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Thermal comfort and occupant responses during summer in a low to middle income housing development in South Australia

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ABSTRACT

This paper presents a study conducted to investigate occupants' thermal comfort and responses during a summer period in a low to middle income housing development. The study was conducted with the overall aims of understanding how occupants in this context responded to their indoor environment during hot weather and the strategies they used to achieve thermal comfort. The study found that resorting to air-conditioners was the least preferred strategy due to implications for their energy bills. Turning on ceiling fans, opening or closing windows and doors, and opening or closing curtains were the first set of actions taken by most occupants when they wanted to be cooler. The occupants also adjusted their clothing and activity according to the anticipated weather condition. The study highlights the importance of providing appropriate thermal comfort provisions, such as operable windows and ceiling fans, in houses in general, and particularly in low to middle income housing developments.

1. Introduction

It is predicted that Australia's climate will become hotter in the coming decades and that many locations will experience heatwaves of both higher temperatures and longer duration [1]. Recent extreme heat events in Australia have illustrated a range of problems associated with heatwaves from infrastructure failure, bushfires and economic loss through to increased morbidity and mortality [2,3]. It is estimated that these problems will get worse in the future and that deaths due to heat could more than double in the next 40 years [4].

Increasing the access to air-conditioners is often perceived or promoted as the quickest way to respond to elevated temperatures. The World Health Organisation, however, advises that "climate-adapted building and energy-efficient design should be stressed over air-conditioning" [5,p.93]. This is quite realistic as there is increasing evidence that the people most vulnerable to heat – the elderly, isolated, chronically ill, socially disadvantaged – are often most likely to experience energy poverty[1] [4,6,7].

Studies of heatwaves elsewhere have shown that most of the heat-related deaths occurred in the home or in nursing homes [8,9]. Some aspects of building design such as lack of insulation and overheating in bedrooms were identified as possible causes of deaths during the 2003 heatwave in France [10]; however, there has been little research into house design and heatwaves.

In anticipating the impact of increasing temperatures on occupant thermal comfort and subsequent energy use in housing and realising the crucial role building design has on occupants' comfort, this study was conducted to investigate thermal comfort and responses of the occupants of a low to middle income housing development during hot weather. Specifically, the study aimed to find out: (1) whether the occupants were satisfied with their thermal environment during this period, (2) the actions that were taken if they were not satisfied with their thermal environment, and (3) at what point they would resort to using air-conditioners. The study was part of a research program, *Framework of Adaptation of Australian Households to Heatwaves* supported by the Australian Government's National Climate Change Adaptation Research Facility, where two of the main aims were to investigate occupants' thermal responses and adaptation to heatwaves and whether these would have a significant impact on energy consumption. The research involved monitoring 60 households located in Adelaide, Brisbane and Sydney and the results have been published by Saman et al. [11].

This paper focuses in more detail on the 10 dwellings from the Adelaide section of the research. These dwellings are occupied by

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[1] Energy or fuel poverty is a term used throughout the industrialised world to describe the inability of households to afford power, heating, cooling and lighting [12–14]. It is often associated with low income and high energy cost while living in an energy inefficient dwelling. Households with this condition have a greater health risk from prolonged exposure to extreme temperatures.

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low to middle income earners under an Affordable Homes program [16]. For this study, data collected about the householders' thermal preferences was supplemented by measurements of the dwellings' internal conditions and the external climate to explore the thermal adaptive strategies employed by the occupants. The results are compared to the adaptive comfort standard of ASHRAE 55-2010 [15] as the research project mentioned above [11] indicates that it is possible to apply the adaptive model, which will be briefly discussed below, in residential buildings.

2. Thermal comfort

The assumption that people will take action to be thermally comfortable, be it by relying on air-conditioning or by applying passive design strategies, underlies thermal comfort theory. This theory suggests that humans will have certain thermal sensations (hot to cold), that their thermal satisfaction lies within a certain range of conditions, and when exposed to a thermal environment outside this range they will feel thermally uncomfortable [15]. Fanger's Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD), based on the heat balance method [17] are the most common indices to determine the acceptable range of human thermal comfort. These concepts form the basis of thermal comfort standards such as ISO 7730 and ANSI/ASHRAE Standard 55 [15]. Subsequent work however found that, in buildings that are intentionally designed to be naturally-ventilated, human thermal comfort is not static within the predicted range of thermal conditions. Humans can accept, adapt to, or are acclimatized to conditions beyond the acceptable range of human thermal comfort determined by the heat balance method. In the so-called adaptive approach to modelling human thermal comfort, Brager and de Dear assert that "thermal preference is affected by circumstances beyond the physics of the body's heat balance, such as climatic setting, social conditioning, economic consideration and other contextual factors" [18,p.85].

