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Evaluation of Thermal Comfort Perception in Social Housing Context

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***Abstract* – The influence of people on building performance is becoming increasingly significant. Including users' perspective in decision-making and design processes could help to improve occupants' well-being and the feasibility of interventions by providing more accurate information about heating preferences for energy models. Furthermore, understanding residents' level of thermal satisfaction could enable more appropriate measures to be taken to improve the energy efficiency of buildings. This study aims to define an indicator that measures the level of thermal satisfaction of social housing occupants so that it can be contrasted with other methods of analysis of perceived comfort and can be replicated in different building contexts. A way to analyse occupants' thermal satisfaction is proposed in a quantitative way, measured as the difference of the desired temperature and the perceived indoor temperature. The index was applied to a sample of 283 social housing dwellings in the Basque Country, Spain, with data obtained via surveys that include questions on thermal comfort in winter and households' characteristics. Furthermore, the indicator was compared to other variables, such as household income and energy expenses, to observe behavioural trends and possible cases of energy vulnerability. The obtained variable provides occupants' opinion and perception to ensure the suitability of the solutions for improving the energy efficiency of the building and the thermal comfort. It is also possible to apply it to different building typologies and compare the results with other models of perceived thermal comfort.**

***Keywords* – Built environment; occupant perception; satisfaction; social housing; thermal comfort.**

1. INTRODUCTION

Energy refurbishment policies for residential buildings are now being systematically promoted. While the primary objective of such policies is often focused on energy savings and environmental improvements [1], [2], there are studies that question the benefits of such interventions. Some life cycle analysis studies of retrofitting interventions conclude that the energy balance is negative in the medium term [3]. Furthermore, some studies based on the impact of household energy consumption reveal large divergences between predicted and actual consumption [4], [5], casting doubt on the savings figures used to justify the interventions [6]. Even in studies based on actual measurements of the environmental conditions of dwellings before and after interventions, significant improvements in comfort and air quality standards are sometimes not observed [7].

This is because the environmental quality of the dwelling and the assumed energy savings of retrofitting interventions are strongly influenced by occupants [8]. Regardless of the

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building's characteristics and the quality of the building envelope and installations, the occupant's behaviour have a significant influence on the indoor environmental quality and associated energy consumption [9].

Several factors condition this behaviour. Economic position and the possibility of using alternative resources for climate control of dwellings are key factors [10]. Additionally, the physiognomic, psychological, and cultural characteristics of people significantly influence the perception of thermal comfort [11]. In other words, thermal comfort is a subjective variable. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) defines it as 'the mental condition that expresses satisfaction with the thermal environment and is evaluated subjectively' [12].

Traditionally, stationary methods have been used to measure thermal comfort, which involve two types of variables. The first type consists of environmental variables, such as air temperature, mean radiant temperature, airspeed, and relative humidity. These variables can be measured by devices and are used to define comfort standards that determine the thermal satisfaction of a high percentage of people. The second type of variables are physiological variables, which are determined by metabolic rate and clothing insulation [13].

More recent studies focusing on the behaviour and adaptability of occupants have introduced new variables, such as gender, age, and culture. By using these variables, it has been possible to establish more specific standards that provide temperature values for which a group of people in the same indoor environment would be satisfied [14].

However, in many cases, there is a significant gap between thermal comfort standards and the perceived comfort of the users [15]. Most existing methods do not consider the individuality of occupants in thermal comfort and are based on the responses of large groups of people [16]. Although recent research has focused on studying new variables linked to individual characteristics and their influence on thermal perception, there are still no consolidated methods in this aspect [17].

Therefore, while person-related variables and self-reported data in thermal comfort studies could help to improve the accuracy of thermal comfort assessments and achieve thermal satisfaction in indoor environments [18]. A correct selection of variables could make this possible [19].

