Energy and Buildings 141 (2017) 274–283

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Understanding patterns of adaptive comfort behaviour in the Sydney mixed-mode residential context

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ARTICLE INFO

Article history:
Received 19 September 2016
Received in revised form 24 February 2017
Accepted 26 February 2017
Available online 27 February 2017

Keywords:
Thermal comfort
Behaviour modelling
Adaptation
Building simulation
Air conditioning
Clothing

ABSTRACT

The role of occupants is important as building energy consumption is significantly attributed to their behaviour. Given the diverse activities within, and high levels of personal control over the indoor environment, occupants' behaviour is one of the key uncertainties in predicting energy use in the residential sector. With an aim to better understand residential adaptive thermal comfort behaviours, longitudinal field observations were conducted with smartphone surveys and simultaneous temperature measurements in a sample of Australian homes ($n = 42$). This paper derives statistical models to enable predicting of the percentage of adaptive strategies in use (e.g. operation of air-conditioners, heaters, fans and windows), as a function of temperature. The analysis on our Sydney sample indicated that an outdoor temperature of 25 °C was the most favourable condition, inclusive of all seasons investigated throughout the 2-year monitoring period, maximising the use of natural ventilation and simultaneously minimising the householders' dependence on their home air-conditioning system. This study also revealed personal and demographic characteristics that can have a significant impact on the householder's decision to use their air-conditioning system.

1. Introduction

The energy consumption in the residential sector is known to be one of the main contributors to greenhouse gas emissions in Australia. The Australian government estimates a 56% increase in residential sector energy consumption between 1990 and 2020 [1]. Space conditioning has been identified as one of the fastest growing energy end-uses in the Australian residential sector, with penetration of air conditioners into households more than doubling in the last decade or so. In particular, the energy demand for space cooling is projected to increase five-fold over the period 1990–2020, showing the most rapid growth rate among all the major residential end-uses [1].

On-going efforts to improve the thermal performance of building envelope with policy initiatives such as the *Home Insulation Program* [2] have been positively impacting residential energy efficiency. Whilst buildings become more energy efficient, they are trying to hit a moving target because the comfort expectations of the occupants are not static – they are widely suspected of steadily moving upwards with growing affluence [3–5]. Therefore it is also important to recognise the role of occupants because wide variations in residential energy consumption can be directly attributed to differences in occupant behaviour (e.g. [6–9]). For example, a previous field study conducted in Japanese residential buildings found that 87% of the total air change rate was caused by deliberate occupant behaviours such as operating windows, doors, and air conditioners [10]. Previous intervention studies have also demonstrated that changes in behavioural modification can result in a substantial reduction of energy consumption in both residential [11] and office settings [12].

The impact of occupant behaviour on building energy consumption is expected to greatest in the residential domain where occupants play a more active role in thermo-regulation of their indoor climate by exerting direct control over the surrounding environment, and perform more diverse activities compared to the office worker population, on which the vast majority of extant thermal comfort field studies have been conducted [13]. Obviously environmental interventions by householders, such as the adjustment of temperature set-point and ventilation rate, have a direct influence on energy consumption [14]. Likewise, occupant behavioural factors – such as energy-related attitudes (e.g. ecological beliefs, energy concerns, and price sensitivity), adaptive behaviours (e.g. opening windows or doors, climatically responsive clothing choices, taking a thermoregulatory shower or bath,

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http://dx.doi.org/10.1016/j.enbuild.2017.02.061
0378-7788/

drinking seasonally appropriate hot or cold beverages, and using air conditioner/heater), personal thermal preferences and lifestyle choices, can all be crucial to energy use in the residential sector (e.g. [15,16]). For these reasons, understanding occupant behaviour within households has been identified as a key research area by the Australian government, in order to support more accurate quantification and prediction of household energy consumption that can be a basis for developing strategies against climate change [1].

Occupant behaviour is identified as one of the key sources of uncertainties in building energy use, accounting for a gap between the predicted and the actual energy consumption (e.g. [6,16,17]). Understanding the interaction between occupants and their buildings is therefore deemed highly important in terms of improving the precision of building performance simulations. However, researchers argue that standard occupant behaviour profiles used in building simulation software are rather oversimplistic, failing to fully represent occupants' behavioural patterns observed in real-life situations (e.g. [9,14,16,18]). This argument is supported by significant discrepancies previously reported in the estimation of energy use when different occupant behaviour models were employed in the simulation work [6,8,19]. As a solution to address this problem of over-simplified behavioural schedules, Nicol and Humphreys [20] presented a probabilistic analytical approach to look into the occupant use of controls – operation of windows, lighting, heaters and fans. They performed a logistic regression analysis to predict the likelihood of a certain adaptive strategy employed as a function of the physical stimuli – in this case, the outdoor temperature. This probabilistic approach has been adopted into many subsequent investigations in which occupant behavioural models were further elaborated, and then its integration into building simulation tools was discussed (e.g. [21–29]).