If exposed to conditions that are perceived as uncomfortable, humans tend to make adjustments so that they will once again feel comfortable [18–20]. Nicol and Humphreys states that this is the fundamental assumption of the adaptive thermal comfort approach – "if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort" [21,p.564]. These reactions or adaptations vary from adjusting their own personal variables or behaviour (for example by changing clothes or activities), to adjusting or changing the surroundings to affect air movement, increase or decrease temperature and humidity and increase or decrease radiant heat. Fountain, Brager and de Dear [22] call these 'behavioural' and 'technological' adjustments. It is often assumed that technological adjustments, such as turning on air-conditioners or heaters, will have an impact on building energy. Holmes and Hecker, however, argue that if passive strategies are employed, such as having operable windows to reduce or increase air movement or having adjustable shading devices to minimise or maximise solar radiation, they do not necessarily impact on building energy use [23]. The key here is to provide the occupants with the opportunities to control and fine tune their thermal environment to meet their comfort requirements [24]. Following the earlier works in adaptive comfort research, numerous field studies on thermal comfort in naturally-ventilated buildings have been conducted in various locations. For example, among many others, studies were conducted in Europe (France, Greece Portugal, Sweden, and the UK) [25] which led to the development of the European adaptive comfort standard, EN15251 [26,27], in apartments in India [28], in China [29], in Brazil [30], and in office buildings in Japan [31] where the results were compared with the adaptive model developed by de Dear and Brager [32].

With the adaptive approach, the acceptable indoor operative temperatures are predicted to have a linear relationship with the outdoor temperatures as explained in the optional method for determining acceptable thermal conditions in naturally-ventilated spaces in ASHRAE Standard 55-2010 [15]. Note that the recent addendum to the ASHRAE 55-2010 recommends the use of prevailing mean outdoor temperatures to represent the outdoor temperatures [33] instead of monthly mean temperatures which are used in ASHRAE Standard 2010 [15]. Prevailing mean outdoor temperatures are calculated based on a simple arithmetic mean of the mean daily outdoor air temperatures of no fewer than seven and no more than 30 sequential days prior to the day in question, using the exponentially weighted running means as explained in Refs. [34,35].

It is important to note that many thermal comfort studies were conducted in office-like environments (i.e. climate chamber) or real office buildings rather than in a residential setting. Oseland [36] maintains that people will have different thermal responses in these three settings (climate chamber, office, home). Karjalainen finds that occupants accept a wider range of temperatures as comfortable in their home than in offices due to their ability to control their thermal environment [37] while Hwang et al. find that occupants' thermal adaptation behaviour in homes is mostly affected by convenience in use and the cost of the adaptation methods to achieve thermal comfort [38]. Several researchers also find that the range of neutral temperature in the bedroom differs from the range of air temperature normally maintained in workplaces and in the living room, for example [39–41], depending on their clothing value and insulation value of the bedding.

3. The study

The 10 households which are the focus of this paper live in two-storey apartments, built for low to middle income earners, in a housing development situated 8 km northeast of Adelaide CBD, South Australia (34.8° SL, 138.6° EL). Adelaide has a warm temperate climate, with cool wet winters and hot, dry summers. The hottest months are January and February, but the heat often continues into March. In recent years there have been some record-breaking heatwaves.[2] In 2008 Adelaide had 15 consecutive days over 35 °C [42] while in 2009 there were 6 consecutive days over 40 °C [43,44].

In general this housing development was established as a model "green village" with large landscaped areas, wetlands, energy-efficient housing and a recycled water system. There are strict guidelines that cover site planning and the design of the buildings. The design guidelines cover areas such as orientation, set back, window types, shading and more importantly, the requirement for the entire development to achieve a minimum 7.5 Star rating in the Australian Nation-wide Home Energy Rating Scheme (NatHERS). NatHERS provides a framework to assess the thermal performance of a house at a design stage based on the predicted total heating and cooling energy load and comparing this to a reference value for the particular climate zone [45]. The comfort range settings that are used to predict the required heating and cooling are based on an understanding that acceptable thermal conditions vary depending on the climatic zones and activities – the adaptive thermal comfort theory. For heating, NatHERS sets the minimum thermostat settings at 18 °C for sleeping spaces from 08:00 to 09:00 and from

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[2] At the time of the paper being written, although there is no generally agreed definition of a heatwave, in Adelaide it is defined by Australia Bureau of Meteorology as 3 consecutive days with daily maximum temperature of 40 °C or above or 5 consecutive days of 35 °C or above.