Building and Environment 214 (2022) 108930

Contents lists available at ScienceDirect

Building and Environment

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

The effect of climatic conditions on occupants' thermal comfort in naturally ventilated nursing homes

María Teresa Baquero Larriva [a], Ana Sofía Mendes [b], Nuria Forcada [a,*]

[a] Department of Project and Construction Engineering (DPCE), Group of Construction Research and Innovation (GRIC), Universitat Politècnica de Catalunya. (UPC), Colom, 11, Ed. TR5, 08222, Terrassa, Barcelona, Spain

[b] Environmental Health Department, Portuguese National Health Institute Doutor Ricardo Jorge, Porto, Portugal

ARTICLE INFO

Keywords:
Thermal comfort
Older people
Nursing homes
Naturally ventilated
Mediterranean climate

ABSTRACT

Climatic conditions influence thermal comfort. However, the effect of climatic conditions on occupants' thermal comfort in naturally ventilated nursing homes has not been analysed. This paper reports on a study to analyse the climate influence on the thermal perceptions of residents (elderly people) and non-residents (caregivers and therapists) from 18 nursing homes in three climatic zones: Csa-m (Mediterranean climate); Csa-c (continental Mediterranean climate) and Csb (oceanic Mediterranean climate). A mixed methodology was used including environmental measurements and on-site surveys during naturally ventilated seasons. A total of 2690 surveys were collected: 550 in Csb climate nursing homes, 1252 in Csa-m and 888 in Csa-c.

The results highlighted that nursing homes' occupants (elderly people and other adults) from the different climates perceived thermal comfort differently within naturally ventilated conditions. Outdoor temperature and outdoor humidity were found to influence indoor thermal sensation in the climates. Therefore, outdoor relative humidity should be considered when thermal comfort standards are developed, or thermal comfort is analysed. Neutral temperature for elderly people was found to be dependent on climate. These findings carry significant implications for regulatory bodies to develop guidelines for the design and operation of nursing homes in different climates.

1. Introduction

Population ageing is the demographic scenario for most developed countries. The World Health Organization (WHO) has forecast that by 2050, 20% of the population will be over 65 years old [1]. Life expectancy increases but not necessarily the years of a healthy life. Therefore, the number of nursing homes with 24-h care assistance provided by specialized staff is expected to increase. The interaction between microclimate and older people's health could impact the worsening of their chronic illness [2].

Indoor thermal environmental affects people's health and wellbeing [3]. According to the European Commission, people spend 90% of their time indoors [4], especially older people who are one of the groups that are most vulnerable to temperature effects [2,5–7]. Collins [8] has pointed out that indoor air temperatures below 15 °C negatively affect health by increasing the burden on the elderly circulatory system. The WHO recommends a minimum temperature of 20 °C for older people's indoor environments [3], while some studies emphasize the necessity of protecting older people from all kinds of thermal fluctuations [9].

Previous studies have demonstrated that older people's thermal sensations differ from their younger counterparts by up to 4 °C, due to physiological, psychological and behavioural components [10]. With age, some physiological factors like muscle strength, sweating, the ability to transport heat to the skin, hydration levels, vascular reactivity and cardiovascular stability decrease [11–13]. These changes affect their ability to detect and respond to temperature changes, which makes them vulnerable to thermal extremes and consequently to impacts such as pneumonia, cardiac arrest, dehydration, hypothermia, and hyperthermia. Additionally, most older people suffer from multiple chronic diseases [14] that could further alter their thermal regulation [15,16].

Some indoor thermal comfort studies have focused on older people's perceptions in dwelling environments [15,17–20]. Most of them analyse winter or summer seasons. For example, Hwang et al. [17] assessed the thermal sensation of older people in a Cwa climate (humid subtropical climate, dry winter and wet summer) [21] in their homes. According to their results, most older people prefer to open windows in summer to adapt to the thermal conditions instead of using air-conditioning. Cheng

* Corresponding author.
E-mail address: nuria.forcada@upc.edu (N. Forcada).

https://doi.org/10.1016/j.buildenv.2022.108930
Received 22 December 2021; Received in revised form 10 February 2022; Accepted 19 February 2022
Available online 22 February 2022

Abbreviations

Csa	Mediterranean climate
Csa-c	Mediterranean continental climate
Csa-m	typical Mediterranean climate
Csb	oceanic Mediterranean climate
T_a	dry air temperature
RH	relative humidity
T_r	mean radiant temperature
V_a	air velocity
T_{out}	outdoor dry temperature
RH_{out}	outdoor relative humidity
T_{op}	operative temperature
T_{rm}	running mean of outdoor temperature
T_g	globe temperature
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
R	residents (older adults)
NR	non-residents (caregivers, therapist etc.)
N	sample size
W	women
M	men
Tn	neutral temperature
TSV	thermal sensation vote
MTSV	mean thermal sensation vote
P	thermal preference
A	thermal acceptability
PMV	predicted mean vote
PPD	predicted percentage of dissatisfied
Clo	clothing insulation level
Met	metabolic activity

and Hwang [22] analysed the thermal comfort of older people in the same climate in summer and found that the neutral temperature for older adults was 0.4 °C lower than that of younger adults [17]. Ormandy and Ezratty [3] analysed the results of the WHO Large Analysis and Review of European Housing and Health Status (LARES) in eight cities across Europe to assess the relationship between health status, energy efficiency and thermal comfort. They concluded that social and climate characteristics influence the health and thermal comfort of occupants and the energy efficiency of buildings. They called this “the city effect”.

Other authors have assessed thermal comfort in nursing homes [23–27]. Most of them focus on cooling or heating periods [18,20, 28–30]. Forcada et al. [31–33] presented results on the perception of thermal comfort of nursing homes' occupants in summer and winter in the Mediterranean climate (Csa). They concluded that older adults were more tolerant to temperature changes than caregivers [23,24] and had a wider thermal comfort range than expected by the existing standards [27,34]. This study also found that older adults preferred higher temperatures than younger adults [26] and were more vulnerable to cold environments [24]. On the other hand, Mendes, et al. [35] analysed the thermal comfort of older people in an oceanic Mediterranean climate (Csb) and found that 42% of older adults were dissatisfied in winter. While Yang et al. [26] analysed 26 nursing homes in a humid continental climate (Dwa, Köppen-Geiger climate classification [36]) and found that older people prefer the cooling season, which is warm and slightly hot without air conditioning.

The only study on thermal comfort in naturally ventilated nursing homes was performed by Jiao et al. in a northern subtropical monsoon climate (Cfa) [37]. The study found that the factors affecting the thermal satisfaction of older people depend on the season. In winter, “time indoors” and “influence of sickness” were factors that influenced thermal comfort, while in summer “sleeping regularly” was also found to be significant.

Climate conditions vary throughout Europe and affect thermal comfort [38,39]. Considering this, the influence of climate conditions on occupants' thermal comfort might have interesting results for the adaptation of standards and the development of best practices. Other aspects that could be analysed include thermal adaptation apart from physiological (health status, age and metabolic rate), psychological (origin, expectation, experience, attitude, etc.) and behavioural factors (clothing insulation levels, trends in use of heating and cooling, adaptative actions), which are related to cultural and social factors specific to each locality and context [40].

This paper aims to: a) check whether climate affects indoor thermal comfort in naturally ventilated nursing homes by comparing the thermal comfort of occupants in different climatic conditions (Mediterranean [Csa-m], continental Mediterranean [Csa-c] and oceanic Mediterranean climate [Csb]); b) analyse the thermal comfort of the nursing homes' occupants including residents (people over 65 years old) and non-residents (caregivers and other staff) in nursing homes; and c) identify thermal comfort ranges for residents and non-residents in these three climates for naturally ventilated seasons.

2. Methodology

To evaluate the influence of climate on the thermal comfort of older people, 18 nursing homes were selected in three climatic zones of the Iberian Peninsula. Measurements of indoor environmental conditions and surveys of subjective thermal perception, preferences and the acceptability of occupants were collected in common areas, and the outdoor environmental conditions were measured. The experimental campaign lasted from 2019 to 2021 during naturally ventilated periods (neither heating nor cooling).

2.1. Climate description

According to the Köppen-Geiger climate classification (Fig. 1), 40% of the Iberian Peninsula corresponds to what is known as the “Csa” Mediterranean climate (temperate climate with dry and hot summers). Although this is found in most of Spain, there are two sub-climate particularities: the continental climate (Csa-c) in the interior and the Mediterranean climate (Csa-m) corresponding to the coastal area of the peninsula [41].

Csa-c is characterized by its low average relative humidity of 37% and an average temperature of 25°C–32.8 °C in summer. In winter, it has moderate-high humidity that reaches maximums of 71% and average temperatures of 2 °C–11 °C. The average annual temperature is around 14.1 °C [41,42].

