Journal of Sustainable Development of Energy, Water and Environment Systems

http://www.sdewes.org/jsdewes

Year 2023, Volume 11, Issue 4, 1110461

Original Research Article

Analysis of Thermal and Humidity Sensations in Educational Buildings in Eastern European Climate Conditions

Luiza Dębska[*1], Natalia Krawczyk[1], Andrej Kapjor[2]*

[1]Faculty of Environmental, Geomatic and Energy Engineering, Kielce University of Technology, aleja Tysiąclecia Państwa Polskiego 7, 25-314 Kielce, Poland

e-mail: international@tu.kielce.pl

[2]University of Zilina, Slovakia

e-mail: rektor@uniza.sk

Cite as: Debska, L., Krawczyk, N., Kapjor, A., Analysis of Thermal and Humidity Sensations in Educational Buildings in Eastern European Climate Conditions, J.sustain. dev. energy water environ. syst., 11(4), 1110461, 2023, DOI: https://doi.org/10.13044/j.sdewes.d11.0461

ABSTRACT

Perception of temperature and relative humidity has an important influence on feelings of thermal comfort or discomfort. The aim of this study is to analyse the thermal sensations of 222 people aged 19–30 years, taking into account air temperature and relative humidity in four educational buildings at Kielce University of Technology. Two methods were used to conduct the study, indirect (use of an environmental meter) and direct (use of questionnaires). Air temperature ranged from 20ºC–27.5ºC and humidity from 18.16%–50.9%. Approximately 60% of the students rated the humidity as pleasant, nevertheless 32% would prefer it to be more humid. Furthermore, thermal comfort was declared by 69% of the students, while 31% rated their feelings as uncomfortable. In addition, a correlation analysis was carried out for temperature and humidity. In the overall assessment of the students, the buildings created good conditions for feeling comfortable.

KEYWORDS

Thermal comfort, Indoor environment, Indoor air, Thermal sensations, Relative humidity, Humidity sensations

INTRODUCTION

In the modern world, the thermal comfort of people and their well-being are becoming an increasingly important aspect. Thermal comfort depends on many factors. In order to guarantee the wellbeing of the occupants, certain conditions must be met. The factors influencing the feeling of thermal comfort largely depend on the temperature and humidity of the air, as well as the average radiation temperature, air velocity, insulation level of clothing and the level of physical activity and health. If indoor conditions deviate from those considered comfortable, people may experience thermal discomfort which, among other things, results in reduced productivity, concentration, sweating or the appearance of shivering. The thermal comfort conditions are defined in ISO 7730 [1] Moreover, the standard also defines the acceptable percentage of people dissatisfied with the prevailing conditions. Thanks to the analysis of thermal comfort, it is possible to understand the perception of building users regarding environmental conditions.

* ldebska@tu.kielce.pl

Ensuring the right climatic conditions continues to be an important topic. Kaushik et al. [2] discussed the factors of the internal environment that influence human productivity. According to the authors, temperature and air humidity have the greatest impact on performance and comfort. Works on thermal comfort and understanding the influence of air temperature on the thermal comfort of users are discussed in the article [3], [4]. It is not only the temperature that affects the thermal comfort. Air humidity can also be affected. Kong et al. [5] focused on the influence of internal humidity in their research on thermal comfort. The test was performed in a climatic chamber, where the air temperature was 25ºC and 28ºC, and the humidity was between 20% and 90%. The authors showed that the participants of the study staying in the room where the relative humidity was above 70% were dissatisfied with the prevailing conditions. Jin et al. [6] also discussed the impact of relative humidity in rooms on the comfort of people over 80 years of age. The authors showed that the elderly do not feel discomfort with humidity ranging from 25 to 50%. The study in which 10 men and 10 women were examined showed that women feel more uncomfortable than men [7]. Other authors [8] conducted research in a humid region, where respondents felt comfortable with the temperature ranging from 26.1 to 32.8ºC, and the preferred temperature is 27.8ºC. In the work of Tsay et al. [9] the comfort range for the study participants ranged from 25.4ºC –27.4ºC. In another study [10], tests were carried out on 19 people, where the optimal temperature was 24ºC. Moreover, an interesting research proposal was presented by the authors of Draganova et al. [11] who focused on thermal comfort in the opinion of people of different nationalities. The study itself was conducted in central Japan in the Tokai region on a university campus. It turned out that the nationality of the respondents influenced people's thermal well-being. In addition, it has been shown that the Japanese are more prone to feeling changes in the internal environment than people from outside of Japan. The neutral temperature range for the subjects was from 24ºC to 26.5ºC. Furthermore, another study by Guevara et al. [12] focused on the heat and humidity of people in different regions of Ecuador. 429 questionnaires were received showing that students studying in classrooms in hot and humid climates would definitely prefer cooler conditions.

In [13], an analysis was performed for thermal comfort based on a database using the traditional model and others that have been developed over the years. Dębska [14] carried out a study evaluating the internal environment by 164 students aged 16 to 24 at the Kielce University of Technology. The temperature range for the examined rooms was from 19.3ºC to 27.6ºC, which was definitely acceptable by 78% of students. On the other hand, in the assessment of humidity for nearly 65% of people, it was appropriate, however, approximately 25% also assessed it as quite dry, and similarly, in the further interpretation of the results, it was shown that 1/4 of the group would like a more humid environment. Other studies [15]–[18] focus on the thermal sensations of people in educational buildings under heating and winter conditions and the impact of measures used to maintain cleanliness in rooms that may disturb the air quality. However, tests are carried out not only in public buildings, but also in cars, as in the authors [19], who asked 4 participants to complete the questionnaires at 19ºC, 20.5ºC, 22ºC, 23.5ºC and 25ºC in the shade and sun. The analysis provided information that the range of comfortable temperature with the air conditioning on was 20.5ºC, 22ºC and 23.5ºC, respectively. On the other hand, other authors performed studies in hospital buildings [20], [21], where the results showed differences between two indicators, TSV (thermal sensation vote) and PMV (predicted mean vote).

