# Evaluation of thermal comfort in elderly care centres (ECC)

**Nuria Forcada[1] and Blanca Tejedor[2]**

[1] 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. E-mail: nuria.forcada@upc.edu
[1] 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. E-mail: blanca.tejedor@upc.edu

**Abstract:** The demand for elderly care centres (ECCs) is increasing as the population ages. This paper presents a field investigation on the thermal comfort of elderly in ECC and compares the outputs of existing thermal comfort standards with perceived thermal comfort of the elderly occupants of the building. Indoor and outdoor conditions were measured along the year and in different zones of an ECC (bedrooms, living rooms and dining rooms). A questionnaire survey to the residents was used to gather the occupants' thermal satisfaction. The findings indicate that standards based on adaptive models to evaluate the thermal comfort in elderly people are more precise than those based on the predicted mean vote (PMV). Results also highlight that this group prefers higher temperatures than the rest of the population. The findings also suggest that the time of the day and if the space is air conditioned do also influence thermal comfort in ECCs. These results can help standardise thermal comfort of elderly people.

**Keywords:** thermal comfort, elderly people, elderly care centres (ECC), PMV, adaptive thermal comfort model.

## 1. Introduction

According to United Nations estimates, the total number of people aged 65 years and older was 506 million in 2008, and is anticipated to double to 1.3 billion by 2040, which will be 14 percent of the total global population (2015). By 2050, Europe will be the world's oldest region, with its elderly population increasing more than fivefold from 40 million to 219 million (Bentayeb et al., 2013). This trend explains the increasing demand for long-term care services (Damiani et al., 2009) such as elderly care centres (ECCs). Furthermore, considering that persons who are 65 years or older often spend a considerable portion of their lives indoors, the energy consumption of maintaining the indoor conditions of these centres is high (Mendes et al., 2015). Clearly, the thermal comfort of these centres cannot be ignored (Raymann and Van Someren, 2008).

The thermal environment can be described as the characteristics of the environment that affect heat exchange between the human body and the environment (Ashrae 2013). There has been extensive modelling and standardisation of thermal comfort, which both depend on physical and physiological parameters (Taleghani et al 2013).

In general, the elderly population has an average thermal comfort that is different from the general population (Hwang and Chen, 2010; Schellen et al., 2010; deGroot and Kenney, 2007; Hoof and Hensen, 2006) because their energy expenditure decreases (Antunes et al., 2005). Furthermore, indoor environmental conditions vary in space and time. Therefore, the specific features of comfort within different spaces and the well-being of older people living in ECC should be analysed. This paper is based on a literature review and quantitative and qualitative research and analyses thermal comfort needs in ECC. The aim of the study was to: 1) compare the output of existing thermal comfort standards using the monitored data in different zones (bedrooms, living rooms and dining rooms) in ECCs. 2) compare these results with the perceived thermal comfort of the elderly occupants of the building. 3) analyse the validity of existing standards to evaluate the thermal comfort of elders, and 4) study variability among different spaces and time slots within ECCs (bedrooms, living rooms and dining rooms),

## 2. Thermal comfort in ECCs

Thermal comfort in living environments is very important not only for health but also for the well-being (Kameni et al., 2014).

Thermal comfort is affected by clothing, activity, age, health status, sex and adaptation to the climate and local environment of the individual and the household (Vandentorren et al., 2006; World Health Organisation, 1984). However, levels of older people's comfort are an important part of a holistic view of well-being.

### 2.1. Evaluation of thermal comfort

When discussing thermal comfort, there are two main models that can be used: the predicted mean vote (PMV) model and the adaptive model. The most commonly used model for evaluating general or whole body thermal comfort is the PMV model by Fanger (1973). PMV is expressed on the Ashrae 7-point scale of thermal sensation (cold, cool, slightly cool, neutral, slightly warm, warm, hot). The outcome of the model is a hypothetical thermal sensation vote for an average person: i.e., the mean response of many people with equal clothing and activity levels, who are exposed to identical, uniform environmental conditions. Ashrae (2013) defines thermal sensation as a conscious feeling, which requires subjective evaluation. The PMV model is adopted by the international standards ISO 7730 (2005), Ashrae Standard 55 (2013) and EN 15251 (2007). These standards aim to specify conditions that provide comfort to most healthy building occupants. EN 15251 (2007) mentions that for spaces occupied by very sensitive and fragile people, PMV should be kept between -0.2 and +0.2 on the Ashrae 7-point scale of thermal sensation. EN 15251 (2007) includes 3 categories (I, II and III) and indicates that the most restrictive category should be adopted for elderly occupants, while Ashrae Standard 55 (2013) presents only 2 ranges (80% or 90% of satisfied people) and no specific indication for the elderly.