Csa-m has constant average humidity throughout the year (64%–70%) and average temperatures of 18°C–28 °C in summer and 4°C–15 °C in winter. The average annual temperature is around 16 °C [40]. However, most of the northeast of the Peninsula, including the west coast of Portugal, is classified as Oceanic Mediterranean climate (Csb) (temperate with dry or temperate summer). It is influenced by the Atlantic Ocean, which is characterized by warm (but not hot) and dry summers, with an average temperature of 15–22 °C in the summer and 5°C-15 °C in winter. The average annual temperature is around 15.1 °C [41].

2.2. Experimental campaign

To assess the indoor thermal environment in common spaces, a Delta Ohm HD 32.3 instrument was used. The thermometer to measure globe

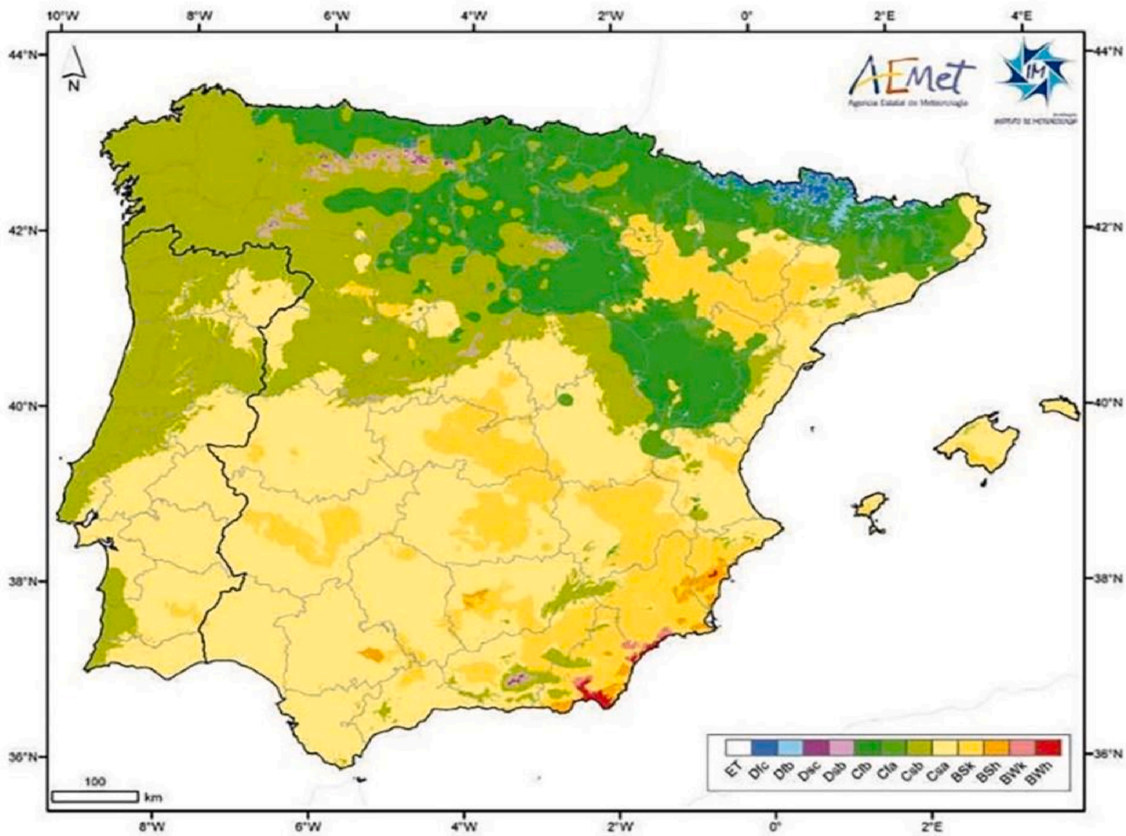

Fig. 1. Köppen-Geiger climate classification for the Iberian peninsula. **Source**: Iberian Climate Atlas [40].

temperature had a precision of ±0.2 °C and a tolerance of −10 °C to 100 °C. The probe to measure air speed had a precision of ±0.05 m/s and a tolerance of 0 m/s to 5 m/s. The thermometer to measure indoor air temperature had a precision of <±0.5 °C and a tolerance of −30 °C to 60 °C, and the probe to measure indoor relative humidity had a precision of ±3HR and a tolerance of 20%–80%.

The instrument was located approximately 1.5 m above ground and recordings were taken in each room, according to ASHRAE 55 [43], at the same time as the surveys were administered (which took between 20 and 40 min, depending on the number of occupants and activity).

For the outdoor dry temperature (T_{out}) and relative humidity (RH_{out}), data from the weather stations closest to each building were used.

Additionally, operative temperature (T_{op}) was calculated as a combination of the mean radiant temperature (T_r) and air temperature (T_a) effects by this formula: $T_{op}=(T_a + T_r)/2$.

To assess the influence of the outdoor environment, the 4-day weighted running mean of outdoor temperature (T_{rm}) was calculated using the formula: $T_{rm}= (T_{ed\text{-}1}+0.8\ T_{ed\text{-}2}+0.6\ T_{ed\text{-}3}+0.5\ T_{ed\text{-}4})/2.9$ [31, 44,45].

To determine the thermal perception of residents and caregivers in nursing homes, a questionnaire survey was administered based on three simple questions: for the thermal sensation vote (TSV), the ASHRAE seven-point scale was used (−3 cold, −2 cool, −1 slightly cool, 0 neutral, +1 slightly warm, +2 warm, +3 hot) [42]. For thermal preference (P), a three-point scale was used (−1 cooler, 0 without change, +1 warmer) and for thermal acceptability (A), a two-option question (1 acceptable, 0 unacceptable) was used.

Additionally, some variables were collected by observation, such as gender, level of clothing (clo) (including the chair) and metabolic rate (met, according to the activity), based on ISO7730 [46] and ASHRAE 55 [43].

All the variables were assessed through statistical analysis carried out using IBM SPSS 22 software, including chi-square tests and linear regressions.

2.3. Description of the case studies

A total of 18 nursing homes were selected for this study, distributed as follows (Fig. 2):

- Eight located in the municipalities of Porto, Matosinhos, Maia, Vila do Conde and Povoa do Varzim in Portugal, as representatives of the Csb climate.
- Five in Bétera, Valencia, Tarragona and Barcelona in Spain, corresponding to the Csa-m climate.
- Five nursing homes representative of the Csa-c climate, located in Las Rozas, Alcobendas, Colmenar Viejo and Madrid in Spain.

The experimental campaign was conducted between June and October 2019 in the “Csb” climate; March and June 2019 in the Csa-m climate and between April and June 2021 in the Csa-c climate, considering only the periods of natural ventilation (neither heating nor cooling), which may differ in each region. All measurements were made during the daytime, between 10 a.m. and 6 p.m., as this is when most of the residents use the common areas (including the living room, dining room, occupational therapy room and gym/physiotherapy room). Both the older adults (residents) and the other adults (caregivers and therapists) were surveyed during the measurements campaign.

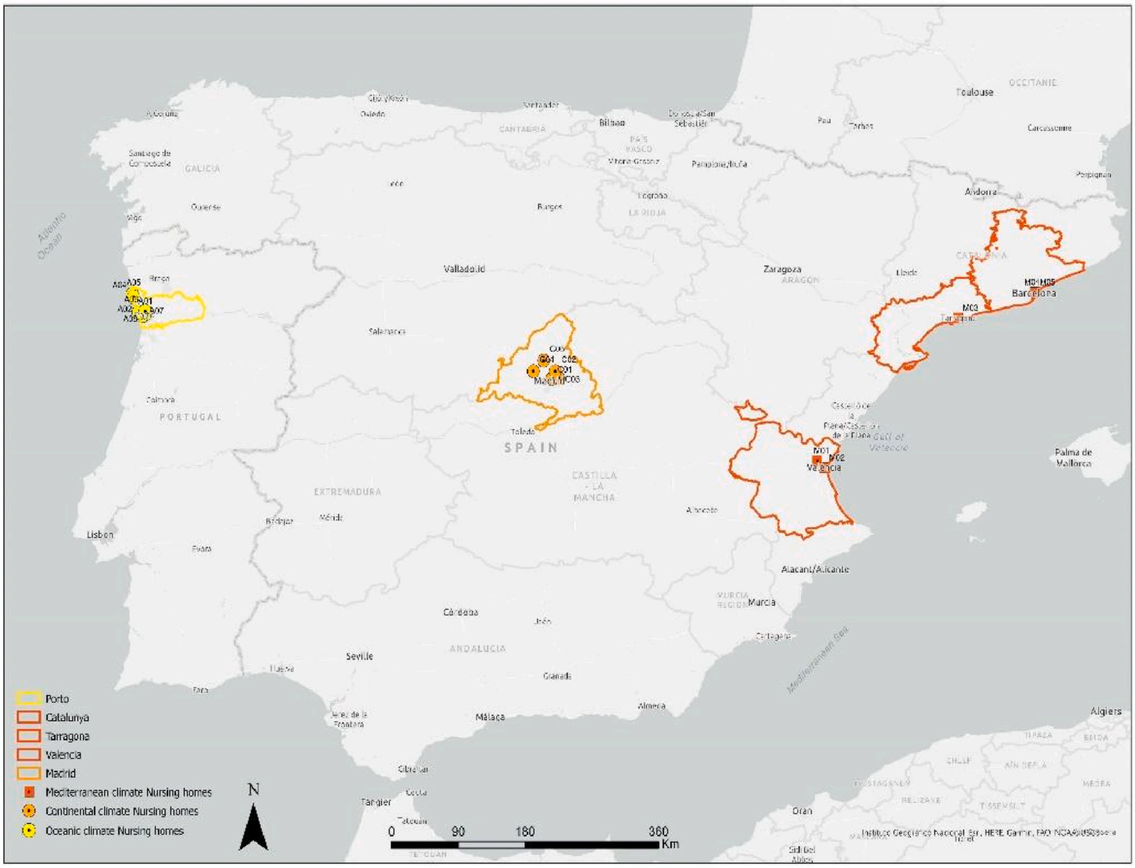

Fig. 2. Distribution of the studied nursing homes.

