2000 and 2050, the difference between city and rural offices is less in 2050 with urban offices producing more CO_2. Also, the difference between offices with high and medium heat gains is less marked in 2050 compared to 2000. A similar trend can be observed for the no night cooled offices. Table 8 shows that a 5–9% increase in CO_2 emission is predicted in 2050 in the reference location and 13–15% in the city centre location. In 2000, the environmental impact is up to 4% less in the city location compared to the reference location while in 2050 is 4.5% more.

Table 7
Comparison of gas consumption for heating of the office variations examined between 2000 and 2050 for the reference and city centre location.

	Gas consumption for heating kWh/m²/year							
	Reference location			City centre location			City/ref ratio	
	2000	2050	2050/2000	2000	2050	2050/2000	2000	2050
H-H-NNC	26.9	16.7	0.62	16.4	8.9	0.54	0.61	0.53
L-H-NNC	24.7	15.5	0.63	15.1	8.4	0.56	0.61	0.54
H-H-NC	27.5	16.8	0.61	16.5	8.9	0.54	0.60	0.53
L-H-NC	25.1	15.7	0.62	15.3	8.5	0.55	0.61	0.54

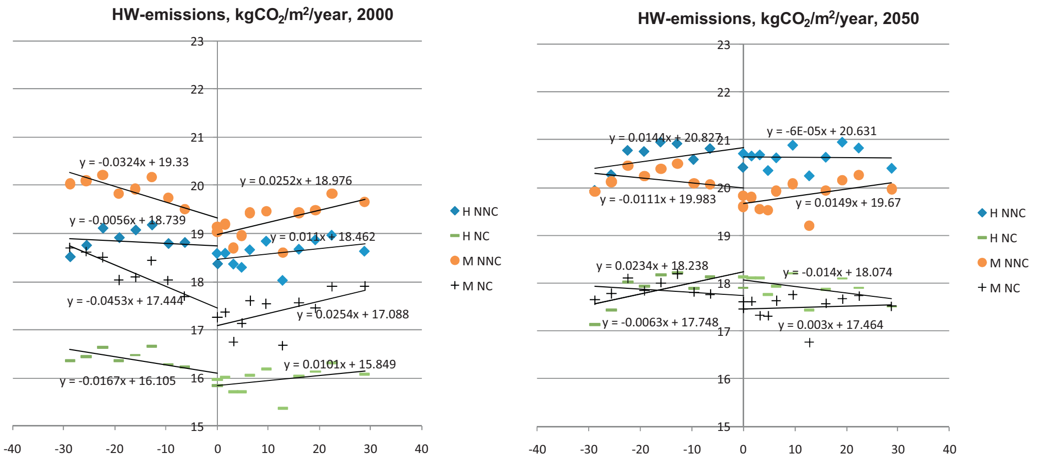

Fig. 6. Predicted Normalised annual CO_2 emissions for heating and cooling using modified weather files for urban location and climate change for a typical office in 20 locations on the West-East axis of London (HW, heavy weight construction; H, high heat gains; M, medium heat gains; NC, night cooling; NNC, no night cooling).

So, in terms of environmental impact city buildings are less polluting today (2000) but will pollute more (5%) than rural buildings in 2050. This comparison assumes that buildings are heated and cooled. However, many buildings in the UK are not cooled at present. Therefore, present energy consumption is mainly for heating; they will be cooled in 2050 because increased external temperatures will create highly uncomfortable internal conditions. This is presented in the following section.

3.6. *Thermal comfort in non cooled offices*

The results so far focus on the comfort cooled office; however many of offices in the UK and in London are not cooled and rely on natural ventilation for summer cooling. This strategy, in many cases, can lead to uncomfortable temperatures during the summer. Without going into detail about thermal comfort theory which is evolving at present, in practical terms in the UK (and other countries) an overheating criterion is defined to give an estimate of the possible problem in buildings. At present, professional and building regulation guidance recommends a cut-off temperature of 28 °C; temperature in offices should not exceed this threshold for more than 1% of occupancy hours. There is evidence that population might adapt to higher temperatures and be prepared to accept them, especially if passive cooling methods are present and behavioural changes are accepted [39]. However, defining acceptable overheating threshold for future climate change is beyond the scope of this study and the 28 °C overheating criterion not to be exceeded for 1% of occupied hours is used for the analysis. Assuming, occupancy of 10 h per day for 250 days per year, air temperature can exceed 28 °C for about 25 h. Results of overheating hours in the models examined are presented in Fig. 7 for the heavy weight building. It is obvious that offices within the London UHI overheat today and will overheat much more in the future. In the results presented in Fig. 7, only a heavy weight office with night ventilation in the reference site might be acceptable today.