Another method to evaluate thermal comfort is the adaptive model, which is based on the idea that outdoor climate influences indoor comfort because humans can adapt to temperatures at different times of the year. Ashrae Standard 55 (2013) and EN 15251 (2007) include models of adaptive thermal comfort. The use of an adaptive comfort model considers people's tendency to adapt to fluctuating environmental conditions (Nicol et al., 2012). Adaptation can be physiological, psychological or behavioural, so a wider range of thermal comfortable conditions and a closer relationship with the external climatic environment can be obtained. The adaptive hypothesis predicts that contextual factors, such as having access to environmental controls, plays a role. This model assumes that occupants are sedentary, with metabolic rates of 1-1.3 met, and a prevailing mean temperature between 10°C and 33.5°C.

The Ashrae adaptive standard only applies to buildings with no mechanical cooling installed, while EN15251 can be applied to mixed-mode buildings provided the system is not running.

### 2.2. Characteristics of older adults living in ECC

The abovementioned standards mainly focus on office situations, which tend to be populated by people roughly aged between 20 and 65 years old. Most of the people in ECCs are aged 65 and over.

Although Ashrae suggested that the thermal sensation of old people and younger adults does not differ, and that the effects of sex and age is due to activity and clothing, several studies have indicated that the optimal thermal sensation of older people differs from that of younger adults (Schellen et al., 2010; Hwang and Chen, 2010; DeGroot, 2007; Hoof, 2006) and the two populations' sensitivity to hot and cold environments may vary. The process of biological ageing may affect the perception of thermal comfort because of a decrease in the ability to regulate body temperature with age. On average, older adults require higher ambient temperatures (Hong et al., 2015; Tweed et al., 2015; Hwang and Chen, 2010; Schellen et al., 2010; van Hoof et al., 2010).

Given the rapid increase in aging population in recent years, attention is now focused on thermal comfort in the design and planning of environments for the elderly (Yang et al., 2016; Walker et al., 2016; Alves et al., 2016; Hong et al., 2015; Tweed et al., 2015; Mendes et al., 2013; Mendes et al., 2015; Hwang and Chen, 2010; Schellen et al., 2010; Hoof et al., 2010).

Some studies focused on older citizens' comfort in housing (Miller et al. 2017, Jiao et al. 2017). However, the special characteristics of EECs where residents do not control thermal parameters and air conditioning systems can help analysing the validity of existing standards and more accurate and objective results can be extracted.

## 3. Method

Indoor occupants' thermal sensation is primarily influenced by the indoor climatic parameters present in the environment and by the behaviour of occupants to adapt to changes.

In this study, the measurements of indoor and outdoor climatic parameters of different zones within an ECC and the subjective questionnaire assessing the elderly people's thermal sensations were conducted simultaneously. Results were contrasted to existing thermal comfort levels to analyse the validity of current standards to evaluate the thermal comfort of elderly people.

### 3.1. Physical measurements

To determine thermal comfort based on the different standards, metabolic activity and clothing insulation were estimated with the assistance of ECCs staff and caregivers. Then, the indoor and outdoor air temperature, the mean radiant temperature and the air speed were also measured. The measurements were made in the places where the occupants were expected to spend time. For this study, temperature and humidity sensors together with globe thermometers were placed in different ECC areas (2 in the dining rooms, 2 in the living rooms and 2 in the bedrooms). Measuring equipment was placed according to ISO 7726 (2002). Physical measurements were collected from April 2013 to March 2014, so that the effect of different seasons could be analysed. In this study, the cooling season ran from June to August 2013, the heating season from December 2013 to February 2014, and midseason from April to May and September to November of 2013 and March of 2014.

These data were used to evaluate the thermal comfort by using the international current standards ISO 7730 (2005), Ashrae Standard 55 (2013) and EN 15251 (2007) and compare and analyse the comfort zones in existing regulations.

The comfort results from using existing regulations were then compared to residents' satisfaction using a questionnaire survey.

### 3.2. Questionnaire Survey

A survey to assess thermal environmental conditions was developed considering the special characteristics of elderly people (defined as people aged 65 and over). Caregivers administered the survey to selected ECCs occupants in winter (21st of February) and in summer (15th of July) at 11:00. Questionnaire survey results were contrasted to thermal comfort results obtained from the standards to evaluate the suitability of existing standards for older adults.

Thermal satisfaction is complex and subjective to the occupants (Kameni et al., 2014).