Research in the eastern part of Europe was conducted by Heracleous and Michael [22] in Cyprus. The main objective of the authors was to improve air quality by combining the operation of natural ventilation with the opening of windows in an educational building, so that heat loss was minimised. During the tests, air temperature and humidity were measured. The same authors [23] continued their research in an educational building related to the operation of natural ventilation during the heating season and beyond. The methodology was based on the monitoring of indoor conditions and the use of questionnaires designed for students. The results suggested that the students surveyed were mostly comfortable in both the summer and winter seasons. In a similar area of the Mediterranean, Romera–Lara et al. [24] compared three cooling systems for school buildings that can have the greatest impact on increasing thermal comfort and thus reducing heat loss, while improving air quality. Furthermore, in Poland, Orman et al. [25] compared intelligent and traditional buildings. The authors considered all seasons. One method was indoor environment measurements carried out with measurement equipment from BABUC–A, an Italian manufacturer, while the other was questionnaires completed by respondents (a total of 1778 questionnaires). Respondents described themselves with a higher percentage of comfort for smart buildings than for the selected traditional building, where the most common answer was "too warm". Furthermore, the authors, also analysed the feelings of indoor relative humidity. One of the two smart buildings, according to the employees, provided too high a percentage of relative humidity, similarly for the traditional building, where the respondents were also not satisfied. The authors of this paper, Majewski et al. [26], made a comparison between two intelligent buildings in central–eastern Poland. The first was an educational building and the second was a court building. The authors analysed 1369 questionnaires for 117 rooms in terms of thermal sensations and the acceptability and preference of the people surveyed, using the BABUC–A measure. The results showed that the people surveyed preferred a warmer environment, and that the thermal comfort and air quality ratings themselves were not high.

It is worth mentioning about an interesting research proposal by Budiawan & Tsuzuki [27] who examined the quality of sleep and thermal comfort of Indonesian students living in Japan. Eighteen men participated in the study to complete the questionnaire about thematic sensations and well–being before bedtime. In the work of Krawczyk and Krakowiak [28] one can find research results which show that the respondents prefer higher air humidity. The study was carried out in two educational buildings, one with mechanical ventilation and the other with no ventilation. Additionally, environmental parameters were measured. It turned out that the quality of sleep in winter was worse than in summer, despite the fact that the temperature in the bedrooms was close to the comfortable temperature in Indonesia. Last but not least, there are also studies conducted in office buildings, as in the case of [9], [29], where some authors stated during the analysis of their research that CO_2 does not have such a significant impact on the perception of air quality, on the other hand, other authors [30] determined a neutral value of 26.8°C, while for women 25°C as the best temperature for work, and 27°C for men. A number of researchers are working on the adaptation of the thermal comfort model, such as Lopez-Perez et al. [31], who conducted a study considering gravity ventilation as well as an air-conditioning system in 27 buildings in Mexico. A total of 496 surveys were collected. The results showed that learners in these buildings with air conditioning running felt 48.1% thermal comfort, while gravity ventilation provided comfort for 59.7% of people. The authors showed that in order to increase the percentage of people satisfied, the thermal adaptability of the people surveyed should be taken into account.

The aim of this paper is to analyse thermal sensations and temperature and relative humidity in 4 educational buildings using 227 questionnaires. The questionnaires collected and the analysis carried out are intended to contribute to a better understanding of human feelings experienced in educational buildings in Eastern Europe. Moreover, the correlation between thermal sensations, preferences, thermal acceptability, internal temperature was analyzed and relative humidity rating and preference were compared to see which of them formed strong relationships with each other. An aspect in favour of this is that such studies are rare in the literature combining these two parameters in this climate zone, in a selected part of Europe.

THEORY AND FORMULA

To The study was carried out in the central part of Poland, in the Swietokrzyskie Voivodeship, where the Kielce University of Technology is located, connecting the scientific and didactic complex of six buildings. Four buildings were selected for the research, including one energyself–sufficient, called "Energis". "Energis" was built in 2012, with high–quality materials [32], with renewable energy sources, building management system, etc., while the other three buildings were built in the 1960s and their modernization took place a decade ago. The traditional and smart "Energis" building have been shown in Figure 1.

(a) (b)

Figure 1. Educational buildings of Kielce University of Technology: "A" building (a), "Energis" (b)

In the buildings surveyed (example in Figure 1), the indoor air temperature in the rooms ranged from 21.5°C to 27.5°C for "Energis" and from 20.0°C to 27.5°C for the rest of the buildings, while the relative humidity ranged from 18.16% to 45.49% for "Energis" and from 25.95% to 50.9% for the rest of the buildings – it can be seen that the lowest humidity in these buildings was about 7% higher and about 5% higher at maximum relative humidity compared to "Energis". The period of the research conducted was within and outside the heating season. The "Energis" smart building had mechanical ventilation in operation during the study, while the other three buildings had gravity ventilation.

In order to carry out the necessary analysis, two measurement methods were used: an indirect one related to the use of a measuring meter and a direct one related to questionnaires about thermal sensations under the current microclimate conditions. The questionnaires included specially created questions specifying thermal impressions, preferences or acceptability of air temperature as well as preferences and assessment of relative humidity. The answers received from the respondents make it possible to get to know the actual feelings of the microclimate in the examined rooms. The second method is to use the Testo 400 environmental meter, which was placed in the central part of the tested lecture rooms, at a height of about 1.0–1.2 m. Figure 2 shows two lecture rooms with the students completing questionnaires and measuring station.

(a) (b)

Figure 2. Photo of a) two selected lecture rooms and b) environmental meter station

The Testo meter consists of five probes that allow information to be collected on the prevailing parameters of the internal environment, recording the results every 1 second. As shown in **Figure 2**, the five probes used during the test are highlighted. The first one reports the height of the air temperature and relative humidity. The second probe is characterized by the recording of the radiant temperature (calculates the average temperature of all exposed surfaces in the room), the third by the air flow, and the fourth by the measurement of carbon dioxide concentration. And last but not least, the probe numbered 5, records results related to the illuminance of the rooms. **Table 1** shows the accuracy of all measurement probes.

Table 1. Measurement accuracy by probe

No	Parameter	Accuracy of the probe	
1	Air temperature	± 0.3	[ºC]
2	Black ball sphere/ globe temperature	± 1.5	[ºC]
3	Air speed	± 0.3	[m/s]
4	CO_2 concentration	± 50	[ppm]
1	Relative humidity	± 0.6	[%]
5	Illumination	± 0.1	[lux]

A total of 20 rooms from four buildings were examined, covering 222 people: 89 women and 133 men. There were two groups of students in the age range 19–25 years for 200 students and 22 students aged 26–30 years took part in the study. A total of 222 questionnaires were accepted for analysis; however, it should be mentioned that ten questionnaires out of 232 received were additionally rejected due to the students' health status or the excessive physical exertion and because of an age that was outside the mentioned range carried out. These are factors that can significantly affect the thermal sensations of such people by inflating or deflating them, and therefore cannot be taken into account.