Table 9 shows that overheating hours will increase from 30% to 140% in 2050 in the reference location and between 20% and 110% in the city centre location. Heavy weight construction with night cooling will have the highest increase but in terms of number of hours it still has the lowest number of overheating hours.

4. Discussion of results

Results presented in Section 3.6, show that office buildings in London are already uncomfortable today during the summer and will become more and more uncomfortable in the future

Table 8

Comparison of CO_2 emission for heating and cooling of the office variations examined between 2000 and 2050 for the reference and city centre location.

	CO_2 emissions for heating and cooling $kgCO_2/m^2/year$							
	Reference location			City centre location			City/ref ratio	
	2000	2050	2050/2000	2000	2050	2050/2000	2000	2050
H-H-NNC	18.5	19.9	1.07	18.3	20.7	1.13	0.98	1.04
L-H-NNC	19.0	20.7	1.09	19.0	21.6	1.14	1.0	1.04
H-H-NC	16.3	17.1	1.05	15.7	18.1	1.15	0.96	1.05
L-H-NC	17.7	18.9	1.07	17.3	19.9	1.15	0.98	1.05

Table 9

Comparison of overheating hours of the office variations examined between 2000 and 2050 for the reference and city centre location.

	Overheating hours (air temperature above 28 °C) during occupancy times							
	Reference location			City centre location			City/ref ratio	
	2000	2050	2050/2000	2000	2050	2050/2000	2000	2050
H-H-NNC	847	1172	1.4	1090	1328	1.2	1.3	1.5
L-H-NNC	979	1306	1.3	1212	1445	1.2	1.2	1.5
H-H-NC	261	633	2.4	440	931	2.1	1.7	1.5
L-H-NC	616	1001	1.6	830	1256	1.5	1.3	1.2

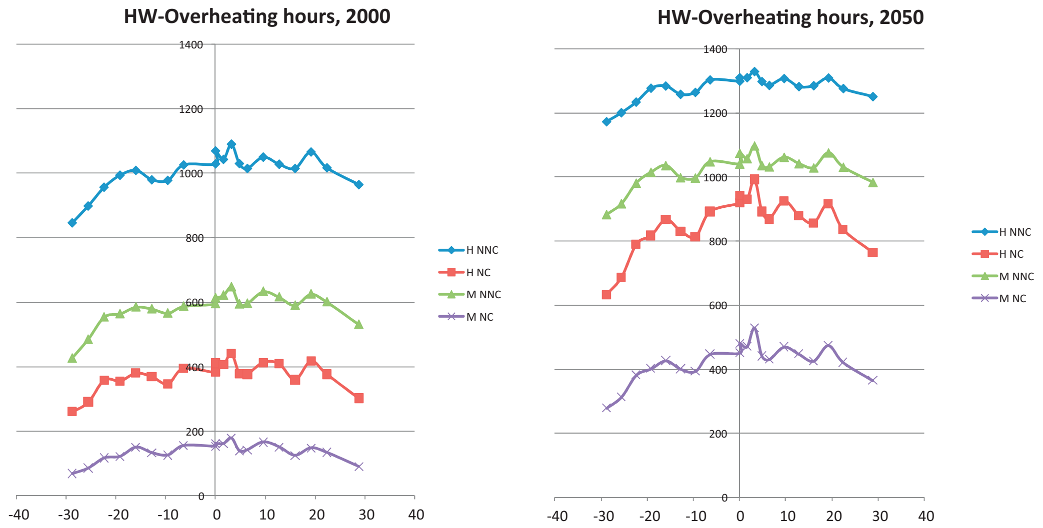

Fig. 7. Predicted overheating hours (>28 °C) during occupancy hours using modified weather files for urban location and climate change for a typical office in 20 locations on the West-East axis of London (HW, heavy weight construction; H, high heat gains; M, medium heat gains; NC, night cooling; NNC, no night cooling).

if not cooled; therefore some form of cooling will be added to existing building and most new buildings will be designed with air-conditioning systems to alleviate this effect.

Results presented in Section 3.5 show that today urban buildings have similar CO_2 emissions to rural buildings and there will be only a marginal increase of CO_2 emissions of urban buildings in comparison to rural counterparts in the future. However, this is an unfair comparison because many office buildings in the UK are not cooled at present but because of increased overheating in the future, cooling will be provided.

