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Solar Energy 80 (2006) 383–392

SOLAR ENERGY

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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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Received 8 November 2004; received in revised form 7 March 2005; accepted 17 March 2005
Available online 17 May 2005

Communicated by: Associate Editor Matheos Santamouris

Abstract

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.

Keywords: 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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0038-092X/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.solener.2005.03.010

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