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Thermal Comfort for Occupants of Nursing Homes: A Field Study

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Abstract

The primary aim of this research was to assess the quality of the thermal environment of six Australian nursing homes, and to understand and quantify the impacts of the indoor thermal environment on the perceptions and comfort of staff, residents and other occupants. The impact of the thermal environment on perceptions and comfort of building occupants of six nursing homes was determined through: 1) a long-term building evaluation survey (staff members only); and 2) a point-in-time thermal comfort study, involving 322 residents and 187 non-residents. In addition, a combination of spot-measurements and long-term monitoring of indoor air temperatures was used to assess the overall quality of the thermal environment in the nursing homes. Results showed that some facilities did not provide a thermally comfortable environment for occupants through both summer and winter seasons, while results from the point-in-time study showed that residents preferred warmer temperatures (0.9°C) and generally wore more clothes than non-residents. The article also presents a discussion of the applicability of adaptive thermal comfort approaches to assessment of the indoor environment in nursing homes and differences between the perceptions/preferences of residents versus staff.

Keywords

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Thermal Comfort for Occupants of Nursing Homes: A Field Study

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Abstract: The primary aim of this research was to assess the quality of the thermal environment of six Australian nursing homes, and to understand and quantify the impacts of the indoor thermal environment on the perceptions and comfort of staff, residents and other occupants. The impact of the thermal environment on perceptions and comfort of building occupants of six nursing homes was determined through: 1) a long-term building evaluation survey (staff members only); and 2) a point-in-time thermal comfort study, involving 322 residents and 187 non-residents. In addition, a combination of spot-measurements and long-term monitoring of indoor air temperatures was used to assess the overall quality of the thermal environment in the nursing homes. Results showed that some facilities did not provide a thermally comfortable environment for occupants through both summer and winter seasons, while results from the point-in-time study showed that residents preferred warmer temperatures (0.9°C) and generally wore more clothes than non-residents. The article also presents a discussion of the applicability of adaptive thermal comfort approaches to assessment of the indoor environment in nursing homes and differences between the perceptions/preferences of residents versus staff.

Keywords: Thermal comfort, nursing homes, aged care facilities, field study, older adults.

1. Introduction

The proportion of older people in the global population is currently at its highest in human history (UN, 2013). The trend towards populations having increasingly higher proportions of older people is widespread across all nations and is certainly the case in Australia (AIHW, 2017a). As a consequence, the need for nursing home care is projected to rise markedly (ACFA, 2016). In 2014-15, in Australia, there were 2,681 residential aged care homes providing 192,370 operational aged care places (ACFA, 2016). Nursing homes (also called residential aged care homes or hostels for the aged) are special-purpose facilities with a domestic-style environment that provide accommodation and 24-hour support to frail and aged residents. Nursing homes in Australia provide care to those who have dementia and are neither hospitals nor psychiatric facilities (AIHW, 2017b).

In Australia, the Australian Aged Care Quality Agency is the supervisory authority which is responsible for ensuring that aged care facilities provide high standards of care to residents (DSS, 2014). However, the current accreditation standards do not set minimum temperature thresholds (for health and thermal comfort) for nursing homes and for spaces occupied by older people (AACQA, 2011). As a result, there is the potential for residents of aged care facilities to be exposed to environmental conditions, which may negatively influence their health (Gupta et al, 2017; OEH, 2014), and affect the behaviours of residents with dementia (Tartarini et al, 2017).

Furthermore, there appears to be a lack of consensus on how the indoor environment is perceived by older adults generally (those aged 65 years or older) and the two main international thermal comfort standards, i.e. ASHRAE 55-2013, ISO 7730:2005, are only

applicable to healthy adults (ASHRAE, 2013; ISO, 2005). Consequently, there is very limited guidance and recommendations available worldwide to help building designers and aged care providers to understand how to properly regulate indoor environmental quality (IEQ) in nursing homes.

Nursing homes represent a hybrid category of buildings, and each facility is generally made up of a mix of residential, offices and commercial spaces. The task of providing a comfortable thermal environment in such buildings is complicated by the fact that they house two distinct groups of occupants, i.e. residents and non-residents, which have different thermal requirements and needs. Residents spend the majority (80% to 90%) of their time indoors (Mendes et al, 2015) and many of them depend on their environment to compensate for the physical and cognitive frailties associated with their conditions (Marquardt and Schmieg, 2009; Wong et al, 2014). On the other hand, caregivers are often involved in physically demanding tasks.

The aim of this field study was to assess the quality of the thermal environment in a sample of Australian nursing homes, and to understand and quantify the impacts of thermal environment on perceptions and comfort of occupants.

2. Case Study Facilities

The research was carried out in six accredited nursing homes. All facilities were located in south-eastern NSW, however, they were situated in areas with a range of diverse climates. The elevation and climatic zone of each nursing home are listed in Table 1, while the key features of each home are presented in Table 2.

Table 1. Climatic zones and elevation above sea level of each nursing home (NH).

		Climatic zone	
Location	Elevation (m)	Australian National Construction Code	Köppen–Geiger
NH 1	9	5	Cfa
NH 2	670	6	Cfb
NH 3	43	5	Cfa
NH 4	643	7	Cfb
NH 5	77	5	Cfa
NH 6	3	5	Cfa

3. Research Method

The field study was divided in three main activities:

- long-term monitoring of indoor air temperatures;
- a long-term building evaluation survey; and
- a point-in-time thermal comfort study.

All the research activities were approved by the University of Wollongong Human Research Ethics Committee (approvals HE14/478 and HE15/235).

3.1. Long-term Monitoring of Indoor Air Temperature

Stand-alone iButton™ sensors/data loggers were used to measure dry-bulb air temperature. The data loggers were cylindrical in shape (17.5 mm in diameter and 6 mm deep) and according to the manufacturer's specification they measured temperature with an accuracy and resolution of ±0.5°C which, therefore, met the accuracy requirements of ISO 7726:1998 standard (ISO, 1998).

Table 2. Key features of the case study facilities. Air Conditioning (AC).

Home	N of beds (dementia section)	Floor area - m^2 / resident	Building features							
			Construction date	External walls	Lighting	Windows	Ceiling	Bedrooms		Common areas
								Heating	Cooling	
NH 1	150 (13)	7040m^2 – 46.9m^2/res	1993; partially renovated in 1997 and 2008	Double-brick no insulation	Incandescent, compact and tubular fluorescent lamps	Single glazed, metallic frame	Partial ceiling insulation	Electric convection and hydronic radiators, split A/C	Few rooms had split A/C	Ducted, split and cassette A/C
NH 2	90 (25)	5410m^2 – 60m^2/res	2007	Double-brick no insulation	Compact and tubular fluorescent lamps	Single glazed, metallic frame	Insulated	Split A/C	Split A/C	Ducted A/C
NH 3	62 (14)	1651m^2 – 26.6m^2/res	1955	Double-brick no insulation	Incandescent, compact and tubular fluorescent lamps	Single glazed, metallic frame	Unknown	Ducted/gas heater	No	Split or cassette A/C
NH 4	160 (25)	6570m^2 – 41.1m^2/res	2008	Double-brick no insulation	Compact and tubular fluorescent lamps	Single glazed, metallic frame	Insulated	Split A/C	Split A/C	Ducted A/C
NH 5	40 (0)	1945m^2 – 48.6m^2/res	1968; in 1985 were added 40 beds	Double-brick no insulation	Incandescent, compact and tubular fluorescent lamps	Single glazed, metallic frame	Unknown	Electric convection radiators and hydronic radiators	No	Split A/C dining room
NH 6	101 (55)	3271m^2 – 32.4m^2/res	1984	Double-brick no insulation	Incandescent, compact and tubular fluorescent lamps	Single glazed, metallic frame	Partial ceiling insulation	Hydronic radiators	No	Split A/C dining room, cassette A/C installed 2/2016

The sensors recorded data at hourly intervals from 1st September 2015 to 11th of January 2017. The sample rate of once per hour was constrained by the limited on-board sensor memory and the need to provide a sufficiently long duration between visits by the researcher to each facility. The specific elevation of each sensor was selected according to the most common type of activity and body position of occupants at a given location (0.6 m when sitting/reclining, 1.1 m standing) as suggested in ISO 7726:1998. Sensors were installed on internal walls next to where occupants spent the majority of their time indoors. They were neither exposed to solar radiation nor to direct radiation/convection from neighbouring heat sources. Temperature data collected when rooms were unoccupied were not included in the analysis, and occupancy profiles for the various indoor areas studied are presented in Table 3.