3. Results and discussion

3.1. *The indoor and outdoor thermal environment during the experimental campaign*

Table 1 presents a summary of the indoor and outdoor environmental conditions for each climate and study period.

Regarding outdoor environmental conditions during the study period, the Csb climate had the lowest air temperature (16.6 °C) and the highest relative humidity (74%) of the three climates, while the mean running temperature (T_{rm}) was similar to that of the Csa-c climate. The Csa-c climate had the lowest relative humidity (46%) as expected, while the Csa-m climate was the most moderate of the three.

The indoor environmental conditions varied among the three climates. Csb nursing homes had the lowest mean operative temperature (T_{op}) of 20.3 °C. The T_{op} was 24.5 °C for the Csa-m climate and 23.6 °C for the Csa-c climate. Indoor relative humidity was similar between Csb and Csa-m climates, while it was very low in the Csa-c climate (38%). In general, the Csa-m climate had higher indoor and outdoor temperatures during the study period.

3.2. *Sample description*

During the experimental campaign, a total of 2690 surveys were collected: 550 in Csb climate nursing homes, 1252 in Csa-m and 888 in Csa-c. Of those, 79% were residents, 21% were non-residents and 71%

Table 1
Summary of indoor and outdoor environmental conditions for each climate during the experimental campaign.

Climate		Indoor						Outdoor		
		T_g (°C)	T_a (°C)	RH (%)	V_a (m/s)	T_r (°C)	T_{op} (°C)	T_{out} (°C)	T_{rm} (°C)	RH_{out} (%)
Csb	Mean	24.0	24	53	0.04	24	20.3	16.6	16.7	74
	Max	30.1	30.6	76	0.22	30	25.7	26.3	22.4	96
	Min	18.6	18.3	32	0.01	18.6	18.4	8.9	9.1	0
	SD	2.1	2.1	10	0.03	2.1	2.7	4.2	3.7	17.4
Csa-m	Mean	24.5	24.6	54	0.02	24.5	24.5	19.2	19.5	63.5
	Max	28.5	28.4	68	0.07	28.5	28.5	28.2	27	84
	Min	19.7	19.6	42	0.00	19.7	19.6	12.1	13.3	50
	SD	1.8	1.8	7	0.01	1.8	1.8	4.5	4.0	8.4
Csa-c	Mean	23.5	23.8	38	0.01	23.5	23.6	17.8	16.9	46.3
	Max	28.9	28.7	56	0.15	29	28.8	27.6	22.3	84.2
	Min	18.2	18.3	20	0.00	18.2	18.2	12.4	10.4	19.3
	SD	1.8	1.9	8	0.02	1.9	1.8	4.1	3.4	15.6

Note: T_g = globe temperature; T_a = air temperature; RH = relative humidity; V_a = air velocity; T_r = mean radiant temperature; T_{op} operative temperature; T_{out} = outdoor air temperature; RH_{out} = outdoor air humidity; T_{rm} = running mean temperature.

were women. Only residents with good cognitive function were included in the study. Caregivers helped to select the participants. Table 2 presents the sample distribution by climate, gender and type of user.

3.3. Influence of the type of occupant on thermal perception

The chi-square test was used to compare the observed and expected frequencies of the subgroups, in this case, the type of users and their thermal perception (TSV, P and A). The null hypothesis was that the two sets of frequencies were equal. To identify groups with significant correlations at the 95% confidence intervals, the asymptotic significance (p) should be less than 0.05.

Differences in thermal sensation votes (TSV) between residents (elderly) and non-residents (adults) were found. These differences might be attributed to the difficulty in regulating body temperature with age [13], the lower basal metabolism and the higher sweat threshold of older people [12]. The existing field studies on nursing homes also found differences between both population groups. Elderly people tended to be colder and preferred a warmer climate [17,47] (Table 3).

3.4. Influence of the climate on thermal perception

To study the influence of the climate on thermal perception, the subgroups were analysed separately (residents/non-residents). Statistically significant differences were found ($p < 0.05$) among the TSV, P and A from the different climates (Csa-m, Csa-c and Csb) and type of users (Table 4).

The Mediterranean climates differ in that Csa-c have more extreme conditions in winter and summer, while for the Csb the environmental conditions in summer are milder than the others. However, the study was carried out during the naturally ventilated period (neither heated nor cooled). This period is mainly during spring and autumn in Csa-c and Csa-m and includes summer in Csb because no cooling is provided during the summer in the analysed nursing homes. If we compare the T_{rm} (Table 1) during the experimental campaign and the average outdoor conditions for each climate, we can conclude that climates with more extreme temperatures in summer (Csa-m) accept higher ranges of temperatures without heating or cooling (around 13°C–27 °C), while for the milder climates (Csb and Csa-c) the outdoor conditions without air conditioning are much lower (around 9°C–22 °C).

In addition to the climatic differences found between the three case studies even though all the nursing homes are in the Iberian Peninsula, the differences in TSV among the three climates and cities could be explained by various factors. These include the personal, psychological, cultural and background (experiences, expectations, habits and traditions) characteristics of each region, which could influence thermal perception and the way people adapt to the thermal environment [3,40,48]. For example, it could affect their clothing choices [49].

Therefore, climate adaptation was found to be a very important factor when thermal comfort limits and characteristics are determined [50]. Some authors noted the importance of the occupant's control over the environment as a physical or behavioural adaptation. In residential buildings, occupants have more freedom to control this by adjusting clothing, opening windows, or switching on cooling or heating systems, than in other environmental contexts such as nursing homes [51,52]. Studies have found that older people's most popular strategy of thermal adaptation is clothing adjustment [17,53].

The results of the present study found that metabolic activity (met) was higher for non-residents in general. In a comparison among climates, the residents' met was found to be higher in Csa-m than in the other climates and the non-residents' met was found to be higher in Csa-c than in the other climates (Table 5).

Regarding clothing levels (clo), significant differences were found for residents and non-residents from the different climates. Csa-m residents wore less clothing (Clo = 0.76) than Csb residents (Clo = 1.14) even though they did the same degree of activity. The same was found with non-residents. However, differences between residents and non-residents in the Csa-c climate were much more marked than in other climates (Table 5).

Adjusting the level of clothing is part of behaviour to adapt to the thermal environment. For this study, clothing adjustment was very high for Csb climate occupants and was not as noticeable for Csa-m occupants. Regarding the type of users, the clothing adaptation was always higher for residents than for non-residents, in all climates (Table 5).

To evaluate the relation between clothing insulation and outdoor conditions, a linear regression was performed between these two variables. Clo insulation and T_{rm} were found to be highly correlated ($R2 = 0.26$) in Csa-m occupants, including residents and non-residents. Jiao Y et al. [53] also found that these two variables were highly related to older people in Shanghai.

A linear regression between Clo and T_{rm} was developed for residents and non-residents in nursing homes climates (Table 5). The slope of the linear regression indicates that the amount of clothing of residents from Csa-m nursing homes were more sensitive to outdoor temperatures than in the other climates. The amount of clothing decreased when T_{rm} increased but the influence was weaker in the case of Csb.

Additionally, Spearman's correlation analysis was used to evaluate the correlation between TSV from the different climates and other quantitative variables (T_{out}, T_{rm}, RH_{out}, RH, V_a, T_g, T_a, T_{op}, clo and met) (Table 6). Spearman's correlation analysis is the measure of sample correlation when one of the variables is ordinal. For this study, the TSV was ranked on an ordinal scale. The sample correlation coefficient denoted "r" ranges between −1 and +1 and quantified the direction and strength of the association between the two variables.

