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Modelling the relative importance of the urban heat island and the thermal quality of dwellings for overheating in London

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A B S T R A C T

The aim of this study was to assess variations in indoor temperatures in London dwellings during periods of hot weather, and the degree to which those dwelling-to-dwelling variations are explained by the thermal characteristics of the dwelling and location within the urban heat island (UHI).

Indoor temperatures during periods of hot weather were modelled using the EnergyPlus simulation programme, taking as input data the building characteristics of 15 notional dwelling archetypes broadly representative of the London housing stock, and assessed under warm future weather conditions at two locations within London. Data on dwelling types and characteristics were determined from Geographic Information System databases, national level domestic building surveys and other sources. External weather data were derived from the London Site-Specific Air Temperature model under the UK Climate Impacts Programme (UKCIP) 2002 2050s Medium–High emissions scenario.

There was substantial variation in indoor temperatures across built forms. The thermal quality of a dwelling has an appreciably greater effect on indoor temperatures during the 'hot' period studied than the UHI itself.

The effects of built form and other dwelling characteristics appear to be more important determinants of variation in high indoor temperatures than the location of a dwelling within London's UHI. This observation suggests that policies aimed at protection against the adverse effects of high summer temperatures may need to focus more on dwelling design and construction than on the amelioration of the UHI.

1. Introduction

High indoor temperatures in dwellings can have adverse effects on energy use, comfort and health. In many cities, high *outdoor* temperatures due to the Urban Heat Island (UHI) effect, may accentuate indoor temperatures during periods of hot weather. What remains unclear however is the relative importance of the UHI compared with dwelling characteristics in determining high indoor temperatures.

London experiences a significant UHI [1], which may make it particularly sensitive to heat-related effects [2]. On a typical summer day, the city centre is initially cooler than the outskirts as the thermal mass of the cityscape absorbs solar energy [3]. Later in the evening, the urban structures slowly reradiate the heat previously absorbed, leading to higher night temperatures. The nocturnal UHI intensity (UHII) is generally around 3–4 °C but can be much higher during prolonged periods of hot, dry weather, such as during August 2003 and July 2006 when the nighttime temperature difference reached 6–9 °C [1]. The temperature pattern is complicated during the day but simpler and more intense during the night and under low wind speed and high-pressure

Abbreviations: UHI, urban heat island; UHII, UHI intensity; GIS, geographic information systems; SAP, Standard Assessment Procedure; BRE, Building Research Establishment; EHCS, English House Condition Survey; CIBSE, Chartered Institute of Building Services Engineers; BREDEM, BRE's domestic energy model; LSSAT, London site-specific air temperature.

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atmospheric conditions [4,5]. The UHI is highly changeable, depending on the time of the day, the wind or rain patterns and the amount of cloud in the sky [1]. The temperatures also vary across the city depending on the type of land cover [6].

The problems of high summer temperatures in urban areas such as London are likely to become worse in the future because of climate change [1]. There is considerable uncertainty concerning the exact magnitude of warming, however projections are for global mean temperatures increase by several degrees Celsius over this century [7]. The exceptional heatwave of 2003 resulted in approximately 35,000 deaths throughout Europe, 2000 of which were in the UK. Current projections suggest a heatwave of similar magnitude may occur as frequently as every third year by the 2050s [2,8].

One of the main foci of research on the impacts of the UHI in London has been on the *energy demand* of buildings. Kolokotroni et al. [9] used dynamic thermal simulations to evaluate the heating and cooling loads of an air-conditioned office building positioned at 24 different locations within the London UHI. It was found that the location-specific outdoor air temperature significantly affects energy consumption for cooling and it was suggested that this should be taken into account as an important design parameter. Apart from the *location* within the UHI, surrounding buildings were also found markedly to affect energy consumption for cooling [9,10]. Mavrogianni et al. [11] also investigated the impact of the UHI on London domestic heating demand and summertime heat-related health risks and found an increased risk of heatwave mortality in areas of increased building height.

Other research has focused on the impact of the UHI on *indoor* summer temperatures in the housing stock. For example, high temperatures were measured in five occupied houses in London and four occupied houses in Manchester during the August 2003 heatwave, and found to be associated with a high level of discomfort in most dwellings [12].