Table 3. Occupancy profiles assumed for the case study facilities by room type.

Type of room	Occupancy profiles
Bedroom, Toilet and Shower, Corridor, nurses station, Staff Dining Room, Corridor	24 hours
Dining Room, Lounge, Sitting Room	Between 5.00 AM and 11.00 PM
Physiotherapy Room, Therapy Room, Laundry, Office, Treatment Room, Reception	Between 7.00 AM and 6.00 PM
Kitchen	Between 5.00 AM and 8.00 PM
Activities Room	Between 9.00 AM and 6.00 PM

When analysing the temperature dataset the lower and the upper limits of the comfort temperature range were taken to be 20°C and 26°C, respectively. This range was selected following the recommendations provided in Annex A of the ISO 7730:2005. Guidelines from ISO 7730:2005 were used since, at the time of writing, the Australian residential aged care Accreditation Standards did not provide guidelines in regards to a temperature range to be maintained in nursing homes. Furthermore, the World Health Organization suggests that a minimum air temperature of at least 20°C be maintained in indoor environments for people

with special requirements, to avoid the possibility of their body temperature decreasing, potentially leading to hypothermia or other issues (WHO and UNEP, 1990).

For this phase of the research, air velocity and mean radiant temperature were not recorded during the long-term monitoring, since this would have required significant additional financial expenditure. This approach aligns with advice in ASHRAE 55-2013, which states (page 45) that “Measuring indoor air movement in long-term studies is very difficult and rarely done. In many indoor situations the indoor airspeed conforms to the still air conditions of the PMV comfort zone (0.2 m/s [40 fpm]), in which case, air speed measurement is not necessary”.

In addition, the decision was taken not to measure mean radiant temperature since values of mean radiant temperature are used solely to estimate operative temperature, however, operative temperature can only be determined if air velocity values are known.

3.2. Long-term Building Evaluation Survey

Several types of long-term evaluation surveys, also known as post occupancy evaluation surveys, have been previously developed by other researchers to assess the correlation between IEQ factors and occupant satisfaction with the indoor environment (Peretti and Schiavon, 2011). However, the majority of these tools comprise questions that are not relevant in nursing home settings, and limited benchmark data is available regarding performance of nursing homes.

Thus, a bespoke survey was developed by the present authors to assess the IEQ performance of nursing homes. This was implemented as an on-line resource so as to recruit as many responses as possible across the wide geographic locations of the facilities, differing staff working hours, etc. The framework and the great majority of the questions contained in the building survey were developed using the Occupant Indoor Environmental Quality (IEQ) Survey™ developed by the Center for the Built Environment, University of California Berkeley (CBE, 2014) for residential and healthcare buildings and the long-term evaluation survey provided in Appendix K of ASHRAE 55-2013 standard (ASHRAE, 2013).

The questionnaire was sent to all employees working in the six facilities and was used to assess how different facilities/buildings performed during winter 2016 and summer 2015/2016. Data collected on thermal comfort were correlated with the temperature data logged.

The questionnaire comprised more than fifty questions, however, in this article only answers to questions related to thermal comfort are presented. Participants were asked to rate their perception of indoor air temperature over the winter and summer periods (separate questions) using the following scale: -3 ‘cold,’ -2 ‘cool,’ -1 ‘slightly cool,’ 0 ‘neutral,’ +1 ‘slightly warm,’ +2 ‘warm,’ +3 ‘hot.’ Similarly, satisfaction with the thermal environment in summer and winter was assessed by asking participants how satisfied they were with the indoor air temperature using a 7-point scale ranging from ‘very dissatisfied’ to ‘very satisfied.’

3.3. Point-in-time Survey

The target population for this research activity was all occupants of nursing homes (staff members, residents and visitors) since a well-designed nursing home should provide comfortable thermal conditions for all occupants. Residents with dementia were invited to participate in the research only if they were judged to have sufficient cognitive abilities to complete the questionnaire.

The point-in-time survey was administered indoors between 9.00 a.m. and 5.00 p.m. over two separate periods of time at each facility. Data representative of the warm season was collected between November 2015 and February 2016, while data representative of the cold season was collected between March 2016 and July 2016. Each participant completed the questionnaire only once per season. Participants were asked to complete a paper-based copy of the questionnaire after the IEQ-monitoring equipment (IEQ Cart) was brought into the room and placed within a 1-meter radius of the participant for 12 minutes. The delay of nominally 12 minutes was chosen to ensure that all sensors had reached thermal equilibrium with the indoor environment. A detailed description of the IEQ monitoring Cart is provided in Tartarini et al. (2017).

The questionnaire was used to collect both the physical characteristics of participants (e.g. age, height, weight) and to assess their perceptions of the thermal environment using the ASHRAE seven-point thermal sensation scale subdivided as follows: -3 'cold,' -2 'cool,' -1 'slightly cool,' 0 'neutral,' +1 'slightly warm,' +2 'warm,' and +3 'hot' (ASHRAE, 2013).

Clothing insulation and activity levels were assessed through observation by the first author and by asking participants to list the garments that they were wearing. Activity level was selected using the tables provided in ISO 7730:2005 and ASHRAE 55-2013 Standards.

Assessment of Indoor Environmental Parameters

While participants were completing the point-in-time questionnaire, the following environmental parameters were measured and recorded: indoor air temperature T_a (°C), globe temperature T_g (°C), air velocity V_a (m/s), and relative humidity RH (%). The average indoor air temperature ($\overline{T}_a$), average globe temperature ($\overline{T}_g$) and average air velocity ($\overline{V}_a$) for each resident were calculated based on the body position of occupants as specified in ISO 7730:2005 Standard. All sensors were calibrated prior to data collection according to manufacturers' instructions.

Data Analysis

For each participant the following indices were also calculated: total clothing insulation (I_{clo}), operative temperature (T_o), mean radiant temperature (T_{mrt}), metabolic rate (M), Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD). Data analysis was carried out using the IBM SPSS Statistics software (V21, IBM Corporation, Armonk, NY) and MATLAB (R2016b).

Total clothing insulation (I_{clo}) was determined using the methodology and the tables provided in ISO 7730:2005 (ISO, 2005) and ASHRAE 55-2013 (ASHRAE, 2013) standards. However, because these standards cannot be used to determine I_{clo} of people in bed, their I_{clo} was determined by coupling the data collected (i.e. body position, sleepwear, and bedding) with the most similar combination of beds, bedding and sleepwear provided in Lin and Deng (2008).

The mean radiant temperature was calculated using the equations provided in Annex B and Annex G of ISO 7726 standard (ISO, 1998). While the Predicted Mean Vote (PMV) was evaluated using the computer program provided in Appendix B of ASHRAE 55-2013 (ASHRAE, 2013).

4. Results and Discussion

4.1. Long-term Monitoring of the Indoor Air Temperature and Relative Humidity

The outdoor and indoor temperatures from all the sensors installed in the case study facilities are presented in Figure 1. NH 2 and NH 4 were located in climatic zones with relatively cold winters (by Australian standards), the minimum temperature in winter being below 0°C. The

remaining facilities were closer to the coast, hence ambient temperature variations throughout the year were mitigated, to some extent, by their proximity to the ocean.

In NH 2 and 4 all rooms were service by air conditioning systems and the indoor temperature was maintained relatively constant throughout the year. Whereas, in those rooms in the other facilities which were not serviced by air conditioning systems the indoor temperature varied significantly as a function of the outdoor conditions. For example, Figure 1 shows that during summer the median indoor air temperature in NH 5 was significantly higher than the outdoor temperature and exceeded the threshold of 26°C for more than 62% of the time in February. Furthermore, despite the fact that the median outdoor temperature in winter was approximately 15°C, indoor temperatures below 20°C were recorded for approximately 26% of the time in August. Similar indoor temperature profiles also occurred in NH 3 and NH 6. The main causes of such significant temperature variations in the older facilities were thought to be: the relatively poor thermal performance of the building envelope (e.g. wall, windows, floor and ceiling/roof); the absence of air conditioning systems in some areas; and the absence of an adequate air conditioning control system (including the lack of local control of heating to individual rooms).