The research was limited to people living in Poland, more specifically in the Świętokrzyskie voivodship, where the buildings under study are located. For other countries, the results obtained could be different. The research was also limited to the age group 19–30 while the results would be different for different age groups, in particular 60+.

RESULTS AND DISCUSSION

The indoor air temperature ranged from 20ºC to 27.5ºC. The relative humidity for all rooms was in the range of 18.16% to 50.9%. Such a wide range of internal parameters can indicate whether people feel heat discomfort or are satisfied with the microclimate created.

Thermal sensations

Thermal comfort was already defined in the 60s–70s by Fanger [30]. The thermal sensation was determined on the basis of a seven-point scale. Thermal comfort is considered to be provided if it is within the range from -0.5 to +0.5 (for the considered buildings). On the basis of anonymous questionnaires, thermal sensation votes were determined, which are expressed on a seven–point scale which is shown in **Figure 3**.

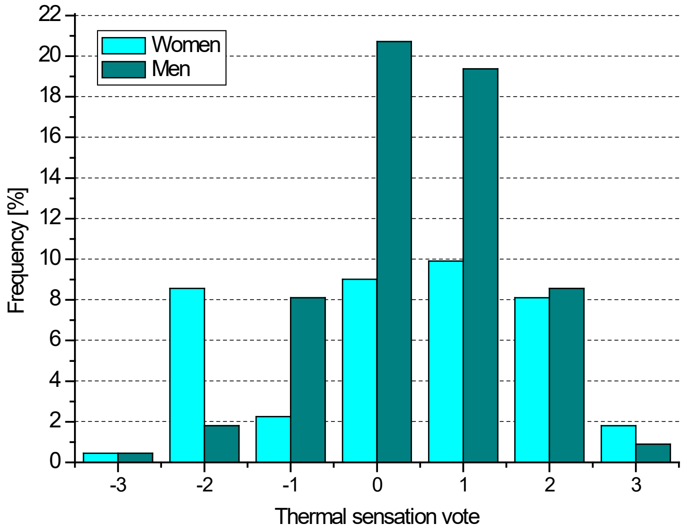

Figure 3. Frequency of responses on thermal sensation vote

The **Figure 3** above shows the frequency of answers to the question about thermal sensations. 222 participants took part in the survey. The respondents had 7 answers to choose from, where negative values mean for –3 – too cold, –2 – too cool, –1 – pleasantly cool. The reverse is true for positive values: +3 – too hot, +2 – too warm, +1 – pleasantly warm, and 0 means comfortable. The chart shows the results for men and women separately. Out of 89 women, 22 (9.91%) women chose the pleasantly warm answer. 20 women (9.01) found the thermal conditions comfortable, 19 (8.56%) too cool, 18 (8.11%) too warm. On the other hand, the lowest number of women considered indoor conditions as pleasantly cool (2.25%), too hot (1.80%) and too cold (0.45%). The situation is similar for men. The most frequently chosen answer was comfortable, which was 20.72%. 43 respondents (19.37%) considered the climatic conditions to be - pleasantly warm. Other 19 men (8.56%) felt it is too warm. 18 men (8.11%) found the rooms pleasantly cool. The least frequently chosen answers by men were too cool (1.80%), too hot (0.90%) and too cold (0.45%). Summing up, it is worth noting that the sum of the answers +3, +2, –2 and –3 for men and women was 31.0% and is greater than 10% according to the norm. This means that out of 225 participants, 68 were dissatisfied with the conditions. Therefore, it can be concluded that thermal comfort was not experienced by many respondents, which might be related to the indoor temperature. The next, **Figure 4** shows the dependence of thermal sensations on the operative temperature.

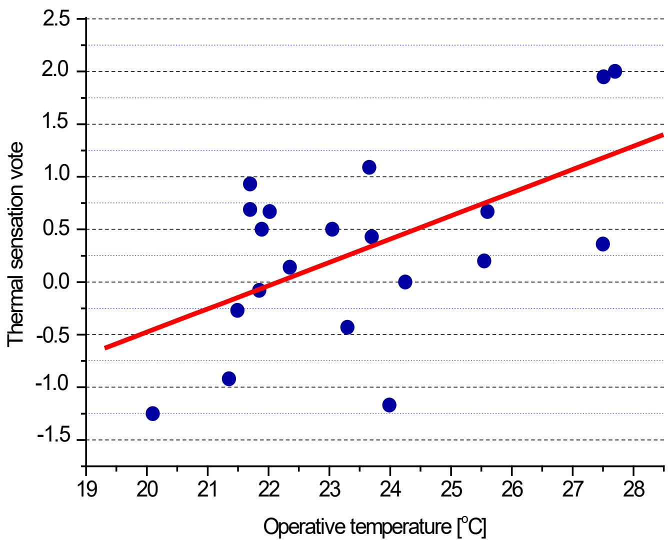

Figure 4. Relationship between thermal sensation vote and operative temperature

The above diagram shows the relationship between the operating temperature and the average results for the thermal sensation vote made in 20 rooms. It can be noticed in **Figure 4** that typically thermal sensations are more positive with rising operative temperature, however this phenomenon cannot be observed for all the rooms (possibly due to the impact of other factors, e.g. humidity).

Thermal Preference Vote determines whether a person would like the inside of a room to be warmer, cooler or unchanged. The Thermal Preference Vote is linked to the Thermal Sensation Vote question, because if a person indicates that it is too warm for them, they will prefer the room to become cooler. The same applies if someone is too cold or comfortable. **Figure 5** shows the preferences of the respondents regarding the climatic conditions in the studied rooms.

