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The London Heat Island and building cooling design

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Abstract

London's urban heat island increases the mean air temperature which affects the demand for heating and cooling buildings. Measured air temperature data have been used as input to a building energy simulation computer program to assess the heating and cooling load of a typical air-conditioned office building positioned at 24 different locations within the London Heat Island. It is found that the urban cooling load is up to 25% higher than the rural load over the year, and the annual heating load is reduced by 22%. The effect of raised temperature and urban context are assessed separately, and the sensitivity of the net impact to the internal gains in a building is determined. For the estimation of peak cooling demand, we propose hourly temperature corrections based on radial distance from London's centre to be applied to standard published temperatures for the region. For more detailed investigations over the cooling season a range of models is available. These are reviewed in this paper and we describe preliminary results of an Artificial Neural Network (ANN) model that predicts location specific hourly temperatures for London, taking into account radial distance from central London, hourly air temperature measured at the meteorological station and associated synoptic weather data.

Keywords: Heat island; London; Energy demand; Building design

1. Introduction

Heat islands are well-established consequences of the urban environment. In general, urban centres are warmer than the surrounding area and this can be beneficial, or not, in terms of the energy used in providing comfortable conditions in buildings. In hot or cold climates the annual balance of the impact of a heat island may be clear, but in temperate regions the reduced heating season loads may significantly offset the higher cooling loads in the summer.

This paper addresses this impact in the case of London. First and in order to demonstrate the effect, the heating and cooling loads for a typical office building have been assessed using measured hourly air temperature data. The methodology of data collection and quantification of the London Urban Heat Island has been recently reported previously in Watkins et al. (2002a) and Kolokotroni et al. (2006). Using these measured air temperature data as one of the input parameters together with additional weather data and building construction and operational characteristics, the energy performance of a typical air-conditioned office building has been modelled using an energy simulation programme in a variety of urban contexts to determine the effect of the heat island over a year. It will be shown that location specific air temperature has a marked effect on energy consumption and therefore, designers should take this into account.

The paper provides information of how location specific urban air temperatures in London can be considered for the calculation of peak cooling demand (Section 4) and proposes a model for hourly air temperature calculation based on available meteorological station data and location of site within the Urban Heat Island (Section 5).

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2. Modelling the energy demand of a typical office building

Much research has been carried out investigating the effect of increased air temperature in urban areas on energy demand by buildings. In London, Chandler, using data from 1951–60, found a reduction in annual heating degree days (base 15.6 °C) of about 10% between central London and a rural area (Chandler, 1965). More recently, climate change has been linked to Urban Heat Island and its impact on building environmental design. Graves et al. (2001) have presented temperature data for designers and guidelines for reducing the effect of the heat island in London. GLA (2002) discusses the effect of climate change including Urban Heat Island on London and CIBSE (2005) examines in detail the effect of climate change on the indoor built environment in the UK.

Elsewhere, in Munich, Bründl reported that annual heating degree days (base 15.0 °C) were 14% lower in a central urban area compared to a suburban one (Brundl and Hoppe, 1984). Energy use for cooling was not considered because summer cooling was not prevalent. Energy requirements for air-conditioning are considered higher than for heating (Landsberg, 1981), and both Landsberg (1981) and Taha (1997) concluded that the elevation of urban temperatures imposes a net energy penalty in several American cities because of increased cooling requirements. Shading effects of surrounding buildings are often neglected in calculating the loads in a building. This can lead to over-sizing air-conditioning equipment, and in general, neglects a basic aspect of urbanization. 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). Akasaka et al. (2002) report that due to the heat island the cooling load of Tokyo has increased about 20% since 1900 with a corresponding decrease of about 40% for heating load. Strategies to reduce cooling energy use in buildings due to the heat island are proposed by Akbari and Konopacki (2005) classified to direct (reducing heat gain through the building shell) and indirect (reducing the ambient air temperature). They have developed summary tables for the US sorted by heating and cooling degree-days based on simulations to quantify the effect of these strategies.

In this research project, a commercial building energy simulation computer program (TAS) has been used to predict the impact of the heat island and the urban environment on energy demand by buildings. Some preliminary results were reported in Watkins et al. (2002b) and Kolokotroni et al. (2004). In this paper, additional analysis is included (Section 3) and new data on proposed temperature corrections suitable for summer cooling design assessment are presented (Section 4).

2.1. External conditions

One year's measured hourly air temperature data from 24 locations within London were combined with regional weather data to form 24 weather files for the building energy simulation model. Wind speed and direction data were obtained from Heathrow airport, 23 km WSW of central London, and humidity, cloud cover, and solar radiation data from the London Weather Centre, central London. These regional data were assumed to be applicable to all 24 sites – an approximation. Wind speed can affect infiltration and convective heat transfer. In this study of an air-conditioned building, both the infiltration and ventilation rates are scheduled and are thus independent of wind-speed. The convective heat loss coefficient is varied by the model according to the hourly regional wind speed, but this is not modified here for urban settings.

2.2. Typical Office building

The dominant type of air-conditioned building in London is the office, and to represent this a typical design has been selected from a set of designs widely used in the UK in comparative energy studies. It is a standard, as distinct from prestige, air-conditioned office termed the ECON 19/3 building; taken from the Energy Consumption Guide 19 (BRECSU, 1999). It is a three storey open plan building, 9 m high, 30 m long and 15 m wide orientated with the longer sides facing north:south, with 60% glazing on these façades. There is clear double glazing with no shading. The end walls are unglazed. Walls and roof are concrete with insulation. Intermediate floors are of concrete with false ceilings, and the ground floor is uninsulated. The walls have a solar absorptance of 40% and the roof 65%. The surrounding land was set to have 20% ground reflectance to solar radiation. An air-conditioning system (vapour compression) and heating system (gas-fired) operates from 06:00 to 18:00 (to include pre-conditioning) maintaining the internal air temperature between 20° and 24 °C. Fresh air is supplied during occupied hours with a total air change rate of 1.1/hour (including infiltration of 0.5 ach/hour at all times). Internal gain from lights, occupants and plant is 43 W/m^2.

2.3. Urban contexts

In urban areas, buildings usually experience a degree of over-shadowing which reduces solar gain. This effect has been modelled by surrounding the test building with neighbouring blocks to the same height (9 m) at a varying distance depending on the appropriate site categorization (Table 1). The spaces formed between the buildings, the street gorges, were given a height to width ratio that varied