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

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A B S T R A C T

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:

$$f_r = \frac{\Sigma(AY) + \mathrm{Cv}}{\Sigma(Au) + \mathrm{Cv}} \quad (3.1)$$

$$C_V = \frac{1}{3}NV \quad (3.2)$$

where f_r is the response factor, dimensionless, A is the surface areas (m^2), Y is the thermal admittance (W/m^{2}K), U is the thermal transmittance (W/m^{2}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