In the specific case study, occupants are older adults who in some cases might have some cognitive problems or mental deterioration. Therefore, a questionnaire survey was designed to get the most precise and objective thermal satisfaction from older adults. ECCs staff and caregivers suggested that using the Ashrae 7-point scale of thermal sensation (cold, cool, slightly cool, neutral, slightly warm, warm, hot) with older adults would bring confusions to the residents. In fact, a test was done with 5 of the residents and they could not distinguish among cold, cool and slightly cool and also among hot, warm and slightly warm. A new qualitative method was designed. The initial option was to show images of the thermal sensation such as a person in the desert sweating (hot), in the beach (warm) or just in summer (slightly warm) so as to distinguish among the different thermal sensations for heat. Symbols, draws and judgments were also used in other research approaches for kindergardens (Fabbri 2013). However, images didn't improve the determination of the thermal sensation of residents. They did only perceived when a room was cool or warm but not the different levels of cold of hot. Finally, the questionnaire was formulated to compare the comfort among zones (bedroom, living room, dining room) and time slots (morning, afternoon, evening). To increase the accuracy of the results, the same aspect was evaluated using several types of questions (for example, respondents were asked to determine the warmest area, and later in the survey to determine the hottest area). The test was successful and results were coherent with what was expected although no quantitative values where obtained to contrast to the calculated PMV from the standards. Then, a qualitative analysis to compare the questionnaire results and the analysis of the measured comfort parameters using the existing standards was carried out.

The survey consisted of three parts. The first included questions about the respondent (age, room number, sex, if he/she is heat sensitive or cold sensitive) and general thermal sensation. The second part included questions about thermal sensations (see Appendix 1). The questions were organised to determine thermal comfort during the day and in the various ECC areas.

Firstly, respondents were asked to determine the time of day (morning, afternoon or evening) when the ECC is cooler, the time of the day when the ECC is warmer, and the time of day when they feel most comfortable. Then respondents were asked to determine which space in the ECC (bedroom, dining room, living room, other) was cooler, which space was warmer, and where they feel most comfortable. The occupants were also allowed to explain their dissatisfaction by answering an open-ended question.

The survey was distributed to all residents who had sufficient physical and mental skills to complete it (48 residents both in summer and winter).

## 4. Building characteristics

The analysed ECC is called Sanitas Mayores Les Corts and is in Barcelona. Barcelona has a humid subtropical climate with mild winters and hot, humid summers. Sanitas Mayores Les Corts consists of two separate buildings with separate entrances that are connected internally on the ground floor. In the middle of the block is a garden for residents. The plot has a total area of 10,780m2: 6.869m2 corresponds to the Evarist building, 2.797m2 to the Caballero building, and 1114 m2 to the garden. Figure 1 shows an aerial view of the ECC.

Figure 1. Sanitas Mayores Les Corts

The Evarist building has six floors of rooms and Caballero has two. On the ground floor, there are shared areas such as cafeterias, multipurpose rooms and waiting rooms, as well as the administrative area. This ECC can accommodate 278 residents.

The main facade of the Evarist building is oriented northwest. The other façade faces southeast, so the rooms are designed to take advantage of the sun all day in the winter, and from morning until noon in the summer. The main facade of the Caballero building is also oriented southeast, but this building is lower.

Both buildings were built with the same construction materials. The structure is made from reinforced concrete and reticular slabs. The roof is flat, with extruded polystyrene insulation and a waterproofing asphalt polymer, finished with a layer of gravel. The exterior walls are ceramic perforated brick, coated with a monolayer coating. The interior dividing walls are plasterboard. The pavements of most areas (halls, corridors, rooms, control rooms, etc.) are made from compact marble, while bathrooms are made from stoneware non-slip flooring.

Sanitas Mayores Les Corts has two independent HVAC systems, one for each building. Both are air-water systems including one chiller, one boiler, an air handling unit (AHU) with heat recovery and several fan coils in the rooms. This is a two-tube system and includes thermostats in each zone, to adjust the set point temperature by 1ºC.

## 4.1. Residents' daily activities

Residents wake up between 8:00 and 8:30. They have a shower and go the dining room for breakfast. At 9:00 several activities are scheduled. Some residents just rest in the lounge while others enrol for these activities. Lunch is at 13:00. After lunch, some residents rest in their rooms while others rest in the living room. The afternoon programme starts at 17:00, and at 19:30 residents have dinner. At 21:00 they go to bed.

## 4.2. Operation of the ECC

In the winter, fan coil units are programmed to work from 7:00 to 11:00, during which time residents wake up and shower. In autumn and spring, fan coil units are scheduled to work from 7:30 to 10:30, and in summer from 8:00 to 10:00.

Then, at 16:00-17:00 (depending on the season) fan coil units are turned on again until 21:00, when residents go to sleep. Fan coils in the dining room and living room have the same schedule.

Although there is an AHU for each building, natural ventilation is found to be enough. Once the residents have left their rooms (8:30), cleaning staff open the windows and tidy up. This process lasts 10 minutes approximately. When residents are in the living room, the dining room is also ventilated.

# 5. Results

## 5.1. Monitored data results

Thermal comfort depends on the indoor and outdoor air temperature and relative humidity, the mean radiant temperature and the air speed.

Thermal comfort also depends on individual parameters such as the degree of activity and the level of clothing. In each area (bedroom, living room and dining room), residents carry out different activities throughout the day (in the morning and evening residents get dressed in the bedrooms, at midday they eat in the dining room, during the day and afternoon they read, play or rest in the living room, etc.). Therefore, the activity factor and the level of clothing was estimated with the support of the care givers and based on these conditions.