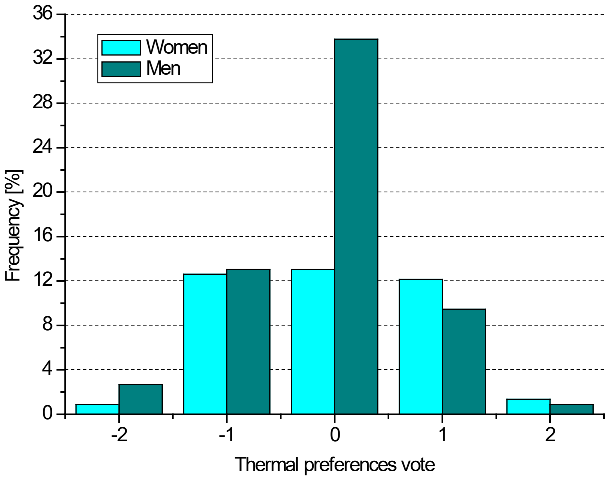

Figure 5. Frequency of responses to voting on thermal preferences

The respondents were also asked about their preferences regarding the air temperature in the examined rooms. Value 0 means no change. Positive values – warmer (+1) and definitely warmer (+2), negative values – cooler (–1) and definitely cooler (–2). It should therefore be noted that 13.06% of women would not like any changes and 12.61% would like the room to be cooler. 12.16% of the participants in the study would like the room temperature to be warmer. 1.35% of women voted for it to be definitely warmer, and less than 1% – definitely cooler. A similar situation occurs with men's responses, where 33.78% want it to be the same, 13.06% – cooler and almost 10% – warmer. And 2.70% of men chose the answer definitely cooler and 0.90% definitely warmer. The following **Figure 6** discusses the dependence of preferences on thermal sensations.

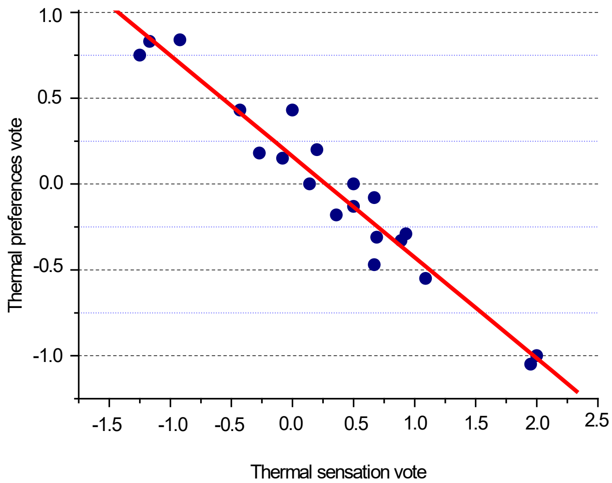

Figure 6. Dependence of thermal preferences on thermal sensations

According to **Figure 6**, the correlation in very clear and strong. When comparing the results of thermal impressions and preferences, it should be noted that only in 8 rooms TPV is close to 0. This means that the respondents preferred the conditions in which they stayed. However, only in one room the respondents felt comfortable (TSV = 0) and their preferences for the prevailing conditions amounted to 0.43. In three rooms, respondents rated the thermal conditions as cool, and their preferences are that they want it to be warmer in the rooms, as shown in the figure above. The opposite is true for two rooms, who assessed the conditions inside the room as too warm and prefer the room to be cooler. The correlation between TSV and TPV is high at R^2 = 0.94. The dependence of thermal preferences on air temperature has also been analysed and presented below in **Figure 7**.

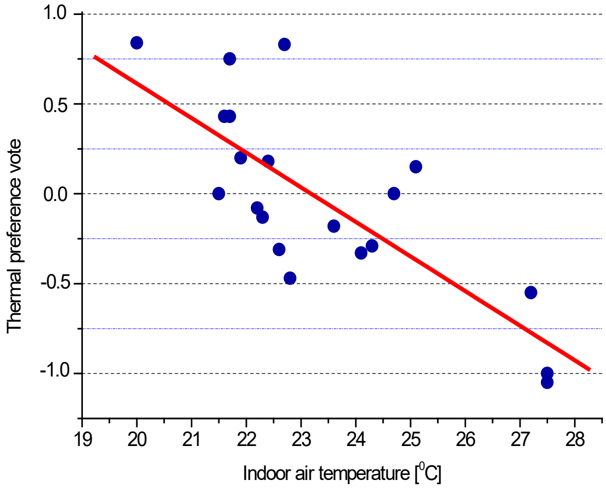

Figure 7. Dependence of thermal preferences on air temperature

Considering the **Figure 7** above, it is worth noting that as the temperature rises people would like to reduce the indoor air temperature, but this relation is not very obvious and strong – possibly due to other factoring influencing these sensations. A closer look at this figure shows that only in one room the respondents do not want to change the temperature inside the room. Note that for most rooms, respondents prefer a temperature ranging from 21.5°C to 25.1°C. The correlation between internal temperature and TPV is low, as R^2 = 0.61 (this is because the sense of thermal comfort depends on many components and these coefficients are generally small). The next **Figure 8** shows the frequency of answers given by the respondents about thermal acceptability.

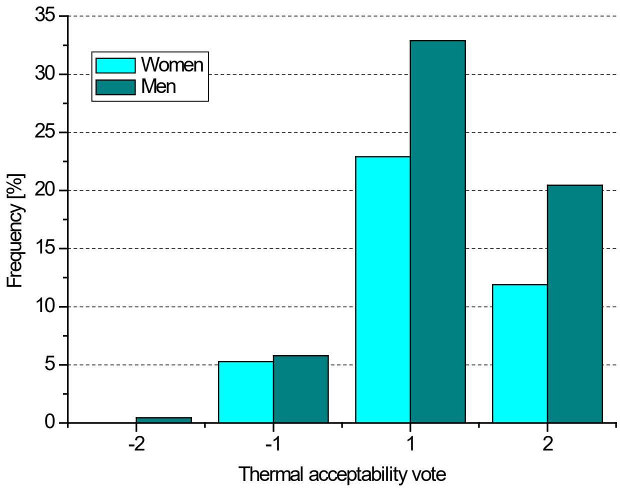

Figure 8. Frequency of responses on thermal acceptability

The **Figure 8** above shows the frequency of responses on thermal acceptability. Negative values mean "unpleasant" and positive values are acceptable. Definitely half of the women chose answer +1 – acceptable (it is 22.52% of all respondents). 27 women (12.16%) gave a comfortable answer on the subject of thermal voting, and 5.41% were unpleasant. 73 men out of 133 chose acceptable, that is 32.88% of all respondents. Then 46 men (20.72%) selected comfortable. Another 5.86% "unpleasant" and one man (0.45%) answered - definitely unpleasant.

The study also discusses the relationship between thermal sensation and acceptability, as shown in the **Figure 9**.

