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Summer thermal comfort in nursing homes in the Mediterranean climate

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ABSTRACT

The number of people living in nursing homes is increasing due to the growth of ageing population. However, existing standards on thermal comfort do not consider how occupants of nursing homes perceive their thermal environment. This study investigated the thermal sensation of elderly people during summer season in care homes from the Mediterranean climate. The study was conducted to 623 nursing occupants (both residents (elderly people) and non-residents (caregivers)) using a thermal sensation questionnaire and measurement of indoor climatic parameters. Elderly's results were compared with the results of caregivers to study the differences between these groups of population that coexist in the same building. The results showed that elderly people have a different thermal comfort perception than adults. The comfort temperature for elderly people was found to be 24.4ºC while for non-elderly was 23.5ºC while residents were found to be more tolerant with high temperatures than non-residents. Results also showed that residents do not modify the clothing to adapt to unsatisfactory thermally conditions or to the activity. The results of this research may assist regulatory bodies to develop guidelines to design and operate nursing homes based on real thermal needs of their occupants.

Author keywords:
Thermal comfort, elderly, nursing homes, thermal acceptance.

Nomenclature

T_a: Air temperature
RH: Relative humidity
T_r: Mean Radiant Temperature
T_g: Globe Temperature
v_a: air velocity
T_{op}: Operative temperature
T_{out}: Outdoor air temperature
RH_{out}: Outdoor air humidity
T_{rm}: Running mean temperature
TSV: Thermal Sensation Vote
A: Acceptability
P: Preference

1 INTRODUCTION

The aging society is universally regarded as a major challenge for many countries. The number of people aged over 65 in the European Union was at 28.8% in 2015, and it is forecasted to increase to 39.1% by 2030 and 50% by 2050 [1].
Aging populations pose significant social challenges for many countries. While around 3.4 million old people lived in nursing homes in 2018, this figure is likely to increase by around 18 percent to over 4 million by 2023. New nursing homes will be built and many existing ones will require refurbishment works due to their age and condition [2].
Considering that elderly people spend a considerable portion of their lives indoors, their indoor environment such as thermal quality, should be carefully analysed and controlled considering the specific needs and requirements of this group of population.
The thermal environment can be described as the characteristics of the environment that affect heat exchange between the human body and the environment [3]. There has been extensive modelling and standardisation of thermal comfort, which both depend on physical and physiological parameters.
The most commonly used model to evaluate thermal comfort is the predicted mean vote (PMV) [4]. This model considers air temperature (T_a), mean radiant temperature (T_r), relative air velocity (v_a) and air humidity (HR_a), activity level (met) and the clothing insulation (Clo) to be the main influential variables for the thermal comfort and defines the neutral temperature as the optimal condition in which occupants do not prefer colder or warmer environment.
The ISO 7730 [5], Ashrae Standard 55-2017 [3], EN1525:2007[6] and EN16798:2019 [7] standards which aim to specify thermal comfort conditions to design HVAC systems, adopt the PMV model. However, these standards focus on buildings that tend to be populated by people roughly aged between 20 and 65 years old.
Field studies show that current regulations might not be applied to older people [8] [9]. Elderly are vulnerable to extreme thermal environment conditions [10] and may have a different thermal perception from adults because they tend to be frailer and have various

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health problems [11] [12] and difficulties regulating the body temperature [9]. In general, elderly prefer higher temperatures than adults [13] which would lead to less prevalence of cooling systems as well as less cooling requirements in summertime [14].
To date, only a few studies have focused on thermal comfort of elderly. The majority of them focus on homes [15][16][17][18][19] where elderly mainly live alone and adapt their thermal environment based on the available heating and cooling systems and their economical capacity [10].
Nursing homes gather together elderly people to provide them a place to live and health care assistance [20]. Rooms might be occupied individually or by pairs while common areas such as living rooms, dining rooms, gyms and occupational therapy rooms are occupied by a group of residents.
Determining the influential parameters in thermal comfort for elderly is necessary to design comfortable nursing spaces, improve health and wellbeing and allow to adopt new strategies of efficiency and energy saving to consistently comply with the requirements of sustainable development. In fact, indoor environmental conditions are strongly related to thermal comfort which has a direct implication in building energy efficiency. Buildings account for about 40% of the global energy consumption and contribute over 30% of the CO_2 emissions. A significant proportion of the increase in energy use is due to the spread of the 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, accounting for about half of the total energy consumption in buildings especially non-domestic buildings [12][13]. Higher indoor temperatures in summertime conditions would lead to less prevalence of cooling systems as well as less cooling requirements [14]. Raising summer set point temperature has good energy saving potential.
Owing to the fact that residents in nursing homes spend 80% of their time indoors [23][24][25], they must cohabit with other residents in common areas and the cooling season is the one that might bring higher energy savings, thermal comfort analysis under these conditions are necessary.
Although some studies have been conducted on thermal comfort in elderly [10][14][26][27][28][29][30][9][17][31][15][32][8][33][13][34], the only thermal comfort studies in nursing home environments in warm season conditions were conducted in Australia [35] and Korea [29].
Tartarini et al. [35] investigated the thermal perceptions, preferences and adaptive behaviours of occupants in five nursing homes in Australia and found that the neutral temperature for residents was higher than for caregivers and were more tolerant of temperature variations.
Yang et al. [27] studied thermal environmental conditions for elderly people living in 26 nursing homes in Korea and found that residents have lower thermal sensitivity than what PMV propose. They also found that residents prefer the cooling season without air conditioning.
Broadly, thermal sensation is influenced by the thermal adaptation [15], climate conditions [16][17], seasons [18] and building types [19]. Owing to the fact that there are different climatological diversities and climate conditions all over the world, this study investigated **the thermal comfort of elderly in the Mediterranean region in summer.** Their indoor thermal requirements were investigated, and results compared with those of adult people. The objectives of this study were: i) to characterise the thermal performance of elderly people in the Mediterranean climate in summer; ii) to

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determine thermal comfort perceptions and preferences of elderly and compare them with adult people; and iii) to establish the most appropriate temperature ranges for residents and non-residents in nursing homes.

2 METHOD

2.1. Study design

To analyse the thermal comfort in elderly different common areas from five different nursing homes within the Mediterranean climate were selected.