The results of the present study showed that TSV is mainly influenced by indoor temperature (T_{op}) and there is no influence on indoor air velocity (V_a m/s) (Table 6). For the Csa-m climate, the indoor humidity (RH) was found to be a higher correlate ($r = 0.262$) than for the other climates. Indoor humidity for Csa-m nursing homes (mean RH = 54%) was found to be higher than for Csa-b (mean RH = 38%), which might explain the influence of the RH on the TSV in the Csa-m climate. In naturally ventilated buildings, high indoor humidity implies higher heat sensation.

The running mean temperature that was calculated based on the outdoor temperatures for the four previous days [32,44] was found to be highly correlated with the TSV in the Csb climate ($r = 0.349$). For Mediterranean climates, the correlation was found to be weaker. The Csb climate is that with the lowest outdoor temperatures. Therefore, this characteristic might be the main factor of the high influence of the T_{rm} on the TSV. On the other hand, the RH_{out} was found to be more highly correlated in the Csb climate than in the other climates.

Fig. 3 shows the TSV, P and A by climate and type of user. The results

Table 2
Sample characteristics by climate, gender and type of user.

Climate	N	N%	R	R%	NR	NR%	W	W%	M	M%
Csb	550	20	433	79	117	21	291	53	259	47
Csa-m	1252	47	972	78	280	22	934	75	318	25
Csa-c	888	33	733	83	155	17	697	78	191	22
Total	2690	100	2138	79	552	21	1922	71	768	29

Note: N = sample size; R = residents; NR = non-residents; W = women; M = men.

Table 3
Chi-square test between TSV, P, A and type of user.

	TSV		P		A	
	Value	Asymp. Sig. (2-sided)	Value	Asymp. Sig. (2-sided)	Value	Asymp. Sig. (2-sided)
Pearson chi-square	337.52[a]	.000	200.874[b]	.000	19.390[c]	.000
Likelihood ratio	303.67	.000	177.790	.000	18.251	.000
Linear-by-linear association	230.76	.000	158.062	.000	19.382	.000
No. of valid cases	2690		2690		2690	

Table 4
Chi-square test by type of user between TSV, P, A and climate.

	Residents				Non-residents							
	TSV		P		TSV		A		P		A	
	Value	Asymp. Sig. (2-sided)	Value	Asymp.Sig. (2-sided)	Value	Asymp. Sig. (2-sided)	Value	Asymp. Sig. (2-sided)	Value	Asymp. Sig. (2-sided)	Value	Asymp. Sig. (2-sided)
Pearson chi-square	307.17[a]	.00	104.52[b]	.00	146.24[c]	.00	61.37[d]	.00	16.33[e]	0.003	73.07[f]	0.000
Likelihood ratio	308.73	.00	106.55	.00	158.31	.00	67.13	.00	16.27	0.003	84.44	0.000
Linear-by-linear association	24.47	.00	3.70	.05	.39	.52	2.21	.13	11.77	0.001	1.30	0.253
No. of valid cases	2138		2138		2138		552		552		552	

[a] Four cells (19.0%) have an expected count of less than 5. The minimum expected count is 2.03.
[b] No cells (0.0%) have an expected count less than 5. The minimum expected count is 51.64.
[c] No cells (0.0%) have an expected count less than 5. The minimum expected count is 68.25.
[d] Seven cells (33.3%) have an expected count less than 5. The minimum expected count is .42.
[e] No cells (0.0%) have an expected count less than 5. The minimum expected count is 6.99.
[f] No cells (0.0%) have an expected count less than 5. The minimum expected count is 27.77.

Table 5
Activity (met), clothing levels and Pearson's correlation to mean running outdoor temperature by climate and type of user.

Residents				Non-residents				
Climate	Met	Clo	Linear function	Pearson correlation	Met	Clo	Linear function	Pearson correlation
sa-c	1.03	.92	Clo = $-0.022\ T_{rm} + 1.294$	$p < 0.05$	1.55	.67	Clo = $0.036\ T_{rm} + 0.059$	$p < 0.05$
Csa-m	1.17	.76	Clo = $-0.027T_{rm} + 1.289$	$p < 0.05$	1.44	.58	Clo = $-0.02\ T_{rm} + 0.963$	$p < 0.05$
Csb	1.05	1.14	Clo = $-0.009T_{rm} + 1.278$	$p < 0.05$	1.30	.91	Clo = $-0.002\ T_{rm} + 0.873$	$p < 0.05$

of this study found that under the same conditions, 69% of residents reported neutral TSV compared to only 37% of non-residents.

An analysis of TSV by climate showed that in the Csa-m, 69% of residents and only 29% of non-residents perceived the environment as neutral, while 44% of non-residents felt it was "slightly warm". Similarly, in the Csb climate, 51% of residents had a neutral TSV compared to just 36% of non-residents, and 52% had a "slightly warm" TSV. However, in the Csa-c climate, 79% of residents and 54% of non-residents reported having a neutral TSV. This was the climate with the greatest thermal satisfaction for all occupants.

Regarding the MTSV for residents, a slight difference was found among climates (0.2 for the Csa-m climate, −0.1 for the Csa-c climate and 0.1 for the Csb climate).

Similarly, regarding thermal preference (P), most of the occupants did not want to change the indoor environment. This percentage was highest in residents and lowest for the Csb climate. Most occupants found the indoor environment acceptable. However, there were differences between the climates: more occupants experienced an unacceptable thermal sensation in the Csa-m than in the other climates (38% of non-residents and 26% of residents).

For the study period and under natural ventilation, both residents and non-residents had different thermal perceptions depending on the climate. Residents and non-residents in Csa-m felt the most comfortable in terms of thermal sensation (TSV = 0), followed by Csa-c. Residents in the Csb climate perceived greater heat than in the rest of the climates, even though the indoor temperatures were similar (around 23 °C and 25 °C). However, the outdoor percentage of humidity might be an influential factor. For the Csb climate, outdoor average humidity was 74% while for the other climates it was much lower (63% and 46%). The study by Indraganti et al. [54] found that higher outdoor relative humidity leads to higher sensitivity to temperature variations. Although current adaptative indoor thermal comfort standards do not consider outdoor relative humidity, relative humidity might be considered when thermal comfort is analysed, as suggested by Vellei et al. [55] who assessed the thermal sensation in naturally ventilated buildings in 13 locations and proposed a new model that considers this variable.

Regarding acceptability, residents from all climates had the same perception and felt comfortable with the indoor environment, while most non-residents in Csb preferred a cooler environment. Some non-residents from Csa-m (30%) and Csa-c (40%) also preferred cooler environments. The same was found with non-residents but in this case non-residents from Csa-m also felt slightly hotter than residents.

Fig. 4 shows the percentage of P and A against TSV. In nursing homes in the Csa-c climate, 85% of the residents who felt "neutral" did not want to change the thermal environment and 97% of them found the environment acceptable. Regarding the Csa-m climate, although 92% of residents who perceived the environment as "neutral" did not want to change, 22% found it unacceptable (A = 0). The figure was similar for non-residents: 89% would not change and 18% perceived the environment as unacceptable.

A total of 71% of residents from nursing homes in the Csb climate with a neutral thermal sensation did not want to change. In this case,

Table 6
Spearman Rho correlation test between TSV by climate and environmental outdoor and indoor variables, level of clothing and activity.

			TSV by climate		
Variables			Csa-c	Csa-m	Csb
Outdoor environment	T_{out} (°C)	Correlation Coeff.	.192**	.148**	**.370****
		Sig. (2-tailed)	.000	.000	.000
	T_{rm} (°C)	Correlation Coeff.	.050	.195**	**.349****
		Sig. (2-tailed)	.137	.000	.000
	RH_{out} %	Correlation Coeff.	-.098**	.061*	**-.172****
		Sig. (2-tailed)	.004	.030	.000
Indoor environment	T_g (°C)	Correlation Coeff.	.328**	.364**	.404**
		Sig. (2-tailed)	.000	.000	.000
	T_a (°C)	Correlation Coeff.	.318**	.361**	.396**
		Sig. (2-tailed)	.000	.000	.000
	RH %	Correlation Coeff.	0.024	.262**	-.099*
		Sig. (2-tailed)	.235	.000	.020
	V_a (m/s)	Correlation Coeff.	.086**	−0.024	.120**
		Sig. (2-tailed)	.005	.394	.005
	T_{op} (°C)	Correlation Coeff.	.326**	.364**	.397**
		Sig. (2-tailed)	.000	.000	.000
Level of clothing	Clo	Correlation Coeff.	-.301**	-.310**	-.283**
		Sig. (2-tailed)	.000	.000	.000
Activity	met	Correlation Coeff.	.286**	.171**	.339**
		Sig. (2-tailed)	.000	.000	.000

**Correlation is significant at the 0.01 level (1-tailed).
*Correlation is significant at the 0.05 level (1-tailed).

31% stated that they had a "slightly warm" TSV (Fig. 3) and 74% of them did not want to change. This could be understood as a preference and indicates the acceptability of higher temperatures for older adults in the oceanic Mediterranean climate.