It was found that occupants actively influenced indoor air temperatures through their control of openable windows. For example, during warmer weather occupants sometimes opened windows to ventilate the building with outdoor air, however, on some occasions this practice led to indoor overheating when outdoor temperatures were high.

Indoor Air Temperature in the Bedrooms

The indoor air temperature data measured in bedrooms is presented in Figure 2. Despite the fact that in all nursing homes the mean maximum temperature in the bedrooms exceeded 26°C, in NH2 and NH4, where all the bedrooms were equipped with direct expansion air conditioners, temperatures above 26°C occurred for less than 4% of the summer period. Whereas, bedrooms of NH 3, NH 5 and NH 6 were not air conditioned and temperatures above 26°C were recorded for a significantly higher fraction of time. For example, in NH 5 indoor air temperatures exceeded 26°C for approximately 49% of the summer period. By contrast, in NH 2 and 4 the indoor temperatures remained almost constant across the two seasons.

Figure 2 also shows that in NH 2, the mean temperature in the bedrooms in winter was 21.6°C and in summer 22°C; suggesting that the set-point temperatures of the Heating, Ventilation, and Air Conditioning (HVAC) units were maintained at a constant, or close to constant, value with minimal variation between seasons. Evidence from previous studies has shown that metabolism and cardiovascular parameters may be positively influenced by exposure to slightly cool and warm environments (van Marken Lichtenbelt et al, 2017). van Marken Lichtenbelt observed that Type 2 diabetes patients, for example, experienced increased insulin sensitivity of more than 40% after ten days of intermittent exposure to mild cold. Hence, allowing air temperatures to vary slightly indoors may have a positive impact on the health of residents of nursing homes.

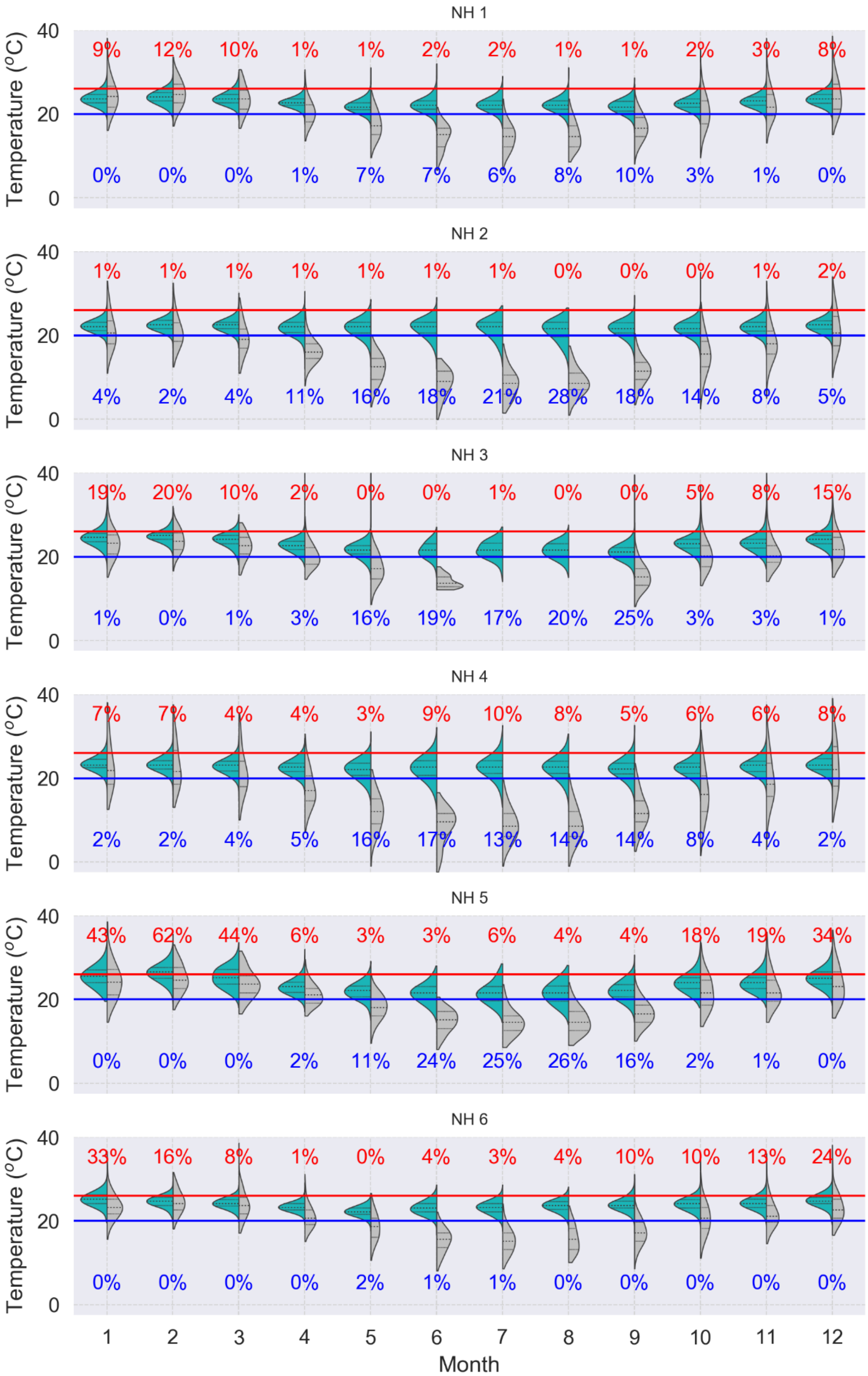

Figure 1. ‘Violin Plot’ of outdoor (grey) and indoor (turquoise) temperatures at the 6 case study facilities and the percentage of time indoor air temperatures were recorded above 26°C (red) and below 20°C (blue). The width of each side of the ‘violin’ is proportional to the number of samples, and the horizontal lines inside each ‘violin’ show the quartiles for each sub set of data.

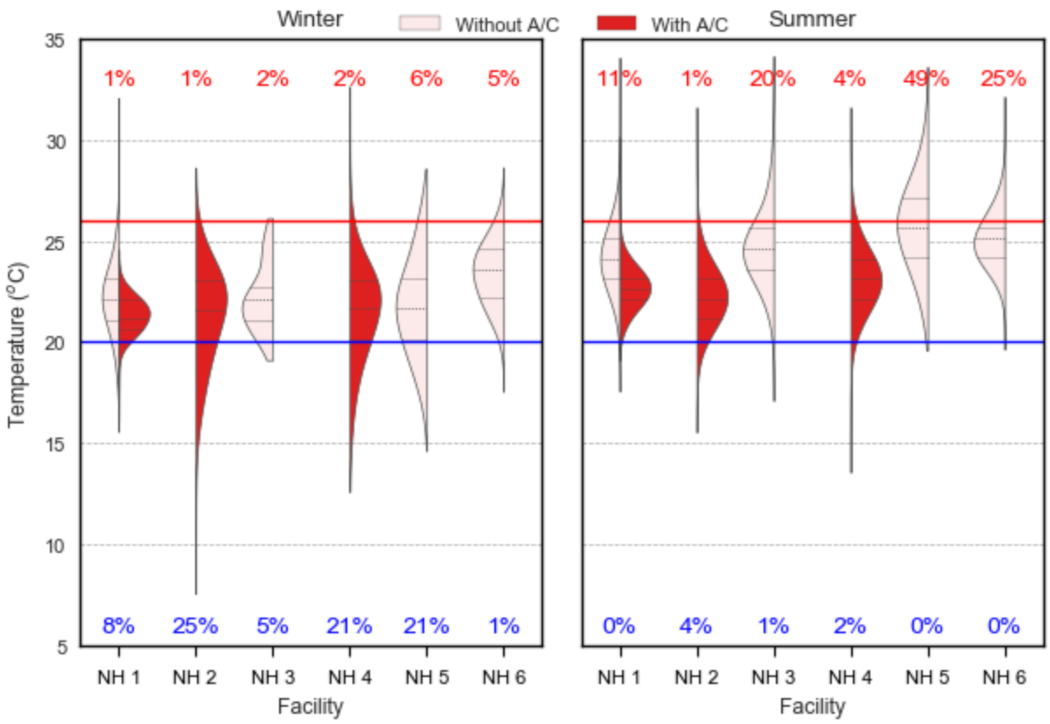

Figure 2. Indoor air temperature data measured in the bedrooms of the six case study facilities in summer (1/12/2015-29/2/2016) and winter (1/06/2016-31/8/2016). The dataset was split between air conditioned bedrooms (light-red) and non-air conditioned bedrooms (red). Also shown are the percentages of time at which indoor air temperatures above 26°C (red) and below 20°C (blue) were recorded.