A Mediterranean climate is characterized by dry summers and mild, wet winters. The climate receives its name from the Mediterranean Basin, where this climate type is most common. Mediterranean climate zones are typically located along the western sides of continents, between roughly 30 and 45 degrees north and south of the equator. The main cause of Mediterranean, or dry summer climate, is the subtropical ridge which extends northwards during the summer and migrates south during the winter due to increasing north-south temperature differences. Under the Köppen climate classification, "hot dry-summer" climates and "cool dry-summer" climates are often referred to as "Mediterranean" [29].
Information about the indoor and outdoor environmental thermal characteristics in the same time of the subjective thermal perceptions and preferences of nursing occupants was collected. To determine the thermal comfort influential factors, the physical characteristics of the occupants were also gathered.

2.1.1. Indoor and outdoor environmental parameters

Indoor environmental data included: Air temperature (T_a), Relative humidity (RH%), Mean Radiant Temperature (T_{rm}) and air velocity (v_a). These data were determined using a portable Delta Ohm HD32.1 instrument with an anemometer, thermometer and a black globe thermometer during the occupied period.

The mean radiant temperature (T_r) was estimated using a black-globe thermometer which measures the globe temperature (T_g). According to ISO 7726 [42] standard, 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 and Figure 1 shows an image of the instrument.

Table 1. Characteristics of the instruments

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

Figure 1. Instrument for indoor environmental data collection

The instrument was located away from windows and local sources of heat, approximately 1.5m above the ground, in accordance with Ashrae 55 [3]. Short-term measurements (40 min Mean) were collected in each room. After the equipment stabilized, measurements were recorded continuously.

Then, the operative temperature (T_{op}) which is the combined effects of the mean radiant temperature (T_{rm}) and air temperature (T_a) was calculated.

$$T_{op} = (T_a + T_{rm}) / 2 \quad (2)$$

Outdoor environmental conditions included outdoor air temperature (T_{out}) and outdoor air humidity (RH_{out}). These data were obtained from the closest meteorological stations (AEMET) from each nursing home.

Adaptive comfort temperatures are based on outdoor temperatures during the preceding few days. The weighting or influence given to the outside temperatures is higher for recent days, reducing with distance back in time as people "forget". Then the running mean temperature for each measurement day was calculated based on the following expression [20].

$$T_{rm} = (T_{ed-1} + 0.8T_{ed-2} + 0.6T_{ed-3} + 0.5T_{ed-4})/2.9 \quad (3)$$

where T_{ed-1} is the daily mean external temperature for the previous day and T_{ed-2} is the daily mean external temperature for the day before that, and so on.

2.1.2. Perceptions and preferences of participants regarding their thermal environment

At the same time environmental parameters were measured, nursing occupants were surveyed to determine their Thermal Sensation (TSV), Preference (P) and degree of acceptability (A).

A customised right-here-right-now survey was employed to collect subjective comfort evaluations from building occupants throughout the 3-month monitoring period in the different common building zones.

Caregivers helped collecting thermal perceptions and preferences of the residents.

The questionnaire was designed to require less than two minutes to complete, and addressed simple questions.

The survey included the 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) [3]. The TSV was assessed asking participants: “How do you feel at this precise moment? A figure-based survey was provided to residents to facilitate the understanding of the thermal scales (Figure 2).

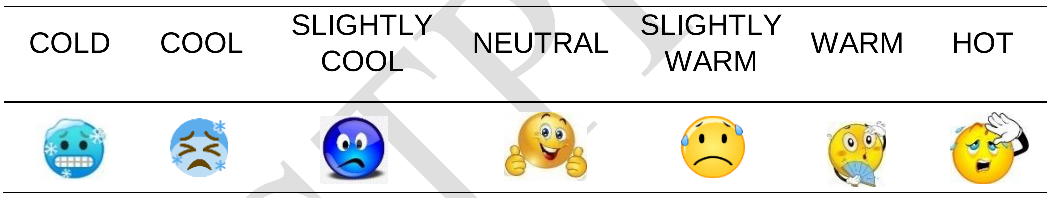

Figure 2. Figure-based evaluation of Thermal Sensation

Thermal preference (P) of each participant was assessed through the following question: “At this precise moment, would you prefer to be … ? ” using a three point scale (−1 cooler, 0 without change,+1 warmer [21].

Thermal acceptability (A) of each participant was assessed through the following question: “At this precise moment, Is the environment thermally acceptable?” using a two-point scale (1 acceptable, 0 unacceptable).

For the correct analysis of the thermal comfort, the clothing level (clo), and the metabolic rate (met) at the time of the survey were also collected.

Total clothing insulation (***clo***) and metabolic rate (met) were assessed by observing the participant and using the tables in ISO 7730 [22] and ASHRAE 55 [3]. Total clothing insulation of the clothing ensemble worn by each participant was determined by adding the insulation level of all individual garments that each participant was wearing [22]. In addition, the effect of the chair or wheelchair on the insulation of the clothing was also considered (Table 2).

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Table 2. Level of individual garment to calculate the total clothing insulation of each participant

Level of clothing	**Clo**
Underwear	
With T-shirt	0.12
Without T-shirt	0.03
Overall	
Long-sleeve shirt	0.25
Short-sleeve shirt	0.15
Long-sleeve knit sport shirt	0.2
Short-sleeve knit sport shirt	0.09
Long-sleeve (thin)	0.2
Long-sleeve (thick)	0.28
Jacket	0.35
Long trousers /Thick skirt	0.25
Short trousers /Thin skirt	0.06
Shoes	
Closed shoes	0.04
Sleepers	0.02
Sandals	0.01
Boot	0.1

Level of clothing	**Clo**
Therapists and caregivers	
Short-sleeve smock without clothes underneath	0.24
Long-sleeve smock without clothes underneath	0.34
Short-sleeve smock with light clothes underneath	0.63
Long -sleeve smock with light clothes underneath	0.73
Short-sleeve smock with thick clothes underneath	0.75
Long-sleeve smock with thick clothes underneath	0.95
Type of chair	
Normal chair	0.1
Wheelchair	0.12
Sofa	0.15
Accessories	
Kerchief	0.05
Scarf	0.08
Cap	0.05
Socks	
With socks	0.03
Without socks	0

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Metabolic rate was standardized based on the typical activities of both residents and caregivers (Table 3).

Table 3. Metabolic rate of the typical activities of participants.