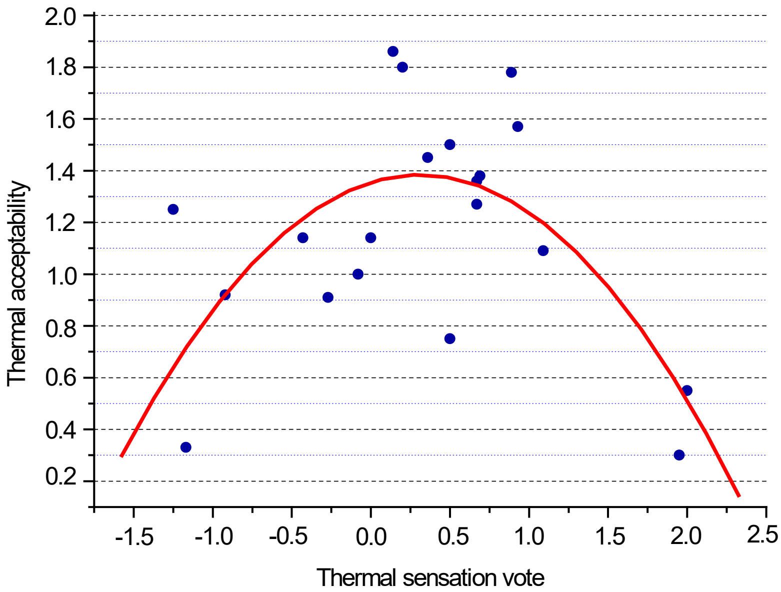

Figure 9. Relation between thermal sensation and acceptability

Respondents determining the acceptability of temperature had a choice of individual answers: +2 – comfortable, +1 – acceptable,–1 – unacceptable and –2 – definitely unacceptable. The **Figure 9** above showed that the highest acceptability for the considered test group was in the range of -0.5 to +1.0 of TSV, proving that people tend to prefer warmer environments (at least in Eastern European climate). Results that are outside this range indicate that the given indoor temperature is unacceptable or definitely unacceptable to the respondents.

Humidity sensations

Relative humidity is an extremely important aspect that may affect the perception of thermal comfort by people. The environment is considered to be comfortable when the humidity is between 40% – 60% [1]. It is important to keep it within this range, because when it is too low, it can cause dry throat, hoarseness, dryness of the nose and eyes mucosa. On the other hand, when the humidity is too high, it can contribute to increased sweating in people or lead to a runny nose. The relative humidity parameters obtained during the measurements with the environmental meter ranged from 18.16% to 50.9%. Taking this into account, it was decided to conduct a study assessing the current relative humidity in the rooms according to 222 people. The responses were divided according to the opinions of 89 women and 133 men. They rated their impressions on a scale from "too dry" (-2), "pleasantly dry" (-1), "pleasantly" (0), "pleasantly humid" (+1), and "too humid" (+2). The responses received are shown in **Figure 10**.

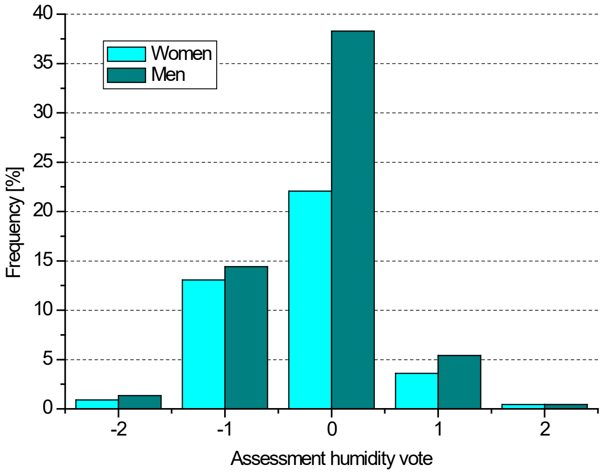

Figure 10. Percentage of responses on humidity rating

Figure 10 shows that, out of 89 women, 22.07% thought the humidity was "pleasant", while for 133 men there were 38.29%, assessing the same as women. A similar percentage share in terms of the assessment of humidity in a similar gender range can be found in the publication by Dębska [14]. Similar results can be seen for the "pleasantly dry" answer, where women constitute 13.06% and men 14.41%. Comparing this to the results obtained in the study [14], the percentage of women was definitely lower than in the current study. The responses for "pleasantly humid" and "too humid" relatively did not have a high percentage of responses, because for the first option it amounted to 3.60% for women, 5.41% for men, and for the second option equally for both sexes – about 0.45%. Additionally, for two women and three men it was much too dry in the tested room. It is interesting that in [14] the men did not mark any answers with the numbers (–2) and (+2), which may indicate that they considered humidity as better in these rooms than those in the currently conducted study, for which the total percentage of their impressions of humidity was 3.1%.

Knowing the assessment of the humidity according to the studied groups in the rooms, it is possible to analyse their humidity preferences. This question makes it possible to find out what humidity conditions in this case would be desired by the respondents. Contrary to the data from figure 10, the students could use the scale from –1, 0, +1, where the first value indicated that people wanted "drier" conditions in the room, the second value described the lack of humidity to change "no change", and the third value expressing a desire to change the humidity to "more humid". Figure 11 presents the analysis of the results from the question on Humidity Preferences Vote.

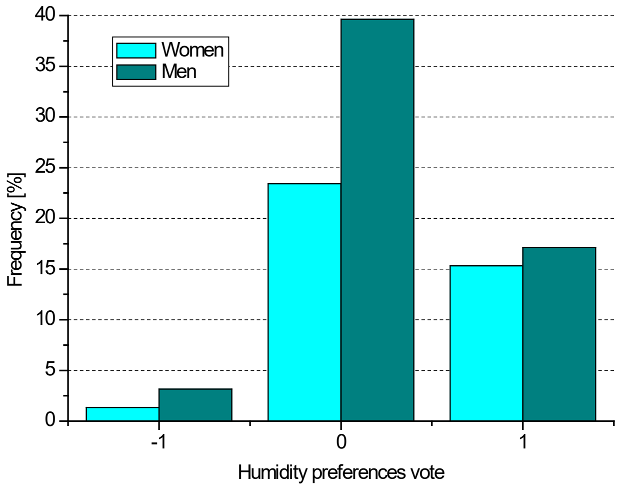

Figure 11. Humidity preferences vote according to the respondents

Based on the data from **Figure 10**, a certain analogy can be noticed in the responses of the respondents with **Figure 11**. For both sexes a slight percentage increase was noted for the "no change" answer – for women 23.42% and for men 39.64%. On the other hand, women who in **Figure 10** rated the humidity as "pleasantly dry" or "too dry", in the question about the humidity to change this humidity, chose that the room should be "more humid' for 15.32%, as in the men's responses, except that this percentage was 17.12%. Insignificant number of people would like it to be "drier" in lecture halls. A similar analogy was also analysed in **[14]**, where people who previously assessed the humidity as dry, in the next step, would definitely like it to be more humid.