In NH 5 and NH 6 air temperatures lower than 20°C where observed for more than 20% time during winter. Three factors were thought to be the main causes of such low temperatures: 1) when rooms were unoccupied, cleaners tended to leave the windows open to ventilate the space; 2) occupants preferred temperatures lower than 20°C at night-time; 3) residents did not know how to properly control the heating systems in their rooms. The latter issue could have significant implications for the health of residents. It was observed that in more than one room residents felt cold in the early morning and attempted to warm up their room quickly by turning on the heating and selecting a high set-point temperature. However, it was then observed that around lunch time the rooms were often overheated (e.g. in one bedroom in winter the indoor air temperature was higher than 25°C for approximately 50% of the time) and it appeared that occupants turned off the heating manually, instead of decreasing the set-point temperature of the unit, and consequently the room temperature decreased significantly overnight.

The set-point temperature of hand-held remote controllers installed in the bedrooms, could range from 16°C to 28°C, and residents may have had difficulties in using remotes which had a display with low contrast and buttons which were not clearly marked. Thus, allowing residents, particularly those with dementia, to manually control split air conditioners is unlikely to be the optimal solution when endeavouring to enhance thermal comfort conditions in nursing homes.

Indoor Air Temperature in Dining Rooms

Figure 3 shows the temperature data recorded in the dining rooms, which were all equipped with heating/cooling systems. Air conditioners appeared to have been of sufficient capacity to offset summer thermal loads, as a result there were a relatively small number of hours when temperatures above 26°C occurred.

Mean temperatures were not consistent across the nursing homes during a given season. For example, the median indoor air temperature at NH 2 was 2.1°C lower than at NH 6, which could possibly have been due to differences between the set-points programmed at each facility. Furthermore, in NH 4 (a fully air-conditioned facility) the median indoor air temperature was lower in summer (23.1 °C) than in winter (23.6 °C) due to a low set-point programmed at the facility in summer.

Occupants of NH 4 and NH 2 may have had to compensate for cool indoor air temperatures in summer by wearing extra clothes. Maintaining low air temperatures in summer not only significantly increases the energy consumption of the HVAC units but may also worsen the thermal comfort conditions, especially for those residents who have low metabolic rates.

It was also observed that in several areas of the nursing homes, which were occupied only during office hours and were locked at night-time, the air conditioning system was neither switched off at night-time nor when the rooms were unoccupied.

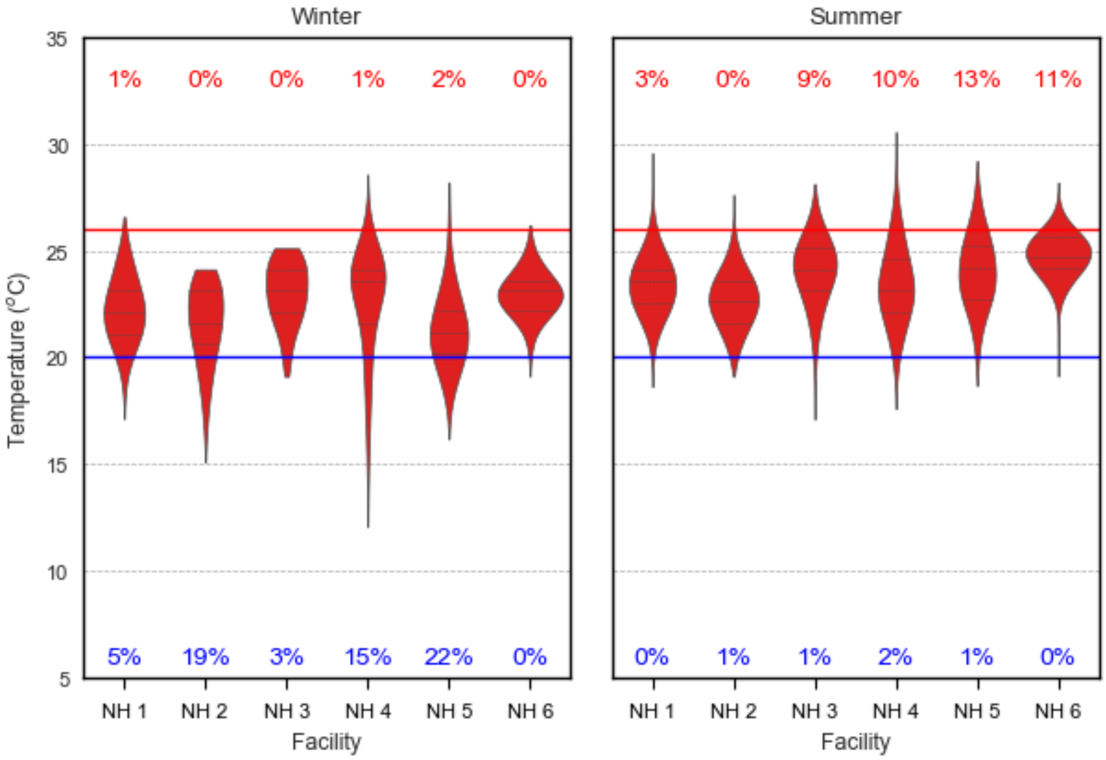

Figure 3. Indoor air temperature data measured in the dining rooms of the six case study facilities in summer (1/12/2015-29/2/2016) and winter (1/06/2016-31/8/2016). All the spaces were air-conditioned.

Comparison with the Adaptive Thermal Comfort Model

The experimental data collected in all the indoor spaces that were not equipped with air conditioning units are plotted versus the prevailing mean outdoor temperature in Figure 4, in order to compare the measured data with the 80% acceptability limits of the Adaptive Thermal Comfort zone as defined by ASHRAE 55-2013. The figure shows that the great majority of the temperature data recorded were within the comfort zone. Also of note was the fact that indoor air temperatures colder than those recommended by the Adaptive Thermal Comfort model were recorded for a higher percentage of time than temperatures above the comfort zone.

It is also important to highlight the fact that the metabolic rates of many residents who were using these spaces were lower than the range specified by the Adaptive Thermal

Comfort model (1.0 – 1.3 met). Therefore, this may even imply that the lower boundary of the Adaptive Thermal Comfort zone could be r to compensate for low metabolic rates of occupants in nursing homes.

Furthermore, some areas of the older facility were serviced by air conditioning systems. Hence, occupants may have spent part of their day in air-conditioned spaces and the remaining part in spaces that did not have mechanical cooling/heating. Figure 5 shows the temperature profiles of three rooms that were located in close proximity to each other in NH 6. Both the dining room and the reception were equipped with mechanical cooling, whilst the bedroom was not. In January 2016, for approximately 26% of the time the temperature difference between the bedroom and the reception was greater than 6°C, consequently occupants were likely to have felt uncomfortable as they moved from one room to another. Staff attempted to mitigate this problem by cross ventilating the spaces using pedestal fans in the corridor.