Activity	**Met**
Sport activity group - Physiotherapist	1.6
Lower activity group - Physiotherapist	1.4
Walking	1.4
Seated - Bike	1.4
Individual Treatment - Physiotherapist	1.2
Seated - Table games / drawing	1.2
Seated - TV	1

2.1.3. Physical characteristics of the occupants

For the correct analysis of the thermal comfort sensation and preferences, the basic information of the respondents also included: sex, age, height, weight and body mass index.
This study was carried out in nursing homes, where a complete database of their residents exists. From this point of view, this controlled database helped on analysing these factors that in other buildings without this information of their occupants would not. Since such information contained personal data, the confidentiality of the information was respected.

2.2. Data analysis

Two groups of nursing (residents and non-residents (caregivers and therapists)) were analysed separately in relation to their thermal comfort perceptions and preferences. Other variables such as the building or room where nursing occupants were surveyed were also analysed. For residents their physical characteristics such as gender and age were also analysed.
Statistical data analysis was carried out using the IBM SPSS26 Statistics software. Answers that had missing data were eliminated from the analysis. Descriptive statistics such as percentages and mean were used to summarize the characteristics of the respondents.

Spearman correlation analysis and Chi square-test to evaluate the relationship between the respondents' preferences and their characteristics were used in this study while linear regression was used to determine the relation between TSV and Top in the different groups (residents / non-residents)).

2.2.1. Spearman correlation analysis

Spearman correlation analysis was used to evaluate the correlation between occupants' TSV, P and A and other quantitative variables (age, clo, met, T_{op}, etc.). Spearman's correlation analysis is the measure of sample correlation when one of the variables is ordinal. In this case, the TSV, P and A 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.

2.2.2. Chi square-test

A chi-square (x2) test was used to determine the dependence between gender (male-female), type of occupant (resident/non-resident), rooms (living room (LR), dining room (DR), gym (GM) and occupational therapy room (OT)) and TSV, P and A. This test allows a comparison to be made of the 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 those variables with significant correlations at the 95% confidence intervals, the asymptotic significance should be less than 0.05.

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2.2.3. Linear regression

A linear regression was used to determine the relation between mean thermal sensation votes (MTSV) and T_{op} in the different groups of population (residents / non-residents). From this linear regression the 'neutral temperature', the temperature at which participants reported their thermal perception of feeling "neutral" [23], was calculated. Linear regression was also used to determine the relation between the outdoor conditions (T_{rm}) and the thermal sensation (MTSV) of the different groups.

2.3. Sample characteristics

The sample of this study was the occupants of nursing homes in the Mediterranean climate. All building occupants (residents and non-residents (caregivers and therapists)) were included in the study.
The field study was conducted in five nursing homes located in Mediterranean climate in Spain. Two nursing homes were located in Barcelona (P and SF), one in Tarragona (T) and two in Valencia (B and V).
Building zones included those common nursing homes: living room (LR), dining room (DR), gym (GM) and occupational therapy room (OT).
During the period of data collection, 623 surveys were collected: 77% were residents and 23% non-residents. Approximately the same proportion of surveys per nursing home. Table 4 presents the participants of the different nursing homes and rooms.

Table 4. Number of participants by nursing home and building area

	Nursing home					
Room	**B**	**P**	**SF**	**T**	**V**	**Total**
LR	4	86	53	34	30	207
OT	68	0	17	40	18	143
GM	51	33	25	16	27	152
DR	0	18	0	67	36	121
Total	123	137	95	157	111	623

The participants involved **476 residents** (343 women and 133 men) and **147 non-residents** (124 women and 23 men) (Table 5).

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Table 5. Sample characteristics

	Non-residents	Residents	Total
Men	23	133	156
Women	124	343	467
Total	147	476	623

The age of the residents was in Mean 84,84 years with an average height of 153.3 m and an average weight of 68.9 kg.

Table 6. Residents' characteristics

	Minimum	Maximum	Mean	Standard deviation
Age (years)	46	99	84.84	8.836
Height (m)	1.4	178.0	153.3	23.332
Weight (kg)	39.0	135.2	68.9	15.177

2.4. Data collection

Data was collected during the warm season between July and September 2019. During this period the outdoor temperature ranged between 19.7 and 28.2 with an average of 25ºC, while the calculated running mean temperature ranged between 22.2ºC and 27.4ºC with an average of 25.3ºC (Table 7).
The outdoor humidity ranged between 56 and 80 with a mean of 70%.

Table 7. Outdoor conditions

	Min	Max	Mean	Deviation
T_{out} (ºC)	19.7	28.2	25.0	2.48069
RH_{out} (%)	56.0	80.0	69.5	6.58334
T_{rm} (ºC)	22.2	27.4	25.3	1.56127

The mean indoor conditions were: T_a=25,23ºC, T_g=25,24ºC, HR= 61,75%, v_a= 0,06 m/s. Maximum, minimum and deviation of indoor conditions are summarized in Table 8.

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Table 8. Indoor conditions

	Min	Max	Mean	Deviation
T_g (ºC)	23.14	28.46	25.24	1.029
T_a (ºC)	23.21	28.41	25.23	1.022
RH (%)	52.38	69.32	61.75	4.53
V_a (m/s)	0.00	0.35	0.06	0.08
T_r (ºC)	23.13	28.48	25.25	1.04
T_{op} (ºC)	23.17	28.45	25.25	1.02

3. RESULTS

3.1. Thermal sensation by different groups of population

60.8% of residents stated that they had a neutral thermal sensation. 16.5% claimed to feel slightly warm and 12.1% of slightly cold. In contrast, under the same conditions, only 13.3% of non-residents affirmed having a neutral thermal sensation, while 67.2% affirmed having a sensation of hot (+1, +2, and +3) (Table 9 and Figure 3).

Table 9. TSV for residents and non-residents.