The data averaged for each test room has been shown as "assessment of humidity" vs. "humidity preference vote". It has been presented in **Figure 12**.

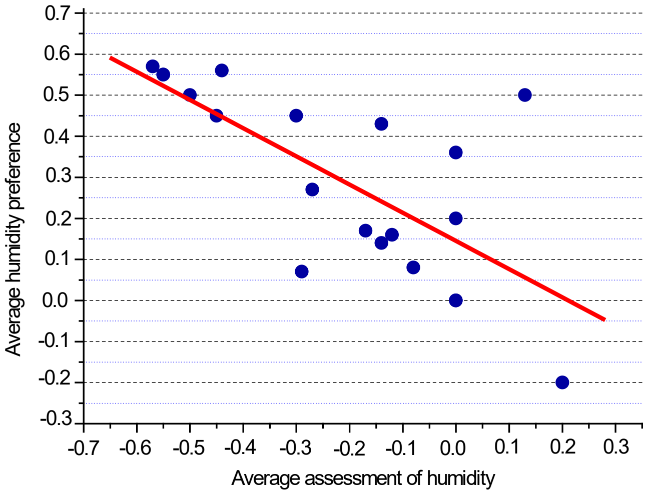

Figure 12. Dependence of humidity preferences on humidity assessment

From the relationship between the average humidity rating and the average preference vote, it can be seen that the test subjects prefer more humid environment when it is quite dry or too dry. However, **Figure 12** presents that the correlation is not strong on the contrary, it is weak, and therefore indicates the influence of other factors. The correlation was for $R^2 = 0.50$.

In spite of many factors that impact human sensations in rooms, thermal conditions as well as the heat transfer issues should be regarded as dominant **[33], [34]**. Consequently, future studies might be focused on this aspect of indoor environment.

CONCLUSION(S)

When analyzing the air temperature, the following conclusions can be drawn. The results, based on 222 questionnaires, showed that respondents were 69% satisfied with the thermal conditions in the rooms surveyed. On the other hand, some 31% of the people surveyed marked on a scale of +3, +2, –2, –3 a feeling defining a zone of thermal discomfort. According to ISO 7730, the percentage of people dissatisfied should not exceed 10%. However, this does not change the fact that 5/7 of all people surveyed, felt comfortable in the study rooms. The analysis provided information that women would prefer to change the internal environment as opposed to men who accept the microclimate in the lecture halls. 88.28% of the respondents considered the temperature as comfortable and acceptable, while 11.55% of the students described it as unpleasant and definitely unacceptable. Additionally, the temperature acceptability range proved to be –0.5 to +1.0 of TSV. The respondents were satisfied with the relative humidity in the rooms tested. However, about 30% of people described it as "quite dry", which made them want to change the humidity to a more humid environment. Moreover, it should be noted that about 32% men and women prefer more humid microclimate in the rooms. It turned out that there is no significant correlation between the assessment of humidity and the preference for changing humidity. The same was noted for thermal preference and internal temperature. This is in contrast to thermal sensation (TSV) vs. thermal preference (TPV), where the correlation was very strong and equal to $R^2 = 0.94$. This demonstrates that the way in which feelings are assessed is strongly related to the will or will not of the internal environment.

To sum up, the analysis of the obtained results provided information that the buildings met the students' thermal expectations in general terms. This is an important fact, because nowadays many people study at universities, spending a lot of time on acquiring knowledge, therefore it is necessary to create the best possible internal conditions so that everyone feels comfortable.

NOMENCLATURE

TSV	Thermal Sensation Vote
TPV	Thermal Preferences Vote
SD	Standard deviation
Length	[m]
Width	[m]
Hight	[m]
Air temperature	[ºC]
Relative humidity	[%]

REFERENCES

1. "ISO International Organisation for Standardization, 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," International Standard ISO 7730, 2005.
2. Kaushik, M. Arif, P. Tumula, and O. J. Ebohon, "Effect of thermal comfort on occupant productivity in office buildings: Response surface analysis," Build. Environ., vol. 180, p. 107021, Aug. 2020, https://doi.org/10.1016/j.buildenv.2020.107021.
3. P. Zheng, H. Wu, Y. Liu, Y. Ding, and L. Yang, "Thermal comfort in temporary buildings: A review," Build. Environ., vol. 221, p. 109262, Aug. 2022, https://doi.org/10.1016/j.buildenv.2022.109262.
4. W. Cao, X. Xuan, W. Wu, L. Chen, and Q. Zhang, "A new method for determining the optimal adaptive thermal comfort model with grey relational analysis," Build. Environ., vol. 221, p. 109277, Aug. 2022, https://doi.org/10.1016/j.buildenv.2022.109277.
5. D. Kong, H. Liu, Y. Wu, B. Li, S. Wei, and M. Yuan, "Effects of indoor humidity on building occupants' thermal comfort and evidence in terms of climate adaptation," Build. Environ., vol. 155, pp. 298–307, May 2019, https://doi.org/10.1016/j.buildenv.2019.02.039.
6. Y. Jin, F. Wang, M. Carpenter, R. B. Weller, D. Tabor, and S. R. Payne, "The effect of indoor thermal and humidity condition on the oldest-old people's comfort and skin condition in winter," Build. Environ., vol. 174, p. 106790, May 2020, https://doi.org/10.1016/j.buildenv.2020.106790.
7. L. Schellen, M. G. L. C. Loomans, M. H. de Wit, B. W. Olesen, and W. D. van M. Lichtenbelt, "The influence of local effects on thermal sensation under non-uniform environmental conditions — Gender differences in thermophysiology, thermal comfort and productivity during convective and radiant cooling," Physiol. Behav., vol. 107, no. 2, pp. 252–261, Sep. 2012, https://doi.org/10.1016/j.physbeh.2012.07.008.
8. M. Faheem, N. Bhandari, and S. Tadepalli, "Adaptive thermal comfort in naturally ventilated hostels of warm and humid climatic region, Tiruchirappalli, India," Energy Built