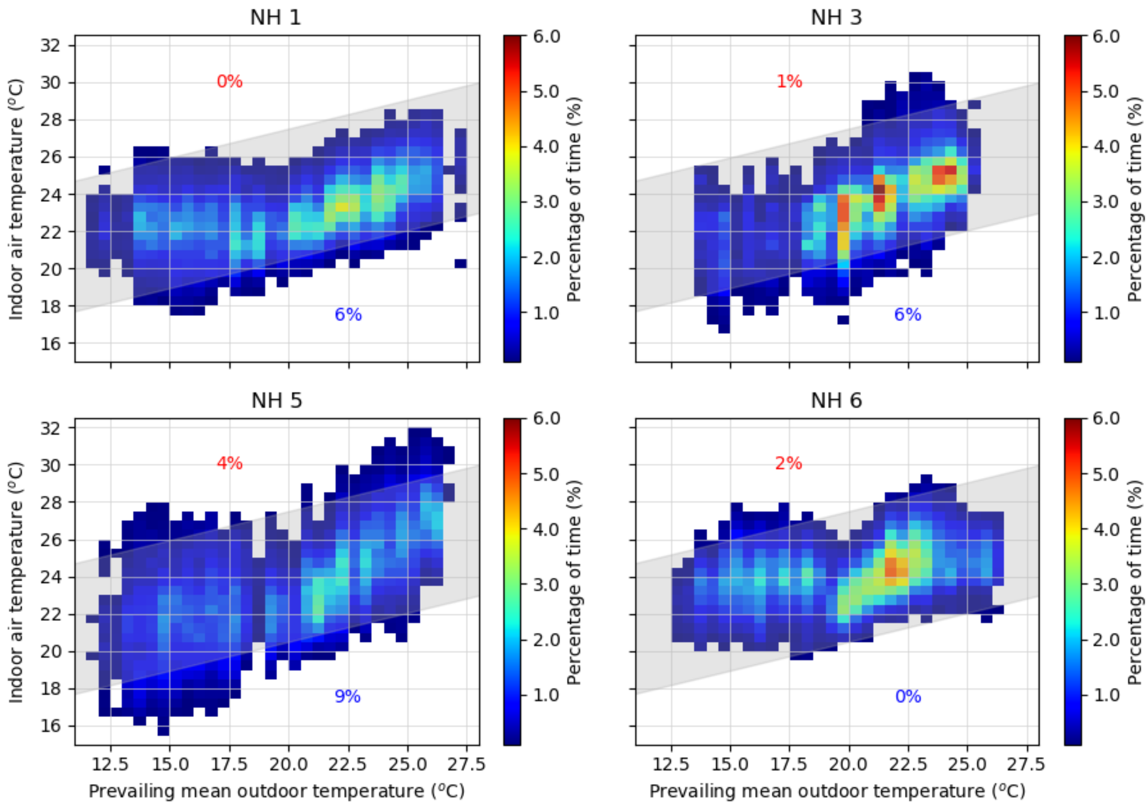

Figure 4. Experimental data collected in spaces that were not mechanically cooled in summer. The figures also show the 80% acceptability limits of the Adaptive Thermal Comfort zone as defined by ASHRAE 55-2013 and the percentage of time temperature above (red) and below (blue) the comfort zone were recorded indoors.

4.2. Long-term Building Evaluation Questionnaire

A total of 85 staff members completed the long-term evaluation survey described in Section 3.2. Participants completed the questionnaire between 29th of September and 27th of October 2016 and they rated the performance of the facility in which they were working over two separate periods: summer (1/12/2015-29/2/2016), and the winter (1/6/2016-31/08/2016).

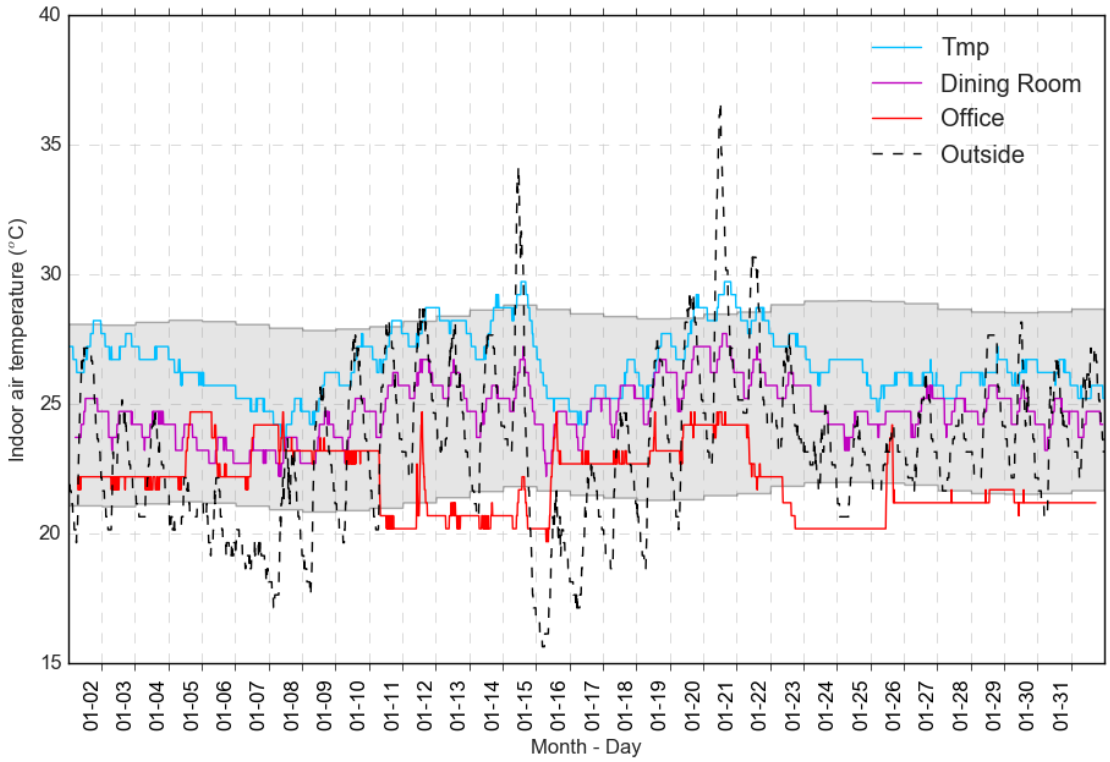

Figure 5. Indoor air temperature data measured in four adjacent spaces of NH 6 between the 10/1/2017 and 2/2/2017. The shaded area shows the comfort zone as defined by the Adaptive Thermal Comfort model.

Table 4 summarizes the characteristics of the staff member sample. The great majority of participants were females (85%), and 52% were aged between 45 and 65 years old. Approximately 42% of the participants were caregivers and 27% were receptionists or administration officers. Participants reported that for approximately 41% of their time they were involved in demanding activities with high metabolic rates (e.g. lifting, walking fast, cooking, etc.), while they spent approximately half of their remaining time doing either activities with low metabolic rates (e.g. a sedentary activity or standing at rest) or medium metabolic rates (e.g. walking slowly or light standing activity). Staff reported that they were spending the majority of their time in rooms with air-conditioning units.

Thermal Comfort

Answers to the question which assessed participants' perceptions of indoor air temperature are presented in Figure 6. Overall newer facilities performed better than older ones; for example, in NH 1 approximately 57% and 56% of the participants rated the temperature to be 'neutral' in summer and winter, respectively. Whereas, more than 40% of the staff working in NH 5 and NH 6 reported the temperature to be either warm or hot in summer and more than 20% of the participants were not satisfied with the indoor environment in winter.

Figure 7 illustrates the fact that staff members who were working at the NH 2 and NH 4 facilities were more satisfied with the indoor air temperature in both seasons, than staff members working in other facilities. This implies that air conditioners effectively reduced the number of hours of uncomfortable indoor temperatures.

Table 4. Characteristics of the study sample.

		NH 1	NH 2	NH 3	NH 4	NH 5	NH 6	Row Total	% Total
N° participants		20	9	9	22	6	19	85	
N° participants/ N° beds		13%	10%	15%	14%	15%	19%		14%
Age	<45	12	5	2	14	2	5	40	47%
	45-65	8	4	6	8	4	14	44	52%
	66-75			1				1	1%
Gender	Female	17	9	8	18	5	15	72	85%
	Male	3		1	4	1	3	12	14%
	Prefer not to say						1	1	1%
Job description	Caregiver	8	1		14	2	9	34	42%
	Administration/Receptionist	6	3	2	4	4	3	22	27%
	Registered nurse	1	2	1	1		3	8	10%
	Recreational activities officer	2		3	1		1	7	9%
	Maintenance officer	2		1	1		2	6	7%
	Physioterapist		1	1				2	2%
	Kitchen staff				1			1	1%
	Laundry staff			1				1	1%
N° hours per week worked	<20	2	2	1	4		4	13	15%
	20-30	9	1	2	3	2	2	19	22%
	30-40	8	5	3	13	2	8	39	46%
	>40	1	1	3	2	2	5	14	16%
Time worked facility	Less than 6 months	1	1		1			3	17%
	6 - 12 months	1	1		6		1	9	4%
	1 - 2 years	4		2	3		2	11	11%
	2 - 5 years	7	3		7	4	5	26	13%
	More than 5 years	7	4	7	5	2	10	35	31%
Percentage working hours	Low metabolic rate	31%	32%	33%	24%	39%	26%		29%
	Medium metabolic rate	22%	34%	47%	27%	21%	35%		30%
	High metabolic rate	46%	34%	19%	49%	40%	39%		41%
Room spend most time	Offices	8	4	2	5	2	1	22	27%
	Residents' bedrooms	4		2	7		3	16	20%
	All	2		1	2		7	12	15%
	Recreation areas	2	1	2	1	1		7	9%
	Bathrooms or showers	2	1		3			6	7%
	Reception		1		1	2	1	5	6%
	Corridors	1	1				3	5	6%
	Sitting Room/Lounge			1	2	1		4	5%
	Dining Room	1					1	2	2%
	Laundry			1				1	1%
	Kitchen				1			1	1%
	Physio room		1					1	1%
Room has heating	No	1					1	2	2%
	Yes	19	9	9	22	6	18	83	98%
Room has cooling	No			2	1		1	4	5%
	Yes	20	9	7	21	6	18	81	95%