Thermal comfort is also influenced by variability during the day and over time in crowding or under-occupancy (Ormandy and Ezratty, 2012). For our study, only occupied times of the day in the different areas were analysed, and there was no variability in occupation. Residents always have the same routine every day and in all seasons. The same is true of weekdays and weekends. The special characteristics of an ECC where there is no unusual behaviour or improvisation make it easy to evaluate. Fluctuations in exterior conditions and the residents' routine led to the following hourly analysis: night: from 22:00 to 7:00; early morning: from 7:00 to 9:00; morning: from 9:00 to 13:00; midday: from 13:00 to 16:00; afternoon: from 16:00 to 20:00; evening: from 20:00 to 22:00.

Although thermal comfort also depends on health status and sex (Mendes et al., 2015), the proportion of men and women in ECC is generally similar. In the analysed ECC, residents do not have major diseases and can move around by themselves or in wheelchairs.

Based on ECC staff and caregivers, the following clothing characteristics (Clo) and degree of activity (Met) were selected for the areas and periods. Tables 1, 2 and 3 present this information, the interior and exterior conditions, and the fulfilment of ISO 7730 (2005), Ashrae Standard 55 (2013) and EN 15251 (2007).

Exterior conditions were typical from a Mediterranean country with mild winters and hot, humid summers.

At night exterior temperatures in winter are around 11ºC, in summer 24ºC and midseason from 15 to 20ºC, while relative humidity ranges from 67 and 75%RH along the year. At midday is when major differences among seasons exist. In winter, exterior temperature is around 15ºC, in summer 30ºC and in midseason from 22 to 23ºC.

## Bedrooms

Table 1 presents activity levels, clothing level, exterior conditions, interior conditions and thermal evaluation based on the standards for the different seasons and time slots for the bedrooms. At night, residents are sleeping, in the morning (from 7:00 to 9:00) they are changing, at midday they are resting and in the evening (from 20:00 to 22:00) they get undressed to go to bed.

Table 1. Bedroom data and thermal comfort analysis

| | Activity (Met) | Level of clothing (Clo) | T ext (ºC) | H ext (%) | T int (ºC) | H int (%) | Mean radiant T (ºC) | PMV | | | Sensation (Ashare) | PMV (EN-15251) | PPD (%)EN-15251 | Cat EN-15251 | Status Class I EN- |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Winter** | | | | | | | | | | | | | | | |
| Night | 0.8 | 0.96 | 11.1 | 67 | 24.2 | 39.6 | 24.2 | * | | | C | -0.88 | 21 | IV | C |
| Early morning | 1.2 | 0.57 | 12.5 | 64 | 24.5 | 41.3 | 24.5 | 0.01 | 5 | N | B | 0.01 | 5 | I | C |
| Midday | 0.8 | 0.96 | 15.2 | 55 | 25.1 | 37.5 | 25.3 | * | | | C | -0.55 | 11 | III | C |
| Evening | 1.2 | 0.57 | 12.1 | 66 | 24.2 | 38.7 | 24.2 | -0.09 | 5 | N | C | -0.09 | 5 | I | C |
| **Spring** | | | | | | | | | | | | | | | |
| Night | 0.8 | 0.75 | 15.7 | 70 | 25.8 | 44.7 | 25.8 | * | | | C | -0.64 | 14 | III | C |
| Early morning | 1.2 | 0.57 | 17.1 | 66 | 26 | 45.5 | 26 | 0.46 | 9 | N | A | 0.46 | 9 | II | C |
| Midday | 0.8 | 0.75 | 22.1 | 50.9 | 25.9 | 41.9 | 26.2 | * | | | C | -0.57 | 12 | III | C |
| Evening | 1.2 | 0.57 | 17.8 | 66.4 | 26 | 43.5 | 26 | 0.45 | 9 | N | A | 0.45 | 9 | II | C |
| **Summer** | | | | | | | | | | | | | | | |
| Night | 0.8 | 1 | 23.5 | 73.1 | 26.3 | 64 | 26.3 | * | | | B | 0.2 | 6 | II | C |
| Early morning | 1.2 | 0.57 | 25.8 | 65 | 25.8 | 63.7 | 25.9 | 0.55 | 11 | S.W. | A | 0.55 | 11 | III | C |
| Midday | 0.8 | 1 | 30.1 | 53 | 25.8 | 60.3 | 26.3 | * | | | B | 0.06 | 5 | I | T.C. |
| Evening | 1.2 | 0.57 | 24.8 | 70 | 26 | 63.7 | 26 | 0.6 | 12 | S.W | B | 0.6 | 12 | III | C |
| **Autumn** | | | | | | | | | | | | | | | |
| Night | 0.8 | 0.75 | 19.2 | 75 | 25.9 | 57.8 | 25.9 | * | | | B | -0.46 | 9 | II | C |
| Early morning | 1.2 | 0.57 | 21.5 | 70 | 25.7 | 57.4 | 25.7 | 0.46 | 9 | N | A | 0.46 | 9 | II | C |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Midday | 0.8 | 0.75 | 23.2 | 62 | 26.3 | 52.8 | 26.6 | * | | | B | -0.29 | 7 | II | C |
| Evening | 1.2 | 0.57 | 19.8 | 74 | 26 | 55.9 | 26 | 0.54 | 11 | S.W. | A | 0.54 | 11 | III | C |

