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TOWARDS AN UNDERSTANDING OF COMFORT AND WELLBEING OF OLDER PEOPLE USING OCCUPANT-CENTRIC MODELS

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ABSTRACT

The worldwide demographic trend of an ageing society has important implications in the built environment. As the ageing population increases, designers are increasingly challenged to manage the diverse needs of older citizens so that health and quality of life are improved and independent living – or "ageing in place" - can be guaranteed. In this context, since older people's individual differences are excessively wide, considering them as a single and uniform population can lead to misleading conclusions. Consequently, this study aims to investigate relationships between thermal comfort and well-being of older people on an individualized level, by developing occupant-centric and data-driven comfort models using machine learning algorithms, as opposed to the generalized static models traditionally used today. This approach seeks to enable more adequate design guidelines and thermal conditioning management for older people's built environment, which could help decrease health-related vulnerability, enhance well-being, minimize reliance on heating and cooling, reduce energy use and ultimately diminish fuel poverty.

Key words: thermal comfort, personal comfort model, machine learning, older people

1. INTRODUCTION

The world's population is ageing at a fast rate. As stated by the United Nations Department of Economic and Social Affairs, Population Division, the number of older people (aged 60 years old or over[1]) is considerably growing as a proportion of the world's population (United Nations, 2017). By 2050, this number will reach 20%, exceeding the number of younger people aged 10-24 years old for the first time. Like the rest of the world, Australia is going through the same demographic changes. By 2061, it is expected that over 22% of Australia's population will be aged 65 or over (Australian Bureau of Statistics, 2013). In consequence, this ageing phenomenon is already acknowledged by the Australian Department of Treasury as having important effects on public policies, especially in areas such as health and housing (Australian Government - Department of Treasury, 2010).

Regardless of age, people have great diversity when it comes to health, quality of life and overall needs and preferences; however, this heterogeneity tends to be greater for older adults. An explanation of this is that, throughout the ageing process, older adults have been submitted to a greater range of cumulative social, economic and environmental factors and trajectories across their individual life course (World Health Organization, 2015). Consequently, while some elderly will have high levels of frailty and there will be a high demand for care institutions, there will also be many older adults who will be active and continue as resources for their families and communities (Olshansky et al., 2011)

In addition, a growing body of policy, research and program development over the last 25 years accepts that ageing-in-place is beneficial in the interests of both older people's independence, health and wellbeing as well as reducing the economic burden on governments for the provision to aged care institutions. On a recent study for the Australian Housing and Urban Research Institution, researchers Judd et al. (2010) confirmed not only the desire of older homeowners to remain in their own homes and neighbourhoods for as long as possible, but also that this older population greatly recognises the importance of the design of the dwelling for remaining independent and participating in the community throughout their ageing course. Therefore, as the majority of the increasing number of older people prefer to live independently and age-in-place, accommodating their diverse needs and preferences in appropriate, affordable and, most of all, comfortable housing is essential to guarantee health and well-being (Howden-Chapman et al., 1999; Miller et al., 2017).

Nonetheless, international standards like ASHRAE 55 adopt models such as the PMV model (Fanger, 1972) and the adaptive model (De Dear and Brager, 1998; Humphreys *et al.*, 2016) as the base to stablish the thermal requirements for human occupancy in the built environment. As both are aggregate models, they were designed to predict the average comfort of large populations. Therefore, the current practice for thermal comfort management in the built environment is focused on the population level. This implies that assessing design options is often based on complying with an averaged thermal comfort zone, disregarding the occupants whose comfort perception deviates from the population mean (Schweiker *et al.*, 2018). However, since older people's individual differences are excessively wide, considering them as a single population in terms of thermal perception could result in leaving a significant number of older occupants in discomfort, which could affect their wellbeing to different extents depending on their health-related vulnerability. Consequently, investigating thermal comfort and thermal performance for older people on a much more individualized level is essential to provide environments that meet their requirements and preferences and thus enable healthy ageing.