3.5. *Neutral temperature and comfort zone*

Regression equations that represent the mean occupants' thermal sensation (MTSV) as a function of the operative temperature (T_{op}) with weighted 0.5 °C binned data were obtained to evaluate sensitivity and obtain the neutral temperature (T_n) [32,56–59].

Table 7 and Fig. 5 present the linear regression of MTSV plotted against T_{op} by climate for residents and non-residents. All regression equations passed the goodness-of-fit ($R^2 > 0.5$).

From the linear regression analysis, both the neutral temperature and the sensitivity of residents in the different climates were found to be different.

For Csb, the neutral temperature was found to be much lower than for the Mediterranean climates (Csa-c and Csa-m). The results highlighted the same tendency for non-residents.

The high difference between the continental climate ($T_nR[Csb] = 18.1$ °C) and the Mediterranean climates (T_n R [Csa-c] = 24.4 °C and T_n R [Csa-m] = 22.7 °C) might be attributed to the adaptive behaviour of residents. In fact, the amount of clothing of residents in the continental climate was much higher (Clo = 0.91) than for Csa-c (Clo = 0.67) or Csa-m (Clo = 0.58).

In the equations (Table 7), the slopes represent thermal sensitivity to a change in the natural ventilated indoor environment. The results showed that all residents from the climates had similar thermal sensitivity, which was lower than for non-residents. Although both groups considered the temperature to be comfortable over a wide range of temperatures, residents were found to be more tolerant than non-residents. Most authors described similar results in terms of physiological characteristics, and the fact that thermal sensitivity decreases with

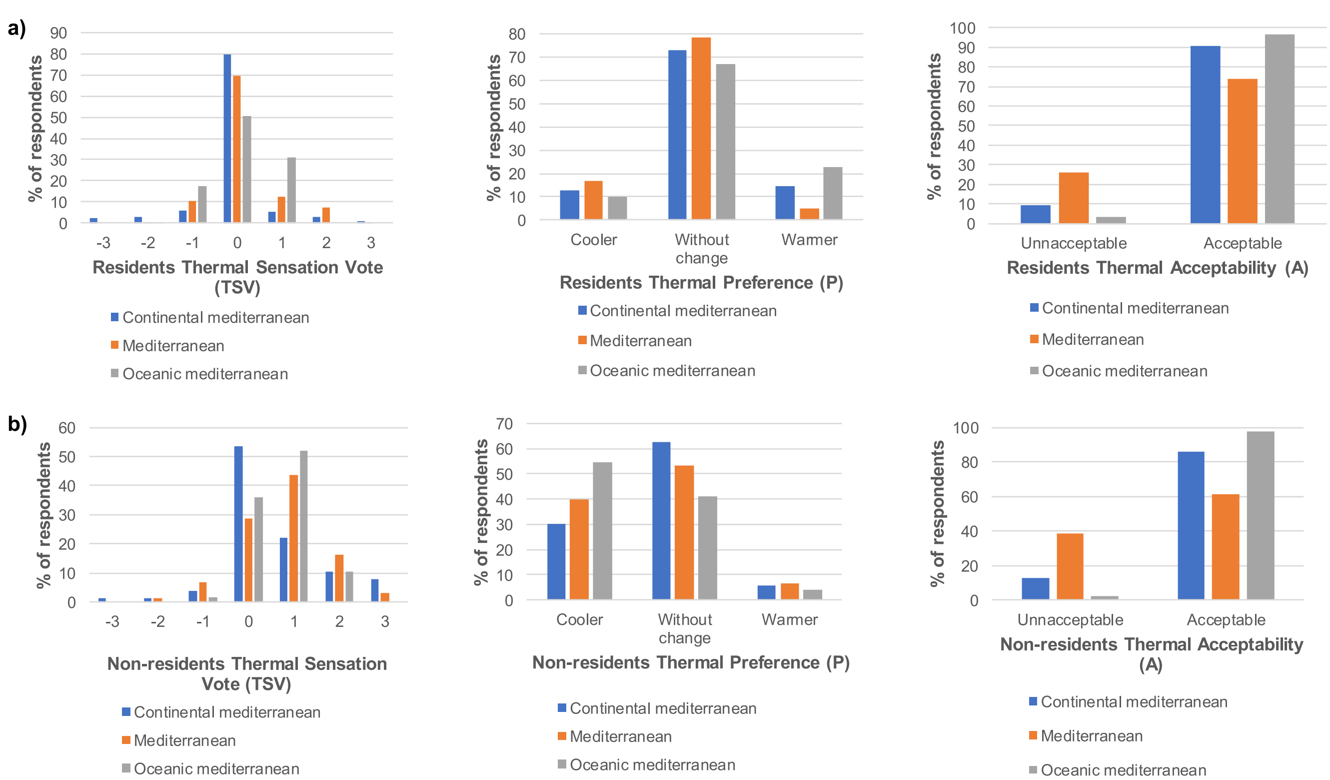

Fig. 3. Thermal sensation votes, preference, and acceptability by climate: a) residents; b) non-residents.

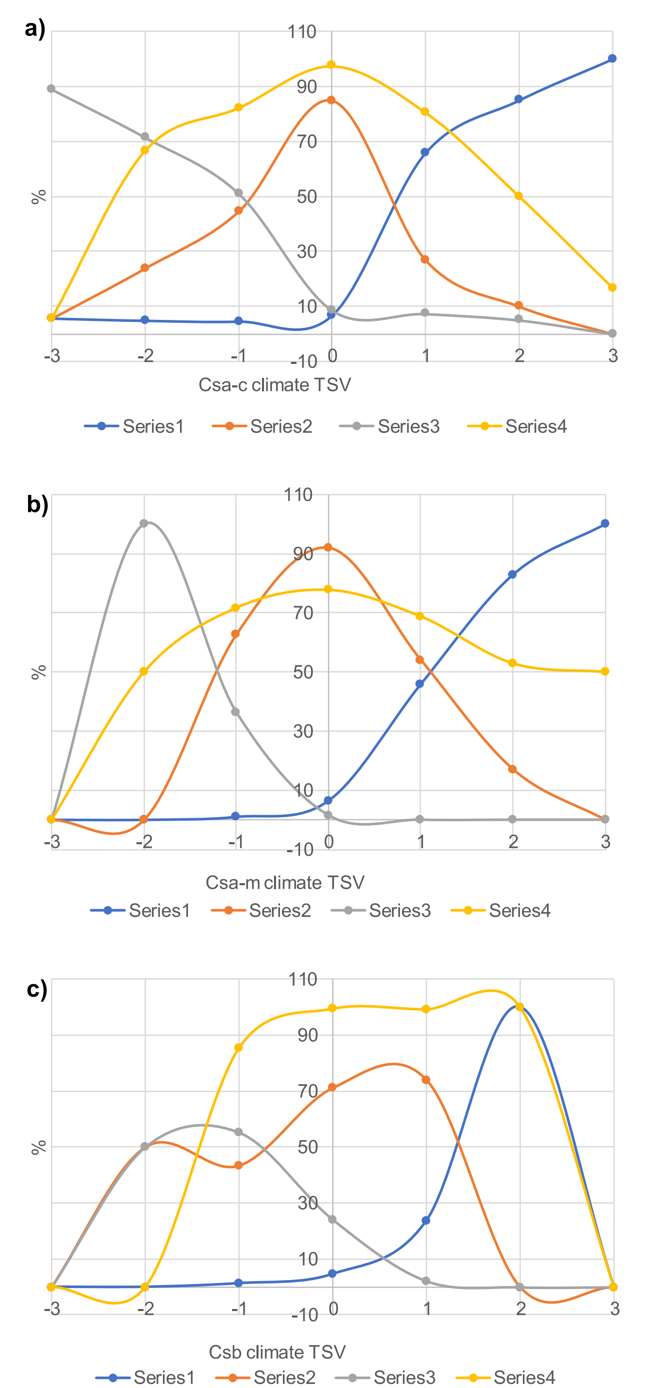

Fig. 4. Percentage of thermal sensation votes against thermal preference and thermal acceptability for residents. a) Csa-c climate, b) Csa-m climate and c) Csb climate.

age [10]. Hoof et al. [13] suggested that in most of the studies, older people tend to be less active, have a lower metabolic rate, wear more clothing and prefer warmer environments than younger adults. Other authors explained these differences in the perception of thermal environments between young healthy adults and older adults in hospitals or nursing homes due to the presence of pathologies and disabilities that may require medication and technical aids (wheelchairs) that also affect thermal comfort [60].

De Dear & Brager [61] highlighted the dependence of indoor comfort temperatures on outdoor air temperatures, especially in naturally ventilated spaces. In the present study, cooling systems in nursing homes in the Csb climate were not used (at any time of the year), and the heating periods were shorter, which is customary in this region due to its normally mild climate. Thus residents might acclimatize to not having air conditioning [50] and have a lower neutral temperature than residents from the other climates. Some authors stated that thermal comfort depends on some “not quantifiable” factors including acclimatization to a particular climate. This may vary in terms of the long-term experience of a humid and warmer climate, and how they could be more tolerant to higher temperatures than people who are native to colder or dryer regions [50].

