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High resolution mapping of overheating and mortality risk

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ABSTRACT

Both the Paris heat wave of 2003 and recent high-resolution climate change predictions indicate a world where mortality from extreme weather events will increase. Most heat wave deaths occur in buildings, and are driven by the thermal characteristics of the buildings and their local environment. Unfortunately previous work on the topic has ignored such spatial variations by either assuming the climate has little variation over a large area, or using archetypes of buildings from stock models. The latter forgetting that neither building characteristics nor landscape context are uniform over a city, with for example suburbs having a different architecture and shading to the inner city. In this work we use a statistical method combined with a new remote surveying tool to assemble accurate models of real buildings across a landscape then map the spatial variability in overheating and excess deaths now and in the future at a resolution of 5 km × 5 km. High spatial variation in the risk of overheating and heat-related mortality was found due to the variability of architecture, context and weather. Variability from the architecture and shading context were found to be a greater influence on the spatial variation in overheating than climate variability. Overheating risk was found to increase significantly with heat-related mortality tripling by the 2050s. The method was validated against data collected during the northern hemisphere 2006 hot summer. The maps produced would be a highly useful resource for government in identifying populations of greatest concern when developing policies to combat such deaths.

1. Introduction

Despite international efforts to combat global warming since the Rio Earth Summit in 1992 [1], global surface temperatures are projected to rise by up to 4.8 °C by the end of this century [2]. Such warming increases the risk of overheating in non-air-conditioned buildings; a risk which might be further exasperated by fabric improvements [3]. In August 2003, 14,729 excess deaths occurred in France [4] and 2139 in England and Wales, due to a severe heat wave, primarily in large urban centres [5]. Interestingly, it was found that the top floor presented a higher risk of heat-related mortality, and lack of home insulation was one of the major risk factors for the excess deaths [6]. This indicates that architectural detail and lack of shading are both risk factors in such mortality.

Unfortunately, many weather events that are currently classed as extreme will become more frequent as a result of climate change. For instance, it is reported that the frequency and duration of heat waves are very likely to increase during the 21st century [2], with the heat wave of 2003 representing a typical summer by the 2040s, and heat related deaths tripling by the 2050s [3]. Indeed, it is estimated that human activities have already increased the likelihood of a 2003 type event from one in several thousand to ~1:100 in little over a decade [7]. Looking further into the future, heat related deaths are predicted to increase 5-fold under a medium carbon emission scenario (SERS A1B), by the 2080s [3]. A first step to avoiding such deaths and providing occupants with a comfortable indoor environment is a locally-relevant assessment of overheating risk which takes climate change into account.

There have been several general different assessments of future overheating risk, using dynamic thermal models of buildings and future weather files, and all show that overheating risk is on the rise [8–21]. Appropriate weather files are the prerequisites for any reliable thermal simulation. These take various forms in various parts of the world, for example Test Reference Years (TRYs) and Design Summer Years (DSYs); however, these are normally on too coarse a spatial grid to be locally accurate [22]. Previous research [23] which simulated indoor environmental conditions for different locations across two regions with varying topography, using

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weather files at a spatial resolution of 5 km found that there are distinct variations in overheating risk with location, especially in regions with large topographic differences. Hence it is possible to conclude that location-specific (future) weather data is required to perform accurate overheating risk assessments of populations. Although Eames et al. [23] used weather files at a high spatial resolution, they failed to take into account any variability in the building characteristics and urban form.

It is well known that the presence and form of surrounding buildings can have a major impact on overheating risk due to mutual shading and radiative exchange [24]. The materials used and the architectural form will also have a considerable impact, particularly the thermal mass and the glazing ratio. Hence an accurate assessment would require building information about a large number of buildings across the study area. It is however, not easy to find sufficient building information containing all the necessary variables required for thermal modelling at a large scale. Examples such as housing surveys [25], energy follow-up surveys [26] and energy efficiency databases [27], etc. Provide nationwide building information, but none of these datasets are primarily collected for the purpose of thermal modelling [25]. Hence there is a lack of information regarding building orientation, local shading and glazing ratios [24,28,29], i.e. they lack context. This has led to there being very few studies that model a large number of real existing buildings individually; instead representative or archetype models of dwelling types have been used with little to no concern of, for example, the surrounding obstructions or how built form, or density, changes across a region or country [9,19,21,28,30,31].