This study aims to define an indicator that measures the level of thermal satisfaction of social housing occupants. This indicator can be contrasted with other methods of perceived comfort analysis and can be replicated in different building contexts. The proposed method uses two subjective variables and can be applied to studies with large sample sizes or to obtain initial approximations of comfort perception. It also can be contrasted with objective data and other techniques for the study of thermal satisfaction, such as PPD or PMV.

Designing energy refurbishment strategies or specific actions in buildings or dwellings involves not only including human factors in the process, but also understanding the perception of the people who reside there.

Perception is a subjective factor associated with the particularities of each individual, regardless of whether they share common socio-economic or socio-demographic characteristics. The phrasing of survey questions, along with the respondent's motivation and interest, can influence both the answers and their subsequent interpretation [20]. Therefore, comfort models that measure perception can yield disparate results. In this regard, it is suggested that asking individuals whether they are comfortable or not may not be sufficient. The proposed indicator suggests integrating two variables that can address the single comfort response and enable comparison with other existing thermal comfort models.

While the ideal scenario would be to propose specific solutions for the improvement of each household, providing solutions that cover the requirements of individuals in a building could

lead to greater well-being for those people. Incorporating users' perspective in decision-making and design processes could help to improve occupants' well-being and the feasibility of interventions and the adequate performance of the building stock by providing more accurate information about heating preferences for energy models. Furthermore, understanding residents' level of thermal satisfaction could enable more tailored measures to be taken to improve the energy efficiency of buildings considering its context.

2. METHODOLOGY

This study applied qualitative analysis to define a winter thermal comfort index for residential buildings.

2.1. Data collection

The thermal comfort index was applied to a sample of 283 social housing dwellings in the Basque Country, Spain. The data used for the index was obtained from surveys conducted as part of a project for energy management of social housing in the Basque Country. The surveys were conducted by telephone in May 2021, and participation was voluntary. Collected data is anonymous in order to exclude any possible identification of the dwelling. The survey included information related to housing, home characteristics, comfort, and preferences. The variables that were used to calculate the thermal comfort index and its relationship with the households are as follows:

- Desired indoor temperature;
- Perceived indoor temperature;
- Average monthly energy expenditure;
- Average household income;
- Number of occupants in the dwelling;
- Heating system and Domestic Hot Water (DHW);
- Use of the heating system.

The responses for temperature, expenses and income were given as a range, obtaining ordinal categorical data. The variable on the use of the heating system refers to the type of system used: no heating system (NHS), use of the building's heating system (NUHS), use of other appliances having a heating system (UOA).

2.2. Research approach

An indicator is proposed to measure thermal comfort as the difference between the perceived indoor temperature and the desired indoor temperature. The indicator is applicable to winter and summer, however, in this study the winter thermal comfort condition was analysed.

The temperature responses were collected as four categories: less than 16 °C, 16–19 °C, 19–21 °C and more than 21 °C. It was intended as a more accessible and intuitive response, which facilitated the perception response rather than giving a specific numerical value. This data was transformed as units for the contrast of the two variables. In this way, the result of the indicator were difference points: positive if the desired temperature was lower than the perceived temperature, neutral if the desired temperature coincided with the perceived temperature, and negative if the desired temperature was higher than the perceived temperature. The difference could therefore be 1, 2, 3 points (positive or negative) or neutral. If the person perceived more temperature in their dwelling than they would like, the result

was a positive number. On the other hand, if the person felt that the temperature was lower than they would like, the result was a negative number.

Comfort was considered to exist when the perceived indoor temperature coincided with the desired temperature, i.e., when the difference was zero. If the indicator was positive or negative, some discomfort is considered to exist. The higher the result of the difference, the greater the difference between the desired temperature and the perceived indoor temperature.

This indicator makes it possible to contrast two variables with subjective response. In contrast to a single thermal comfort response (hot, good or cold), this indicator makes it possible to determine in what way the thermal satisfaction is given or to what extent it differs from what is desired. It can also be contrasted with other variables related to the home or dwelling.

As this is subjective data, it is important to bear in mind that the actual temperature of dwellings may not coincide with the perceived temperature. This variable is only used to determine the thermal satisfaction of households and not to assess the indoor environmental quality of the dwelling.

