Forcada, N. [et al.]. Field study on thermal comfort in nursing homes in heated environments. "Energy and buildings", Agost 2021, vol. 244, 111032. DOI: <10.1016/j.enbuild.2021.111032>.

N.Forcada, M.Gangolells, M.Casals, B.Tejedor, M.Macarulla, K.Gaspar (2021) FIELD STUDY ON THERMAL COMFORT IN NURSING HOMES IN HEATED ENVIRONMENTS**. Energy and Buildings,** Volume 244, **1 <https://doi.org/10.1016/j.enbuild.2021.111032>.**

Final version available at: < https://www.sciencedirect.com/science/article/pii/S0378778821003169>.

Field study on thermal comfort in nursing homes in heated environments

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ABSTRACT

Considering the progressive population aging, the fact that old people spend around 90% of their time indoors and the high energy expenditure of heating systems, thermal comfort in nursing homes should be analysed. The aim of this study is to analyse the thermal comfort during the winter of elderly people living in nursing homes (residents) and compare it with the thermal comfort of caregivers and therapists (non-residents). Longitudinal field measurements were conducted in 25 common rooms of five nursing homes in a Mediterranean climate during the winter, from January to March 2019. Room air temperature (Ta), relative humidity (HR%), mean radiant temperature (Tr) and air velocity (va) were recorded using a Delta Ohm HD32.1 instrument with an anemometer, thermometer and a black globe thermometer. "Right-here-right-now" thermal responses of occupants were collected using a face-to-face questionnaire delivered intermittently. A total of 881 questionnaires were collected and then matched against concurrent indoor and outdoor thermal conditions. The results indicate that residents of nursing homes in the Mediterranean climate were less sensitive to variations in room temperature than therapists and caregivers, and less sensitive than found in previous studies conducted in non-elderly adults. The neutral temperature for residents was 21.6ºC while for caregivers and therapists it was 21.9ºC. The results also showed that clothing adaptation to the activity of caregivers would increase their thermal comfort and might help thermal adaptation to residents' thermal needs. The modification of temperature setpoints in nursing homes based on the results of this

study could influence energy use and should be carefully considered by policy makers and nursing homes' facility managers.

Author keywords:
Thermal comfort, elderly people, nursing homes, thermal acceptance, heated environments

1 INTRODUCTION

Buildings account for about 40% of global energy consumption and contribute to over 30% of CO_2 emissions. A significant proportion of the increase in energy use is due to the spread of heating, ventilation and air conditioning (HVAC) installations in response to the growing demand for better thermal comfort within the built environment. In general, in developed countries, HVAC is the largest energy end-use [1] [2]. In Mediterranean countries of the EU, the main use of energy by the residential sector is for heating (59.6 % of final energy consumption), followed by water heating. A total of 27% of this final energy consumption is provided by natural gas while 20% is provided by oil and petroleum products [3].

Europe has experienced substantial increases in life expectancy and thus in population aging [4].This life expectancy growth has resulted in an increase in the number of nursing homes, and is likely to increase by around 18 percent by 2023 [5]. A nursing home is a place of residence with 24-hour care and assistance offered by professionals to people who can no longer stay in their own home environment due to increasing need for assistance with activities of daily living, complex health care needs and vulnerability [6]. In these buildings, several types of occupants (residents, and caregivers and therapists [non-residents]) share the same indoor environment [7]. Indoor thermal environments significantly influence human health and comfort, especially for older people who spend 90% of their time indoors [8][9]. However, nursing home occupants may have different thermal perceptions due to variations in their level of activity and clothing insulation and due to age. Existing studies have confirmed that the thermal sensation of elderly people is different from that of younger adults. For example, Natsume et al. [10] and Xiong et al. [11] found that elderly people have lower thermal sensitivity, and Schellen et al. [12] and Mendes et al. [13] suggested that elderly people prefer higher temperatures to non-elderly adults. The difficulty in regulating body temperature with age [14] and the decrease in metabolic rate may affect the perception of thermal comfort. However, a well-designed facility should be able to meet the thermal comfort requirements of all occupants [15]. Therefore, thermal comfort should be considered an important issue in nursing home design and HVAC operation.

Although there has been extensive modelling and standardisation of thermal comfort, existing standards (ISO 7730 [16], ASHRAE Standard 55:2017 [17] and EN16798:2019 [18]) focus mainly on non-elderly adults.

To date, only a very few studies have analysed thermal comfort in nursing home environments [7] and thus no clear design and maintenance guidelines exist.

Cena et al. [19] and Becker and Paciuks [20] conducted a field survey in 101 healthy elderly people in Canada and 494 in Israel, respectively. Both found no statistically significant age-related difference in functional dependence of thermal sensation on operative temperature. Peng's field study of 600 home residents in Nanjing China [21] and Indraganti and Raos' field study of 113 home residents in India [22] also found no significant impact of age on thermal comfort.

However, Wu et al. [23] and Jiao et al. [24] compared the thermal comfort of elderly people with existing comfort models during the summer in six nursing homes in Chongqing and 17 nursing homes in Shanghai, respectively. They revealed that elderly people have low thermal sensitivity and a lower thermal sensation that the predicted mean vote (PMV) model [25] used in many standards. The same conclusions were obtained by Hughes et al. [26] who studied the thermal conditions of elderly people in the United Kingdom in their homes in winter. They concluded that current thermal comfort models are potentially unsuitable for predicting comfort in an elderly population and may significantly over-prescribe comfortable temperatures.
Tartarini et al. [27] and Wong et al. [28] stated that elderly people were more tolerant than non-elderly adults and preferred higher temperatures than adults in the analysed 5 nursing homes in Australia and 19 nursing homes in Hong Kong. In their field study of 26 nursing homes in South Korea, Yang et al. [29] also found that the comfort range of the elderly was wider than might be expected by PMV.
Fan et al. [30] compared the indoor thermal comfort of elderly people in rural and urban homes in Beijing, China. They found that rural elderly people who live in a cooler environment and experience a greater temperature difference between indoors and outdoors consider the indoor temperature acceptable. The reason could be that elderly people in rural areas wear thicker clothes indoors in winter. Neutral temperatures for elderly people living in rural areas were also found to be lower than for those living in urban areas.
Hwang and Chen [10] studied the thermal sensation of 87 old people in their homes in Taiwan and indicated that clothing adaptation was the predominant strategy for thermal adaptation in winter, while in the summer it was window opening.
Regarding the Mediterranean climate region, Giamalaki and Kolokotsa [31] investigated the thermal sensation of 30 elderly people in their homes in Crete and indicated a preference among the elderly for warmer thermal conditions in winter, instead of cooler in summer.