* Metabolic rates below 1.0 are not covered by ASHRAE Standard 55-2013.
N: Neutral, S.W.: Slightly warm, C: Comfortable, T.W: Too warm, T.C: Too cool.

The activity level is different when residents are sleeping, dressing or undressing and just resting. The level of clothing does also differ for the different seasons.

At night, interior conditions in the bedrooms are very variable. In winter 24.2ºC and 39.6%HR while in summer 26.3ºC and 64%HR. Relative humidity is much higher in summer than in winter provoking a hotter thermal sensation.

In the midday, interior temperatures in bedrooms are kept quite constant (around 25 and 26ºC) but relative humidity is still very different (in winter 37.5%HR and in summer 60.3%HR).

**Living rooms**

Table 2 presents activity levels, clothing level, exterior conditions, interior conditions and the thermal evaluation based on the standards for the different seasons and time slots for the living rooms. During the morning (from 9:00 to 13:00) and the afternoon (from 16:00 to 20:00) residents spend the time resting, playing or reading in the living room.

Table 2. Living room data and thermal comfort analysis

| | Activity (Met) | Level of clothing (Clo) | T ext (ºC) | H ext (%) | T int (ºC) | H int (%) | Mean radiant T (ºC) | PMV | | Sensation (Ashare) | | PMV (EN-15251) | PPD (%)EN-15251 | Cat EN-15251 | Status Class I EN-15251 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Winter** | | | | | | | | | | | | | | | |
| Morning | 1 | 1.01 | 14.6 | 57.4 | 24.5 | 39.4 | 24.5 | 0,26 | 6 | N | B | 0,26 | 6 | II | C |
| Afternoon | 1 | 1.01 | 13.6 | 61.6 | 25.1 | 40.3 | 25.1 | 0,43 | 9 | N | B | 0,43 | 9 | II | C |
| **Spring** | | | | | | | | | | | | | | | |
| Morning | 1 | 0.74 | 21.4 | 53.5 | 25.8 | 45.7 | 25.8 | 0,31 | 7 | N | B | 0,31 | 7 | II | C |
| Afternoon | 1 | 0.74 | 19.1 | 60.1 | 26.6 | 45.7 | 26.6 | 0,56 | 12 | S.W. | C | 0,56 | 12 | III | C |
| **Summer** | | | | | | | | | | | | | | | |
| Morning | 1 | 0.61 | 29.7 | 55.5 | 25.5 | 62.8 | 25.6 | 0,14 | 5 | N | A | 0,14 | 5 | I | T.C |
| Afternoon | 1 | 0.61 | 27.1 | 62.2 | 25.5 | 63 | 25.7 | 0,16 | 6 | N | B | 0,16 | 6 | I | T.C |
| **Autumn** | | | | | | | | | | | | | | | |
| Morning | 1 | 0.74 | 22.7 | 63.1 | 24.4 | 59.4 | 24.4 | -0,02 | 5 | N | A | -0,02 | 5 | I | C |
| Afternoon | 1 | 0.74 | 21.2 | 69.7 | 24.7 | 61.1 | 24.7 | 0,09 | 5 | N | A | 0,09 | 5 | I | C |

* Metabolic rates below 1.0 are not covered by ASHRAE Standard 55-2013.
N: Neutral, S.W.: Slightly warm, C: Comfortable, T.W: Too warm, T.C: Too cool.

The activity level is the same in the morning and in the afternoon. Only, the level of clothing varies in the different seasons.

Interior conditions in the living room do only vary 1ºC from winter and summer but relative humidity differs more than 20% (relative humidity in winter is around 40%HR while in summer around 63%HR). However, interior conditions in the morning and in the afternoon are nearly the same.

## Dining rooms

Table 3 presents activity levels, clothing level, exterior conditions, interior conditions and the thermal evaluation based on the different standards for the various seasons and time slots for the dining rooms. The time slots in which residents are in the dining room are early morning (from 7:00 to 9:00), midday (from 13:00 to 16:00) and evening (from 20:00 to 22:00).

