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Low energy ventilation and cooling within an urban heat island

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ABSTRACT

More recent UK climatic data for use in the design of naturally ventilated buildings show that passive stack ventilation alone is unlikely to maintain summertime comfort in a new University College London building within the London city heat island. A stack ventilation strategy developed by the design team was evolved by the introduction of passive downdraught cooling (PDC). PDC enables cooled air to be distributed throughout the building without fan assistance. The underlying principles of the technique were explored using computational and physical models. The architectural integration and seasonal control modes are described. Predicted performance of PDC is compared with actual measurements.

1. Introduction

In the UK, nine of the eleven warmest years in the twentieth century have occurred since 1985. The UK Department of Trade and Industry attributes 47% of UK greenhouse gas emissions to the occupancy of buildings and their associated activities, including construction [1]. Natural ventilation and its potential to offer passive cooling of domestic buildings, within an overall strategy of reducing internal heat gains, can offer low technology, economically viable "easy wins" in national and international energy reduction campaigns. The UK Energy Policy Review target is a 60% reduction in UK carbon emissions [2]. The Stern Report, however, states 'ultimately stabilisation at whatever level requires that annual emissions be brought down to more than 80% below current levels' [3].

The lead author of the present paper has exploited passive stack ventilation and night purging in a number of city centre buildings in the English Midlands: the Queens Building, Leicester [4]; the Contact Theatre, Manchester [5]; the Lanchester Library and Learning Resource Centre at the University of Coventry; [6].

Even in the context of a generally warming environment these buildings appear to perform well. Krausse reports on the Lanchester Library;

> "The building benefits from the exposed thermal mass and the night ventilation strategy. Isolated warm days caused minimal rise in internal temperatures. Even during prolonged hot spells, which, in the period June 2004–June 2006, included outside air temperatures as high as 35.4 °C, the internal temperature did not exceed 26.4 °C: thus internal temperatures were up to 9 K below peak ambient temperatures." [7].

The design research team was commissioned to devise the new School of Slavonic and East European Studies (SSEES) for University College London (UCL) in 2002, located in a Conservation Area in the heart of Bloomsbury, central London. Practical completion was achieved on 12th December 2005. However, newly assembled CIBSE climate data [8] and recently published measurement of the warming of central London [9] indicated unassisted natural ventilation would not deliver performance to current comfort guidance.

2. Design constraints

Traffic noise and pollution affect the SSEES site. It is located within a Conservation area, designated under the Planning (Listed Buildings & Conservation Areas) Act 1990, sections 69 and 70 as an area of special architecture or historical interest [10]. The planning approval process which accompanies this designation is in part

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political, an elected committee responds to professional officers' recommendations. It renders the design liable to value judgments in the pursuit of an established urban design policy, potentially restricting such design features as vent stacks. However the dominant environmental design constraint was the expectation of higher summer night temperatures.

CIBSE reconsidered the weather data to be used with thermal simulation programs. Two weather years have been produced for each of the three locations (Manchester, Edinburgh and London Heathrow), a Design Summer Year (DSY) and a Test Reference Year (TRY).

To create the DSY for Heathrow, the average dry-bulb temperature for each of the six months between April and September in each year from 1976 to 1995 was calculated. These averages were ranked in order of magnitude and the third ranked (i.e. only two years were hotter) was selected as the DSY. This year, 1989, had an absolute peak temperature of 33.68 °C and 267 h with a dry-bulb temperature in excess of 25 °C (Fig. 1). The DSY was used to assess whether or not there is an acceptably low risk of summertime overheating in the SSEES building.

The TRY for London was created by selecting the most typical month from the 20 available and repeating the process for all 12 months. Thus, a TRY consists of successive typical months that have been extracted from different years (Fig. 1). The TRY can be used to estimate long-term energy demands and the expected annual occurrence of different internal temperatures.

3. The London heat island

Graves et al. (2001) [9] reported a mean annual temperature difference of 2 Kelvin (K) between the centre of London and its urban fringe. This was based on measurements made between June 1999 and September 2000.

The researchers noted that the elevation in temperature was most significant on still summer nights, with the eye of the heat island being near the British Museum, which is approximately 600 m from the site of the SSEES building (Fig. 2). In Central London, on an early August night, the temperature at the SSEES site was recorded as 7 K higher than in the Green Belt adjacent to Heathrow Airport. The effectiveness of night purging is greatly reduced or potentially even counterproductive in this peak summer situation.

