Rocznik Ochrona Środowiska
Volume 26 Year 2024 ISSN 2720-7501 pp. 30-40
https://doi.org/10.54740/ros.2024.003 open access
Received: January 2024 Accepted: January 2024 Published: February 2024

Investigation of Thermal Comfort, Productivity and Lighting Conditions in Higher Education Buildings

Natalia Siwczuk[1*], *Jerzy Zb. Piotrowski*[2], *Stanislav Honus*[3]
[1]*Faculty of Environmental Engineering, Geodesy and Renewable Energy, Kielce University of Technology, Kielce, Poland*
https://orcid.org/0000-0002-4003-3355
[2]*Faculty of Environmental Engineering, Geodesy and Renewable Energy, Kielce University of Technology, Kielce, Poland*
https://orcid.org/0000-0002-8479-1406
[3]*Faculty of Mechanical Engineering, VSB – Technical University of Ostrava, Ostrava-Poruba, Czech Republic*

[*]*corresponding author's e-mail: nkrawczyk@tu.kielce.pl*

Abstract: Thermal comfort and lighting conditions are essential aspects of indoor environmental quality. They are considered to influence the productivity of room users. The paper presents the experimental test results of research conducted in the university educational building of Kielce University of Technology (Central Poland) using anonymous questionnaires and physical measurements of indoor air parameters with a high-precision microclimate meter. It covers the analysis of the subjective assessment of thermal sensations, acceptability and preference, as well as productivity, lighting and air quality in eleven rooms (both lecture rooms and classrooms). The study analyses the impact of the indoor environment (mostly air temperature and illuminance) on the subjective sensations of the respondents they expressed in the questionnaires. The experiments have enabled us to provide valuable insights into developing the proper indoor environmental conditions to maximise room users' comfort and productivity.

Keywords: lighting, productivity, thermal comfort

1. Introduction

Thermal comfort is a key aspect of everyday life, significantly impacting the well-being and efficiency of people in various environments. As society progresses and climatic conditions change, issues related to thermal comfort are becoming more and more important both in the context of building design and in the field of research on the relationship between humans and the environment. Understanding and ensuring appropriate thermal comfort is becoming a priority in architecture, environmental engineering and urban design. However, the mechanisms influencing the thermal sensations of individuals are complicated, covering both physiological and psychological aspects. Therefore, researching thermal comfort is essential for the effective design of spaces that not only serve a functional purpose and promote users' health and mental well-being.

Thermal comfort is the level of awareness at which an individual experiences satisfaction with the thermal environment. In turn, thermal sensations are a subjective assessment of the environment as "cold" or "hot" (ASHRAE Standard 55-2017). The authors of (Su et al. 2023) focus on the research analysis of how people perceive and react to various environmental thermal conditions. They also raise issues related to the impact of heterogeneous thermal conditions on the experience of thermal comfort, thermoregulatory behaviour of people and possible implications for the design of thermal environments. The authors (Kramer et al. 2023) discuss a study on thermal comfort conducted in 13 air-conditioned office buildings in Australia. This article focuses on personal differences in the perception of thermal comfort based on observations made during a field study, in which they found a high level of discomfort among residents (as much as 28%) caused by the cold and hypothermia of the workplace. They also showed that offices are characterised by extremely heterogeneous internal thermal conditions, significantly affecting user dissatisfaction. The range of comfort temperatures for office workers in different cities and building types was thoroughly examined in the literature review conducted as part of this study. Research conducted in Singapore (Wang et al. 2018) concerned both houses without air conditioning (NV) and offices with air conditioning (AC), with designated neutral temperatures of 28.5°C and 24.2°C, respectively. A study (Taib et al. 2022) conducted in air-conditioned offices in Singapore found that the optimal temperature range for these environments is between 23.6°C and 26.4°C, with 24.8°C considered a neutral temperature. In turn, the authors (Allah et al. 2023) demonstrated several factors affecting thermal comfort, including workplace dress codes and an environment with diverse ventilation techniques. Workers who had the opportunity to choose from various clothing insulation options expressed greater thermal satisfaction than those required to adhere to restrictive clothing standards. It highlights the importance of providing a variety of clothing options to enable adjustments to individual comfort preferences. Thermal conditions perceived as optimal by humans are subjective and depend on the specific climate.

A study conducted (Singh et al. 2018) during the summer in India, which included 900 mostly male students, focused on assessing thermal comfort in naturally ventilated classrooms. The average comfort temperature was 29.8°C. The rooms had an average air temperature of 30.4°C (ranging from approximately 26.6°C to approximately 36°C). It was reported that 59% of respondents expressed a neutral feeling of warmth, and 69% indicated "no change" as their preferred temperature. Additionally, approximately 81% of the responses were within the comfort range. The survey indicates that most participants were satisfied with conditions that could be considered unsatisfactory for European respondents. The authors (Yang et al. 2018) presented research in school buildings that assessed the health and thermal comfort of school-age people in 54 classrooms in the Netherlands. They measured parameters such as carbon dioxide concentration, temperature and air humidity. Research showed that students were most bothered by noise and sunlight. Less than 40% of respondents did not like the temperature in the classroom, with a wide temperature range (from 21°C to 26.2°C). The authors (Homed et al. 2012) concluded that air temperature and humidity have the greatest impact on the feeling of thermal comfort.