3. RESULTS

3.1. Thermal comfort perception

The comfort indicator was obtained for 283 social housing dwellings of 16 different buildings. After comparing the comfort temperature or the desired indoor temperature and the perceived indoor temperature of the households listed in Table 1, it can be observed that 50 % of households would like to be at a temperature from 19 to 21 °C and 43.11 % at temperatures from 16 to 19 °C. As for the perceived indoor temperature, 78.8 % perceived their dwelling to be from 19 to 21 °C, while only 1.77 % perceived their dwelling to be from 19 to 21 °C.

TABLE 1. COMFORT TEMPERATURE AND PERCEIVED INDOOR TEMPERATURE

	Desired indoor temperature		**Perceived indoor temperature**	
	Absolute frequency	**Percentage, %**	**Absolute frequency**	**Percentage, %**
<16 °C	2	0.71	54	19.08
16–19 °C	122	43.11	223	78.8
19–21 °C	143	50.53	5	1.77
>21 °C	16	5.65	1	0.35

The results of the indicator showed that in 40 % of the dwellings the desired temperature corresponded to the perceived indoor temperature, so that 113 of the 283 dwellings analysed were in a comfortable situation. 60 % of the dwellings are 1, 2 or 3 points below the desired temperature, 44 %, 15 % and 1 %, respectively, as shown in Fig. 1. Furthermore, there were no dwellings above the desired temperature.

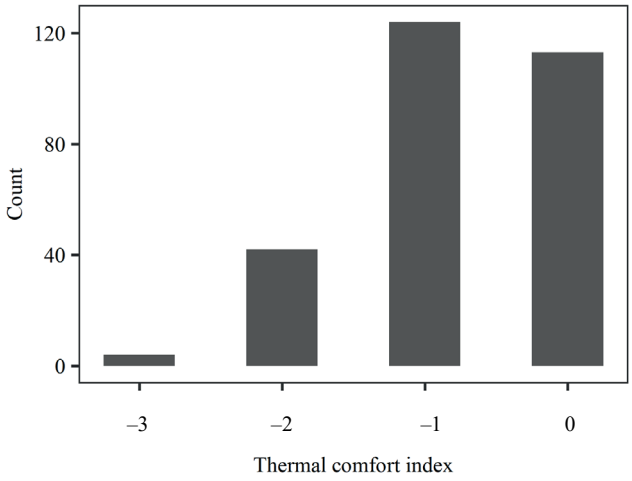


Fig. 1. Thermal comfort index levels.

Fig. 2 shows the results of the comfort temperatures and the perceived temperatures of the sample. Temperature responses, both perceived indoor temperature and comfort temperature are as follows: 1 (less than 16 °C), 2 (16–19 °C), 3, (19–21 °C), 4 (more than 21 °C). It shows the predominance of indoor temperatures from 19 to 16 °C and comfort temperatures predominantly in the 19 to 21 °C range.

The line connecting the different points marks the dimension of the thermal satisfaction index. It is observed that 47.1 % of households with indoor temperature ranges from 16 to 19 °C would maintain those temperature ranges and 48 % would like ranges from 19 to 21 °C. 57.4 % of the households that perceive their dwelling to be below 16 °C responded that their comfort temperature was 19–21 °C. Likewise, 3.7 %, 31.5 % and 7.4 % would prefer to be at temperatures of 16 °C, 16–19 °C and above 21 °C, respectively. All households with temperatures above 19 °C responded that they were in thermal comfort, compared to 3.7 % and 47.1 % of households with temperatures below 16 °C and 16–19 °C.

The results provide information on the residents' requirements, such as 50 % of the sample preferring temperature ranges between 19–21 °C, with only 2 % respondents to be within this range. However, the intention of this study is not to provide a single solution for the entire sample, as it consists of 16 different buildings. A detailed analysis of other indicators would be necessary to identify the most appropriate solution for each case. Further analysis could help detect problems related to construction, facilities, social issues, energy vulnerability, and other factors. The proposed indicator is not meant to be used as a standalone tool for decision-making. Instead, it should be used as a complementary tool alongside other qualitative or quantitative indicators, which may come from subjective or objective sources.