		TSV						Total
		-2	**-1**	**0**	**1**	**2**	**3**	
Non-resident	**N**	0	28	19	59	25	12	143
	%	0.0%	19.6%	**13.3%**	41.3%	17.5%	8.4%	100%
Resident	**N**	9	58	292	79	36	6	480
	%	1.9%	12.1%	**60.8%**	16.5%	7.5%	1.3%	100%
Total	**N**	9	86	311	138	61	18	623
	%	1,4%	13,8%	49,9%	22,2%	9,8%	2,9%	100%

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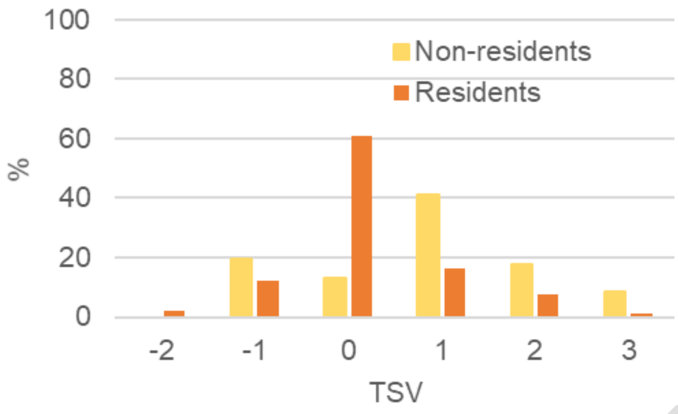

Figure 3. Distribution of percentages (TSV for residents and non-residents).

The Chi-square test was performed to examine the independence of the distribution of thermal sensation for each group (residents-non-residents), and the result showed that the thermal sensation of residents (elders) and non-residents (adults) was statistically different (sig < 0.05) with a tendency of the residents to be colder (Table 10 and Figure 3).

Table 10. Chi square test between the TSV and the type of user

	Value	df	Asymptotic significance (2-sided)
Pearson Chi-square	118.31[a]	5	.000
Likelihood ratio	125.782	5	.000
Lineal-by-lineal association	44.893	1	.000
N of valid cases	623		

a. 2 cells (16.7%) have expected count less than 5. The minimum expected count is 2.07.

For residents, the thermal sensation was also found to be different by gender. More male express to have a neutral thermal sensation (66%) than female (44.5%) (Table 11, Figure 4).

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Table 11. TSV for residents divided by gender

		TSV						Total
		-2	**-1**	**0**	**1**	**2**	**3**	
Men	**N**	3	13	103	27	8	2	156
	%	1.9%	8.3%	**66.0%**	**17.3%**	5.1%	1.3%	100%
Women	**N**	6	73	208	111	53	16	467
	%	1.3%	15.6%	**44.5%**	**23.8%**	11.3 %	3.4%	100%
Total	**N**	9	86	311	138	61	18	623
	%	1,4%	13.8%	49.9%	22.2%	9.8%	2.9%	100%

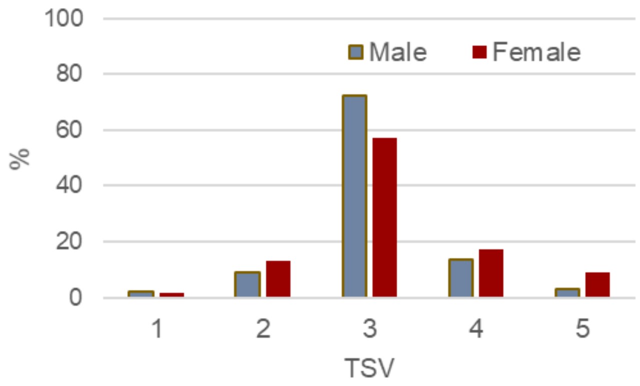

Figure 4. Distribution of percentage (TSV for residents divided by gender).

The Chi-square test was performed to examine the independence of the distribution of thermal sensation (TSV) of gender within residents, and the result showed that the thermal sensation of male and female was statistically different (sig < 0.05). (Table 12) with a tendency of the residents to be colder (Figure 3).

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Table 12. Chi square test between the TSV and gender

	Value	df	Asymptotic significance (2-sided)
Pearson Chi-square	24.342[a]	5	.000
Likelihood ratio	25.334	5	.000
Lineal-by-lineal association	623		
N of valid cases	24.342[a]	5	.000

b. 2 cells (16,7%) have expected count less than 5. The minimum expected count is 2,25.

Table 13. Residents' TSV, Clo and Met by gender

	Men				**Women**			
	Min.	**Max.**	**Mean**	**St. dev.**	**Min.**	**Max.**	**Mean**	**St. dev.**
TSV	-2.00	2.00	0.06	0.66	-2.00	3.00	0.24	0.91
Clo	0.30	1.04	0.63	0.15	0.25	1.04	0.54	0.15
Met	1.00	1.40	1.18	0.15	1.00	1.40	1.18	0.14

Surprisingly, results showed that female feel warmer (mean TSV=0.24) than male (mean TSV=0.06) while wearing less clothes. The neutral temperature for female was also found to be 24,3ºC while 25ºC for male.

Regarding the different nursing areas, in the dining room, while residents tend to be comfortable (52.1% affirm to have a neutral thermal sensation) non-residents tend to be hot (60% declared to be between slightly warm to hot) (Table 14).
In the Gym, 66.3% of the residents reported to have a neutral temperature, only 20.8% of the non-residents affirmed that.
In the occupational therapy room is the room were both residents and non-residents have similar comfort perceptions although non-residents also claimed to be bit warmer (84% of residents and 80% of non-residents affirm to have a neutral or slightly warm thermal sensation).

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Table 14. TSV in the different nursing areas

Non-residents		TSV					
		-2	-1	0	1	2	3
DR	**N**		9	1	8	4	3
	%		**36.0%**	4.0%	32.0%	16.0%	**12,0%**
GM	**N**		11	10	12	11	4
	%		22.9%	20.8%	25.0%	22.9%	8,3%
LR	**N**		7	6	19	8	4
	%		15.9%	13.6%	43.2%	18.2%	9.1%
OT	**N**		2	2	22	3	1
	%		6.7%	6.7%	**73.3%**	10.0%	3.3%
Total	**N**		29	19	61	26	12
	%		19.7%	12.9%	41.5%	17.7%	8.2%
Residents							
DR	**N**	5	19	50	13	9	0
	%	5.2%	19.8%	**52.1%**	13.5%	9.4%	0,0%
GM	**N**	1	15	69	10	8	1
	%	1.0%	14.4%	66.3%	9.6%	7.7%	1,0%
LR	**N**	2	14	91	41	13	2
	%	1,2%	8.6%	55.8%	25.2%	8.0%	1.2%
OT	**N**	1	9	82	13	5	3
	%	0,9%	8.0%	72.6%	11.5%	4.4%	2.7%
Total	**N**	9	57	292	77	35	6
	%	1,9%	12.0%	61.3%	16.2%	7.4%	1.3%

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3.2. Thermal sensitivity and neutral temperature

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

For residents: $MTSV=0.2838*T_{op}-7.1687$ ($R^2=0.5957$)

For non-residents: $MTSV=0.5599*T_{op}-13.395$ ($R^2=0.6113$)

Figure 5 shows the linear regression of the MTSV plotted against the indoor operative temperature (T_{op}) for residents and non-residents.

