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The effect of the London urban heat island on building summer cooling demand and night ventilation strategies

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This paper investigates the effect that increased air temperature due to the London heat island has on the effectiveness of stack night ventilation strategies for office buildings. Stack ventilation was investigated as the most suitable night ventilation strategy because this is largely independent of wind variations affected by local urban morphology. The paper presents a summary of the results of air temperature measurements carried out in London in 1999/2000 which were used to quantify the London Urban Heat Island Intensity. It then presents data for two representative weeks, one with extreme hot weather and one with typical hot weather in the centre of the London heat island and a rural reference site. These data are used to carry out a parametric analysis by using a thermal and air flow simulation tool specifically designed for offices in SE England. A reference and optimised office module are described. A comparison of the building types based in the same location suggests that during the typical hot week the rural reference office has 84% energy demand for cooling compared to a similar urban office. A rural optimised office would not need any artificial cooling and would be able to maintain temperatures below 24 C. An urban optimised office would not be able to achieve this. A rural optimised office would need 42% of the cooling required for an optimised urban office. A comparison of the optimised to the reference office module suggests that an urban optimised office reduces the cooling demand to 10% of the urban reference office.
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: Urban heat island; Stack ventilation; Night ventilation; Cooling demand

1. Introduction

The heat island phenomenon, caused by microclimate changes brought about by man-made alterations of the urban surface, is being extensively investigated worldwide. It is usually quantified by the term Urban Heat Island Intensity (UHII), which is the maximum difference between urban and background rural temperatures. Research to-date focuses on the quantification and understanding of the UHII as well as proposing models for its prediction.

1.1. London urban heat island intensity quantification

Numerous studies have been carried out measuring the urban heat island intensity and a comprehensive

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review on recent advances is given in (Arnfield, 2003). The effect on building construction and in particular passive design is reviewed in (Santamouris, 2004a). There are numerous experimental studies carried out in order to quantify the heat island intensity in many regions; a review is included in (Santamouris and Georgakis, 2003).

In the case of London, Luke Howard in 1820 published an analysis of ten years of daily temperature measurements which established the existence of London s heat island, i.e. an area of elevated temperature, (Landsberg, 1981). These data show a mean 24 h temperature for July in the city about 0.6 K higher and in November 1.2 K higher than in the country. Howard also noted (in Fahrenheit) that, ''Night is 3.70 warmer and day 0.34 cooler in the city than in the country. Thus the latter has 4 more variation'' (2.05 K, 0.18 K and 2.22 K respectively). Howard s data provide the first scientific evidence for two important characteristics of temperature anomalies, viz. diurnal and seasonal variation of the size of the anomaly, and change in sign of the anomaly (a heat island to a cold island). His reference to there being greater temperature variation in the countryside underlines another important property of urban areas—that they can act as moderators of climate.

Since Howard first identified the heat island, the urban climate of London has been extensively studied, and was described in detail in The Climate of London (Chandler, 1965). Meteorological Office temperature data for London (1931–1960), reported by Chandler, show the annual mean temperature of central London to have been 1.4 K warmer than the surrounding country. The heat island effect in London varies from year to year. For example, the years 1933–1934 were milder and calmer than the preceding years and drier than those which followed. These years were notable for having particularly strong heat islands (Chandler, 1965). Of perhaps longer term importance is the trend identified by Lee (1990), looking at the temperature difference between St.James s Park and Wisley for the period 1962–1989. He found that daytime heat islands have decreased over time, from about 0.5 K down to 0.25 K in the summer, and night-time heat islands have increased by about 0.5 K.

Previous work of the authors focused on measurements to quantify the urban heat island intensity and some results are reported in (Watkins et al., 2002a,b). This work has indicated that the UHII in London varied widely from a maximum of +8 C down to a cool island of 4 C. In the summer, the mean 24 h heat island intensity was 2 C with the night-time mean heat island intensity 3.2 C. For 10% of the night-time the heat island intensity was more than 5 C. The heat island intensity varied spatially in several ways with a general reduction with increasing distance from the centre and levels of urbanisation. However, not all variance can be explained in this way and weather parameters were shown to have an effect particularly during the night. In the summer, greener sites were associated with lower air temperatures and when sites were re-assessed on the basis of their upwind greenness, computed on an hourly basis, the separation in temperature between the green and less-green sites increased. On a sunny summer s day, lighter-coloured surfaces in streets were 6–10 C cooler than darker ones for similar material and solar exposure. Mean surface temperatures in a street gorge were found to be well-correlated with the air temperature at mid-gorge height on both sunny and cloudy days.

1.2. London urban heat island and energy consumption

The urban heat island has a direct effect on the urban microclimate and energy consumed for heating and cooling buildings. Recent publications indicate that the energy impact of the heat island is significant (Santamouris and Georgakis, 2003). Studies also indicate that passive ventilation and cooling might be affected in London buildings (Ren et al., 2003). A review of recent advances on the understanding of the potential of natural ventilation in urban areas is given in (Santamouris, 2004a) where the increase of cooling load in buildings in Athens because of the canyon effect is discussed based on experimental and simulation studies. In central Athens, the annual cooling load for an apartment block with windows shaded 50% of the time was found to be 15–50% higher than when modelled using weather data from an open site on a hill 2 km away (Hassid et al., 2000). Also in Athens, where the mean heat island intensity exceeds 10 C, it was found that the cooling load of urban buildings may be doubled and the peak electricity load for cooling purposes may be tripled especially for higher set point temperatures. During the winter, the heating load of central urban buildings is found to be reduced up to 30% (Santamouris et al., 2001).