4.3. Point-in-time Survey

A total of 509 participants completed the point-in-time questionnaire (322 residents and 187 non-residents); 343 (67% of the total) were females and 157 (31% of the total) were aged 85 years and over. The mean metabolic rate of residents (0.96 met, SD = 0.34) was lower than for non-residents (1.22 met, SD = 0.15) and residents were found to wear significantly more clothing (1.03 clo, SD = 0.60) than their counterpart (0.62 clo, SD = 0.21).

The operative temperature data measured while participants were completing the questionnaire are presented in Figure 8. More than 37% and 60% of residents and non-residents that were exposed to operative temperatures higher than 26°C reported feeling 'warm' or 'hot', respectively.

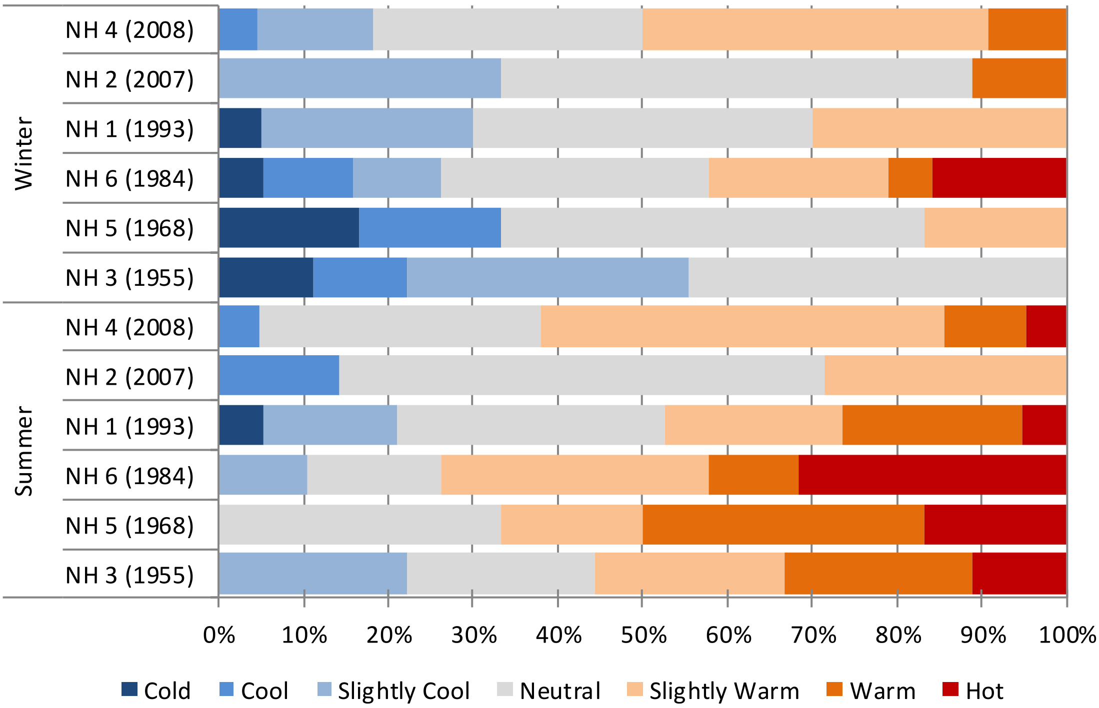

Figure 6. Perception of staff of the indoor thermal environment in summer and winter in the 6 case study facilities. The construction date of each facility is shown in parentheses.

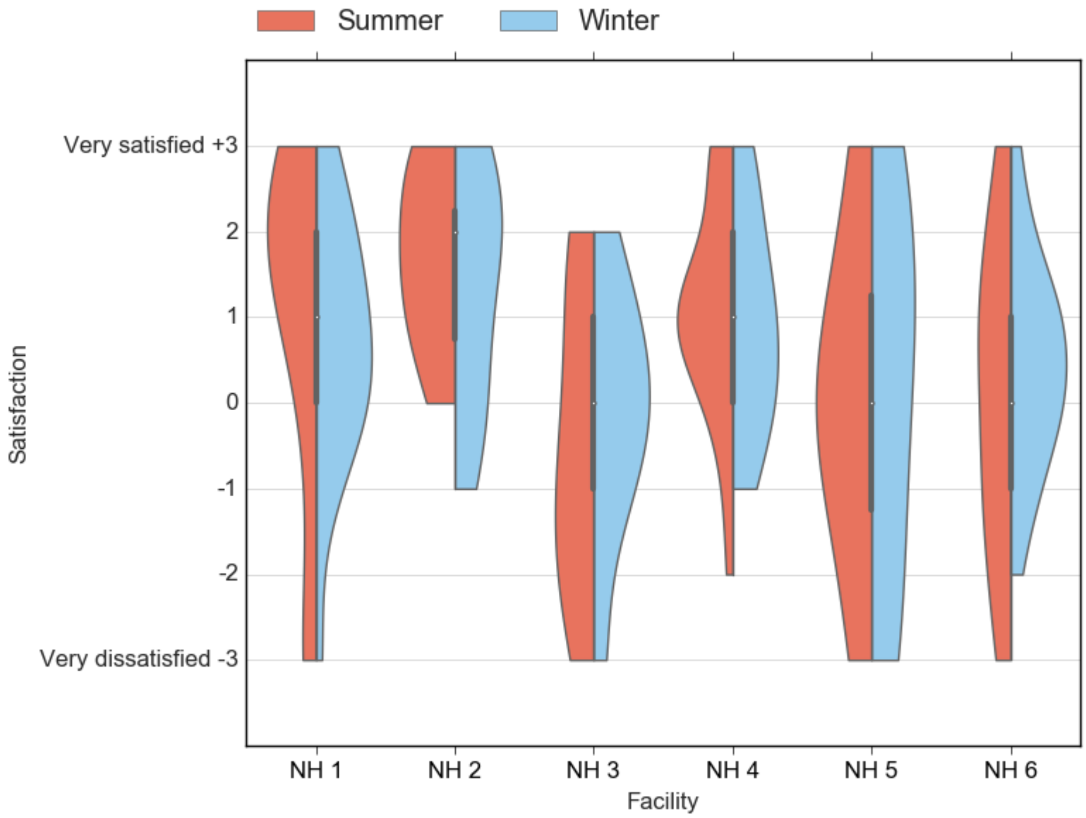

Figure 7. Staff satisfaction with indoor air temperature in summer (red) and winter (blue) as a violin plot.

Among those participants who were wearing light clothes and feeling thermally neutral, the median operative temperature was significantly higher for residents (23.2°C) than for non-residents (22.3°C). In other words, residents felt thermally neutral at higher operative

temperatures than non-residents. Insufficient data was available to compare responses between the two cohorts of participants when total clothing insulation exceeded 0.75 clo. Figure 8 also shows that 24 participants (9 non-residents and 15 residents) were exposed to temperatures higher than 28°C, and 3 were exposed to temperatures lower than 18°C.