This study focuses on current and future spatial variation in overheating risk and heat-related mortality across a landscape. A new method is developed and then applied to a representative medium-large mid-latitude city with large topographic and density differences, and the results validated against calculated excess mortality from measured temperatures in London during 2006. As mentioned above, the problems for such a large scale overheating risk assessment are lack of detailed building information and unrepresentative weather years. These problems have been solved in this study by modelling a large number of randomly selected real dwellings sitting in their real surroundings and the use of probabilistic Hot Summer Years (pHSYs) [32] at a resolution of 5 km. In total, 907 distinct thermal models have each been simulated with 100 pHSYs, resulting in 100 probabilistic projections of overheating risk per dwelling for the current climate i.e. 2020s (2010–2039) and a possible future climate scenario for the 2050s (2040–2069). Maps of the distribution of the overheating risk and the expected heat-related mortality rate across the study area have then been created.

2. Methodology

Sheffield (53.38° N, 1.47° W) was selected as the study area. Sheffield covers an area of 367.94 km^2 and is the 5th largest city in the UK. There are approximately 553,000 people and 237,000 dwellings in the city [33]. The topography varies greatly from east to west, with a National Park bordering the west of the city. The difference in elevation between the east and west areas is around 200 m. Hence, given a surface temperature lapse rate 0.8 °C/100 m [34], there should be approximately a 1.6 °C difference in temperature between these two regions. The housing density varies across the study area varies from fewer than 10 units per km^2 to more than 7000 per km^2 [35].

2.1. Representative weather data

Given sufficient observed hourly weather data from a high spatial resolution network of weather stations and climate projections from either global or regional climate models, it is possible to create future weather data for any location in the world using the morphing methodology [36]. Such localised observed hourly weather data however, is typically not available, so synthetic weather data has to be used, for example the UKCP09 weather generator [37] can produce large amounts of synthetic weather data at a 5 km by 5 km resolution for the current century. The UKCP09 weather generator randomly chooses projections of climate change from probability density functions of possible climate change anomalies, and uses these to perturb weather data from a synthetic control period (1961–1990) [38]. It can generate weather data for three emission scenarios (SRES B1, A1B and A1FI) and seven overlapping 30-year time periods spanning 2010 to 2099, in addition to control data spanning 1961–1990. A downside of such weather generators is that each grid square is treated independently with no consistency in underlying weather patterns between adjacent grid squares. However, it has been shown that the differences caused by random sampling within the UKCP09 weather generator are much smaller than the differences due to other factors such as topography between adjacent grid squares [23]. Furthermore, a comparison of future weather data produced by morphing and the UKCP09 weather generator [39], concluded that simulations with morphed future weather files could underestimate the total overheating hours, but at the same time overestimate peak temperatures, providing further justification for the choice of synthetic weather data over a morphing methodology. (Note, there have been several different approaches [32,40–44] to constructing future weather files for building simulation using the outputs of the UKCP09 weather generator. A review of these different methodologies can be found in the papers written by Mylona [45] and Liu et al. [32].)

For this study the new probabilistic Hot Summer Years (pHSYs) [32] have been used. There are 100 sets of 30-year period weather data obtained from each run of the UKCP09 weather generator. The one with the hottest summer was selected from the 30-year period. In total, 100 hottest summer years were selected from 100 sets and they are ranked based on the ascending order of warm summers to produce 1st to 100th percentile HSYs. Two metrics were used for identifying the warmth of a summer so that there were two types of pHSYs: one is based on Weighted Cooling Degree Hours (WCDH) (pHSY-1) and the other is based on the Physiologically Equivalent Temperature [46] (pHSY-2). In this paper, pHSY-1 (from now on referred to as pHSY) has been used, as this has been shown to be suitable for assessing the severity of overheating risk [32]. Each run of the UKCP09 weather generator can output 100 sets of equiprobable climate and weather projections and hence 100 pHSYs. For each grid square 100 pHSYs were created for two time periods, the 2020s (2010–2039) intended to represent the current hot summer years and the 2050s (2040–2069) to represent possible future hot summer years.

The city of Sheffield is covered by eighteen UKCP09 grid squares as shown in Fig. 1, whilst grid square 0 is within the city's limits, it contains no dwellings and hence no simulations were performed for grid square 0. Using the SRES A1FI emission scenario, 17 sets of 100 pHSYs (1st to 100th percentile HSYs) were produced for the 2020s and 2050s respectively. In total, 3400 pHSYs (i.e. 100 pHSYs × 17 grid squares × 1 emission scenario x 2 future time periods) were used for this study. The pHSY represent warm/hot summers but are unlikely to include heat waves with a return period of greater than 15 years, hence they are not extreme. With respect to mean summertime air temperature, in this study the 90th percentile pHSY's represented on average the 98th percentile (15 °C), and the 50th percentile pHSY's the 90th (14 °C) in an ordered list of the weather files used to assemble them in each grid square. With respect to maximum mean three-day air temperature, the