Forcada et al. [32] also investigated the thermal sensation of occupants of nursing homes in the Mediterranean climate during the summer and found that residents prefer higher temperatures than caregivers and therapists.
In general, field studies in buildings occupied by elderly people during the summer revealed that elderly people prefer higher temperatures than non-elderly adults [13]. The acceptance of higher indoor temperatures during the cooling period leads to less prevalence of cooling systems and thus a reduction in electricity consumption for air conditioning systems [48] [33]. However, during the winter, it is widely assumed that the energy consumption for heating nursing homes is higher due to the higher required indoor temperature and the longer heating periods [34]. Nevertheless, limited studies and insufficient evidence to support this assumption suggest a need for future research.
This article reports on a study to analyse **thermal perceptions and preferences of occupants in nursing homes in heated environments in the Mediterranean region**. The objectives of the study were to: i) characterise the thermal performance of elderly people in nursing homes in winter; ii) determine thermal comfort perceptions and preferences of elderly (residents) and compare them with non-elderly adults (caregivers

and therapists); and iii) establish the most appropriate temperature ranges for residents in nursing homes in winter.
The results of this study will allow new strategies of energy efficiency and energy saving to be adopted to consistently comply with the requirements of sustainable development, to design comfortable nursing spaces, and to improve health and wellbeing.

2 METHOD

To analyse the thermal comfort of nursing home occupants during the heating period in the Mediterranean climate, longitudinal field measurements were conducted in 25 common rooms of five nursing homes in the Mediterranean climate during the winter, from January to March 2019.
This study respects the fundamental principles established in the Declaration of Helsinki and was approved by the ethics committee of the Universitat Politècnica de Catalunya (UPC). An informed consent form was signed by all participants during the experimental campaign. The reference number of the ethics application is A-01269.

2.1. Climate description

All selected nursing homes were in the Mediterranean climate, which is characterised by dry summers and mild, wet winters under the Köppen climate classification [35]. Within this climate, temperatures range from 4ºC to 15ºC in winter, while the average humidity is very constant (between 64% and 70%) [36].

2.2. Nursing homes' information

Data were collected in five nursing homes in the Mediterranean climate in Spain during the heating period. Two nursing homes were in Barcelona (Nursing Home 1, Nursing Home 2), one in Tarragona (Nursing Home 3) and two in Valencia (Nursing Home 4 and Nursing Home 5). These nursing homes were selected because they are all in the Mediterranean climate, have the same HVAC system (an air-water system with fan-coils), and have similar resident capacity.
Nursing Home 1 has a capacity of 124 residents and 7 floors. The ground floor includes the offices, the gym, the examination room, the hairdresser and the reception. The rest of the floors have a dining room, living room and residents' rooms. The HVAC system is a two-pipe all-water system including two condensing boilers for radiators in the residents' rooms, common room fan coils, heated water and one chiller. For ventilation, two air recovery systems are installed in the roof.
Nursing Home 2 has a capacity of 145 residents and consists of 5 floors. The ground floor includes the common areas (two living rooms, the dining room, offices and reception). The first floor includes the services (hairdresser, examination room, etc.), the gym and the occupational therapy room. The rest of the floors includes rooms and living rooms. The HVAC system is a two-pipe all-water system including two boilers and two chillers and different fan coils for the common rooms and the residents' rooms. For ventilation, seven air recovery systems are installed in the roof.
Nursing Home 3 has a capacity of 180 residents and consists of an underground floor and 10 floors. The underground floor includes the common areas (gym, living room and occupational therapy room). The ground floor includes the offices and reception. The

rest of the floors include a dining room, a living room and residents' rooms. The HVAC system is a multi-split system with several air recovery systems installed in the roof.
Nursing Home 4 has a capacity of 115 residents. It consists of an underground floor for the kitchen and laundry; a ground floor for occupational therapy, a hairdresser, gym, examination room and offices and three floors for the residents' rooms. The HVAC system is a two-pipe air water system with two condensing boilers, one air handling unit and several fan coils for the common rooms. Residents' rooms are heated by radiators.
Nursing Home 5 has a capacity of 150 residents and 5 floors. The ground floor includes the common areas (three living rooms, the dining room and the gym). The rest of the floors contain the residents' rooms. The HVAC system is a two-pipe all-water system including a boiler, a heating pump and different fan coils for the common rooms and the residents' rooms.

2.3. Field measurement of environmental conditions

A portable Delta Ohm HD32.2 instrument with an anemometer, thermometer and a black globe thermometer was used to measure indoor environmental parameters (air temperature [Ta], relative humidity [HR%], mean radiant temperature [Tr] and air velocity [va]).
The mean radiant temperature (Tr) was estimated using a black-globe thermometer which measures the globe temperature (Tg).
According to ISO7726 standard [37], the radiant temperature is calculated as:

$$T_r = (T_g+273)^4+2.5\cdot 10^8\cdot v_a^{0.6}\cdot(T_g-T_a)^{1/4}-273 \quad (1)$$

Table 1 shows the characteristics of the portable Delta Ohm HD32.1 instrument.

Table 1. Characteristics of the instruments

Parameter	Type of probe	Precision	Tolerance
Globe thermometer temperature (ºC)	TP3276.2 probe	±0.2°C	-10ºC to 100ºC
Air speed (m/s)	AP3203.2 probe	±0.05 m/s	0 m/s to 5 m/s
Indoor temperature (ºC)	HP3201.2 probe	<±0.5ºC	-30ºC to 60ºC
Indoor relative humidity (%)	HP3217.2 probe	±3 HR	20% to 80%

The instrument was placed in the centre of the room, far from local sources of heat. It was put 1.5 m above the ground in accordance with ASHRAE 55 [38]. In each case, after 10 minutes of stabilisation, measurements were recorded continuously for 40 minutes. Field measurements of environmental conditions were collected in the daytime when residents were in the common areas.
Outdoor environmental data during the measurements were collected from the closest Spanish meteorological data stations [27]. The data included outdoor air temperature (Tout) and outdoor air humidity (RHout).
The running mean temperature for each measurement day was calculated based on the following expression [39].

$$Trm = (Ted\text{-}1 + 0.8Ted–2 + 0.6Ted–3 + 0.5Ted\text{-}4)/2.9 \quad (2)$$

where Ted-1 is the daily mean external temperature for the previous day and Ted-2 is the daily mean external temperature for the day before that, and so on.
The operative temperature (Top), which is the combined effects of the mean radiant temperature (Tr) and the air temperature (Ta), was also calculated.

$$Top = (Ta + Tr) / 2 \quad (3)$$

During the measurements, the mean indoor conditions were Ta=23.4ºC, Tg=23.3ºC, HR= 47.2% and va= 0.22 m/s. The outdoor temperature ranged from 9.4ºC to 18.2ºC with a mean of 13.1ºC following the typical Mediterranean climate environmental conditions. Table 2 summarises the indoor and outdoor conditions during the field measurements.