The personal comfort model was created to overcome most of the restrictions that the PMV and adaptive models present. Instead of an average response from a large population, this personalized model is designed to predict individuals' thermal comfort responses. Besides taking the individual person as the unit of analysis, the personal comfort model uses direct feedback from inhabitants and their personal characteristics to calibrate, adapt and train itself. Moreover, according to the key study by Kim et al. (2018), the model is designed to give priority to easy-obtainable data and, since it employs a data-driven approach, is usefully flexible when testing different modelling methods and variables. In addition, the application of emerging new concepts such as the Internet of Things and Machine Learning Algorithms allow better data collection and better model evaluation and calibration (Zhao *et al.*, 2014; Auffenberg *et al.*, 2015; Konis and Annavaram, 2017; Guenther and Sawodny, 2019; Shetty *et al.*, 2019).

Therefore, this paper argues that personal comfort models could be the best path towards the effective prediction of older people's thermal preferences, as this methodology allows older people's diversity and specific susceptivity to environmental conditions to be taken into consideration. The overall

[1]Although the United Nations define older people as aged 60 years old or over, in Australia the term is used to define people aged 65 years old or over.

goal of developing personalized comfort models for older people is to provide a better understating of their diverse individual differences and specific requirements and consequently design and plan their built environment in a more adequate way.

2. OBJECTIVES

The main aim of this research project is to develop occupant-centric comfort models to support adequate residential design for older people to live independently and age-in-place. Considering this, this study seeks the following objectives: (1) investigate the thermal environment of a sample of houses in South Australia occupied by older people; (2) collect data on the occupants' diverse preferences and sensations during various seasons and weather conditions; (3) develop occupant-centric models for older people, considering their personal and behavioural characteristics as well as the conditions of their thermal environments; (4) test and validate the performance of the occupant-centric models in predicting not only thermal comfort but also overall well-being; (5) and demonstrate how design guidelines can be developed by the application of occupant-centric models for older people's dwellings.

3. METHODS

3.1. Study design and participants

As part of the Australian Research Council Discovery Project (ARCDP180102019) entitled "Improving thermal conditions in housing for older Australians", this study is currently collecting data from 69 participants from 55 households located in South Australia. The total number of households monitored was determined considering the previous stages of the study, as well as the project's reach in terms of budget, number of equipment available and number of researchers involved.

The inclusion criteria for the participants were: aged 65 years or above, living independently and able to communicate fluently in English. The participants were voluntarily drawn from previous stages of the ARCDP (where focus groups and telephone surveys were conducted). Other types of media, such as radio interviews, newspaper articles and tear-off flyers were also used to attract and recruit the research participants.

The geographical area analysed was chosen to include 3 different climate zones in South Australia: hot dry (Bsk), warm temperate (Csa) and cool temperate (Csb) according to the Köppen–Geiger climate classification system. BSk climate is found in the Iron Triangle area (Port Pirie, Port Augusta and Whyalla), Csa is found in the Greater Metropolitan Adelaide and Csb is found in the Adelaide Hills and the Fleurieu Peninsula.

The data will be collected during a period of 9 months (from January 2019 to September 2019) in order to cover both hot and cold seasons. This will provide the range of variations in environmental conditions necessary for a comprehensive analysis.

3.2. Data collection and tools

The data collection process initially involves visiting each house. During this visit, the researchers apply a short questionnaire, conduct an open-ended interview (guided by a check-list) about the house details and install *indoor environment data loggers* (Figure 1) inside the house's main living room and main bedroom. The researchers also leave in each house one *thermal comfort survey tablet* (Figure 2) to be used by the participants to answer a survey about their thermal environment and their preferences and sensations each day.

Figures 1 and 2 - Indoor environment data logger and thermal comfort survey tablet

The questionnaire, interview, check-list, survey and measurements were designed to collect a wide range of variables and factors known in the architecture science, medicine and public health fields of study to influence and affect thermal comfort, sensation and preference.

The questionnaire covers participant's personal data and their general behaviour towards thermal comfort. The questionnaire is conducted once, while visiting the participants, being applied manually, using a paper form and pen, taking from 10 to 40 minutes.