Therefore, a comparison on the environmental impact (CO_2 emissions) was carried out between non-cooled office of today (2000) versus comfort cooled offices of the future (2050). The results are presented in Table 10. In this case, CO_2 emissions are increased between 230% and 340% in the reference location and between 480% and 670% in the city centre location.

The positive effect of the UHI on heating buildings is highlighted as the city to reference ratio is 0.6 today (2000), indicating the urban buildings heated only emit 40% less CO_2 than their rural counterparts. In 2050, comfort cooling is assumed, so the city to reference ratio is 1.04–1.05 which indicates that urban building have a slightly higher environmental impact than rural buildings.

Results also show that heavy weight night cooled office, consistently has the lowest impact today and in the future. In some cases, percentage increases in the future are higher than other building types but in terms of numbers is still the lowest.

A summary of all results for the case of heavy weight night cooled office, is presented in Table 11. It can be seen that electricity needed for cooling is increased in both rural and city-centre locations and gas need for heating is reduced. CO_2 emissions are increased 15% in the city location compared with rural in 2050. CO_2 emissions are increased 230% in 2050 in reference location

Table 10
Comparison of CO_2 emissions between an office heated only in 2000 and heated and cooled in 2050 for the reference and city centre location.

	CO_2 emissions for heating and cooling $kgCO_2/m^2$/year							
	Reference location			City centre location			City/ref ratio	
	2000	2050	2050/2000	2000	2050	2050/2000	2000	2050
H-H-NNC	5.1	19.9	3.9	3.1	20.7	6.6	0.6	1.04
L-H-NNC	4.7	20.7	4.4	2.8	21.6	7.7	0.6	1.04
H-H-NC	5.1	17.1	3.3	3.1	18.1	5.8	0.6	1.05
L-H-NC	4.8	18.9	3.9	2.9	19.9	6.8	0.6	1.05

Table 11
Summary of energy requirements and environmental impact of heating and cooling of an heavy weight office building with high internal heat gains in 2000 and 2050 in a rural and city centre location.

	H-H-NC							
	Reference location			City centre location			City/ref ratio	
	2000	2050	2050/2000	2000	2050	2050/2000	2000	2050
kWh/m^2/year								
Cooling load	16.6	31.4	1.9	24.1	43	1.8	1.45	1.37
Heating load	23.1	14.3	0.62	14.0	7.6	0.54	0.61	0.53
Electricity-cooling	21.5	26.8	1.25	24.2	31.6	1.30	1.12	1.18
Gas-heating	27.5	16.8	0.61	16.5	8.9	0.54	0.60	0.53
$kgCO_2/m^2$/year								
CO2 emissions	16.3	17.1	1.05	15.7	18.1	1.15	0.96	1.05
CO2 emissions for heating only (2000), heating and cooling 2050	5.1	17.1	3.3	3.1	18.1	5.8	0.6	1.05

Table 12
Summary of energy requirements and environmental impact of heating and cooling of an heavy weight office building with medium internal heat gains in 2000 and 2050 in a rural and city centre location.

	H-M-NC							
	Reference location			City centre location			City/ref ratio	
	2000	2050	2050/2000	2000	2050	2050/2000	2000	2050
kWh/m^2/year								
Cooling load	6.5	16.3	2.5	10.5	25.3	2.4	1.61	1.55
Heating load	42.0	29.1	0.7	32.6	21.4	0.65	0.77	0.73
Electricity-cooling	17.9	21.4	1.2	19.4	24.6	1.27	1.08	1.15
Gas-heating	49.4	34.2	0.7	38.4	25.2	0.66	0.77	0.73
kgCO$_2$/m^2/year								
CO2 emissions	18.7	17.6	0.94	17.3	17.6	1.02	0.92	1.0
CO2 emissions for heating only (2000), heating and cooling 2050	9.4	17.6	1.87	7.3	17.6	2.41	0.77	1.0

and 480% in the city location if a cooled office in 2050 is compared with a heated only office in 2000.

Table 12 presents the same results but for medium internal heat gains, assuming a better energy efficient operation and equipment (medium internal heat gains). In this case too, electricity needed for cooling is increased in both rural and city-centre locations and gas need for heating is reduced. However, CO$_2$ emissions are reduced by 6% in the rural location in 2050 compared with 2000 but they are increased marginally 2% in the city-centre location. CO$_2$ emissions are increased by 87% in 2050 in reference location and 141% in city centre location if a cooled office in 2050 is compared with a heated only office in 2000. This is significantly less than the increase in the case of high internal heat gains.