Table 3. Dining room data and thermal comfort analysis

| | Activity (Met) | Level of clothing (Clo) | T ext (ºC) | H ext (%) | T int (ºC) | H int (%) | Mean radiant T (ºC) | PMV | | Sensation (Ashare) | | PMV (EN-15251) | PPD (%)EN-15251 | Cat EN-15251 | Status Class I EN 15251 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Winter** | | | | | | | | | | | | | | | |
| Early Morning | 1 | 1.01 | 12.5 | 64 | 24 | 35.4 | 24 | 0.1 | 5 | N | A | 0.1 | 5 | I | C |
| Midday | 1 | 1.01 | 15.2 | 55 | 24.4 | 37.6 | 24.4 | 0.22 | 6 | N | B | 0.22 | 6 | II | C |
| Evening | 1 | 1.01 | 12.1 | 66 | 23.1 | 38.8 | 23.1 | -0.12 | 5 | N | A | -0.12 | 5 | I | C |
| **Spring** | | | | | | | | | | | | | | | |
| Early Morning | 1 | 0.74 | 17.1 | 66 | 24.7 | 44.4 | 24.7 | -0.05 | 5 | N | A | -0.05 | 5 | I | C |
| Midday | 1 | 0.74 | 22.1 | 50.9 | 25.8 | 44 | 26 | 0.32 | 7 | N | B | 0.32 | 7 | II | C |
| Evening | 1 | 0.74 | 17.8 | 66.4 | 25.1 | 44.9 | 25.1 | 0.08 | 5 | | A | 0.08 | 5 | I | C |
| **Summer** | | | | | | | | | | | | | | | |
| Early Morning | 1 | 0.61 | 25.8 | 65 | 25.8 | 60.9 | 25.8 | 0.21 | 6 | N | B | 0.21 | 6 | II | C |
| Midday | 1 | 0.61 | 30.1 | 53 | 26 | 60.9 | 26.3 | 0.33 | 7 | N | B | 0.33 | 7 | II | T.C |
| Evening | 1 | 0.61 | 24.8 | 70 | 26 | 63.4 | 26 | 0.31 | 7 | N | B | 0.31 | 7 | II | C |
| **Autumn** | | | | | | | | | | | | | | | |
| Early Morning | 1 | 0.74 | 21.5 | 70 | 23.6 | 57.4 | 23.6 | -0.29 | 7 | N | B | -0.29 | 7 | II | T.C |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Midday | 1 | 0.74 | 23.2 | 62 | 23.9 | 55.9 | 24.1 | -0.18 | 6 | N | B | -0.18 | 6 | I | T.C |
| Evening | 1 | 0.74 | 19.8 | 74 | 23.8 | 58.3 | 23.8 | -0.22 | 6 | N | B | -0.22 | 6 | II | C |

* Metabolic rates below 1.0 are not covered by ASHRAE Standard 55-2013.
N: Neutral, S.W.: Slightly warm, C: Comfortable, T.W: Too warm, T.C: Too cool.

The activity level is the same in all time slots but the level of clothing varies in the different seasons.

The temperature of the dining room in winter is around 24ºC and the relative humidity 37%. Summer temperatures and relative humidity are higher (around 26ºC and 61%HR). Midseason temperatures are similar to winter but with higher relative humidity.

### 5.2. Questionnaire results

Fifty-eight per cent of the respondents considered themselves to be neither heat nor cold sensitive. Twenty-seven percent considered themselves to be cold sensitive, while only 15% thought they were heat sensitive.

For the summer period, most respondents did not consider any time of day (53%) or any space in the ECC (57%) to be cooler. However, 24% of the respondents found the bedrooms to be the coolest space in summer. Regarding the sensation of warmth, almost all the respondents (47%) considered the afternoon to be the warmest time of the day, but no difference was perceived among spaces. The time of day when the ECC was considered most comfortable was the afternoon (45%), while 52% of the respondents considered there was no difference between spaces. Twenty-five percent considered the living room to be the most comfortable area. The warmest period of the day was considered the afternoon, and it was also stated to be the most comfortable time. These results reinforce the idea that old people would rather be hot than cold.

For the winter period, no respondents considered the afternoon the coldest time of day, while the morning and the evening were both considered to have the same cooling sensation. A total of 55% of respondents considered that there was no difference between spaces in terms of cooling sensation, followed by 27% of respondents who considered the bedroom to be the coolest area. The warmest time of the day was stated to be the afternoon (50%), although 42% of respondents considered that there was no difference. The dining room (42%) and living room (42%) were equally considered to be the warmest space in winter. Finally, respondents also considered that the afternoon was the most comfortable time of day (42%), followed by the evening (25%). A total of 33% of respondents considered there was no difference between areas regarding thermal comfort, but 25% of respondents believed that the living room was the most comfortable. These results also confirm that in cool periods (winter), the warmer spaces were believed to be the most comfortable.

The main finding is that both for summer and winter, the afternoon was the warmest time of day and the most comfortable. Respondents preferred higher temperatures in summer and winter.