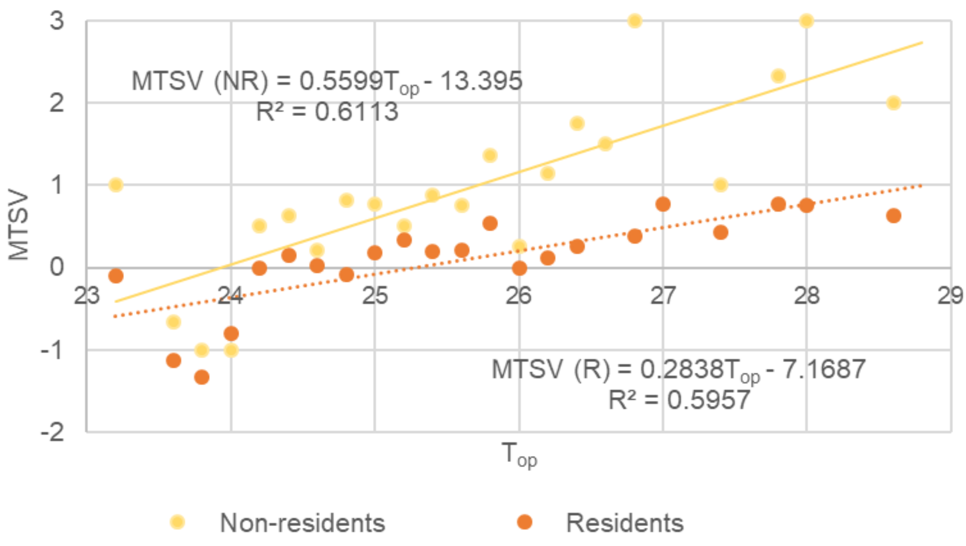

Figure 5. MTSV against Top

Although both groups considered the temperature to be comfortable over a wide range of temperature, residents were found to be more tolerant than non-residents. Residents claimed that the environment was “warm” or “hot” only when temperatures exceeded 28.7 °C while for non-residents the threshold was 25.7 °C.

From the linear regression analysis, the neutral temperature was found to be 25.3 °C for residents and 23.9ºC for non-residents.

Figure 6 shows the linear regression of MTSV plotted against the running mean temperature (T_{rm}) for residents and no-residents.

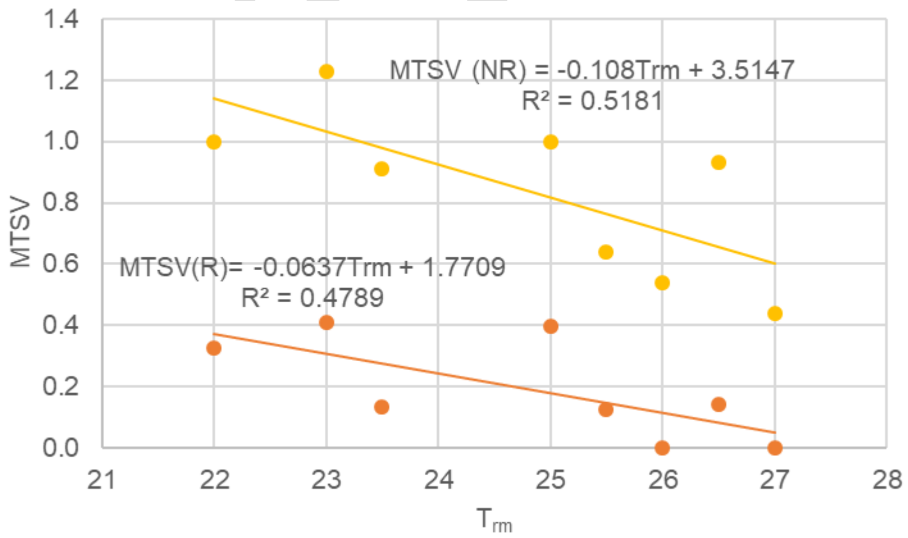

Figure 6. MTSV against T_{rm}

Thermal sensation for all groups was found to be dependent on the outdoor conditions. As the running mean temperature increases, occupants’ thermal sensation tends to be more neutral. However, the thermal sensation of residents is always lower than non-residents.

3.3. Thermal preference, acceptability and thermal comfort zone

Thermal comfort standards [4] [6] for elderly people recommend a 90% thermal comfort acceptability while, the 80% acceptability temperature range is recommended for other occupants because older people are more vulnerable to extreme temperatures [4].

Figure 7 shows the distribution of thermal preference votes (P) and acceptability votes (A) for both groups.

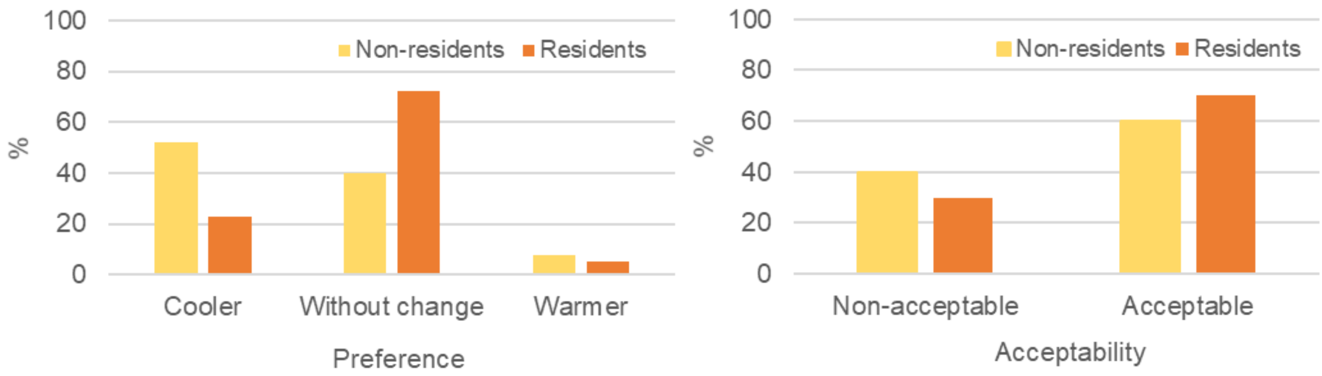

Figure 7. Distribution of percentages (Preference (left) and the Acceptability (right))

The preference for warmer environments for both groups was between 24ºC and 25ºC with higher operative temperatures for residents. This means that residents preferred higher temperatures than non-residents.