Table 2. Indoor and outdoor environmental conditions

	Min	**Max**	**Mean**	**Deviation**
T_g (ºC)	19.23	27.10	23.3	1.31
T_a (ºC)	19.60	26.61	23.4	1.23
RH (%)	33.92	58.11	47.2	6.51
V_a (m/s)	0.00	0.39	0.22	0.04
T_r (ºC)	19.00	27.43	23.28	1.35
T_{op} (ºC)	19.31	26.83	23.35	1.28
T_{out} (ºC)	9.4	18.2	13.1	2.09
RH_{out} (%)	34.0	77.0	63.1	12.19

2.4. Thermal comfort survey

At the same time as the indoor and outdoor environmental conditions were measured, a customised right-here-right-now survey was used to collect subjective comfort evaluations from building occupants during the three-month period of monitoring the common areas (living room, dining room, gym and occupational therapy room) of the selected nursing homes.
All surveys were conducted in the daytime when residents were in the common areas. Caregivers helped to collect the residents' comfort evaluation. The questionnaire was designed to take less than two minutes to complete, and consisted of simple questions. The survey included a thermal sensation vote (TSV), which was assessed using the ASHRAE seven-point thermal sensation scale (−3 cold, −2 cool, −1 slightly cool, 0 neutral, +1 slightly warm, +2 warm, +3 hot) [38]. The TSV was assessed by asking participants: "How do you feel at this precise moment? A figure-based survey was given to residents to facilitate their understanding of the thermal scales (Figure 2).

COLD	COOL	SLIGHTLY COOL	NEUTRAL	SLIGHTLY WARM	WARM	HOT

Figure 1. Figure-based evaluation of thermal sensation [40]

The thermal preference (TP) of each participant was assessed using the following question: "At this precise moment, would you prefer to be … ? " and a three-point scale (−1 cooler, 0 no change, +1 warmer [41].
The thermal acceptability (TA) of each participant was assessed using the following question: "At this precise moment, is the environment thermally acceptable?" and a two-point scale (1 acceptable, 0 unacceptable).
Total clothing insulation (IC***lo***) and metabolic rate (M) were assessed by observing the participant and using the tables in ISO 7730 [42] and ASHRAE 55 [38]. Total clothing insulation of the ensemble worn by each participant was determined using the same method as Forcada et al. [32].
The sex, age, height and weight were also collected from the nursing homes' databases.

2.5 Characteristics of the participants

During the data collection period, 881 surveys were gathered: 77% were residents and 23% non-residents. Approximately the same proportion of surveys were collected in each nursing home. Table 3 presents the number of participants in different rooms.

Table 3. Number of participants by nursing home and building area

Room	**Total**
Living room	330
Occupational therapy room	240
Gym	162
Dining room	149
Total	881

The participants were **737 residents** (559 women and 178 men) and **157 non-residents** (127 women and 30 men).

Residents were between 65 and 99 years old and thus considered elderly. The average age was 87 years, the average height 1.52 m and the average weight 66.3 kg (see Table 4).

Table 4. Residents' characteristics

	Minimum	Maximum	Mean
Age (years)	65	99	87
Height (m)	1.42	1.78	1.52
Weight (kg)	39.0	135.2	66.3

Since 5% of the population over 65 and 20% of the population over 85 suffers from dementia [43] and this might bias the results [44], caregivers helped select residents with good cognitive function for inclusion in the survey. Only those residents with good cognitive function were included in the study.
All non-residents were therapists and caregivers between 20 years and 65 years old and therefore were considered non-elderly adults.

2.6. Data analysis

A chi-square (x2) test was used to determine the dependence between gender (male-female), type of occupant (resident/non-resident), rooms (living room, dining room, gym and occupational therapy room) and TSV, thermal preference (TP) and thermal acceptability (TA). This test can be used to compare observed and expected frequencies. For a chi-square test, the null hypothesis is that the two sets of frequencies (i.e., observed and expected) are equal. The alternative hypothesis is that they are unequal. To identify variables with significant correlations at the 95% confidence interval, the asymptotic significance should be less than 0.05.

Spearman's correlation analysis was used to evaluate the correlation between occupants' TSV, TP, TA and other quantitative variables (age, I_{Clo}, M, etc.). Spearman's correlation analysis is the measure of sample correlation when one of the variables is ordinal. In this case, the TSV, TP and TA are ranked in an ordinal scale. The sample correlation coefficient, denoted "r", ranges between -1 and +1 and quantifies the direction and strength of the association between the two variables.
A linear regression was used to determine the relation between thermal sensation votes (TSV) and T_{op} [37] in the population groups (residents and non-residents). From this regression the "neutral temperature", that is, the temperature at which participants reported their thermal perception of feeling "neutral" [25], was calculated.
Statistical data analysis was carried out using IBM SPSS26 statistics software.

3. RESULTS

3.1. Thermal sensation votes by type of occupant

Most of the residents (77.6%) reported a neutral thermal sensation during the interviews. In contrast, under the same conditions, only 42.2% of non-residents stated that they had a neutral thermal sensation while 46.5% said they had a hot sensation (+1, +2 and +3) (Table 5 and Figure 2).

Table 5. TSV for residents and non-residents

		TSV							Total
		-3	**-2**	**-1**	**0**	**1**	**2**	**3**	
Non-resident	**N**	0	3	15	66	52	19	2	157
	%	0	1.9	9.6	42.0	**33.1**	**12.1**	1.3	100
Resident	**N**	2	5	39	533	96	40	9	724
	%	0.3	0.7	5.4	**73.6**	13.3	5.5	1.2	100
Total	**N**	2	8	54	599	148	59	11	881
	%	0.2	0.9	6.1	68.0	16.8	6.7	1.2	100

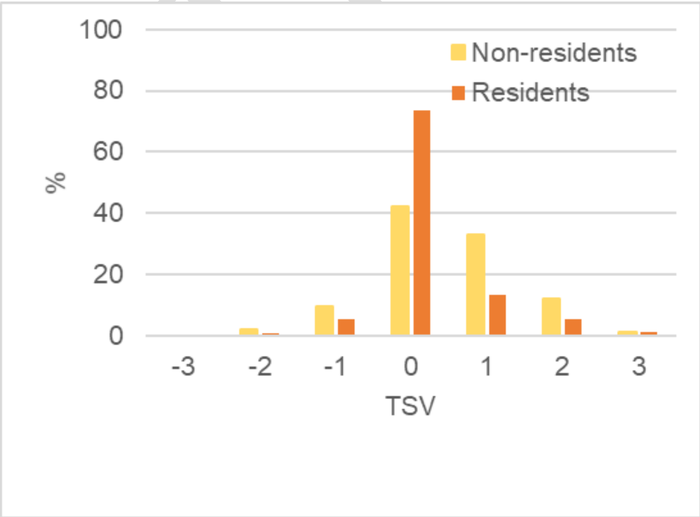

Figure 2. Distribution of TSV percentages by type of occupant

The Chi-square test was performed to examine the independence of the distribution of thermal sensation for each group (residents and non-residents). The result showed that the thermal sensation of residents (elderly people) and non-residents (non-elderly adults) was statistically different (sig < 0.05) (Table 6). The residents tended to be colder (Figure 3).