The authors have carried out a study using a commercial building simulation tool to predict the impact of the heat island and the urban environment on energy load in a typical office building in London. Heating and cooling energy demand simulations were carried out for 24 locations of the notional office and some results were published in (Watkins et al., 2002c). It was found that for a standard air-conditioned office operating with internal gains of 43 W/m^2, annual heating load decreases by 22% from a rural site, with cooling load increasing 25%.

Buildings provide mutual over-shadowing, and for building types where cooling dominates, this is an advantage in reducing solar gain. This offsets, but only partly, the higher air temperatures that are associated with urban areas, which alone would always increase cooling demand. Modelling of a standard air-conditioned office building has shown that energy demand for cooling always exceeds the need for heat, wherever

the building is located. The minimum total energy demand and CO_2 production is therefore always found when the building is positioned away from the heat island in a rural site.

1.3. London urban heat island, cooling demand and passive ventilation strategies

The urban heat island has a major effect on the cooling energy use in the summer. In many cases in temperate climates such as in London and other cities in the UK, passive ventilation strategies are used to reduce required cooling energy. However, in most the urban heat island will negatively influence the effectiveness of passive ventilation and in particular night ventilation because the UHI was found to be a predominantly nocturnal phenomenon in London. This effect was also reviewed and discussed in (Santamouris et al., 2001; Santamouris, 2004b) where the potential of single and cross natural ventilation in hot climates is presented. However, for cooler climates, stack ventilation is used in many low energy design buildings and it might be used during the night for cooling. In this case also external temperature at night (when the heat island is at its peak) might reduce the effectiveness of the strategy. This point is investigated in this paper for a typical office space using a thermal and ventilation software tool and comparing the simulation results for two locations of the office; central London and a rural site outside the London UHI.

2. Cooling demand and night ventilation simulation study

A building simulation tool specifically designed for office buildings in SE England has been used to predict the impact of the heat island on cooling energy use and passive ventilation strategies during the summer on a typical air-conditioned office building. The choice of summer external conditions together with a description of the simplified tool and the building model used are discussed in the following sections.

2.1. External conditions

For the purpose of the present study and from an available database of more than one year s hourly air temperature data in 80 locations in London, two locations were selected; one in central London (near the British Museum) and one at a rural area (Langley Park, West of London). This rural location has been used as the reference location for all previous studies and it is outside the London UHI area. Air temperature at both locations were measured simultaneously at hourly intervals recorded by dataloggers (Tinytalks) inside radiation shields at a height of 6 m (Fig. 1). Care was taken for the position of the air temperature measuring station in the rural location so as not to be influence by vegetation; it was therefore mounted on the branch of a dead tree in the middle of grassed area.

One week for each of the years 1999 and 2000 has been selected according to the maximum temperatures in the London area. Graphs representing the maximum and minimum temperature variations in central London and rural reference stations are presented in Fig. 2. The peak week for the year 1999 has been observed to be from Saturday the 31st of July until Friday the 6th of August, while for the year 2000 the peak week has been observed to be from Saturday the 5th of August until Friday the 11th of August. These maximum and minimum air temperatures were used as the air temperature input in the simulation tool. Hourly temperatures were

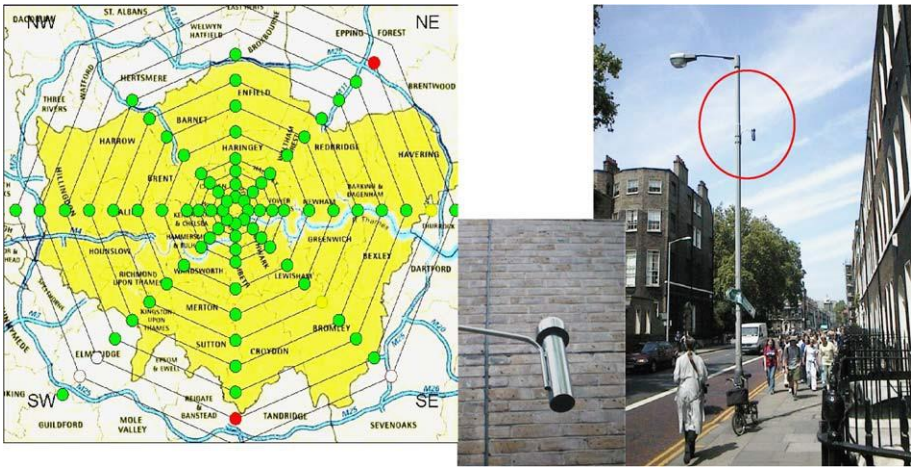


Fig. 1. Map of Greater London with air temperature stations (rural location marked) and monitoring equipment mounted in a street near to the British Museum (central London location).