Regarding the open-ended question, respondents mentioned that when the heating is on they feel dryness that causes breathing problems, and mouth dryness which is uncomfortable. However, ECC staff mentioned that humidity cannot be very high, because it can cause various respiratory allergies. Microorganisms that reproduce on wet surfaces (such as mites) also particularly affect people with chronic respiratory diseases (e.g., asthma). Humidity also acutely affects the symptoms of rheumatism and other bone diseases (e.g., arthritis).

## 6. Analysis of results

Questionnaire survey results were contrasted to thermal comfort results obtained from the standards to evaluate the suitability of existing standards for older adults. Although the results of the questionnaire survey were qualitative conclusions and comparisons could be drawn.

In bedrooms, for winter mornings and evenings when the temperature is around 24.5ºC and humidity around 41%RH and residents are getting dressed or undressed, all standards consider the bedroom to be within the comfort conditions or slightly warm.

Based on the EN15251 (2007) categories, in the bedrooms nearly all time slots and seasons met the comfort conditions for Category I, which is used for spaces occupied by very sensitive, fragile people.

Surprisingly, in the summer, when interior temperatures vary from 25ºC to 26ºC in bedrooms and Ashrae Sandard 55 (2013) considers the environment to be slightly warm (both in the morning and in the evening), with a PMV index of 0.6 (slightly warm) and 12% PPD, the results of the survey revealed that 24% of residents considered the bedrooms to be the coolest space. This suggests that, special comfort analysis and comfort thermal levels should be defined for these areas of the building.

On summer mornings, the adaptive standard considers the bedrooms to be too cool. This result corresponds with residents' feelings: they considered the bedrooms the coolest place in summer.

At night, Asharae 55 (2013) is not applicable, but the PMV in winter for the bedrooms (EN 15251 [2007]) was -0.88 with 21% of PPD not meeting old people's required comfort levels. At night, summer and autumn obtained 6% and 9% of PPD. However, the adaptive analysis for the night revealed a comfortable environment that met status class I for old people. The only residents' input for the night was that nobody complained about thermal comfort at this time.

Although residents consider the bedrooms to be the coolest space in summer, for them the most comfortable area is the living room in the afternoon, with 25.5ºC and 63%HR. However, it was slightly too warm according to the PMV method and slightly higher than defined by Spanish regulation (23-25ºC, 45-60%RH). Morning conditions (temperature and humidity) during summer do not vary from afternoon conditions. Then, solar radiation and natural lighting might be the main cause of their varying perceptions. Living rooms have high window façades to let the sun into the spaces. Outdoor conditions, which are normally better during the afternoon, directly affect the comfort sensation, although temperature and humidity are very similar. The fact that residents consider the living room to be the most comfortable place during the afternoon might also be because it is the zone where they spend much of their time and elder adults are not used to changes.

In winter, residents consider the warmest and most comfortable place to be the living room in the afternoon (25.1ºC, 40.3%HR), rather than in the morning (24.5ºC, 39.4%HR). These results also confirm that for cool periods (winter) the warmer spaces are considered the most comfortable (Hoof and Hensen, 2006; Hwang and Chen, 2010; Mendes et al., 2015).

Although PMV methods did not find any differences in comfort from morning to afternoon in the living room in winter, both temperatures are outside of Spanish Royal Decree 1027 (2007) levels of thermal comfort, but within humidity levels (20-23ºC, 40-50% RH).

According to ISO 7730 (2005) and EN 15251 (2007), the recommended level of thermal comfort for the elderly is not achieved in winter or spring. Both standards consider these conditions to be acceptable only for a normal level of expectation; not for a high level of expectation.

The temperatures in the living room were also within comfortable conditions according to Class I acceptability limits on the Adaptive EN 15251 (2007), except in the summer when they were too cool, mainly because of extreme exterior conditions (29.7ºC and 55.5% of RH in the morning and 27.1ºC and 62.2% of RH in the afternoon). These results contrast with residents' sensations, as they did not consider any time of day (53%) or any space in the ECC (57%) to be cooler.

The dining room was also considered to be the warmest place but also the most comfortable together with the living room, according to residents, although they did not meet the expected limits for ISO 7730 (2005) and EN 15251 (2007). The results for the dining room show that the PMV index (Asharae 55 [2013]) in all seasons ranges from -0.12 to 0.33 (neutral) while interior conditions in summer were around 26ºC.

The temperature of the dining room in winter ranges from 23.1 to 24.6 (higher than the comfort temperatures defined by Spanish regulation RITE (2007) [20-23ºC]) and humidity from 35.4% to 38.8% (lower than the range of comfort humidity defined by this regulation [40-50%]). However, conditions in winter were considered comfortable and within the high comfort levels of the different standards.

With the Asharae 55 (2013) PMV method, the sensation in the summer and autumn in the early morning, midday and evening in the dining room was comfortable, but the interior conditions did not meet the expected limits for ISO 7730 (2005) and EN 15251 (2007) for elderly people.

Furthermore, in summer, the temperature of the dining room was about 26.3ºC (higher than the comfort temperatures defined by Spanish regulation RD 1027 [2007] [23-25ºC]) and humidity 60.1% (a bit higher than defined by this regulation [45-60%]).