Table 6. Chi square test between the TSV and the type of occupant

	Value	df	Asymptotic significance (2-sided)
Pearson Chi-square	63.762[a]	6	0.000
Likelihood ratio	59.331	6	0.000
Linear-by-linear association	881		
N of valid cases	63.762[a]	6	0.000

a. Four cells (28.6%) have an expected count of less than 5.

The thermal sensation of residents was also analysed by gender. Although more males stated that they had a neutral thermal sensation (66%) than females (44.5%) (Table 7), the results of the Chi-square test showed that the thermal sensation of males and females was statistically the same (sig > 0.05) (Table 8).

Table 7. TSV for residents by gender

		TSV							Total
		-3	**-2**	**-1**	**0**	**1**	**2**	**3**	
Men	**N**	1	2	5	137	23	9	1	178
	%	0.6	1.2	3.0	75.2	13.9	5.5	0.6	100
Women	**N**	1	3	30	425	67	27	6	559
	%	0.2	0.6	6.1	72.9	13.6	5.5	1.2	100

Table 8. Chi square test between TSV and gender

	Value	df	Asymptotic significance (2-sided)
Pearson Chi-square	13.177[a]	12	0.356
Likelihood ratio	14.964	12	0.243
Linear-by-linear association	881		
No. of valid cases	13.177[a]	12	0.356

b. Six cells (50.0%) have an expected count of less than 5.

An analysis of clothing insulation and level of activity of residents by gender showed that although they had the same thermal sensation, females wore less clothes than males (females I_{Clo}=0.87, males I_{Clo} =0.96) (Table 9).

Table 9. Residents' TSV, I_{Clo} and M by gender

	Male				Female			
	Min.	**Max.**	**Mean**	**Deviation**	**Min.**	**Max.**	**Mean**	**Deviation**
TSV	-3	3	0.20	0.72	-3	3	0.20	0.73
I_{Clo}	0.44	1.62	0.96	0.18	0.46	2.39	0.87	0.21
M	1.0	1.4	1.14	0.02	1.00	1.40	1.15	0.15

Table 10. TSV in the different areas of the nursing homes

Non-residents		**TSV**						
		-3	**-2**	**-1**	**0**	**1**	**2**	**3**
Dining room	**N**	0	1	2	8	12	4	0
	%	0.0	3.5	10.7	28.6	**42.9**	**14.3**	
Gym	**N**	0	2	2	16	11	3	0
	%	0.0	5.8	5.9	**47.1**	**32.4**	8.8	0.0
Living room	**N**	2	0	2	24	16	7	4
	%	0.6	0.0	4.0	**48.0**	**32.0**	**14.0**	**1.4**
Occupational therapy room	**N**	8	0	8	18	13	5	1
	%	17.8	0.0	17.8	**40.0**	**28.9**	11.1	2.2
Total	**N**	3	15	66	52	19	2	3
	%	1,9%	9.6	42.0	33.1	12.1	1.3	1.9
Residents								
Dining room	**N**	2	5	19	50	13	9	0
	%	1.7	5.2	19.8	**52.1**	13.5	9.4	0
Gym	**N**	0	1	7	95	20	3	2
	%	0.0	0.8	5.5	**74.2**	15.6	2.3	1,6
Living room	**N**	1	1	13	213	33	15	4
	%	0.4	0.3	4.0	**76.1**	11.8	5.4	1.4
Occupational therapy room	**N**	0	1	9	139	32	14	0
	%	0.0	0.5	4.6	**71.3**	16.4	7.2	0
Total	**N**	2	5	39	533	96	40	9
	%	0.3	0.7	5.4	**73.6**	13.3	5.5	1.2

The Rho Spearman correlation analysis showed that neither the Body Mass Index (BMS=weight /height) of the residents (r=0.01, $p < 0.01$) nor the age (r=0.02, $p < 0.01$) were correlated with the TSV.

Some differences were found in the thermal sensation between residents and non-residents depending on the area of the nursing home.

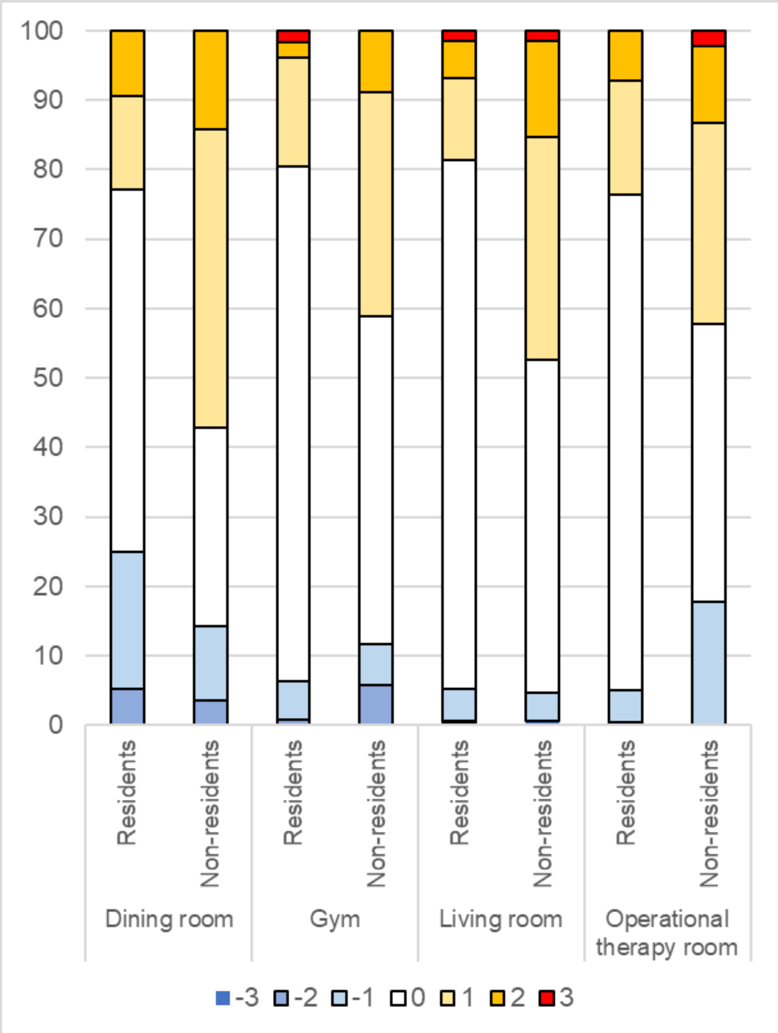

Figure 3. Distribution of TSV percentages for residents and non-residents in different areas of the nursing homes

For example, in the dining room, residents tended to be comfortable (52.1% affirmed that they had a neutral thermal sensation), while non-residents tended to be hot (60% declared they felt between slightly warm and hot) (Table 10 and Figure 3).