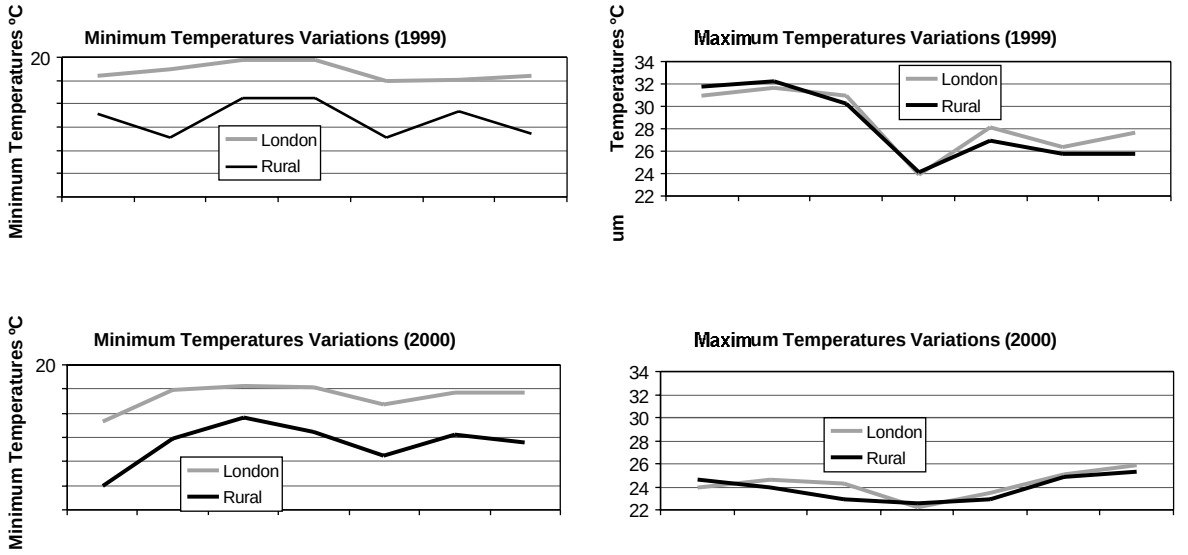


Fig. 2. Minimum and maximum air temperature variations in central London and rural reference stations of the hottest week (London max temperature) during the two monitored summers.

calculated by sinusoidal curve fitting. It can be observed that the London station was warmer than the rural reference station, especially during the night. Minimum temperatures were always higher in London compared to rural reference station while a small cool island can be observed for a number of the maximum temperatures. It can also be observed that the hottest period in 2000 was generally cooler than the hottest period in 1999. Therefore in this paper, the selected week in 2000 is termed extreme hot week and the week in 1999 typical hot week . This is consistent with weather data published by CIBSE (2002b). During the summer period (June–September) in London, hourly dry bulb temperatures exceed 32 C (max temperature of the extreme hot week) for less than 0.12%, while hourly dry bulb temperatures exceed 25 C for 3.88% (i.e. 113.6 h for the four month summer period). The average maximum temperature of the extreme hot week is 28 C and the typical hot week 23.8 C. These temperatures are exceeded for 0.98% and 5.88% correspondingly. Therefore, there is the potential that 23.8 C is exceeded almost every day if it occurs as maximum temperature. UHI intensities have been observed at their highest during hot clear and calm days. This has been also observed in London. Fig. 3 shows graphs of wind speed and UHI intensity during the two examined weeks. It can be seen that the indicative 1999 week (extreme hot week) includes lower wind speeds compared with the corresponding 2000 week. Although not a conclusive relationship, it can be seen that for both summer weeks the UHI generally decreases as wind speed increases.

2.2. Building, energy and ventilation model

The calculations are based on the BRE s high speed thermal simulation program 3TC (Tindale, 1993). In this

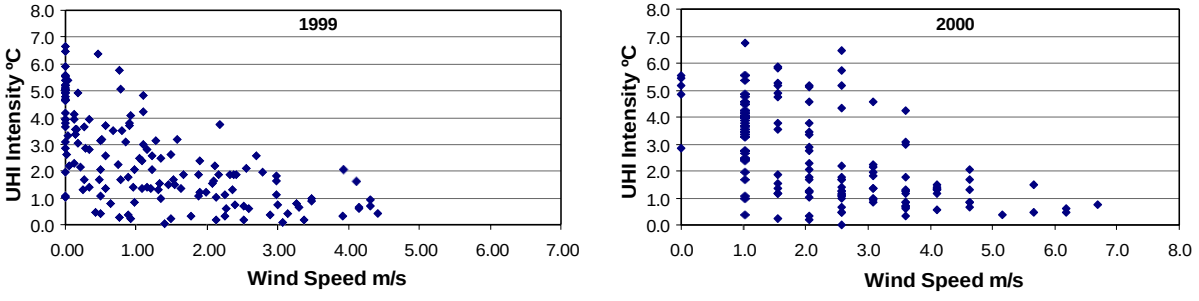


Fig. 3. Wind speed vs UHI intensity for the two indicative weeks in 1999 and 2000.

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