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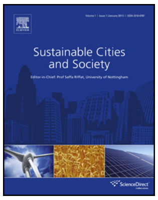

Modelling the correlation between building energy ratings and heat-related mortality and morbidity

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ABSTRACT

Climate change has led to an increase in the frequency and intensity of heatwaves as well as the risk of heat stress within buildings. To provide habitable indoor conditions without air-conditioning during heatwave, residential building energy efficiency need to be upgraded. The aim of this research is to investigate the possible correlation of building energy rating upgrading with heat-related health hazard during heatwave, with case data drawing from Melbourne, Australia. Using building simulations, indoor heat stress conditions of different energy rated houses were calculated using wet bulb globe temperature and discomfort index under the Melbourne 2009 heatwave conditions. The results showed that during three days heatwave period, residents of 0.9 star energy rated house were exposed to extreme heat stress conditions for almost 25 h compared to only 6 h experienced by the occupants of 5.4 star energy rated house. Several robust empirical relationships were proposed to predict deaths, ambulance calls, emergency department presentations and after hour doctor calls during heatwave. It was concluded that mortality rate from a Melbourne 2009 type, as well as, future more intense heatwave may reduce by 90% if entire existing lower energy star rated houses can be upgraded to minimum 5.4 star energy rating.

1. Introduction

Heatwaves pose a significant risk to human health all over the world. Heat-related illness can range from mild conditions, such as rash or cramps, through to heat exhaustion, and to potentially fatal conditions such as heat stroke (Steffen, Hughes, & Perkins, 2014). In Europe, heatwaves recently received significant attention due to the gravity of its impact on public health (Black, Blackburn, Harrison, Hoskins, & Methven, 2004). Europe has experienced one of the most severe heat waves in the history during June and August 2003. Average monthly temperatures across Europe were significantly higher than usual, and mean June and August temperatures over central Europe were 4.2 °C and 3.8 °C hotter than the long term (1958–2002) average respectively (Black et al., 2004). More than 70,000 additional deaths occurred in Europe due to heatwaves during 2003 summer (Robine et al., 2008). In July and August 2010, even more intense heatwave scorched enormous areas of Eastern Europe and Russia which claimed up to 56,000 lives (Munich, 2011).

In Australia, heat events have killed more people than any other natural hazard experienced over the past 200 years (Steffen et al., 2014). In 2004, around two-thirds of continental Australia recorded temperatures above 39 °C for the period of over three weeks (1–22 February). Brisbane recorded over 40 °C for two consecutive days in this period which caused 116 excess deaths (Tong, Ren, & Becker, 2010). In 2009, South Australia and Victoria were affected by one of the most extreme heatwaves in its history. Over the five days, 27–31 January, maximum temperatures were 12–15 °C above normal (VGDHS, 2009). In Melbourne, which is the capital of Victoria State, the temperature was above 43 °C for three consecutive days. The Victorian Department of Human Services (2009) estimated 374 excess deaths during the first week of the heatwave (VGDHS, 2009). The residents of Melbourne experienced another scorching heatwave in 2014 with the temperature above 41 °C for four consecutive days which resulted in 167 excess deaths (VGDHS, 2014).

The impact of heatwaves is further intensified by the Urban Heat Island (UHI) effects, a phenomenon where urbanised population centres experience warmer temperatures compared with surrounding rural areas (Mirzaei, Olsthoornb, Torjanb, & Haghighat, 2015). Due to the severe nature of the heatwaves and UHI, extensive studies were carried out to identify the factors affecting the indoor thermal condition as well as heat-related mortality and

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morbidity. Mirzaei (2015) summarised recent advances in the modelling of UHI effects. It was concluded that meso-scale model has the capability for modelling large-scale effect of UHI, but their accuracy is low compared to building scale and micro-scale modelling. Mirzaei et al. (2015, 2012) developed a predictive tool based on Artificial Neural Network (ANN) to predict the hourly indoor dry bulb temperature based on outdoor weather conditions, building volume, building aspect ratio and neighbourhood characteristics like thermal mass and land use/land cover ratio. ANN network was reported to be more accurate approach for the prediction of indoor air temperature than the regression method (Ashtiani, Mirzaei, & Haghighat, 2014). Through hourly indoor temperature measurements in 30 different homes in Detroit, White-Newsome et al. (2012) reported that residents of single family homes, made of asphalt, in residential surroundings experience higher indoor temperature compared to others and, therefore, are at higher risk. The impact of heatwave was reported to be higher in low-income houses characterised by low thermal protection standards, high infiltration levels and poor indoor environment quality (Sakka, Santamourisa, Livadaa, Nicolb, & Wilson, 2012). Vandentorren et al. (2004) associated houses with poor ventilation and poor or no insulation with increased rate of mortality and morbidity in the 2003 heatwave in France. Several studies (Barnett et al., 2013; Porritt, Shaoa, Croppera, & Goodier, 2011; Porritt, Croppera, Shaoa, & Goodier, 2012; Saman et al., 2013) reported that increased external wall insulation, improved window glazing and light coloured roof reduces the time of overheating hours inside buildings during heat waves that in turn can reduce heat-related health hazards. Porritt et al. (2011, 2012) reported that integration of external shutters, internal blinds, curtains and implementation of proper night ventilation can also be effective in reducing overheating hours.