The thermal comfort zone is defined by ASHRAE as the range of temperature in which at least 80% of the occupants are satisfied with the thermal environment or 90% for older people (Category I) [43,45]. Some authors suggest that the comfort zones are considered within the TSV interval of −1 and +1 [17–19,24,43,61–63].

Table 7 presents the thermal comfort zone by climate and type of users. It is striking that the lower limits of the ranges obtained for the Csb climate are well below those of the other two climates, especially in the case of non-residents.

The results for thermal comfort zones emphasize the lower thermal sensitivity of elderly people (residents) compared to other adults (non-residents) and their preferences for higher temperatures. Residents' comfort zones go up to 30 °C while non-residents only accept temperatures up to 25 °C. Differences were also found among climates. The comfort zones for the continental climate (Csb) were much lower than the thermal comfort zones for the Mediterranean climates (Csa-c and Csa-m).

3.6. *Predicted mean vote (PMV) vs. thermal sensation (TSV)*

Although the PMV model is usually associated with air-conditioned spaces and might not be suitable in surveys of people who adjust their environment, such as in naturally ventilated buildings [58], the applicability of the PMV model was analysed to demonstrate it and determine the variation of the results between climates.

The PMV for residents for all climates was calculated based on indoor environment (T_a, RH, T_r, V_a) and personal (clo, met) characteristics [42]. Linear regressions representing the PMV as a function of the operative temperature (T_{op}) with weighted 0.5 °C binned data were obtained (Table 8).

From the regression equations, the neutral temperature (PMV = 0) was calculated.

The conclusions on differences in thermal comfort for the different climates using the PMV model were similar to those obtained from the field survey (MTSV). The analysis of PMV regression equations showed that residents from the continental climate (Csb) were less sensitive to

Table 7
Linear regression models between MTSV and T_{op}, neutral temperature (T_n) and comfort zone by climate for residents and non-residents.

	Residents				Non-residents			
Climate	Equations	R^2	T_n °C	Comfort zone	Equations	R^2	T_n °C	Comfort zone
Csa-c	$MTSV = -4.3813 + 0.1799T_{op}$	0.85	24.4	18.9–29.7	$MTSV = -5.8175 + 0.2789T_{op}$	0.79	20.9	17.3–24.4
Csa-m	$MTSV = -2.789 + 0.1231T_{op}$	0.83	22.7	14.5–30.8	$MTSV = -6.9458 + 0.3191T_{op}$	0.83	21.8	18.6–24.9
Csb	$MTSV = -1.8058 + 0.0997T_{op}$	0.63	18.1	8.1–28.1	$MTSV = -1.7371 + 0.1235T_{op}$	0.54	14.1	6.0–22.2

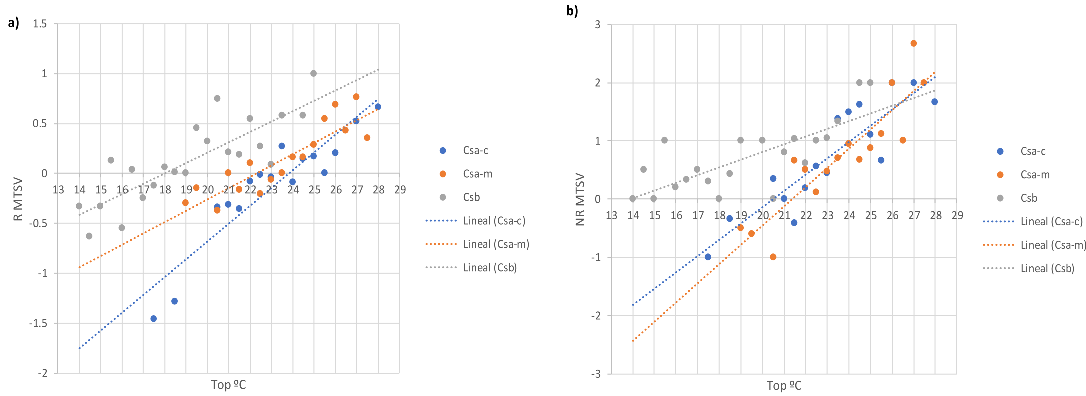

Fig. 5. Mean thermal sensation votes against T_{op} by climate: a) residents; b) non-residents.

Table 8
Linear regression models between PMV and Top by climate for residents.

Climate		Equations	R^2	T_n °C (PMV = 0)	Comfort zone °C (PPD = 10)
Csa-c	Residents	PMV = − 5.1572 + $0.2214T_{op}$	0.91	23.2	21.6–26.2
Csa-m	Residents	PMV = − 4.5275 + $0.2016T_{op}$	0.84	22.4	20.8–26.1
Csb	Residents	PMV = − 2.6081 + $0.1551T_{op}$	0.84	16.8	13.6–20.4

temperature changes (the slope of the regression equation was lower) than residents from Mediterranean climates (Csa-m and Csa-c). Residents' neutral temperatures for the climates using the PMV model were found to differ between 0.3 to 1 °C from those obtained from the MTSV.

Results from the analysis of the PMV model also found differences in thermal comfort of the elderly between climates, mainly between the continental climate and Mediterranean climates, which were similar to those obtained from the MTSV analysis.

Therefore, we can conclude that with some deviations, the PMV model for natural ventilated conditions might also be suitable for analysing differences among climate conditions in thermal comfort of older adults.

4. Conclusions

This paper reports on a study to analyse the climate influence on thermal perceptions of residents (elderly people) and non-residents (caregivers, workers, therapists, etc.) in nursing homes. Two Mediterranean climates (Csa-m, Csa-c) and an oceanic climate (Csb) were analysed through a field study based on environmental measurements and a survey during naturally ventilated seasons. A total of 2690 surveys were collected: 550 in Csb climate nursing homes, 1252 in Csa-m and 888 in Csa-c.

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

1. Climatic conditions affect occupants' thermal comfort in naturally ventilated nursing homes. Nursing home occupants (elderly people and other adults) from different climates perceive thermal comfort differently within naturally ventilated conditions. Statistical differences were found that were related to thermal perceptions in the three climates. This difference might be attributed to the outdoor conditions. The oceanic climate (Csb) had higher relative humidity and lower air temperature, while the relative humidity in the Csa-c was lower. Similarly, indoor relative humidity was lower in Csa-c, the operative temperature was lower in Csb, and Csa-m had higher air and operative temperatures.
2. The TSV within the analysed climates was mainly influenced by the indoor conditions (temperature [T_{op}] and humidity [RH]) but not by the indoor air speed (V_a m/s). Note that these results may be due to the very low air velocity that was present in these case studies (the windows were not always open). However, this relationship could change under other conditions. In naturally ventilated buildings, high indoor humidity implies a higher thermal sensation (warmer).
3. TSV was also influenced by outdoor conditions (T_{rm} and RH_{out}). Therefore, the influence of outdoor relative humidity should be considered when thermal comfort is analysed, since it is not normally considered in studies of this type, and they focus more on the influence of temperature.
4. Neutral temperature for elderly people was also found to be climate dependent. The neutral temperature differed for all the climates. It was 24.4 °C for Csa-c and 22.7 °C for Csa-m. It was found to be much lower for the Csb climate (18.1 °C). Clothing adaptation to thermal conditions was mainly adopted by the elderly in the different climates to adapt to the changing thermal environments. The amount of clothing decreased when T_{rm} increased but the influence was weaker in the oceanic climate.
5. The results from the comparison between thermal sensation votes (TSV) obtained from the field study and the calculated predicted mean vote (PMV) show that the PMV model also differentiated thermal comfort among the climates. The analysis of results from the PMV model were found to be similar to those obtained from the field study, which suggests that the PMV model could be suitable to analyse the influence of climatic conditions in naturally ventilated buildings for older people.

Table 9 presents a summary of the main differences among the field characteristics in nursing homes in the three assessed climates.

These results suggest that acclimatization and cultural factors influence thermal sensation in the three assessed climates. This research highlights the need for more research on naturally ventilated buildings, to better understand the factors that affect thermal comfort in older people in the different climates.

The gender bias of the samples (three quarters of the residents were women in Csa climates while only half were women in the Csb climate) is a limitation of this study. The influence of gender might also be analysed in future studies.

These findings have significant implications for regulatory bodies to develop guidelines for the design and operation of nursing homes in

Table 9
Main differences between the three case studies.