In the gym, 66.3% of residents reported having a neutral temperature, while only 20.8% of non-residents reported this.

The occupational therapy area is the room where residents and non-residents had more disparate comfort perceptions. A total of 35.6% of non-residents and only 5.1% of residents claimed they were cold (-3, -2 and -1).

3.2. Thermal sensitivity, neutral temperature and thermal comfort zone

Thermal sensitivity and neutral temperature can be obtained from the linear regression of the thermal sensation votes (TSV) against T_{op} [37]. The following equations express the best fitted TSV for residents and non-residents:

For residents: $TSV=0.115*T_{op}-2.484$ (4)

For non-residents: $TSV=0.335*T_{op}-7.331$ (5)

Figure 4 shows the linear regression of the TSV plotted against the indoor operative temperature (T_{op}) for residents and non-residents.

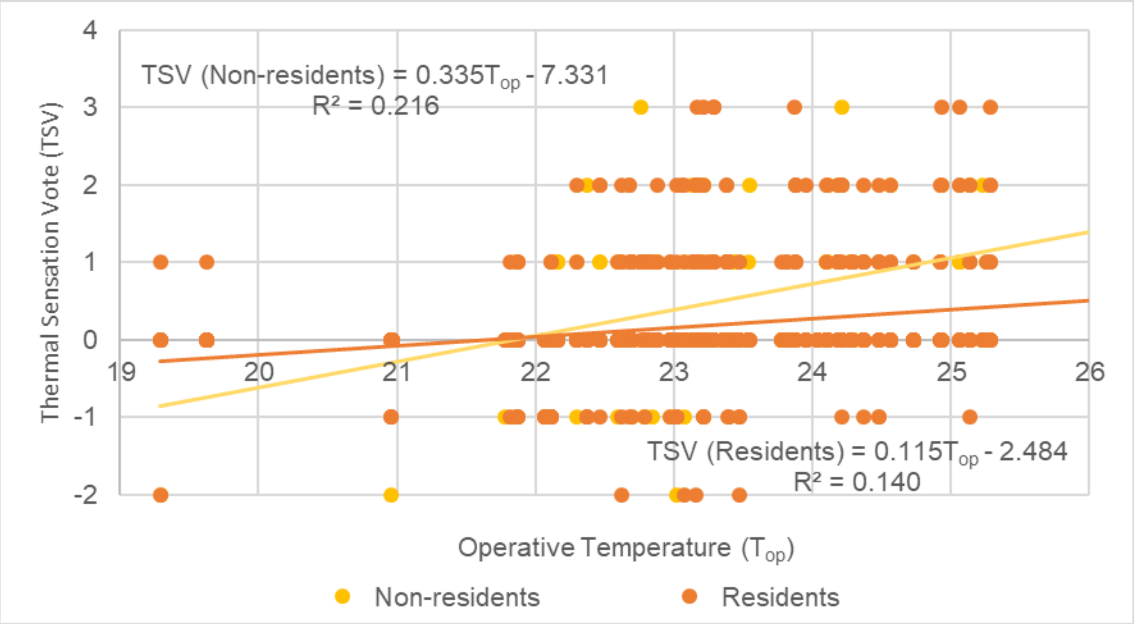

Figure 4. Thermal sensation vote against T_{op}.

From the regression analysis, the neutral temperature was found to be 21.6°C for residents and 21.9ºC for non-residents.

Table 11 and Figures 5 and 6 and show the percentage of acceptability and preference of residents and non-residents against the TSV.

Table 11. Percentage of TA and TP against TSV

	Residents				Non-residents			
	TP			TA	TP			TA
TSV	Cooler	No change	Warmer		Cooler	No change	Warmer	
-3	-	-	100	50	-	-	-	-
-2	-	20	80	4	-	-	100	67
-1	-	51	49	82	-	40	60	87

	Residents				Non-residents			
	TP			TA	TP			TA
TSV	Cooler	No change	Warmer		Cooler	No change	Warmer	
0	3	95	2	91	-	98	2	86
1	43	54	3	83	87	13	-	83
2	70	27	2	65	100	-	-	74
3	67	33	-	-	50	50	-	-