The open-ended interview and check list are used to gather information about the participant's house. It is conduct once, manually on paper. Photographs and measurements are also taken. This also take from 10 to 40 minutes depending on the size of the house, complexity of systems and level of details shared by the participants.

The indoor thermal conditions of the most frequently occupied space in the house are monitored automatically every 30 minutes by the indoor environment data loggers, which measure and store data such as temperature, humidity and air speed. The logger is self-contained and do not need to be moved, handled or plugged to the house's electricity or internet systems. The data is also automatically sent to a web-based server and can be accessed remotely from the University. This equipment was designed and built by the researchers especially for the ARC project.

The outdoor thermal conditions are collected from the Bureau of Meteorology weather stations records, available online.

The daily survey is administered digitally in the thermal comfort survey tablet. It is designed to assess and record participants' thermal sensations and thermal preferences, as well as behavioural, personal and health data daily. The participants were told to complete the survey preferably once a day, but the frequency may vary according to the participant's willingness to engage. The survey takes no more than a few minutes to be completed. The tablet is also self-contained and does not require to be plugged to the house's electricity or internet systems. It can be moved to different rooms in the houses and it is connected to the indoor environment data loggers so that a completed survey is always followed by an immediate automatic measuring of the environmental conditions. This equipment was also designed and built by the researchers especially for the ARC project.

3.3. Data analysis and modelling process

The conceptual framework that will guide this project is based on the work of Kim *et al.* (2018). By correlating daily environmental measurements and a series of thermal sensation, behavioural and well-being related survey answers, the study will apply machine learning algorithms to develop individual occupant-centric models for each participant, which can predict not only the participant's thermal comfort sensation, but also their well-being for each combination of environmental conditions.

The modelling process will involve the following processes: (1) Data collection, which is currently in progress; (2) Data preparation, processing the raw data into the adequate format for modelling; (3) Model selection, selecting the best machine learning algorithm for the chosen outputs and inputs, which also comprehends the analysis of the significance of each chosen variable; (4) and Model evaluation, validating the predictive performance of each individual model and comparing it to the results expected from the conventional models (PMV and adaptive) used today.

4. PRELIMINARY RESULTS

As the study commenced in mid-January 2019, most of the data is still being collected. However, sociodemographic data from the 69 participants involved so far are already available. A sample of the sociodemographic data collected can be seen in Table 1. The data already reveals relevant diversity in terms of weather preference, for example, with 30,4% of the participants stating a preference for hot weather and 30,4% of the participants preferring the opposite, cold weather. Although almost 70% of the participants perceived their health as good (between 76 and 100, in a scale from 0 to 100), it is essential to focus on the individual in order to analyse in depth both the healthy and unhealthy participants and how this affects their thermal perceptions and sensations.

Table 1 – Sample of sociodemographic data collected

Gender	**N**	**%**
Male	23	33,3%
Female	46	66,7%
Total	69	100,0%
Age		
65-69 years	7	10,1%
70-74 years	19	27,5%
75-79 years	23	33,3%
80-84 years	13	18,8%
85 years or over	7	10,1%
Total	69	100,0%
Living Arrangement		

alone	30	43,5%
with spouse	36	52,2%
other	3	4,3%
Total	69	100,0%
Weather preference		
Hot weather	21	30,4%
Cold weather	21	30,4%
Neither hot nor cold	12	17,4%
No preference	12	17,4%
Other	3	4,3%
Total	69	100,0%
Self-rated health/wellbeing		
0-25	0	0,0%
26-50	6	8,7%
51-75	16	23,2%
76-100	47	68,1%
Total	69	100,0%

In addition, until the end of April 2019, a total of 3992 thermal comfort votes and corresponding thermal measurements were collected. The participants are engaging in the surveys regularly, with most of them inputting their perceptions every day. It is expected that by the end of the data collection period, in September 2019, more than 9000 entries will be available to be analysed.