The preference for cooler environments for both groups was between 25ºC and 26ºC with higher operative temperatures for non-residents. This reinforces the fact that elderly feel more comfortable with higher temperatures.

To determine the thermal comfort zone, the percentage of dissatisfied participants (PPD) (%Acceptability=0) against the MTSV of the results of the survey was calculated and a second-order polynomial regression model was developed (Figure 8).

The best fitted polynomial equation of PPD against MTSV for residents was found to be:

$$PPD=5.0417*MTSV^2-5.8367*MTSV+28.958 \quad (R^2=0.7687)$$

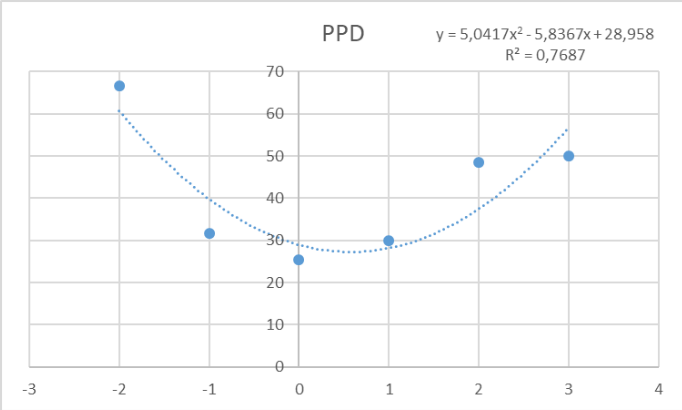

Figure 8. PPD against MTSV for residents.

From both the equation and Figure 7 we can observe that from the survey results it is not possible to achieve neither 10% nor 20% of thermal satisfaction. When asking for the thermal sensation, although when residents expressed being neutral, slightly warm or slightly cold they considered this environment not to be acceptable. Therefore, the results of the acceptability cannot be used to interpret the thermal comfort zone.
Otherwise, the PPD proposal from Ashrae 55 [3] will be used to evaluate the thermal comfort zones for this study. Therefore, the thermal comfort with a 90% of acceptability for residents using the Ashrae 55 model ranges from 23.2 to 28.4ºC while for non-residents from 23.2 to 26.3ºC. For non-residents the thermal acceptability with an 80% of acceptability ranged 23.2 to 25.6ºC.

3.4. Influence of clothing insulation, level of activity and participants characteristics

The level of activity varied substantially between residents and non-residents, 1.18 met for residents and 1.483 met for non-residents. The level of activity for residents was mainly conditioned by the space where they were. In the gym (G) although some of the residents were doing activities while seated and others were cycling, the level of activity was much higher than in the living room (LR) where all residents were watching TV or sleeping. In the occupational therapy room (OT) therapists were guiding activities such as painting, card gaming, crafts, sewing, pet therapy, singing or even dancing. In the gym, therapists and caregivers were mainly leading activity groups either sport or crafts activities or monitoring gym activities.
Surprisingly, the clothing insulation for residents and non-residents in the analysed nursing homes in summer was not very different; 0.567 clo for residents 0.487 clo for non-residents.

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Table 15. Met and clo participants' characteristics

		Non-residents	Residents
Met	N	143	480
	Mean	1.483	1.177
	Deviation	0.19	0.143
	Min	1	1
	Max	1.6	1.6
Clo	Mean	0.487	0.567
	Deviation	0.145	0.155
	Min	0.19	0.25
	Max	0.69	1.04

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The Rho Spearman correlation analysis showed that the total clothing insulation of residents (clo) was negatively correlated with the TSV ($r=-0.179$, $p < 0.01$). When they were wearing more clothes, they felt warmer. Caregivers and therapists actively modify their clothing by wearing more or less under clothes below the long or short leaves smock.