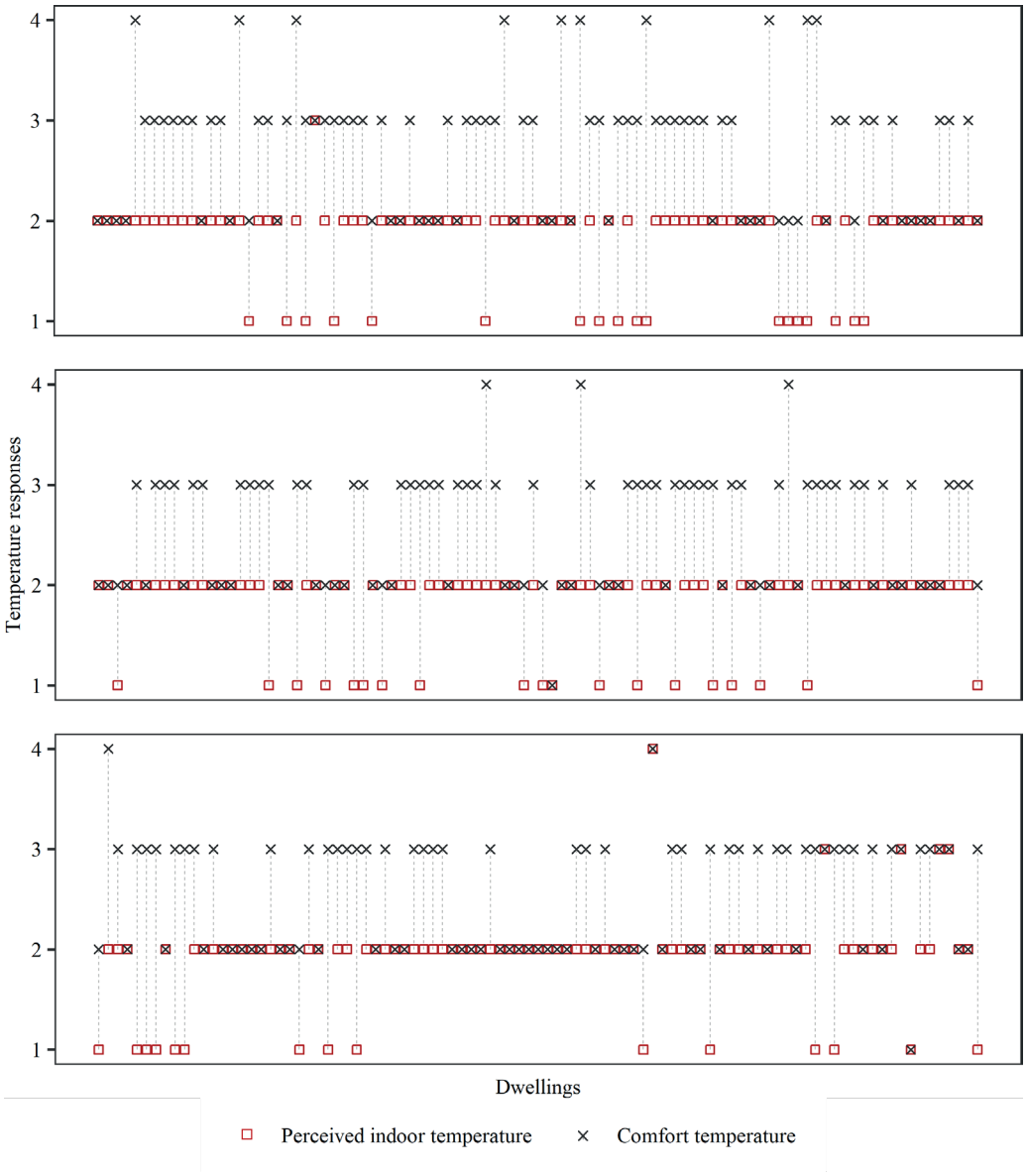


Fig. 2. Perceived indoor temperature and desired indoor temperature by dwelling.