Residential air-conditioning is recognized as a key contributor to the problem of peak electricity demand on the grid. It has been estimated that as much as half of the residential sector's demand on summer temperature maximum days was attributable to air conditioners in Australia [30]. The fraction is certain to have increased since that estimate because the penetration of air conditioning into the residential market has risen above the 50% level prevailing in Australia in 2004. Direct Load Control (DLC) represents a common *demand response* strategy in which the utility cycled specific customer air-conditioning on and off, or initiate thermostat setback during peak demand events [30]. Therefore additional justification for observational studies of residential air conditioner usage patterns and occupant thermal comfort can be made by pointing to (1) a better understanding of the weather sensitivity of peak electricity demand resulting from residential air conditioner usage, and potentially (2) a better informed and designed Demand Response strategy within the Australian residential sector [31].

Occupant behaviours and perceptions of thermal comfort are indeed complex matters, being largely influenced by contextual factors. Notwithstanding the previous attempts to understand the interaction between occupant behaviour and the built environment, little is known in the residential context because a majority of extant field studies have been performed in the office environment, probably because of the relative ease, in logistical terms, of building up a large sample size of questionnaire responses. Occupant behaviour models derived from office settings are very unlikely to be generic and generalizable across to residential contexts, because of all the contextual factors mentioned above, including the fact that occupants' behavioural degrees of freedom to modify the office workplace environment would be relatively restricted compared to the residential context. For example, the shared use of space along with organisational culture and dress codes would represent constraints on office occupants' behaviour, or adaptive opportunity [32]. Only a small fraction of research activities into modelling of occupant behaviour have been directed at residential settings (e.g. [14,24–26,33,34]).

Table 1
Monthly minimum and maximum outdoor temperatures (°C) recorded in the BOM stations during the monitoring period.

Month	Sydney		Sydney Inner West		Sydney West		Wollongong	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
JAN	20.2	27.3	18.4	29.5	17.3	31.1	19.1	24.9
FEB	19.7	26.2	18.4	27.5	17.6	28.6	18.8	23.7
MAR	18.4	25.6	16.3	26.5	15.8	26.7	17.9	23.7
APR	15.2	23.8	12.7	24.0	11.7	24.2	15.6	22.2
MAY	11.6	21.1	8.2	20.8	6.1	20.9	12.7	19.8
JUN	10.3	17.9	7.7	17.6	6.2	17.5	11.3	17.0
JUL	9.4	18.6	5.6	18.3	4.1	18.3	10.6	17.3
AUG	10.0	20.5	5.6	20.6	3.9	21.0	10.6	18.8
SEP	12.9	23.5	9.1	24.4	7.3	25.2	13.0	21.5
OCT	14.4	24.5	11.0	26.1	9.7	27.1	13.8	22.6
NOV	16.6	24.1	14.8	25.9	13.9	27.9	15.8	21.8
DEC	18.6	26.2	17.0	28.4	16.1	29.5	17.8	23.6

This paper presents the results of a longitudinal field study carried out in residential buildings located in the temperate climate zone of eastern Australia (Sydney). With the aim of better understanding occupant adaptive behavioural patterns in the residential context, statistical analyses were performed on the participating householders' self-reported behavioural data to quantify the likelihood that a particular adaptive behaviour will occur in relation to climatic drivers, both indoors and out. When considered within the broader conceptual framework of thermal adaptation, behavioural adjustments offer an effective mechanism to maintain occupant comfort. In effect behavioural adjustments represent an immediate feedback link between the sense of discomfort and corrective response [35]. A previous review paper on thermal adaptation classifies behavioural adjustment into three categories – personal (adjusting to the surroundings), environmental (modifying the surroundings) and cultural (social/organisational customs) [35]. Among those three sub-categories of behavioural adaptation, the current study is primarily positioned within the second category – environmental adjustment i.e. opening windows/doors, turning on fans, and operating air conditioners/heaters.

2. Methods

The recruitment of participants was launched with a radio interview and after that with several flyers distributed at households' mailbox and university campus. Among those who heard the radio broadcast about the study or read the flyer, our research team contacted those who responded to the call for volunteers. A total of 42 households in two neighbouring Australian cities (Sydney and Wollongong, circa 34° South) participated in the study. The two cities are separated by about 40 km of national parkland and both fall within the same east coast climate zone with humid sub-tropical summers and mild, temperate winters. Online questionnaire surveys and instrumental monitoring were carried out for a period of two years, from March 2012 (the Austral autumn) through March 2014. Hourly outdoor weather observations were obtained from the *Australian Bureau of Meteorology* (BOM) stations that fell closest to each participating household. In general, those homes in the sample fell within a 7 km radius from the closest BOM stations. During the two-year monitoring period, the average of monthly minimum and maximum outdoor temperatures recorded in those BOM stations were 13.6 °C and 23.7 °C respectively, with the coldest month being July at 7.4 °C (monthly min .) and the warmest month being January at 28.2 °C (monthly max .) (Table 1). Ownership of at least one air-conditioning (AC) system plus a smartphone were the two main prerequisites for recruitment to our sample.