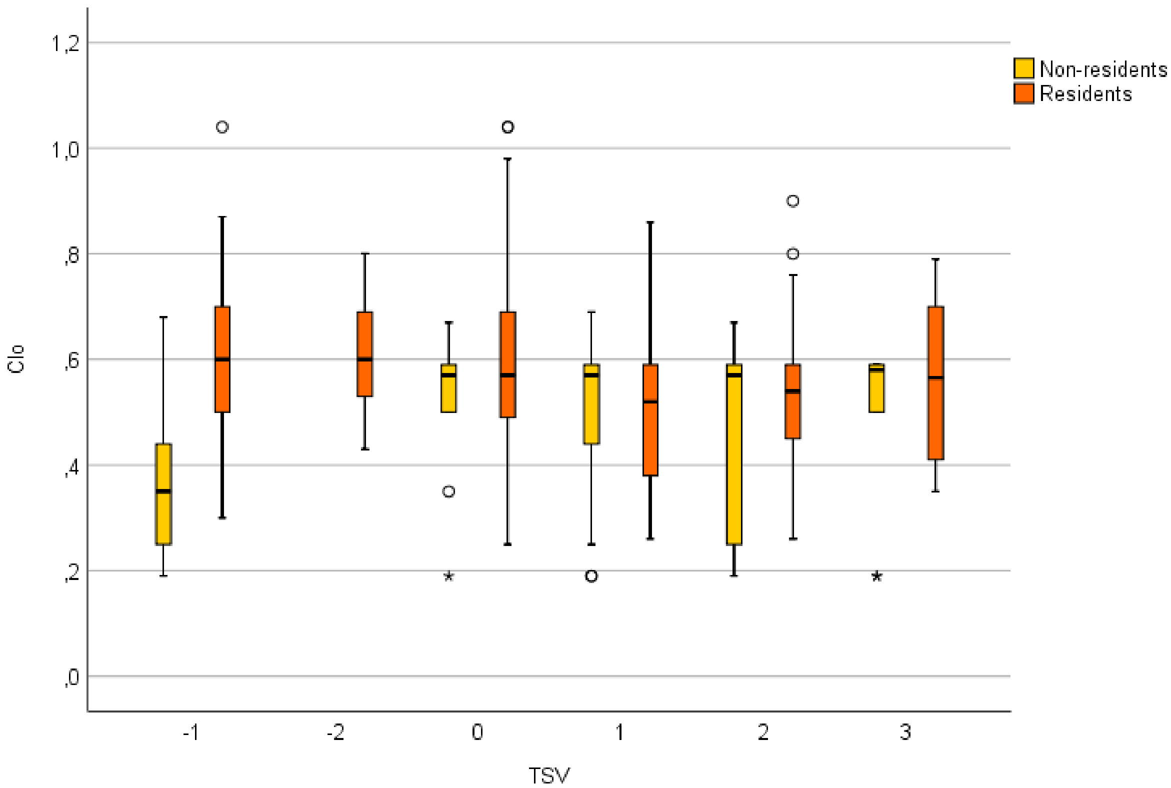

Figure 9. Box plot of the Clo against TSV for residents and non-residents

For residents, the level of activity (met) was also negatively correlated with the preference (r=-0.118, $p < 0.01$). When having more activity, they preferred cooler environments.
The TSV and the preference were positively correlated with the T_{op} (r=0.298 and 0.291, $p < 0.01$) respectively.
The results showed that the mean total clothing insulation of non-residents (Mclo) was negatively correlated with an increase in metabolic rate (r=−0.650, $p < 0.01$) and with a linear regression of MClo(NR)=-1.7362Met+3.1053. Surprisingly, the total clothing insulation of residents was not correlated neither with the metabolic rate (r=0.03, p < 0.01). nor the Body Mass Index (BMS) (r=0.02, $p < 0.01$) nor the age (r=0.02, $p < 0.01$). The linear regression of residents of MClo against met was found to be MClo(R)=8.8955Met-9.744.

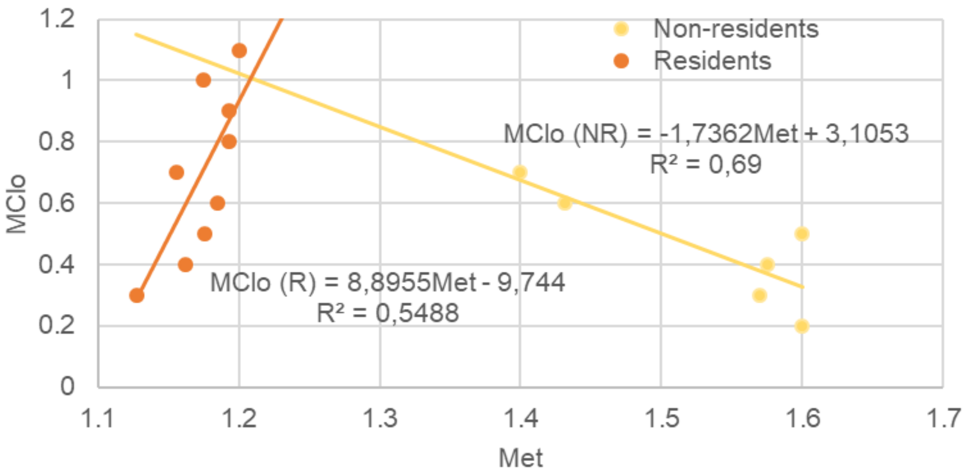

Figure 10. MClo against Met for residents and non-residents

4. DISCUSSION

Although some studies have been conducted on thermal comfort in elderly [8][14][24][25][26][27][28][10][29][30][31][32][7][33][11][34] very few focused on summer season in nursing homes. These studies range from tropical climate, to humid continental climate and subtropical humid climate [35][7][36][37][27][38].
Thus, results of the present study were compared with findings from the study investigated the thermal perceptions, preferences and adaptive behaviours of occupants in five nursing homes in Australia; those obtained by Hwang and Chen [7] who investigated the thermal sensations elderly people aged 60 years and over living in their homes in Hong Kong; and those obtained by Yang et al. [27] who studied thermal environmental conditions for elderly people living in 26 nursing homes in Korea. All these studies were carried out in the warm season.
Results found that the neutral temperature for elderly were 25.3 °C, while Hwang and Chen [7] found in Taiwan the neutral temperature for elderly people to be 25.2ºC, Tartarini et al [35] found in Australia to be 22.9 °C, and Yang et al. [27] found in Korea to be 25,8ºC.

All studies found neutral temperatures to be higher than 25ºC except the one from Australia. Although both studies were carried out in the summer, the outdoor temperatures were different for these studies. In our study the T_{rm} ranged from 22.2ºC to 27.4ºC while for example the study in Korea ranged from 26.2 °C to 34.8 °C [27]. In fact, the outdoor conditions and the climate does influence the thermal conform.
The common result about those studies that compared elderly with adults is that the neutral temperature was found to be different for elderly than for adults. Results of this study found that the neutral temperature for non-residents (caregivers and therapists) was 23,9ºC, 1.4 degrees below compared to elderly. Tartarini et al [35] also found that the neutral temperature for non-residents were lower than for residents. In this case 1.7ºC lower. This reinforces the fact that elderly feel more comfortable with higher temperatures.
In all studies [7] [27] [35], elderly people were found to be more tolerant than adults. However, previous studies have shown that older people are more vulnerable to extreme temperatures [3]. Thus, thermal comfort standards [3] [4] for elderly people recommend a 90% thermal comfort acceptability while, the 80% acceptability temperature range is recommended for other occupants. Table 16 summarise the results obtained in the present study, and results obtained by previous researchers who have studied the thermal comfort requirements of occupants of nursing homes.
Although the maximum temperature recommended by ISO 7730 [4] for the general population is 26 °C to obtain a 90% of acceptability, elderly people in different climate regions feel comfortable with higher temperatures (28.4ºC in the present study, 26,2ºC in the tropical climate and 26.3 in the subtropical humid climate).