3.2. Thermal comfort and household characteristics

The results of the indicator have been compared with household-related data, such as average monthly income and energy expenditure. While there was some increase in comfort with higher income, there was no association between these two variables (p-value = 0.55). However, households with average monthly incomes over 1200 € were those with the highest percentage of coincidence between comfort temperature and perceived indoor temperature with 53.3 %, compared to households with incomes from 800 to 1000 €, with 34.7 % of

households, as shown in Fig. 3. Only 4 households out of the 283 analysed had 3 points of difference between comfort and perceived temperatures, coinciding with households with incomes below 1000 € per month.

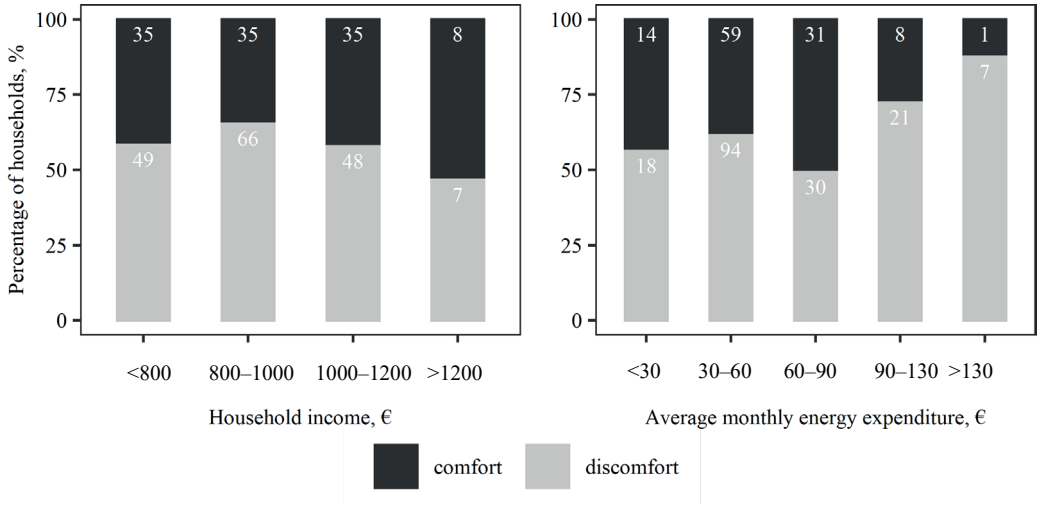


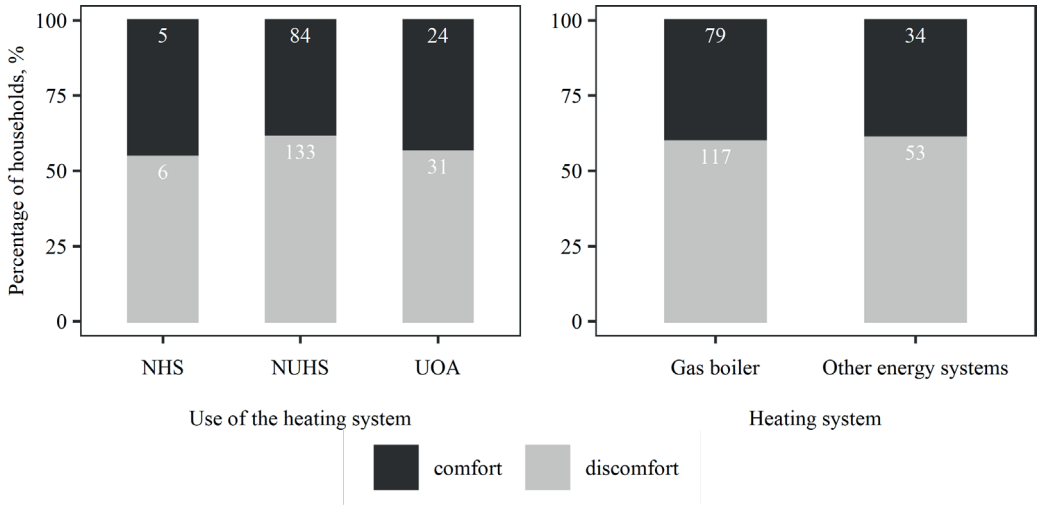
Fig. 3. Thermal comfort by household income and energy expenditure.