Environ., p. S2666123322000307, Apr. 2022, https://doi.org/10.1016/j.enbenv.2022.04.002.
9. Y.-S. Tsay, R. Chen, and C.-C. Fan, "Study on thermal comfort and energy conservation potential of office buildings in subtropical Taiwan," Build. Environ., vol. 208, p. 108625, Jan. 2022, https://doi.org/10.1016/j.buildenv.2021.108625.
10. Y. Geng, W. Ji, B. Lin, and Y. Zhu, "The impact of thermal environment on occupant IEQ perception and productivity," Build. Environ., vol. 121, pp. 158–167, Aug. 2017, https://doi.org/10.1016/j.buildenv.2017.05.022.
11. V. Y. Draganova, H. Yokose, K. Tsuzuki, and Y. Nabeshima, "Field Study on Nationality Differences in Adaptive Thermal Comfort of University Students in Dormitories during Summer in Japan," Atmosphere, vol. 12, no. 5, p. 566, Apr. 2021, https://doi.org/10.3390/atmos12050566.
12. G. Guevara, G. Soriano, and I. Mino-Rodriguez, "Thermal comfort in university classrooms: An experimental study in the tropics," Build. Environ., vol. 187, p. 107430, Jan. 2021, https://doi.org/10.1016/j.buildenv.2020.107430.
13. Lourenço Niza and E. E. Broday, "Thermal comfort conditions in Brazil: A discriminant analysis through the ASHRAE Global Thermal Comfort Database II," Build. Environ., vol. 221, p. 109310, Aug. 2022, https://doi.org/10.1016/j.buildenv.2022.109310.
14. L. Dębska, "Assessment of the Indoor Environment in the Intelligent Building," Civ. Environ. Eng., vol. 17, no. 2, pp. 572–582, Dec. 2021, https://doi.org/10.2478/cee-2021-0058.
15. Zhang, P. Li, and M. Ma, "Thermal Environment and Thermal Comfort in University Classrooms during the Heating Season," Buildings, vol. 12, no. 7, p. 912, Jun. 2022, https://doi.org/10.3390/buildings12070912.
16. X. Wang, L. Yang, S. Gao, S. Zhao, and Y. Zhai, "Thermal comfort in naturally ventilated university classrooms: A seasonal field study in Xi'an, China," Energy Build., vol. 247, p. 111126, Sep. 2021, https://doi.org/10.1016/j.enbuild.2021.111126.
17. L.-R. Jia, J. Han, X. Chen, Q.-Y. Li, C.-C. Lee, and Y.-H. Fung, "Interaction between Thermal Comfort, Indoor Air Quality and Ventilation Energy Consumption of Educational Buildings: A Comprehensive Review," Buildings, vol. 11, no. 12, p. 591, Nov. 2021, https://doi.org/10.3390/buildings11120591.
18. M. Shrestha, H. B. Rijal, G. Kayo, and M. Shukuya, "A field investigation on adaptive thermal comfort in school buildings in the temperate climatic region of Nepal," Build. Environ., vol. 190, p. 107523, Mar. 2021, https://doi.org/10.1016/j.buildenv.2020.107523.
19. N. Krawczyk, L. Dębska, and A. Białek, "Thermal Comfort in the Modern Car-Experimental Analysis and Verification of the Fanger Model," Int. Rev. Mech. Eng. IREME, vol. 15, no. 12, p. 609, Dec. 2021, https://doi.org/10.15866/ireme.v15i12.21473.
20. F. Yuan et al., "Thermal comfort in hospital buildings – A literature review," J. Build. Eng., vol. 45, p. 103463, Jan. 2022, https://doi.org/10.1016/j.jobe.2021.103463.
21. N. M. Abd Rahman, L. C. Haw, A. Fazlizan, A. Hussin, and M. S. Imran, "Thermal comfort assessment of naturally ventilated public hospital wards in the tropics," Build. Environ., vol. 207, p. 108480, Jan. 2022, https://doi.org/10.1016/j.buildenv.2021.108480.
22. C. Heracleous and A. Michael, "Experimental assessment of the impact of natural ventilation on indoor air quality and thermal comfort conditions of educational buildings in the Eastern Mediterranean region during the heating period," J. Build. Eng., vol. 26, p. 100917, Nov. 2019, https://doi.org/10.1016/j.jobe.2019.100917.
23. C. Heracleous and A. Michael, "Thermal comfort models and perception of users in free-running school buildings of East-Mediterranean region," Energy Build., vol. 215, p. 109912, May 2020, https://doi.org/10.1016/j.enbuild.2020.109912.
24. M. J. Romero-Lara, F. Comino, and M. Ruiz de Adana, "Seasonal Analysis Comparison of Three Air-Cooling Systems in Terms of Thermal Comfort, Air Quality and Energy

Consumption for School Buildings in Mediterranean Climates," Energies, vol. 14, no. 15, p. 4436, Jul. 2021, https://doi.org/10.3390/en14154436.
25. Ł. J. Orman, G. Majewski, N. Radek, and J. Pietraszek, "Analysis of Thermal Comfort in Intelligent and Traditional Buildings," Energies, vol. 15, no. 18, p. 6522, Sep. 2022, https://doi.org/10.3390/en15186522.
26. G. Majewski, Ł. J. Orman, M. Telejko, N. Radek, J. Pietraszek, and A. Dudek, "Assessment of Thermal Comfort in the Intelligent Buildings in View of Providing High Quality Indoor Environment," Energies, vol. 13, no. 8, p. 1973, Apr. 2020, https://doi.org/10.3390/en13081973.
27. W. Budiawan and K. Tsuzuki, "Thermal Comfort and Sleep Quality of Indonesian Students Living in Japan during Summer and Winter," Buildings, vol. 11, no. 8, p. 326, Jul. 2021, https://doi.org/10.3390/buildings11080326.
28. N. Krawczyk and J. Krakowiak, "The comparison of thermal comfort test results in selected traditional and modern buildings," E3S Web Conf., vol. 286, p. 02008, 2021, https://doi.org/10.1051/e3sconf/202128602008.
29. C. C. de Oliveira, R. F. Rupp, and E. Ghisi, "Assessment of Air Quality Perception and Its Effects on Users' Thermal Comfort in Office Buildings," Sci, vol. 3, no. 4, p. 47, Dec. 2021, https://doi.org/10.3390/sci3040047.
30. E. W. Shaw, "Thermal Comfort: analysis and applications in environmental engineering, by P. O. Fanger. 244 pp. Danish Technical Press. Copenhagen, Denmark, 1970. Danish Kr. 76, 50," R. Soc. Health J., vol. 92, no. 3, pp. 164–164, Jun. 1972, https://doi.org/10.1177/146642407209200337.
31. A. López-Pérez, J. J. Flores-Prieto, and C. Ríos-Rojas, "Adaptive thermal comfort model for educational buildings in a hot-humid climate," Build. Environ., vol. 150, pp. 181–194, Mar. 2019, https://doi.org/10.1016/j.buildenv.2018.12.011.
32. J. Zb. Piotrowski, Ł. J. Orman, X. Lucas, E. Zender-Świercz, M. Telejko, and D. Koruba, "Tests of thermal resistance of simulated walls with the reflective insulation," EPJ Web Conf., vol. 67, p. 02095, 2014, https://doi.org/10.1051/epjconf/20146702095.
33. Ł. J. Orman, "Boiling heat transfer on single phosphor bronze and copper mesh microstructures," EPJ Web Conf., vol. 67, p. 02087, 2014, https://doi.org/10.1051/epjconf/20146702087.
34. Ł. J. Orman, "Boiling heat transfer on meshed surfaces of different aperture," presented at the XIX. The Application of Experimental and Numerical Methods in Fluid Mechanics and Energetics 2014: Proceedings of the International Conference, Liptovský Ján, Slovakia, 2014, pp. 169–172. https://doi.org/10.1063/1.4892728.