Figure 3 presents the correlation between the measured indoor operative temperature and thermal sensation votes (TSV, on a 5-point scale from -3, representing 'cold' sensation, to 3, representing 'hot' sensation) collected to date. The graph shows that neutral sensation (TSV = 0) was experienced at indoor temperatures ranging widely from 15 to 33°C and that the same wide ranges of temperatures can be seen for each sensation experienced. This means that participants' thermal sensation can vary greatly for the same indoor temperature and that although a statistical approximation can predict an optimal temperature for the whole cohort, it is still relevant to analyse each person from an individualized in-depth level.

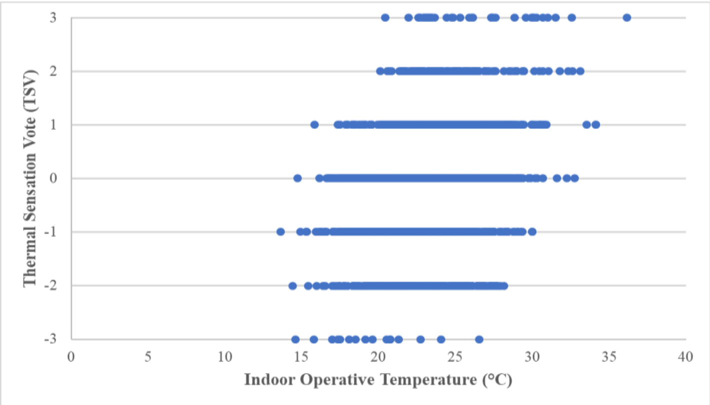

Figure 3 - Indoor Operative Temperature vs Thermal Sensation Vote

Apart from being asked how they described their thermal sensation at that time of the survey, on a 5-point sensation scale from 'cold' to 'hot' (Thermal Sensation Vote), participants were also asked whether they preferred to change the way they felt thermally, on a 3-point scale from 'preferring to feel warmer' to 'preferring to feel cooler' (Thermal Preference Vote). Figure 4 presents the results from a cross-tabulation analysis between the number of votes for these two entries. As it can be seen, a considerable proportion of participants reported other than neutral sensation ('cool', 'slightly cool', 'slightly warm') without, however, the preference for a change in that condition. This emphasizes that thermal neutrality and thermal preference for 'no change' are not the same for all individuals, and that experiencing non-neutral sensations, although not thermally ideal according to traditional comfort models, can still be acceptable depending on the individual's characteristics.

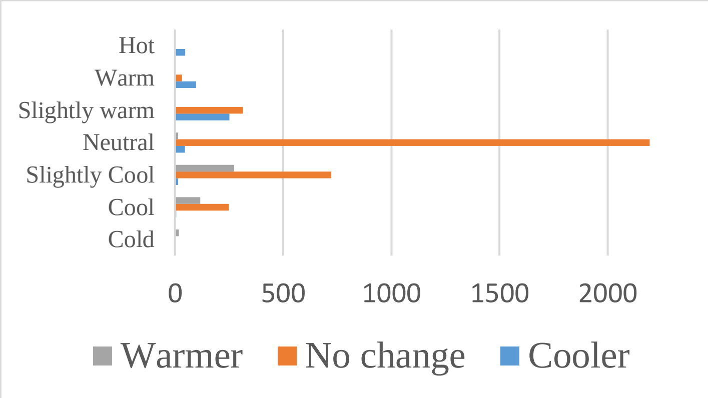

Figure 4 – Cross-tabulation between number of Thermal Sensation Votes and Thermal Preference Votes

5. NEXT STEPS

In order to achieve the objectives of this study, the collection period will continue until the end of September 2019. After that, the raw data will be processed and formatted to enable the model selection step. This selection will depend on factors such as the types of predictions expected from the model (e.g. numerical or categorical, binary or not), the data size available and the intended final application goals. The model evaluation will take place following its development, validating the predictive performance of each model individually.

Finally, the models' application will be studied to enable more adequate design guidelines and thermal conditioning management for older people's built environment, targeting possible health/wellbeing and energy-efficiency related improvements.

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