Table 16. Range of comfort temperature in different research studies

Study	**Residents (90% acceptability)**	**Non-residents (80%acceptabilitiy)**
Mediterranean climate	23.2 to 28.4ºC	23.2 to 25.6ºC
Tropical climate (Australia) [35]	19.1 to 26.2ºC	18.7 to 25.3ºC
Subtropical humid climate (Taiwan) [7]	25.6 to 26.3ºC	

The upper comfort temperature obtained from results of this study is much higher (28.4ºC) than those obtained in the previous studies (26.2 and 26.3ºC). Other factors such as the clothing level and the outdoor conditions affect these results. Considering that the upper comfort temperature for adults was also found to be higher than in the previous studies, other influential factors such as the culture, the type of ventilation and cooling system might condition the results and should be explored in the future.
This study also found differences among men and women indicating that gender is a significant factor on the requirements of thermal comfort for elderly people in summer. Surprisingly and in contrast to other studies [7] [30] men were found to have higher neutral temperatures (25ºC) than women (24,3ºC) in summer.
Women tend to prefer higher temperatures than men in cold seasons [39]. However, this study highlights that in hot climates the behaviour is the opposite.
Within the residents, the age was not found to be correlated with the TSV, indicating that the thermal sensation of residents in nursing homes is not conditioned by their age. No information about the age of non-residents was available but they all were in the age

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of working (between 20 and 65). Therefore, the age was implicitly evaluated when analysing residents and non-residents separately. However, no differences regarding thermal comfort between those 65-year-old residents and those 95-year-old residents were found. Other factors such as the health, activity or if they live there permanently might also influence their thermal preferences.

Regarding the clothing adjustment, Hwang and Chen [7] in Taiwan observed that in summer, clothing adjustment was the most common strategy used by the participants for adaptation when thermal conditions were uncomfortable. However, in our study the level of clothing for elderly people didn't vary among TSV suggesting that residents do not adjust clothing to adapt to the uncomfortable thermal conditions.

Tartarini et al [35] and Hwang and Chen [7] also investigated the correlation between the clothing insulation and operative temperature of elderly people and found that the clothing insulation was correlated with the T_{op} by a linear regression ($Clo=2.37 - 0.07 *T_{op}$ for Hwang and Chen [7], and $Clo=2.20 - 0.0623* T_{op}$ for Tartarini et al [35]). In the present study the total clothing insulation of residents (clo) was also negatively correlated with the TSV ($r=-0.179$, $p < .01$). However, the operative temperature had a much lower influence on the total clothing level that the other studies ($Clo =0.5303-0.0015*T_{op}$). The level of clothing for residents did not vary among TSV suggesting that in the analysed nursing homes, the majority of residents do not adjust clothing to compensate for various thermal comfort conditions and wear the clothes that the caregivers prepare. However, under the same conditions, caregivers and therapists actively modify their clothing by wearing more or less under clothes below the long or short leaves smock. From this study, it is really relevant to notice that the clothing adjustment might improve the thermal comfort of elderly so caregivers might encourage residents to check how residents feel and modify their clothing adjustment based on their thermal satisfaction.

The same happens with the activity. The results showed that the total clothing insulation of non-residents (clo) was negatively correlated with an increase in metabolic rate ($r=-0.650$, $p=.01$). Surprisingly, the total clothing insulation of residents was not correlated neither with the metabolic rate, nor the Body Mass Index (BMS) ($r=0.02$, $p=.01$) nor the age ($r=0.02$, $p=.01$).

Results of this study also found that residents do have different thermal comfort sensations in the different common areas of the nursing home. The occupational therapy room is the area where residents feel more comfortable. This area is where residents are more entertained, doing intellectual of physical activities. These results suggest that different setpoint temperatures should be defined for the different common areas of the nursing homes and residents' routines might be redefined to exploit the physical and environmental conditions of the different areas of the nursing homes.

Further research needs to be conducted to provide detailed guidance to nursing home facilities management teams as to the best way to maintain comfortable temperatures for both groups of cohabitants of these buildings.

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5. CONCLUSIONS

This paper reports on an investigation into thermal perceptions and preferences of residents (elderly people) in nursing homes and compares them with their caregivers and therapists (adults).

The analysis of the results showed that although both groups considered the indoor environment to be comfortable over a wide range of temperature, residents were found to be more tolerant with high temperatures than non-residents since. The neutral temperatures estimated using a linear regression analysis were 24.4 °C for residents and 23,5ºC for non-residents.

Both groups had very similar thermal acceptability temperature. However, the thermal comfort with a 90% of acceptability for residents ranged from 23,2 to 28,4ºC while for non-residents from 23,2 to 26,3ºC. For non-residents the thermal acceptability with an 80% of acceptability ranged 23,2 to 25,6ºC. This confirms that elderly prefer higher temperatures than adults.

Although the TSV for residents was positively correlated with the T_{op} ($r=0.298$, $p < 0.01$), the Rho Spearman correlation analysis showed that the total clothing insulation of residents (clo) was negatively correlated with the TSV ($r=-0.179$, $p < 0.01$) indicating that residents do no modify the clothing to adapt to unsatisfactory thermally conditions or to the activity. In contrast, although the level of clothing of residents and non-residents is similar, caregivers and therapists actively modify their clothing by wearing more or less under clothes below the long or short leaves smock.

This study manifests that nursing homes should be designed and operated to provide appropriate indoor thermal environments to their different type of occupants.

Building design, environmental operational strategies and residents' activities scheduling might help improve thermal comfort in different areas of the nursing homes.

However, clothing adjustment of residents might be a simple and cheap way of adapting to uncomfortable thermal environments. Caregivers should be trained to help residents to address their thermal needs, particular for residents who may not have the ability to change clothes to adapt to their thermal preferences.

Caregivers should also facilitate behavioural thermal adjustments in residents (e.g. consuming cold drinks, attending to activities, etc.), which can significantly improve residents' thermal comfort.

The results of this research can be used to develop or refine guidelines to design and operate nursing homes based on real thermal needs of their occupants.

These results can be used to support the development and continuous refinement of guidelines to design and operate nursing homes based on real thermal needs of their occupants.

This study will contribute on a better quality of life for the elderly, extending their life expectancy and reducing energy consumptions and CO_2 emissions.

The results of this study will also enhance the promotion of good practices and regulations 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 similar studies in future but also professionals who manage nursing homes.

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Future steps include extending this analysis to the cold season and analysing the building and HVAC influence in the thermal comfort of elderly in the Mediterranean climate.

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