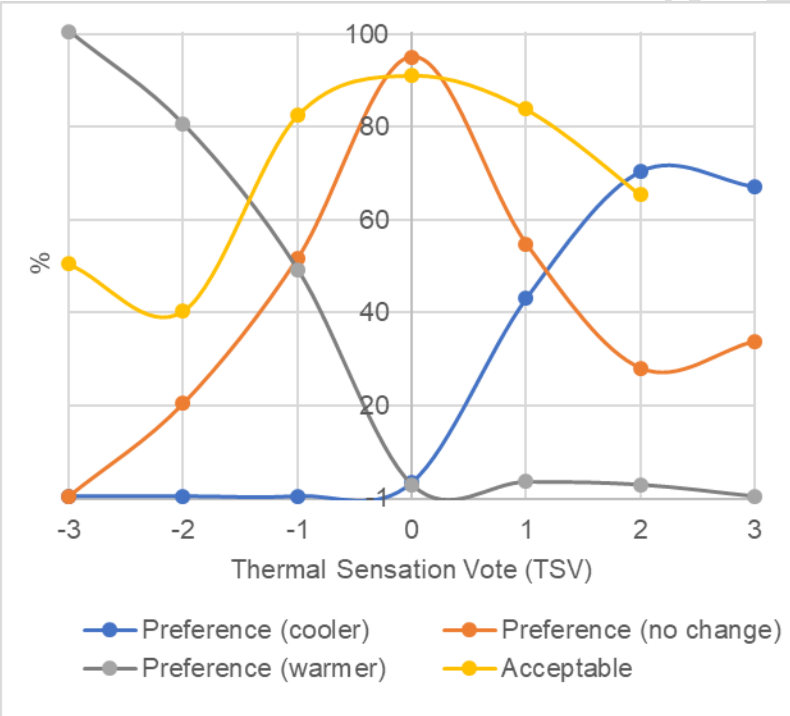

Figure 5. Percentage of TA and TP for residents against TSV

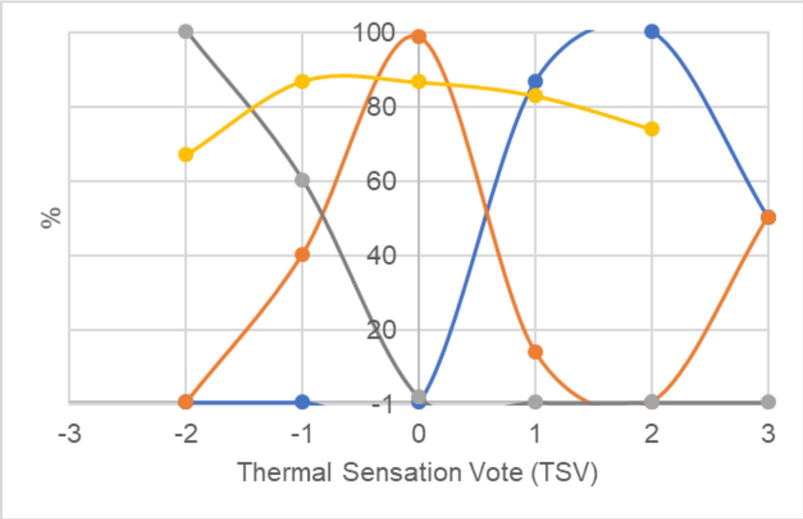

Figure 6. Percentage of TA and TP for non-residents against TSV

In winter, even when the occupants stated that they had a “neutral” sensation, 9% of residents and 14% of non-residents did not feel that the thermal environment was acceptable. In contrast, although residents voted for a thermal sensation of -2, -1, +1 or +2, over 20% accepted this thermal condition and did not want to change it.

When non-residents stated that they were warm, they mainly preferred a colder environment. However, when residents stated that they were warm, only around 60% preferred a colder environment.

To determine the thermal comfort zone, the percentage of dissatisfied participants (PPD) (%TA = 0) against the TSV of the results for cold (Figure 7) and warm discomfort (Figure 8) of residents was calculated.

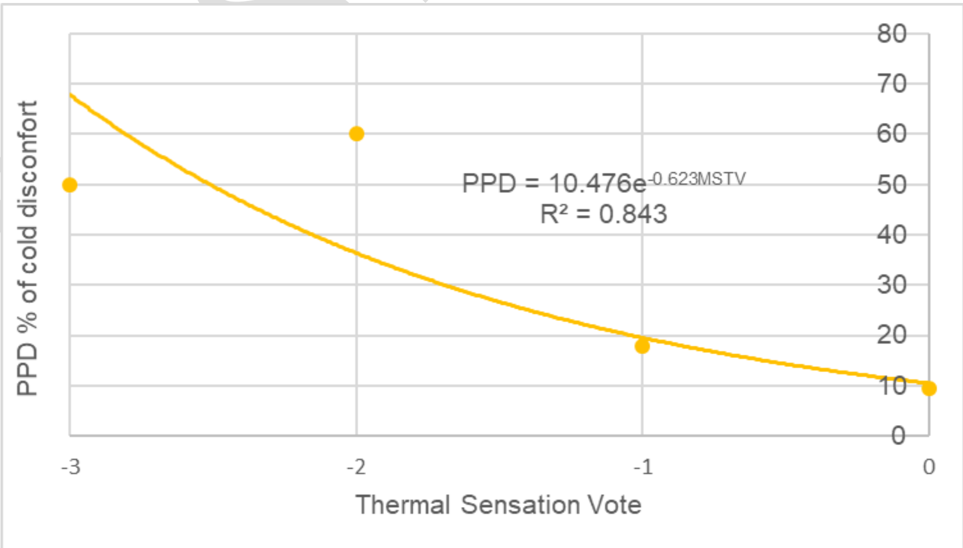

Figure 7. Percentage of dissatisfied participants (PPD) against the thermal sensation vote of cold discomfort for residents

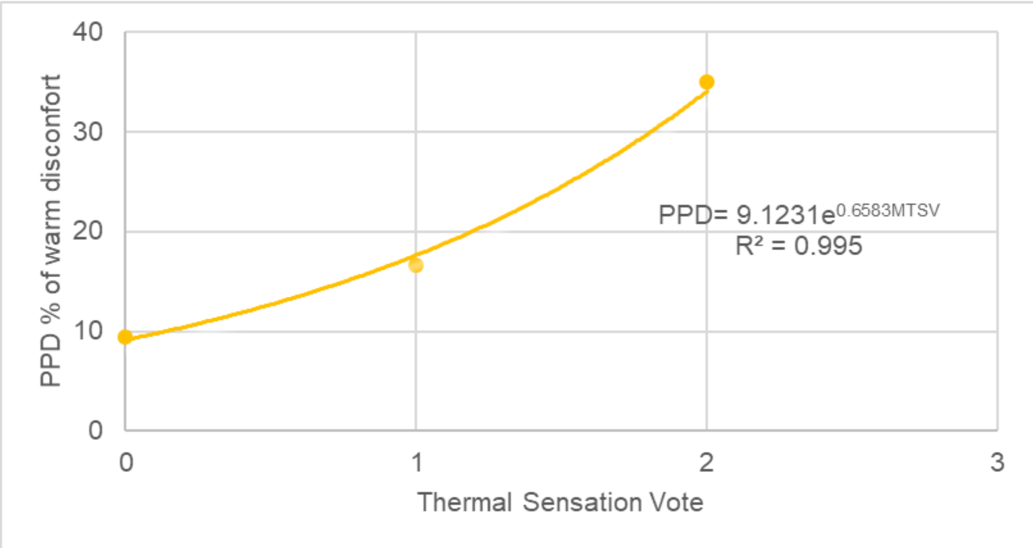

Figure 8. Percentage of dissatisfied participants (PPD) against the thermal sensation vote of warm discomfort for residents

For the 10% of dissatisfied residents, the TSV was between 0 and 0.15 and the comfort range of temperature was between 21.6ºC and 22.9ºC.

3.3. Influence of adaptive behaviours

People are not passive, but constantly interacting with and adapting to the environment by adjusting the body's heat balance to maintain thermal comfort. For example, they may change their activity and clothing [45] [46]. Furthermore, in naturally ventilated buildings, behavioural adjustments and psychological adaptations increase occupants' tolerance of a wider range of temperatures [39].

The results of this study indicated that the level of activity varied substantially between residents and non-residents (M[residents] =1.15 met and M[non-residents]=1.44 met) (Table 12). The level of residents' activity was mainly affected by the space they were in. In the gym, some of the residents were doing activities while seated and others were cycling. However, in general the level of activity was much higher than in the living room where all residents were watching TV or sleeping. In the occupational therapy room, therapists guided activities such as painting, playing cards, crafts, sewing, pet therapy, singing or even dancing. In the gym, therapists and caregivers were mainly leading group activities such as sports or craft activities or monitoring gym activities.

The clothing insulation for residents (I_{Clo}[residents] = 0.89 clo) was also higher than for non-residents (I_{Clo}[non-residents] = 0.67 clo). Therefore, non-residents who were doing more activity wore less clothes than residents who were doing less activity. Residents usually wear underwear, long-sleeve shirts and knits, long trousers or skirts with pants and in many cases a scarf. Non-residents usually wear a long-sleeve smock with light clothes underneath.