The dwellings in London recorded indoor temperatures higher than 25 °C more than 90% of the time, with six out of nine rooms above 25 °C for an entire week, and temperatures higher than 28 °C between 22% and 80% of the time [12]. The indoor day and night temperatures were highly correlated with the external temperature, as well as with the type of structure. Several modelling case studies [13] also showed that there is high risk of thermal discomfort and heat stress due to climate change in many existing buildings if no adaptation measures are taken. Six different buildings (two of which were houses) were tested against data relating to a hypothetical warm summer, both in the way they were originally designed and most likely used currently, as well as adapted to improve their performance. The results showed high indoor temperatures, especially in buildings lacking shading, controllable ventilation, or with low thermal mass, little insulation and/or poor air-tightness. A review of experience in real buildings [14] confirmed that even well insulated dwellings can develop high indoor temperatures if no measures are taken to control overheating. A recent study by Mavrogianni et al. [15] based on monitoring carried out in 36 houses in London showed that during a hot period of the 2009 summer, approximately one third of the bedrooms, many of which were located in purpose built flats, reached uncomfortable nighttime temperatures. This study suggests that summertime overheating may be determined both by dwelling factors and the site-specific microclimate.

There is currently very limited evidence as to what level of *indoor* temperature constitutes a risk to human health, although the relationship between outdoor temperature and mortality/morbidity is known with some precision from epidemiological studies. For London, for example, mortality begins to rise on days when the day maximum outdoor temperature reaches 24.7 °C – the 'heat threshold' [16]. During the 2003 heatwave there were at least 600 excess deaths in Greater London many of which were among the elderly [1,17].

In this paper we present evidence from a modelling study to examine variations in indoor temperatures in London dwellings during periods of hot weather, and the degree to which those variations are influenced by the thermal characteristics of the dwelling and the UHI effect.

2. Materials and methods

The study is based on modelling of the indoor environment using the EnergyPlus [18] simulation programme, and taking as input data the building characteristics of 15 notional dwelling types broadly representative of the London housing stock. Simulated indoor temperatures for these dwelling types were assessed under a 'future' weather file (see Section 2.2.3, para 2–3) and at two different locations within London. As yet it is not clear what the critical metric for indoor temperatures with regards to impact on health is. Thus, for simplicity and clarity, air temperature rather than *operative* temperature (air and radiant) has been reported. Future work will investigate the optimal metric.

2.1. Selection of housing types

Data on building form and construction age for the London housing stock were derived from two Geographic Information System (GIS) databases: Ordnance Survey MasterMap Topography Layer, and Cities Revealed. Built form and construction data at the individual building level were available for only 29% of the Greater London Area household spaces, details of which are presented elsewhere [19]. Amongst 92 different built form and dwelling age combinations identified, the 15 most common were selected for simulation. This excluded house types with occurrence of less than 1.5%. The set of 15 represents approximately 76% of the housing stock in the area under examination, and many of the excluded dwelling types were similar in built form and age to these 15.

2.2. Data inputs to the thermal models

2.2.1. Geometry and structure

The 15 selected dwelling types were modelled in EnergyPlus (see Section 2.3) using the following data sources and assumptions. GIS routines were used to calculate the average footprint area and storey height of each dwelling type. Internal layouts were specified using typical floor plans and facades for dwellings of the corresponding age and form [20–25]. The total window area was calculated as a function of the total floor area, built form and age, using a geometrical model of UK dwellings devised by Chapman [26] for use in energy calculations. This method was preferred over others, i.e. Standard Assessment Procedure (SAP) [27] as it takes into account built form thus offering more elaborate results. The building fabric characteristics were obtained by tabulation of data for the corresponding dwelling types in the 2005 English House Condition Survey (EHCS) database [28], the thermal properties from the SAP data [27] for dwellings of the relevant age and insulation level. The proportions of dwellings that have been refurbished or that are 'newly built' (i.e. post the 2006 revisions of the Building Regulations) have also been taken into consideration in the following manner. Different sources have been used.