	Climate		
Variable	Continental (Csa-c)	Mediterranean (Csa-m)	Oceanic (Csb)
Outdoor environment	Lowest RH_{out} %		Highest RH_{out}% Lowest T_{out} °C
Indoor environment	Lowest RH%	Highest T_{op} °C RH% similar to Csb RH%	Lowest T_{op} °C RH% similar to (Csa m) RH%
Thermal perception	Highest % of TSV = 0	Highest % of A = 0	Lowest % of TSV = 0
Clothing level (clo)		Lowest Clo	Highest Clo
Activity (met)	NR highest met	R Highest met	
Neutral temperature °C	T_n for residents was 1.7 °C > T_n Csa-m		Lowest T_n
Comfort zone range			Lowest comfort zone and wider ranges
PMV vs. MTSV	Different PMV and MTSV	Similar PMV and MTSV	Different PMV and MTSV

different climates. The current findings support the use of natural ventilation at broader setpoint temperatures without compromising occupants' comfort and well-being. The adaptation of comfort setpoint temperatures based on the climate can significantly reduce energy consumption in nursing homes.

Funding

This research was funded by: 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; FEDER funds under project reference 6/2018_CIE_6 and the Spanish Ministry of Economy, Industry and Competitiveness under R&D project Thecoelen, reference no. PID2019-106777RB-C21.

CRediT authorship contribution statement

María Teresa Baquero Larriva: Writing – original draft, Investigation, Formal analysis, Conceptualization. **Ana Sofía Mendes:** Validation, Funding acquisition, Investigation, Resources. **Nuria Forcada:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

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. We would also like to thank Sanitas Mayores and especially the Eng. Marc Vallet and Eng. Albert Ayala 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.

References

[1] World Health Organization, Global Age-Friendly Cities: A Guide, 2007. France.

[2] F. Salata, I. Golasi, W. Verrusio, E. de Lieto Vollaro, M. Cacciafesta, A. de Lieto Vollaro, On the necessities to analyse the thermohygrometric perception in aged people. A review about indoor thermal comfort, health and energetic aspects and a perspective for future studies, Sustain. Cities Soc. 41 (2018) 469–480, https://doi.org/10.1016/j.scs.2018.06.003.

[3] D. Ormandy, V. Ezratty, Health and thermal comfort : from WHO guidance to housing strategies, Energy Pol. 49 (2012) 116–121, https://doi.org/10.1016/j.enpol.2011.09.003.

[4] EC-European Commission, Indoor Air Pollution: New EU Research Reveals Higher Risks than Previously Thought, 2003.

[5] Y. Sunwoo, C. Chou, J. Takeshita, M. Murakami, Y. Tochihara, Physiological and subjective responses to low relative humidity in young and elderly men, J. Physiol. Anthropol. Appl. Hum. Sci. 25 (2004) 229–238, https://doi.org/10.2114/jpa2.25.229.

[6] J. Xiong, Z. Lian, X. Zhou, J. You, Y. Lin, Potential indicators for the effect of temperature steps on human health and thermal comfort, Energy Build. 113 (2016) 87–98, https://doi.org/10.1016/j.enbuild.2015.12.031.

[7] World Health Organization, The Effects of the Indoor Housing Climate on the Health of the Elderly: Report on a WHO Working Group, Graz, Australia, 1982.

[8] K. Collins, C. Dore, A.N. Exton-Smith, Urban hypothermia: preferred temperature and thermal perception in old age, Br. Med. J. 282 (1981) 175–177, https://doi.org/10.1136/bmj.282.6259.175.

[9] L. Schellen, M.G.L.C. Loomans, B.R.M. Kingma, M.H. de Wit, A.J.H. Frijns, W. D. van Marken Lichtenbelt, The use of a thermophysiological model in the built environment to predict thermal sensation: coupling with the indoor environment and thermal sensation, Build. Environ. 59 (2013) 10–22, https://doi.org/10.1016/j.buildenv.2012.07.010.

[10] M.T. Baquero Larriva, E. Higueras García, Thermal comfort for the elderly: a systematic review of the scientific literature, Rev. Esp. Geriatr. Gerontol. 54 (2019) 280–295, https://doi.org/10.1016/j.regg.2019.01.006.

[11] D.T. Novieto, Y. Zhang, Thermal comfort implications of the aging effect on metabolism , cardiac output and body weight, in: Adapt. To Chang. New Think, Comf., 2010.

[12] J. Van Hoof, J.L.M. Hensen, Thermal comfort and older adults, Gerontechnology 4 (2006) 223–228, https://doi.org/10.4017/gt.2006.04.04.006.00.

[13] J. Van Hoof, L. Schellen, V. Soebarto, J.K.W. Wong, J.K. Kazak, Ten questions concerning thermal comfort and ageing, Build. Environ. J. 120 (2017) 123–133, https://doi.org/10.1016/j.buildenv.2017.05.008.

[14] A. Marengoni, S. Angleman, R. Melis, F. Mangialasche, A. Karp, A. Garmen, B. Meinow, L. Fratiglioni, Aging with multimorbidity: a systematic review of the literature, Ageing Res. Rev. 10 (2011) 430–439, https://doi.org/10.1016/j.arr.2011.03.003.

[15] L. Schellen, W. van Marken Lochtenbelt, M.G.L. Loomans, J. Toftum, M. de Wit, Differences between young adults and elderly in thermal comfort, productivity , and thermal physiology in response to a moderate temperature drift and a steady-state condition, Indoor Air 20 (2010) 273–283, https://doi.org/10.1111/j.1600-0668.2010.00657.x.

[16] A. Schneider, R. Rückerl, S. Breitner, K. Wolf, A. Peters, Thermal control, weather, and aging, Curr. Environ. Heal. Rep. 4 (2017) 21–29, https://doi.org/10.1007/s40572-017-0129-0.

[17] R. Hwang, C. Chen, Field study on behaviors and adaptation of elderly people and their thermal comfort requirements in residential environments, Indoor Air 20 (2010) 235–245, https://doi.org/10.1111/j.1600-0668.2010.00649.x.

[18] R. Bills, V. Soebarto, T. Williamson, Thermal experiences of older people during hot conditions in Adelaide, in: J. Zuo, L. Daniel, V. Soebarto (Eds.), Revisiting Role Archit. Sci. Des. Pract. 50th Int. Conf. Archit. Sci. Assoc. Proceedings, 2016, 2016, pp. 657–664.

[19] G. Fan, J. Xie, H. Yoshino, U. Yanagi, K. Hasegawa, C. Wang, X. Zhang, J. Liu, Investigation of indoor thermal environment in the homes with elderly people during heating season in Beijing, China, Build, Environ. Times 126 (2017) 288–303, https://doi.org/10.1016/j.buildenv.2017.09.031.

[20] R. Bills, Cold Comfort : thermal sensation in people over 65 and the consequences for an ageing population, in: Proc. 9th Wind. Conf. Mak. Comf. Relev., Cumberland Lodge, Windsor, UK, 2016.

[21] W. Koppen, E. Volken, S. Brönnimann, The thermal zones of the Earth according to the duration of hot, moderate and cold periods and to the impact of heat on the organic world, Meteorol. Z. 20 (2011) 351–360, https://doi.org/10.1127/0941-2948/2011/105.

[22] M. Cheng, R. Hwang, Thermal comfort requirements in air-conditioned residences in hot-humid climate, Tongji Univ. 38 (2008) 817–822.

[23] F. Tartarini, P. Cooper, R. Fleming, Thermal perceptions, preferences and adaptive behaviours of occupants of nursing homes, Build. Environ. 132 (2018) 57–69, https://doi.org/10.1016/j.buildenv.2018.01.018.

[24] L.T. Wong, K.N.K. Fong, K.W. Mui, W.W.Y. Wong, L.W. Lee, A field survey of the expected desirable thermal environment for older people, Indoor Built Environ. 18 (2009) 336–345, https://doi.org/10.1177/1420326X09337044.

[25] Y. Jiao, H. Yu, T. Wang, Y. An, Y. Yu, Thermal comfort and adaptation of the elderly in free-running environments in Shanghai, China, Build, Environ. Times 118 (2017) 259–272, https://doi.org/10.1016/j.buildenv.2017.03.038.

[26] J. Yang, I. Nam, J.R. Sohn, The influence of seasonal characteristics in elderly thermal comfort in Korea, Energy Build. 128 (2016) 583–591, https://doi.org/10.1016/j.enbuild.2016.07.037.

[27] Y. Wu, H. Liu, B. Li, R. Kosonen, D. Kong, S. Zhou, R. Yao, Thermal adaptation of the elderly during summer in a hot humid area: psychological, behavioral, and physiological responses, Energy Build. 203 (2019) 109450, https://doi.org/10.1016/j.enbuild.2019.109450.

[28] R. Bills, V. Soebarto, Understanding the changing thermal comfort requirements and preferences of older Australians, in: Living Learn. Res. A Better Built Environ. 49th Int, . Conf. Archit. Sci. Assoc., 2015, pp. 1203–1212. http://anzasca.net/category/conference-papers/2015-conference-papers.