Looking in the comparison of high versus medium internal heat gains, the CO$_2$ emissions are lower in 2050 in the city centre location by about 3%. This indicates that energy efficient design which minimises internal heat gains is important.

5. Conclusions

Urban buildings are likely to experience an increasing degree of summer overheating due to climate change and the intensification of the UHI. This is likely to lead to installation of ad-hoc cooling systems (perhaps not with the highest efficiency) in existing building and more carefully designed cooling systems in new buildings. The environmental impact of such interventions in a heating dominated climate (London, UK) which will be unavoidable in the future due to higher temperature in the summer is investigated in this study taking office buildings as a case-study.

The study simulated the heating and cooling energy loads of a typical UK office building in 20 locations on an East-West axis through London for the present situation and for a 2050s Medium-High emissions scenarios. The LSSAT model was used to generate air temperatures within the London UHI. Electricity and gas energy consumptions were calculated, making typical assumptions for HVAC system's efficiency and additional energy needed for distribution.

The findings can be summarised as follows and directly apply to a heating dominated climate (London):

- *Energy for heating*: Heating load decreases from reference to city-centre at present and in the future. Heating demand will be less in 2050 due to higher temperatures. Gas consumption will be also lower in urban building in 2050, approaching 50% less of their rural counterparts. Of the examined building parameters, heat gains is most important and determines heating load. This is consistent with other studies in the UK [18].
- *Energy for cooling*: Cooling load increases from reference to city-centre at present and in the future. Cooling demand will be higher in 2050 due to higher external temperatures; electricity consumption is also higher. The increase varies according to the type of construction (heavy weight or light weight), internal heat gains and availability of passive cooling in the form of natural night ventilation. The difference in city to reference ratio in 2000 and 2050 is not significant both in cooling demand and electricity consumption for cooling.
- *Summer overheating for non-cooled offices*: Overheating hours are increased in urban buildings at present and will be increased further in the future for both rural and urban locations. Relative increase in urban buildings is linked to similar parameters as for the increase of cooling demand. It is likely that passive measures alone will be able to provide acceptable internal temperatures in urban building which will lead to an increase of air-conditioning installed capacity.
- *Environmental impact*: Considering the CO$_2$ emissions due to heating and cooling, simulations reveal and for the systems considered in this study that there is a modest burden by rural buildings at present (less than 10%) and this is increased to about 15% for urban buildings in 2050. Urban buildings have marginally less environmental impact at present (less than 5%) and will have an increased burden in 2050 (less than 5%). However, if the same comparison is done between a heated only office at present with a heated and cooled office of the future, environmental impact becomes very significant; CO$_2$ emissions will be more than 200% in 2050 for rural offices and more than 500% for city-centre offices in the case of high internal heat gains.
- *Building construction*: Heavy weight construction seems to result to lower energy consumption in terms of actual energy, although relative increase is in some case higher than light weight construction. However, heavy weight materials are characterised by higher embodied energy and further research is required to calculate the trade off between embodied energy and operational energy savings.
- *Night cooling using natural ventilation*: Night cooled offices utilising natural ventilation have lower cooling demand and therefore perform better in terms of environmental impact both in rural and city locations. However, percentage increases and ratios between rural and city buildings are similar between night cooled and no night cooled offices.
- *Building operation*: Heat gains, is one of the most significant parameters affecting energy consumption. High heat gains will reduce heating and lower heat gains will reduce cooling; simulations indicated that in terms of environmental impact reducing cooling requirements is more important than reducing heating, even in a heating dominated climate. Reducing heat gains fro high to medium, will reduce the environmental impact from 230% to 87% in 2050 in a rural location and from 480% to 140% in an urban location. Finally, the city to rural ratio is the same in 2050 while it was 8% less in 2000 in cooled urban buildings or 23% less in heated only buildings.

The present study focused on office buildings and cooling/heating energy consumption in the future and within an urban heat island; it adds to existing work by many researchers on the impact of wither climate change or urban environment on buildings. The findings will be of interest to building designers and urban planners as it indicated parameters that will affect design issues within a city in the future. The methodology established will be of interest to building scientists as it can be applied to other cities where data exists to generate weather files within the city and projections on future climate scenarios are developed.

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