Adaptive behaviours – Clothing Adjustment

Clothing insulation varied significantly across both groups of participants, ranging from 0.23 clo (summer dress with short sleeves and undergarments) up to 2.87 clo (in bed with blanket and wearing flannel winter clothes) as shown in Figure 9. Active adjustment of clothing was an effective thermal adaptive behaviour that occupants employed to compensate for changes in operative temperature and metabolic rate.

Residents were found to wear more clothes than non-residents. Staff members also actively modified their clothing as a function of the operative temperature; this was possible since they were not obliged to follow a strict dress code.

Adaptive behaviours – Air Velocity Adjustment

Air velocity adjustment was an adaptive behaviour widely adopted by participants to improve their thermal comfort conditions. To facilitate a better understanding of how they modified the environment around them, their thermal sensation votes are plotted against the measured air velocity and operative temperature in Figure 10.

The figure shows that both residents and non-residents increased the air velocity around them as a function of the indoor operative temperature, e.g. by opening windows to maximise natural ventilation, or using ceiling or portable fans. This assisted a fraction of participants to be comfortable even in warm indoor temperatures (26-28°C).

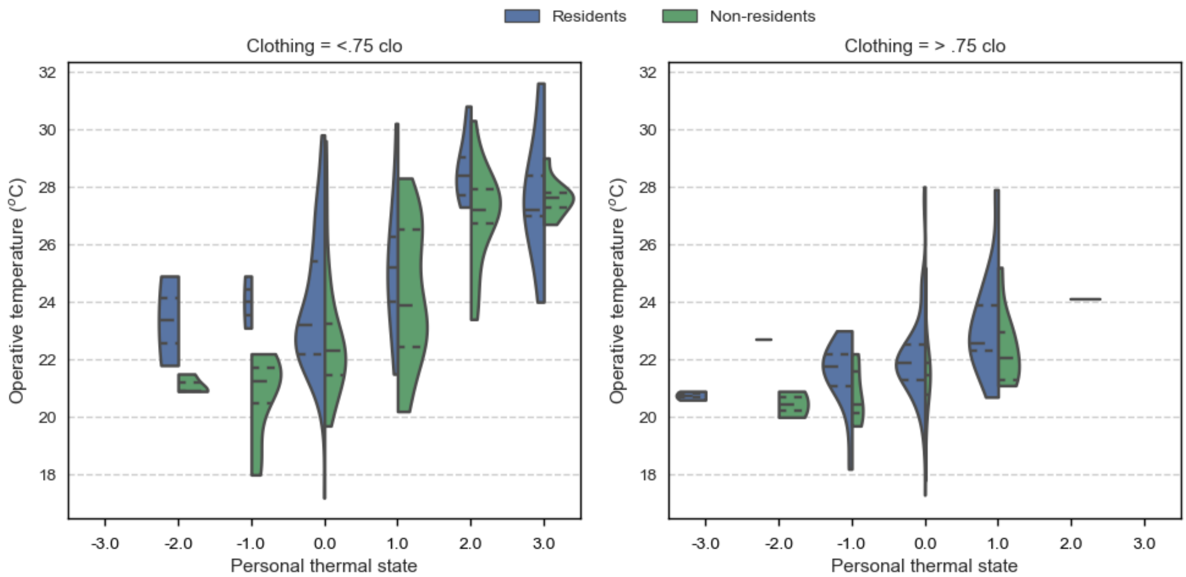

Figure 8. Operative temperature measured during each observation grouped by participant type (residents and non-residents), by personal thermal state vote of participants and total clothing insulation.

Adaptive Thermal Comfort

Thermal sensation votes of 186 participants (130 residents and 56 non-residents) who were not in air-conditioned spaces when they completed the point-in-time questionnaire have been plotted in Figure 11. Approximately 38% of residents and 62% non-residents that were exposed to temperatures higher than 26°C reported feeling thermally uncomfortable (voted 'warm' or 'hot'). Hence, participants in this study preferred significantly lower temperatures than those implied by the upper threshold of the Adaptive Thermal Comfort zone, 80%.

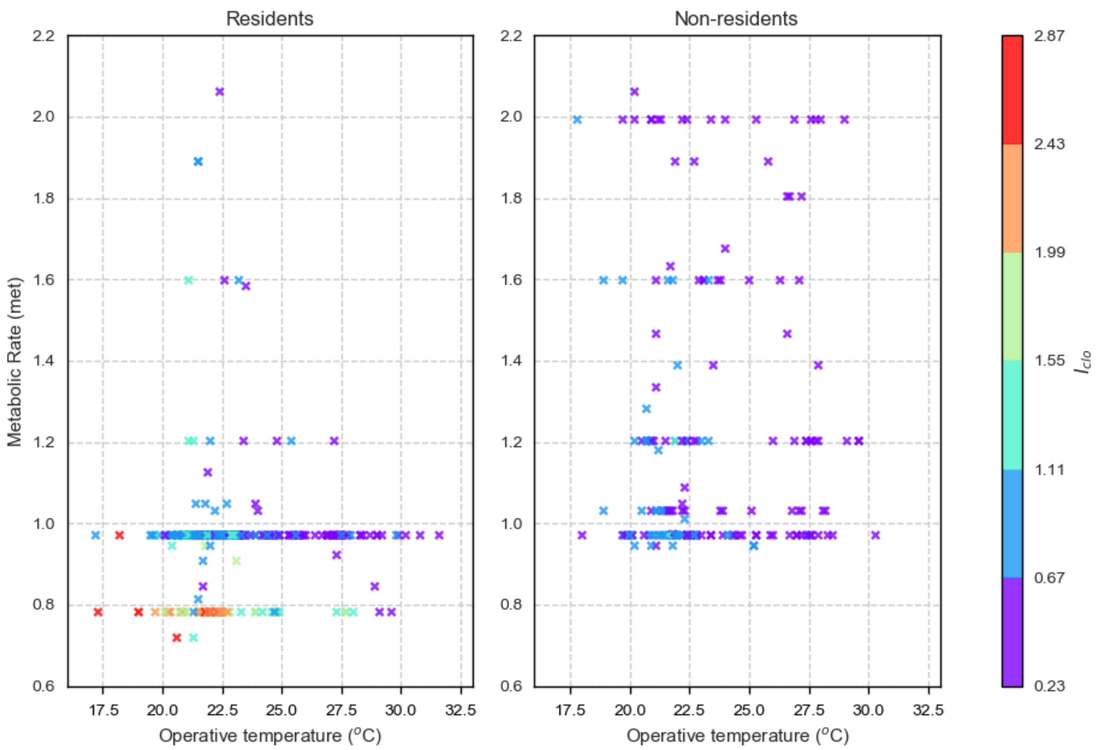

Figure 9. Total clothing insulation plotted in relation to metabolic rate and operative temperature.