Table 12. M and I_{Clo} participants' characteristics

		Non-residents	Residents
M	Mean	1.44	1.15
	Deviation	0.19	0.16
	Min.	1.0	1.0
	Max.	1.6	1.4
I_{Clo}	Mean	0.67	0.89
	Deviation	0.18	0.21
	Min.	0.34	0..44
	Max.	1.58	2.39

Figure 9 shows that residents varied their level of clothing to adapt to their thermal comfort. When residents felt hot (TSV=3) they wore less clothes, while when they felt colder (TSV = -3 or -2) they wore more clothes. However, non-residents wore similar clothes (between 0.6 and 0.7 clo) although their thermal sensation or their level of activity varied (from 1.0 to 1.6 met). They did different activities, from providing support in the gym, serving food and guiding seated activities. However, they did not alter their clothing when they changed activities. Although residents did not do such intense activity, they modified their clothing to adapt to the level of activity. For example, they took off their cardigan when they went to the gym or they wrapped up to watch TV.

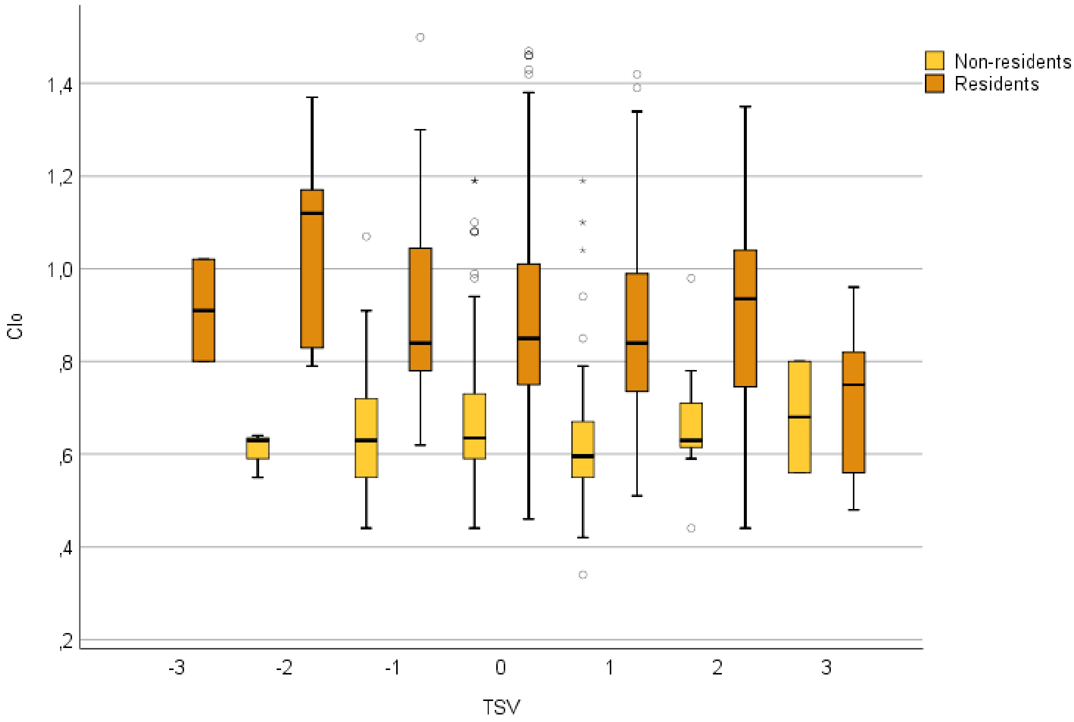

Figure 9. Box plot of Clo against TSV for residents and non-residents

Adaptive comfort theory states that the optimal indoor operative temperature in natural ventilated buildings relates primarily to the mean outdoor temperature, and indoor comfort temperatures increase with warmer outdoor environments [46].

The analysis of the influence of outdoor temperature (T_{rm}) on the TSV of non-residents suggest that a weak relationship exists between these two variables. Figure 10 reveals that there was no influence of outdoor temperature on the indoor thermal sensation in residents. This might be attributed to the fact that residents come from outside and non-residents tend to spend the whole day indoors.

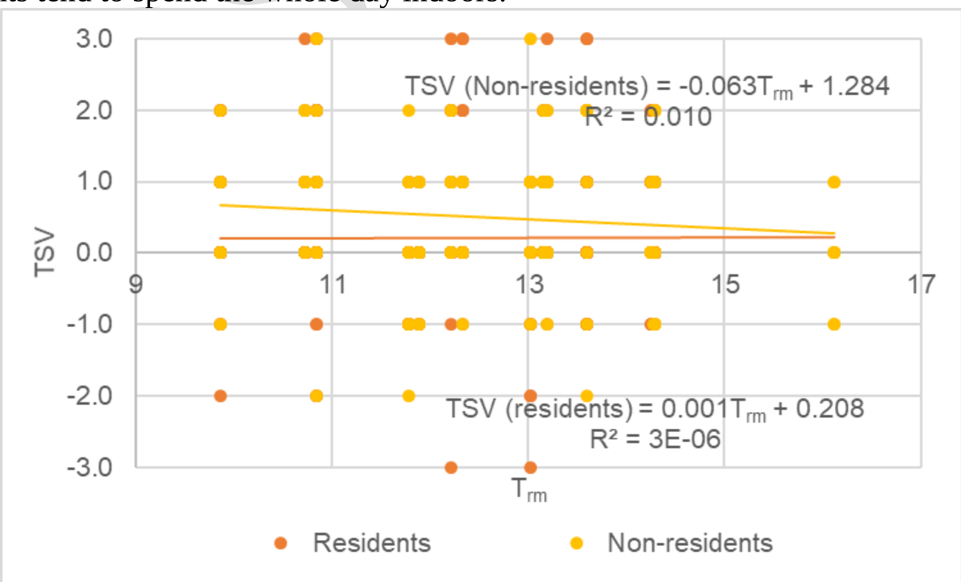

Figure 10. TSV against T_{rm}

However, the low coefficient of determination (R^2) suggests that no conclusions can be drawn from this study and adaptive models in heated environments need to be further analysed in future studies.

4. DISCUSSION

4.1. Thermal comfort zones and energy implications

The results of this study showed that elderly (residents) and therapists and caregivers (non-residents) have different thermal sensations and preferences. The slopes of the TSV vs. T_{op} regression for both groups of occupants represent the sensitivity of the occupants to a change in thermal environment. Residents were found to be more tolerant and less sensitive to cold (slope= 0.115) than non-residents (slope=0.335). In fact, most residents reported a neutral thermal sensation during the interviews, while only 42.2% of non-residents reported this (46.5% of non-residents expressed a hot sensation). This difference might be attributed to the clothing adaptation of elderly people when they do different activities.