APPENDIX

Table A1 presents the dimensions of the rooms studied (length, width, height) and internal parameters such as air temperature and relative humidity.

Table A1. Dimensions and internal parameters for 20 rooms

No	Length [m]	Width [m]	Hight [m]	Air Temperature [°C]	Relative Humidity [%]
1	5.80	8.93	2.9	22.4	18.37
2	5.92	9.81	2.9	24.3	18.16
3	5.81	9.69	2.9	24.7	22.42
4	10.01	7.44	2.9	22.8	19.49
5	19.32	29.32	3.1	22.7	21.97
6	5.82	9.05	2.9	25.1	45.49

7	17.70	8.28	3.7	20.0	44.8
8	17.70	8.28	3.7	22.6	25.95
9	11.67	6.10	3.2	23.6	26.29
10	11.83	5.30	4.6	27.5	50.9
11	13.13	7.47	3.0	21.5	31.50
12	10.01	7.44	2.9	21.7	26.40
13	7.80	8.01	2.9	21.9	28.60
14	7.80	8.01	2.9	22.3	27.20
15	5.92	9,81	2.9	24.1	28.10
16	17.89	9.77	3.0	22.2	30.80
17	13.64	7.92	3.0	21.7	30.80
18	13.13	7.47	3.0	21.6	34.70
19	10.01	7.44	2.9	27.2	33.50
20	13.13	7.47	3.0	27.5	33.00

Table A2 shows standard deviation (SD) calculated from air temperature and relative humidity.

Table A2. Standard deviation for 20 rooms by average temperature and relative humidity

No	Air Temperature [°C]	SD	Relative Humidity [%]	SD
1	22.4	0.35	18.37	0.31
2	24.3	0.37	18.16	0.46
3	24.7	0.16	22.42	0.25
4	22.8	1.26	19.49	0.98
5	22.7	1.30	21.97	0.32
6	25.1	0.35	45.49	0.50
7	20.0	0.30	44.8	0.61
8	22.6	0.12	25.95	0.13
9	23.6	0.13	26.29	0.68
10	27.5	0.09	50.9	0.67
11	21.5	0.36	31.50	0.85
12	21.7	0.10	26.40	0.40
13	21.9	0.25	28.60	0.18
14	22.3	0.05	27.20	0.31
15	24.1	0.37	28.10	0.46
16	22.2	0.55	30.80	0.73
17	21.7	0.36	30.80	1.43
18	21.6	0.48	34.70	0.37
19	27.2	1.15	33.50	1.30
20	27.5	0.59	33.00	0.84

An example questionnaire that was completed by one of the students is scanned below in Polish and the questions translated in English. The survey contains 14 questions. Below are the five questions that were analysed.

1. Jak oceniasz swoje odczucie cieplne w tej chwili?

☐ zbyt gorąco (+3)
■ za ciepło (+2)
☐ przyjemnie ciepło (+1)
☐ komfortowo (0)
☐ przyjemnie chłodno (-1)
☐ za chłodno (-2)
☐ zbyt zimno (-3)

2. Jak oceniasz aktualną temperaturę w tym pomieszczeniu?

☐ komfortowa (+2)
■ akceptowalna (czyli jeszcze do przyjęcia) (+1)
☐ nieprzyjemna (czyli już nie do przyjęcia) (-1)
☐ zdecydowanie nieprzyjemna (-2)

3. Chciałbym/Chciałabym, aby teraz w tym pomieszczeniu było:

☐ zdecydowanie cieplej (+2)
☐ cieplej (+1)
☐ bez zmian (0)
■ chłodniej (-1)
☐ zdecydowanie chłodniej (-2)

4. Jak oceniasz wilgotność powietrza w tej chwili?

☐ zbyt wilgotno (+2)
■ dość wilgotno (+1)
☐ przyjemnie (0)
☐ dość sucho (-1)
☐ zbyt sucho (-2)

5. Chciałbym/Chciałabym, aby teraz powietrze w tym pomieszczeniu było:

☐ bardziej wilgotne (+1) ☐ bez zmian (0) ■ bardziej suche (-1)

1. How would you rate your heat sensation at the moment?
    - Too hot (+3)
    - Too warm (+2)
    - Pleasantly warm (+1)
    - Comfortable (0)
    - Pleasantly cool (-1)
    - Too cool (-2)
    - Too cold (-3)
2. How do you assess the current temperature in this room?
    - Comfortable (+2)
    - Acceptable (+1)
    - Unpleasant (-1)
    - Definitely unpleasant (-2)
3. I would like the room to be in now:
    - Definitely warmer (+2)
    - Warmer (+1)
    - No change (0)
    - Cooler (-1)
    - Definitely cooler (-2)
4. How would you rate the humidity at the moment?
    - Too humid (+2)
    - Quite humid (+1)

- Pleasantly (0)
- Quite dry (-1)
- Too dry (-2)

5. I would like the air in this room now to be:
    - More humid (+1)
    - No change (0)
    - More dry (-1)

Paper submitted: 19.10.2022
Paper revised: 31.05.2023
Paper accepted: 05.06.2023