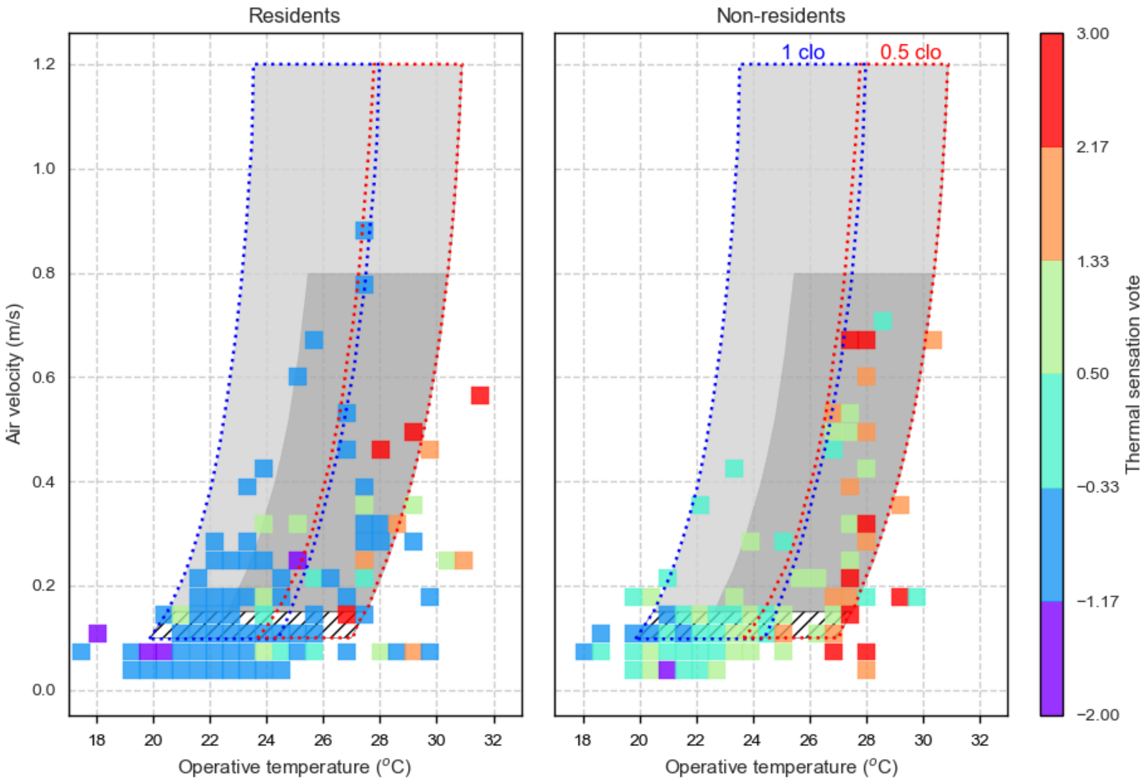

Figure 10. Thermal sensation votes of participants as a function of operative temperature and air velocity. Comfort zones are shown for different clothing insulation as defined by ASHRAE 55-2013. The lightly shaded region indicates acceptable conditions in rooms where occupants do not have control over the local air velocity, the darker region is where occupants do have such control and the hatched region shows the still-air comfort zone.

In addition, results of an ordinal regression data analysis showed that the prevailing mean outdoor temperature was not a statistically significant predictor of the Thermal Sensation Votes of participants ($p > .05$), but the indoor operative temperature was ($p < .05$). In other words, this field study showed that occupant perceptions of their thermal environment was primarily influenced by the indoor thermal conditions with no significant impact from the outdoor environment. This could be explained in part by the fact that often residents of nursing homes spend a very limited portion of their time outdoors.

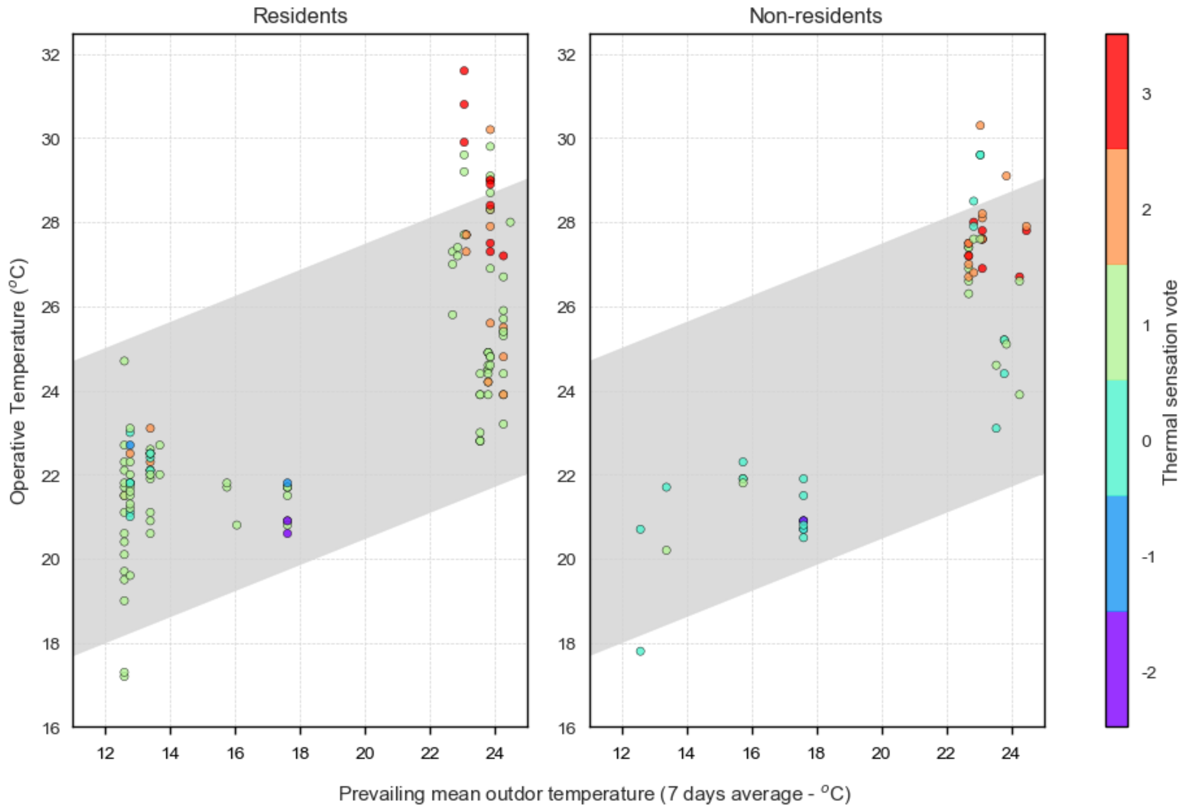

Figure 11. Experimental data displayed on the 80% acceptability limit of the Adaptive Thermal Comfort zone as defined in ASHRAE 55-2013 (ASHRAE, 2013).

5. Discussion

The field data collected showed that occupants of older nursing homes were exposed to significant indoor temperature variations throughout the year. As a result, staff members reported that old facilities were 'hot' in summer and 'cold' in winter. Newer facilities which were fully air conditioned performed better than older ones, however, results showed that air conditioners were not always properly operated. Similar results were obtained by Gupta et al (2017) who investigated magnitude, causes, preparedness and remedies for overheating in nursing homes (Gupta et al, 2017). Gupta found that nursing homes were often overheated in summer, and very few strategies were implemented to mitigated this problem since there was a lack of awareness of the possible impacts that 'hot' temperatures may have on health of residents.

Nursing homes should be designed and operated using strategies that could significantly reduce cooling and heating loads (e.g. insulation, shading, thermal mass, enhance natural ventilation) whilst providing a comfortable environment for both residents and staff members. Furthermore, staff should be trained on how to properly operate air-conditioners and how to provide thermal care to residents. Walker et al (2015) observed that in care homes non-trained staff members, who may not have a clear understanding of how

the HVAC system works, are often required to make adjustments of the heating and cooling system. In the present study, inappropriate operation of air-conditioners exacerbated discomfort in older facilities and this appeared to be the primary cause of high temperature gradients between adjacent zones.

A key finding of the point-in-time survey was that residents preferred warmer temperatures (0.9°C) and wore more clothes on average than non-residents. Similar results were previously obtained by Schellen et al. (2010) and Hwang and Chen (2010) who also observed that older adults preferred warmer temperatures than the adult population. In this study, the great majority of participants effectively adjusted their clothing insulation and modified their surrounding environment (e.g. used electric fans, opened windows) to achieve thermal neutrality with their environment.

Finally our results showed that both residents and non-residents preferred to be exposed to cooler temperatures than those indicated by the upper threshold of the Adaptive Thermal Comfort model. Arguably an Adaptive Thermal Comfort zone that increases linearly without limit as a function of the prevailing mean outdoor temperature may not be appropriate for this cohort of people. Similarly, Gupta et al. (2017) suggested that the use of the adaptive thermal comfort model for assessing the risk of overheating in nursing homes may not be appropriate since residents are less able to adapt to their local environment.

6. Conclusion

The primary aim of this research was to assess the quality of the thermal environment of six Australian nursing homes, and to understand and quantify the impacts of the thermal environment on the perceptions and comfort of occupants.

Our findings add quantitative evidence on how some Australian nursing homes are performing in regards to thermal comfort. Some of the case study facilities failed to provide ideal thermal care to residents since insufficient attention was given to ensuring that residents were not exposed to ‘hot’ and/or ‘cold’ temperatures. The aged care sector should, therefore, increase its awareness on the importance of providing thermal care, to ensure that residents of nursing homes receive high standard of care.

Further research would be beneficial to support the development of best practice guidelines on how to operate heating/cooling systems in facilities that have a fraction of rooms that are air conditioned, with the remainder being naturally ventilated, which is often the case in older nursing homes.

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