For the dining room, the adaptive EN 15251 (2007) results for the autumn revealed that the temperature was too cool for elderly people. These results contrast with residents' sensations: they did not consider any time of day (53%) or any space in the ECC (57%) to be cooler. These results suggest that the adaptive method might not be useful for ECC. Residents do not normally leave the building, are not allowed to adapt the conditions by controlling air conditioning, opening windows, etc., so exterior conditions might not influence their comfort.

## 7. Discussion

The analysis of the results suggest that the standards' comfort zones may be not warm enough for older adults, who reported an optimum temperature above 25ºC in all seasons. These results found significant differences between room and season for air temperature. Respondents felt more comfortable and satisfied during the cooling season than during the other seasons, due to their general preference for a high indoor temperature, in agreement with the results of Mendes et al. (2015).

Based on the results of this analysis, adaptive models to evaluate thermal comfort are more precise for older adults than those based on PMV and PPD. Exterior temperatures are determinant for the interior comfort. However, for midseason, the thermal sensation using the PMV and PPD comfort models in spring and autumn in all zones of the ECC was found to be neutral. Spring and autumn is half of the year in Mediterranean countries. During this period, exterior conditions are mild so interior comfort can be obtained without running the air conditioning. The comfort results during periods when no air conditioning is used leads us to conclude that general standards can be used for midseason. However, a thermal satisfaction analysis during these seasons should be carried out to support this conclusion.

These conditions should be contrasted with workplace regulations. Elderly cohabit with ECC staff and caregivers. The regulations determine temperature limits depending on the activity in the workplace. For example, in Spain, Royal Decree 486 (1997) on workplaces determined temperature limits of about 14-25ºC for light work and 17-27ºC for sedentary work. Depending on the area of the ECC and the activity of the caregivers, thermal limits should be balanced between those defined by the elderly thermal comfort and those acceptable for the workers' activity.

## 8. Conclusions

The aim of the paper was to compare and contrast the validity of existing standards to evaluate thermal comfort of older adults.

It highlighted the differences in thermal sensation between older people and the rest of the population, and the need for specific comfort regulations for older adults. In general, PMV/PPD comfort standards do not currently apply to the older population. They only determine higher restricted limits of PPD, instead of determining the conditions that affect thermal comfort. The results of this study highlighted that adaptive thermal comfort models are more accurate than PMV/PPD for older adults.

This study has developed a new questionnaire to evaluate thermal comfort for older adults. Comparing the thermal comfort among different zones allow getting the thermal comfort from the same respondents in the same time. Although being a qualitative method conclusions and comparisons could be drawn. However, this study should be enlarged to other ECCs and including a bigger sample size.

From the analysis, the comfort sensation in different zones (bedroom, living room and dining room) was found to be constant, due to the residents' routine. However, although with the same indoor conditions, level of activity and clothing, residents found the afternoon in the living room in summer more comfortable than the morning. The only parameter found to be different was the outdoor temperature (29,7ºC for the morning and 27,1ºC for the afternoon). Therefore, adaptive comfort models that are based on the exterior temperatures might be more precise than those based on static information.

This study makes a significant contribution to the continuing development and refinement of comfort standards that acknowledge the links between thermal characteristics for old people and their impact on comfort.

The fact that old people prefer higher temperatures in both winter and summer can be used by facility managers to adjust temperature set points. The results can be used for future design and refurbishment of ECCs and have the potential to be used for improving national and international standards.

Analysis of ECCs such as the one presented in the paper are objective enough to be used in other type of buildings for old people such as houses, elderly day care centres, senior community centres, retirement villages, etc.

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## Appendix A: COMFORT QUESTIONNAIRE

**Section A: respondent's details**

**1.** You are…

- ☐ Sensitive to cold
- ☐ Sensitive to heat
- ☐ Neither of the above

**2.** What would you like the temperature of the ECC to be like?

- ☐ Higher
- ☐ Lower
- ☐ The same as it is

**Section B: Thermal sensation**

**3.** When do you feel that the ECC is coolest?

- ☐ In the morning
- ☐ In the afternoon
- ☐ In the evening

**4.** Where do you feel that the ECC is coolest?

- ☐ Room
- ☐ Living room
- ☐ Dining room
- ☐ Another zone

**5.** When do you feel that the ECC is warmest?

- ☐ In the morning
- ☐ In the afternoon
- ☐ In the evening

**6.** Where do you feel that the ECC is warmest?

- ☐ Room
- ☐ Living room
- ☐ Dining room
- ☐ Another zone

**7.** When do you feel more thermally comfortable?

- ☐ In the morning
- ☐ In the afternoon
- ☐ In the evening

**8.** Where do you feel more thermally comfortable?

- ☐ Room
- ☐ Living room
- ☐ Dining room
- ☐ Another zone