Along with the studies regarding the prediction of the indoor thermal condition during a heatwave, previous researches also focused on the relationship between the outdoor condition and mortality rate during heatwave (Anderson & Bell, 2009; Nicholls, Skinner, Loughnan, & Tapper, 2008; Schifano et al., 2012; Tong et al., 2010; Tong, Wang, Yu, Chen, & Wang, 2014). A consistent and significant increase in mortality during heatwaves was reported. Nicholls et al. (2008) showed that heat-related mortality for the people over 65 years may rapidly increase when the daily mean temperature (average of maximum and minimum temperature of a day) exceeds 30 °C in Melbourne. However, it should be noted that heat-related death occurs both indoor and outdoor. Cadot, Rodwin, and Spira (2007) reported that during 2003 heatwave in Paris, 74% of excess deaths occurred among those who were living at home. Although there is no available information on the locations of heat-related excess deaths in Australia, the situation in Australia may be similar to that in Paris considering that the most vulnerable population is the elderly people group (VGDHS, 2009). To our best knowledge, only Chen et al. (2014) studied the relationship between the indoor condition and mortality rate. It was demonstrated that mortality rate in Melbourne increases when daily mean temperature (average of yesterday's daytime maximum in the living room and this morning's minimum in the bedroom) crosses 28.5 °C. However, the relationships were obtained from the long-term average of daily mean temperature and average mortality rates and are not applicable to heatwave event.

It is evident from the above discussions that building characteristics (insulation, infiltration, glazing, etc.) have a significant influence on indoor thermal condition during heatwave. At present, different building energy rating systems are adopted in different countries to determine the thermal performance of the residential buildings based on their conditions (insulation, infiltration, glazing, etc.). Although the role of building energy rating system in reducing the building energy consumption is well documented (NatHERS, 2014), there is currently no study available in the literature in quantifying the benefits of building energy rating in reducing heat-related mortality and morbidity.

The aim of the present study is to investigate the correlation of building energy rating upgrade with the heat-related mortality and morbidity during heatwave. Building simulation software EnergyPlus V8.3 was used to simulate indoor heat stress conditions of different energy star rated houses in Melbourne during 2009 heatwave. From the simulation, indoor heat stress conditions of different energy rated houses were calculated using two well established heat stress indices. Then, several empirical relationships were developed between mortality and morbidity rate and indoor heat stress conditions. After that the potential reduction in heat-related mortality and morbidity by upgrading building energy star ratings were estimated based on the developed correlation between heat stress indices and mortality rate during Melbourne's 2009 heatwave.

2. The context of the research

In the present study, the city of Melbourne, Australia was selected to investigate the role of building energy rating in reducing heat-related mortality and morbidity because heatwaves appeared to affect mortality more in Melbourne than any other cities in Australia (Tong et al., 2014). In Australia, heatwaves are not yet a specific hazard addressed by building regulations, although the Australian Building Codes Board (ABCB) believes that current energy efficiency standards moderate the risk of heat stress for building occupants (Miller, 2015). The extent of this assumed risk moderation, however, has not been quantified. To quantify the correlation between building energy rating standard and the heat-related health hazards, the indoor thermal condition of different energy rated non-air-conditioned houses in Melbourne was simulated using 2009 heatwave weather. The energy star ratings of the dwellings were determined using Nationwide House Energy Rating Scheme (NatHERS, 2014). NatHERS is an Australian developed house energy rating scheme that rates Australian homes on a scale of 0 to 10 energy stars (ABCB, 2006) depending on the heating and cooling energy requirements of a house for the comfortable indoor environment. The higher the energy star rating, the lower is the requirement for artificial heating and cooling in that building. The heating and cooling energy requirements are calculated hourly over a period of one year, using one year of typical weather data appropriate for the location. Calculated total heating and cooling energy requirement of a house in a particular location is compared to the standard total energy requirement of different NatHERS energy star rated houses in that location and then star rating is issued. Two typical Melbourne residential dwellings: (1) a duplex and (2) a single storey building were used in this study and the constructions of both dwellings were varied to represent different NatHERS energy star rated houses. In Australia, 26% dwellings do not have installed air-conditioners (Australian Bureau of Statistics, 2014) and due to a power outage during heatwave (Queensland University of Technology, 2010) buildings with installed air-conditioner are also unable to receive thermal comfort and hence the thermal performance of the building envelope becomes the dominant factor in maintaining the thermal comfort. The occupants of these dwellings are more vulnerable to heat stress, and that is why, houses were assumed as non-air-conditioned in this study.

3. Research methodology

In this study, two well-established heat stress indicators were selected through extensive literature review. Indoor thermal conditions of the studied duplex house were monitored and then used