Average monthly energy expenditure was associated with thermal satisfaction (p-value = $3.33e^{-5}$). Households with expenditures above 60 € per month show an increase in discomfort the higher the expenditure, from 50.8 % to 12.5 %. Although this association was present in this sample, a detailed analysis would be necessary to determine whether the actual expenditure on heating is similarly associated with the thermal satisfaction indicator.

The thermal satisfaction indicator was also contrasted with the heating and DHW generation system and the heating use made. Fig. 4 shows that households that use the building's heating system rather than other appliances were more dissatisfied. Although the difference between the two categories was not high, the different uses and consequent thermal satisfaction may be conditioned by other socio-economic factors and household habits.

In the case of the heat generation system of the dwelling, no significant difference was observed for those with natural gas systems and those with other types of heat generation systems.

As the socio-cultural context can vary significantly depending on the location of a building within a city, region, or country, the results obtained may differ if the same analysis were conducted in a different setting. Therefore, further analysis of how human factors impact perception and environmental requirements would be needed.



* No heating system (NHS), use of the building's heating system (NUHS), use of other appliances having a heating system (UOA)

Fig. 4. Thermal comfort satisfaction by use of heating system and type of heating system.

4. CONCLUSIONS

The aim of this study was to define an indicator to determine the level of thermal satisfaction of households. To improve energy efficiency and household satisfaction, it may be necessary to consider people's perspectives in housing management processes. This could involve using indicators that can be compared with objective data, as well as other techniques for studying thermal satisfaction, such as PPD or PMV. The indicator was applied to 283 social housing dwellings in the north of Spain and contrasted with socio-economic data of the households.

The results showed a high percentage of coincidence of the perceived temperature with the desired temperature, followed by a difference of 1 point. It was observed that 50 % of the sample indicated a preference for temperature ranges between 19–21 °C, while only 2 % responded to be within this range.

The analysis has also identified the groups with the highest thermal satisfaction in relation to average monthly income and average energy expenditure. Furthermore, the heating and DHW generation system and the use of heating system did not show significant differences for this sample.

The indoor temperature data was conditioned by the subjectivity of the response, and may not coincide with the real temperature of the dwelling. For this reason, the indoor thermal quality is not evaluated with this data, but it is used to determine households' thermal satisfaction.

The proposed indicator is not meant to modify or contradict the results of other indicators or thermal comfort models, but to complement them. In many cases, particularly in social housing, it is not possible to obtain detailed information on households, such as their clothing, activity level, etc. This difficulty is even more pronounced in multi-unit buildings. The proposed indicator could simplify the study of thermal comfort in situations where data access is more restricted. It also worth attention to quantify and determine how human factors affect indoor thermal perception and adaptability.

While a thermal comfort indicator that incorporates people's perception can contribute to improving the building's energy efficiency, it may not necessarily reduce energy consumption. In the field of social housing, heating consumption is often lower than expected. The objective of these types of indicators is to improve people's quality of life by studying each case individually and focusing the interventions and decision-making for individuals.

Further research could investigate in more detail how to adapt the indicators used to evaluate thermal satisfaction to the social and cultural context in which they are applied.

The variable obtained reflects the occupants' opinions and perceptions, helping ensure that solutions for improving the building's energy efficiency and thermal comfort are appropriate. It can also be applied to various building typologies, allowing for comparisons with other models of perceived thermal comfort.

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