Surprisingly, the neutral temperature of residents was found to be lower than that of non-residents (T_n [residents] = 21.6 °C and T_n [non-residents] = 21.9ºC). This result contrasts with the neutral temperatures obtained in a previous study carried out in the same nursing homes in the summer [32], in which elderly people preferred higher temperatures than non-elderly people.

A common practice in developing a thermal comfort zone for a specific indoor environment is defining the range of temperature in which over 80% of the occupants find the thermal conditions acceptable, when T_{op} falls within this range. ASHRAE 55 [38] extended this percentage to 90% for elderly people. The exponential regressions of the percentage of dissatisfied participants based on the results of acceptability for cold and hot discomfort allowed us to obtain the TSV limits of comfort between 0 and 0.15. These values were incorporated into the TSV vs. T_{op} regression equation and the neutral temperature was found to be between 21.6ºC and 21.9ºC for residents.

Tartarini et al. [27] and Hwang and Chen [47] obtained a broader thermal comfort range (between 19.1ºC and 26.2ºC and between 20.5ºC and 25.9ºC, respectively). These differences might be attributed to the climate, the outdoor conditions or the type of HVAC. The field analysis by Tartarini et al. [27] and Hwang and Chen [47] were carried out in a temperate climate that was more humid than the Mediterranean [35]. In this study, the selected rooms were all heated by fan-coils while in the other studies a mixture of HVAC systems was used. Further analyses could be carried out on how outdoor humidity or the type of HVAC influence thermal comfort.

Current nursing homes in Spain tend to overheat common rooms (setpoint temperatures are fixed at around 23ºC in the winter) based on the unsubstantiated idea that elderly people prefer higher temperatures. The acceptance of lower indoor temperatures in wintertime would lead to less use of heating systems [49] and hence less energy consumption by these systems. If indoor temperatures are set to 21.6ºC, overheated rooms will be reduced [50] and the reduction of energy consumption for heating could be greater than 6% [51] and over.

However, residents and non-residents had different thermal sensations depending on the room they occupied, not only due to their level of activity (M) in the space, but also due to their psychological adaptation [48]. In rooms where non-residents perform more physical activity such as serving food, residents have a higher thermal sensation. The room with the greatest thermal sensation differences between residents and non-residents was the occupational therapy room. Non-residents felt cooler in this room. This result is explained by the typical activities that residents do in this room. Residents are very active when they are there: dancing, sewing, playing cards, etc. In the gym, 66.3% of the residents reported having a neutral temperature, while only 20.8% of the non-residents stated the same.

Adapting setpoint temperatures for different rooms in nursing homes could lead to a proper balance between thermal comfort, energy use and environmental impact. However, other aspects such as culture, climate, education and health might influence perceptions of the thermal environment [52] and thus need to be further explored.

1.1.1 4.2. Adaptive behaviours

The results of this study revealed that there is no clear correlation between clothing insulation and thermal sensation. Although residents had a lower level of activity (M[residents] = 1.15 met) than non-residents (M[non-residents] =1.44 met), the clothing insulation for residents was greater (I_{Clo}[residents] = 0.89 clo) than for non-residents (I_{Clo}[non-residents] = 0.67 clo). This study confirmed that, in the winter, elderly people use clothing adjustment to adapt to the environment [47] [27]. For example, they took their cardigan off when they had specific activities such as going to the gym or active therapies. However, therapists and caregivers did not modify their clothing insulation when they changed activity. Therapists' and caregivers' behaviour such as clothing adaptation when they move from one space to another or when they change activities would lead to improved thermal comfort. Consequently, temperature setpoints could be adapted to the residents' requirements with a consequent reduction of energy consumption [49].

Further research should be carried out on adaptive behaviours and the influence of the outdoor environment on indoor thermal comfort, to provide detailed guidance to nursing home occupants and determine behaviours and routines that provide thermal comfort in the different common spaces for both groups of users of these buildings.

5. CONCLUSIONS

Considering the high energy consumption of nursing homes due to HVAC systems, the direct relation between energy consumption and thermal comfort and the potential thermal comfort differences of nursing home occupants, this article reports a field study of 880 nursing home occupants to determine their thermal perceptions and preferences.

The conclusions drawn from the analyses and discussions of this study are as follows:

1) The analysis of the results showed that residents and non-residents have different thermal sensations and preferences in winter. Residents are less sensitive to a change in the thermal environment than non-residents.
2) The neutral temperatures estimated using a linear regression analysis were 21.6°C for residents and 21.9ºC for non-residents.
3) The thermal comfort with 90% of acceptability for residents ranged from 21.6 to 22.9ºC. This range of comfort temperature implies a reduction in setpoint temperatures. During the experimental campaign, the operative temperature was between 19.3 and 26.8ºC, with an average of 23.3ºC. Therefore, temperatures could be reduced in some periods with the consequent reduction of heating prevalence and energy consumption.

4) The results of this study demonstrate that in winter elderly people accept low temperatures because they adapt their clothing insulation to the operative temperature and to their changing level of activity. In contrast, non-residents do not modify their clothing to adapt to unsatisfactory thermally conditions or to the activity. Therefore, this study highlighted that behavioural adaptation can lead to better comfort of occupants and to a reduction in energy consumption.

The implementation of the results of this study will contribute to a better quality of life for residents and non-residents of nursing homes and reduce energy consumption and CO_2 emissions due to a reduction of heating.
Building design, operational strategies and the scheduling of residents' activities might help to improve thermal comfort in different areas of nursing homes in winter.
The results of this research can be used to develop or refine guidelines to design and operate nursing homes based on the real thermal needs of their occupants.
The results of this study will also enhance the promotion of good practices to design new nursing homes or to evaluate existing ones by checking whether a given thermal environment meets the comfort criteria.
The research methodology, analysis processes and outcomes of the study will be useful to a broad spectrum of stakeholders, including not only researchers who intend to carry out similar studies in the future, but also professionals who manage nursing homes. Future steps include extending this analysis to free running environments and analysing the energy reduction by implementing the comfort temperatures obtained from this study.

6. ACKNOWLEDGEMENTS

The authors thank the International Center on Aging (CENIE), the General Foundation of the University of Salamanca (FGUSAL) and the Programa de Cooperación Interreg V-A España – Portugal (POCTEP) 2014-2020 and the FEDER funds for their financial support of this study under project reference 6/2018_CIE_6. This research was also supported by the Spanish Ministry of Economy, Industry and Competitiveness under R&D project Thecoelen, reference no. PID2019-106777RB-C21. We would also like to thank Sanitas Mayores and specially the Eng. Marc Vallet for providing their nursing homes and helping to collect all the required data. We would also like to extend our appreciation to all the caregivers, maintenance staff and elderly people who participated in this project.

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