[29] A. Hansen, P. Bi, D. Pisaniello, M. Nitschke, G. Tucker, J. Newbury, A. Kitson, E. Dal Grande, J. Avery, Y. Zhang, L. Kelsall, Heat-health behaviours of older people in two Australian states, Australas. J. Ageing 34 (2015) E19–E25, https://doi.org/10.1111/ajag.12134.

[30] M. Giamalaki, D. Kolokotsa, Understanding the thermal experience of elderly people in their residences: study on thermal comfort and adaptive behaviors of senior citizens in Crete, Greece, Energy Build. 185 (2019) 76–87, https://doi.org/10.1016/j.enbuild.2018.12.025.

[31] N. Forcada, M. Gangolells, M. Casals, B. Tejedor, M. Macarulla, K. Gaspar, Summer thermal comfort in nursing homes in the Mediterranean climate, Energy Build. 229 (2020) 110442, https://doi.org/10.1016/j.enbuild.2020.110442.

[32] N. Forcada, M. Gangolells, M. Casals, B. Tejedor, M. Macarulla, K. Gaspar, Field study on adaptive thermal comfort models for nursing homes in the Mediterranean climate, Energy Build. 252 (2021) 111475, https://doi.org/10.1016/j.enbuild.2021.111475.

[33] N. Forcada, M. Gangolells, M. Casals, B. Tejedor, M. Macarulla, K. Gaspar, Field study on thermal comfort in nursing homes in heated environments, Energy Build. 244 (2021) 111032, https://doi.org/10.1016/j.enbuild.2021.111032.

[34] P. Fanger, Thermal Comfort: Analysis and Applications in Environmental Engineering, Danish Tec, Copenhagen, 1970.

[35] A. Mendes, C. Pereira, D. Mendes, L. Aguiar, P. Neves, S. Batterman, J.P. Teixeira, Indoor air quality and thermal comfort . Results of a pilot study in elderly care centers in Portugal, J. Toxicol. Environ. Health, Part A Curr. Issues. 76 (2013) 333–344, https://doi.org/10.1080/15287394.2013.757213.

[36] M. Kottek, J. Grieser, C. Beck, B. Rudolf, F. Rubel, World map of the Köppen-Geiger climate classification updated, Meteorol. Z. 15 (2006) 259–263, https://doi.org/10.1127/0941-2948/2006/0130.

[37] Y. Jiao, H. Yu, Z. Wang, Q. Wei, Y. Yu, Influence of individual factors on thermal satisfaction of the elderly in free running environments, Build. Environ. 116 (2017) 218–227, https://doi.org/10.1016/j.buildenv.2017.02.018.

[38] S. Manu, Y. Shukla, R. Rawal, L.E. Thomas, R. de Dear, Field studies of thermal comfort across multiple climate zones for the subcontinent: India Model for Adaptive Comfort (IMAC), Build, Environ. Times 98 (2016) 55–70, https://doi.org/10.1016/j.buildenv.2015.12.019.

[39] M. Frontczak, P. Wargocki, Literature survey on how different factors influence human comfort in indoor environments, Build. Environ. 46 (2011) 922–937, https://doi.org/10.1016/j.buildenv.2010.10.021.

[40] I. Knez, S. Thorsson, Thermal, emotional and perceptual evaluations of a park: cross-cultural and environmental attitude comparisons, Build. Environ. 43 (2008) 1483–1490, https://doi.org/10.1016/j.buildenv.2007.08.002.

[41] Departamento de Producción de la Agencia Estatal de Meteorología de España y Departamento de Meteorología e clima de Portugal, Atlas Climático Ibérico. Temperatura del Aire y Precipitación (1971-2000), Closas-Orc, 2011. http://www.aemet.es/documentos/es/conocermas/publicaciones/Atlas-climatologico/Atlas.pdf.

[42] AEMET, Temperaturas medias y su comparación con las de los últimos 30 años. (Observatorio de Retiro), Banco Datos. Ayunt. Madrid Territ. y Medio Ambient, 2019. http://www-2.munimadrid.es/CSE6/control/seleccionDatos?numSerie=14020000020. (Accessed 22 March 2019).

[43] ASHRAE:55. Thermal Environmental Conditions for Human Occupancy, American National Standard (ANS), 2020.

[44] International Standard Organization, ISO 7726: Ergonomics of the Thermal Environment. Instruments and Methods for Measuring Physical Quantities, 1998.

[45] European Committee for Standardization, EN 15251:2006, Indoor environmental input parameters for design and assessment of energy performance of buildings-addressing indoor air quality, thermal environment, lighting and acoustics (2006).

[46] International Organization for Standardization, ISO 7730, Ergonomics of the Thermal Environment. Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria, 2005.

[47] J. Xiong, T. Ma, Z. Lian, R. de Dear, Perceptual and physiological responses of elderly subjects to moderate temperatures, Build. Environ. 156 (2019) 117–122, https://doi.org/10.1016/j.buildenv.2019.04.012.

[48] M. Nikolopoulou, K. Steemers, Thermal comfort and psychological adaptation as a guide for designing urban spaces, Energy Build. 35 (2003) 95–101, https://doi.org/10.1016/S0378-7788(02)00084-1.

[49] C.K.C. Lam, M. Loughnan, N. Tapper, Visitors' perception of thermal comfort during extreme heat events at the Royal Botanic Garden Melbourne, Int. J. Biometeorol. 62 (2016) 97–112, https://doi.org/10.1007/s00484-015-1125-4.

[50] N. Yamtraipat, J. Khedari, J. Hirunlabh, Thermal comfort standards for air conditioned buildings in hot and humid Thailand considering additional factors of acclimatization and education level, Sol. Energy 78 (2005) 504–517, https://doi.org/10.1016/j.solener.2004.07.006.

[51] H. Feriadi, N.H. Wong, Thermal comfort for naturally ventilated houses in Indonesia, Energy Build. 36 (2004) 614–626, https://doi.org/10.1016/j.enbuild.2004.01.011.

[52] G. Schiller Brager, R. de Dear, A standard for natural ventilation, ASHRAE J. 15 (2000) 250–260, https://doi.org/10.11436/mssj.15.250.

[53] Y. Jiao, H. Yu, T. Wang, Y. An, Y. Yu, The relationship between thermal environments and clothing insulation for elderly individuals in Shanghai, China, J. Therm. Biol. 70 (2017) 28–36, https://doi.org/10.1016/j.jtherbio.2017.07.002.

[54] M. Indraganti, R. Ooka, H.B. Rijal, Field investigation of comfort temperature in Indian office buildings : a case of Chennai and Hyderabad, Build. Environ. 65 (2013) 195–214, https://doi.org/10.1016/j.buildenv.2013.04.007.

[55] M. Vellei, M. Herrera, D. Fosas, S. Natarajan, The influence of relative humidity on adaptive thermal comfort, Build. Environ. 124 (2017) 171–185, https://doi.org/10.1016/j.buildenv.2017.08.005.

[56] M. Khoshbakht, Z. Gou, F. Zhang, A pilot study of thermal comfort in subtropical mixed-mode higher education office buildings with different change-over control strategies, Energy Build. 196 (2019) 194–205, https://doi.org/10.1016/j.enbuild.2019.05.030.

[57] M. Jowkar, H. Bahadur, A. Montazami, J. Brusey, The influence of acclimatization , age and gender-related differences on thermal perception in university buildings: case studies in Scotland and England, Build, Environ. Times 179 (2020) 106933, https://doi.org/10.1016/j.buildenv.2020.106933.

[58] R.J. de Dear, G.S. Brager, Developing an adaptive model of thermal comfort and preference, ASHRAE Trans 104 (1998) 145–167.

[59] Z. Wang, R. De Dear, M. Luo, B. Lin, Y. He, A. Ghahramani, Individual difference in thermal comfort: a literature review, Build. Environ. 138 (2018) 181–193, https://doi.org/10.1016/j.buildenv.2018.04.040.

[60] N. Humphreys, L. Webb, K.C. Parsons, A comparison of the thermal comfort of different wheelchair seating materials and an office chair, in: M.A. Hanson (Ed.), Taylor and Francis, Contemp. Ergon., London, 1998, pp. 525–529.

[61] R. De Dear, G.S. Brager, The adaptive model of thermal comfort and energy conservation in the built environment, Int. J. Biometeorol. 45 (2001) 100–108, https://doi.org/10.1007/s004840100093.

[62] X.L. Ji, W.Z. Lou, Z.Z. Dai, B.G. Wang, S.Y. Liu, Predicting thermal comfort in Shanghai ' s non-air- conditioned buildings, Build. Res. Inf. 34 (2006) 507–514, https://doi.org/10.1080/09613210600722511.

[63] H. Feriadi, N.H. Wong, S. Chandra, K.W. Cheong, Adaptive behaviour and thermal comfort in Singapore's naturally ventilated housing, Build. Res. Inf. (2010) 37–41, https://doi.org/10.1080/0961321021000013830.