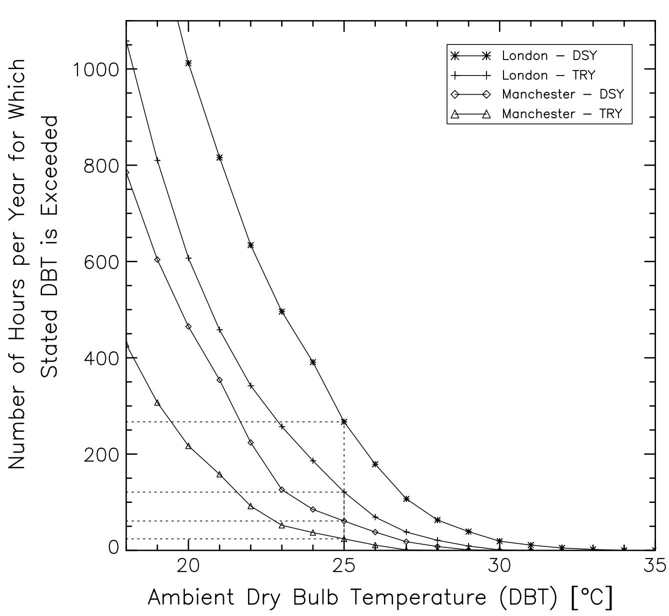

Fig. 1. Annual exceedance of ambient dry-bulb temperature in the CIBSE Design Summer Year and Typical Reference Year. Source: [8].

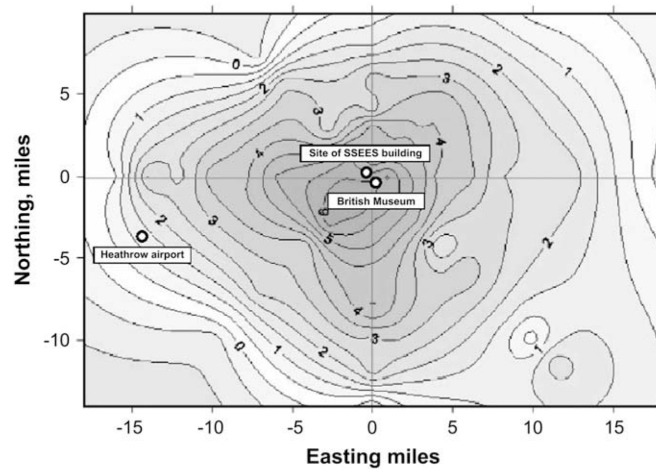

Fig. 2. Ventilation in the urban heat island intensity zones London on 2nd August 1999 at 02:00 h. Temperatures (K) are relative to the rural references. Source: [9].

4. Thermal comfort criteria

CIBSE (2002) suggested that for acceptable thermal comfort the internal temperature should not exceed 25 °C for more than 5% of occupied hours [10]. The design team assumed a typical university building would have a mean occupancy of 10 h/day for 300 days/year. The CIBSE criterion implies no more than approximately 150 h with temperatures over 25 °C. This figure is less than the number of hours over 25 °C in the Heathrow DSY (i.e. 267 h). Even if the internal temperature in buildings in and around London could be maintained at ambient, a challenging environmental design challenge, the CIBSE comfort criterion would not be met. The current CIBSE Guide A recommends that temperatures inside offices should not exceed 28 °C for more than 1% of occupied hours, based on its pre-existing climate data [11]. It has recently been reported by the Meteorological Office that 2006 may have been the hottest year ever recorded. The Lanchester Library in Coventry, approximately 100 miles north of London, comfortably met this criterion [7].

Heathrow, the source of the CIBSE London data, is outside and west of the heat island (Fig. 2). Mechanically assisted cooling during these mid summer peaks would be required to maintain CIBSE's comfort guidelines in the SSEES building. The design challenge was to provide this in an energy efficient manner.

5. Design strategy incorporating passive downdraught cooling

The use of a conventional mechanical system with its associated space requirement and energy consumption for fans and pumps was deemed unaffordable and inappropriate. A mechanism for delivering the cool air passively, i.e. without the use of fans, was sought. The strategy chosen was a development of that which was explored as part of the European Union project on passive downdraught evaporative cooling [13]. The technique involves admitting fresh ambient air at the top of the central lightwell and cooling it so that it flows downwards, filling the space with a static reservoir of denser, cooler air. The air is intended to flow across the floor plates in a controlled manner, driven primarily by the static pressure created by the cool air column and assisted by the internal