A study (Jungsoo & Richard 2018) focused on analysing activities regulating thermoregulation in students. As part of their study, they surveyed primary and secondary school students. Respondents were asked to assess their current thermal comfort and express their classroom temperature preferences. Additionally, students were asked about their adaptive habits, such as changing clothes, opening windows, using fans, etc., in case of thermal discomfort. Based on the 4866 responses collected, the authors concluded that students preferred colder climatic conditions. However, primary school students showed a wider range of tolerance in terms of thermal sensations.

It must be added that the indoor thermal environment is also investigated in buildings supplied with heat through the district heating systems, as indicated in (Nogaj et al. 2017, Stokowiec et al. 2023, Turski & Sekret 2017). However, regardless of the type of heat source, the most crucial aspect in terms of thermal comfort is always an efficient way of releasing heat from the human body to the environment as latent or sensible heat (Koshlak & Pavlenko 2020, Orman 2014, Orman & Chatys 2011, Pavlenko & Szkarowski 2018). This issue is especially vital when using radiant heat sources (Dudkiewicz et al. 2022).

Research on thermal comfort in the context of productivity shows that optimal thermal conditions are crucial for effective work. People working in rooms with thermal comfort demonstrate increased efficiency, concentration and problem-solving ability. Appropriate thermal conditions may also affect psychomotor aspects of work, such as reaction speed or precision of movements. The researchers (Akimoto et al. 2010) conducted tests in which they compared thermal comfort with productivity, analysing parameters such as air temperature, radiation temperature, airflow speed and relative humidity. In the context of feeling tired, the study showed that the most common complaint among participants was drowsiness, which mainly depended on the type of work performed. According to the study's results (Aghniaey & Lawrence 2017), relative humidity had a stronger and more direct effect on productivity and thermal comfort than carbon dioxide. It was found that relative humidity positively affected the productivity and thermal comfort of users up to 55%. A study (Tsay et al. 2022) in Taiwan involving participants aged 20 showed that the most comfortable conditions for the subjects occurred in the temperature range from 25.4°C to 27.4°C. However, the optimal temperature from the point of view of productivity turned out to be different for women, amounting to 25°C, then for men, where it was higher and amounted to 27°C. It was also discovered that the colour of the walls can significantly impact work efficiency. In the authors' research (Latini et al. 2021), conducted on a group of 23 people, the impact of wall colour on users' efficiency was assessed at two different temperatures and using three different wall colours. The study results indicated that the most favourable wall colour was white, while red negatively impacted the participants' comfort at work. The authors (Xie et al. 2023) conducted a study on thermal comfort and productivity, in which they showed that increasing control of the personal environment marginally affects the improvement of occupant comfort. The authors showed that residents with control over thermal conditions show significant preference differences. However, no significant effects on thermal preferences are observed without such a belief. The tests carried out in Poland (Dudkiewicz et al. 2021) on 323 students in a Wroclaw University of Science and Technology lecture room showed that the largest willingness to work was at the mean room temperature of 24.28°C. Moreover, it was also reported that the neutral temperature was not perceived as comfortable.

In turn, research on the impact of lighting on thermal comfort was conducted by the authors (Hu et al. 2023), who showed that people staying indoors for a short time are more sensitive to changes in lighting. It should be noted that people spending a longer time in a given place may adapt to a darker environment, but such conditions will not provide them with adequate lighting. Therefore, when designing lighting in an underground building, special attention should be paid to the comfort of people staying there for a short time, and the needs of those who spend more time there should be considered, ensuring a brighter working environment. The optimal summer temperature range for people staying in the building for longer periods was 25.6-26.3°C; for shorter periods, it was 24.5-24.8°C. In work, (Elbellahy et al. 2024), day lighting was assessed in a dry and hot climate in Saudi Arabia. The research showed that the daily illumination did not exceed 100lx. Only in a few workplaces the daylight exceeded this value. The results showed that 73.1% of respondents were satisfied with the lighting intensity at temperatures ranging from 14.3-25.33°C.

To sum up, creating thermal comfort conditions in the workplace or study is an investment in the effectiveness of the team and the overall quality of the tasks performed. Room users who feel comfortable in terms of temperature are more likely to engage in work, which translates into increased productivity and the quality of services provided. Previously, the authors focused on the phenomenon of the sick building syndrome (Krawczyk et al. 2023), while the present paper analyses selected indoor environment parameters and their impact on human sensations due to the importance of this issue in several aspects (Amanowicz et al. 2023, Kotrys-Działak & Stokowiec 2023). The insufficient data available in the literature regarding the analysed research area needs to be supported by new data, which is the aim of the present paper.

2. Experimental

Thermal comfort tests were carried out in the Central part of Poland in the Swietokrzyskie Voivodship at the Kielce University of Technology, i.e. in the Energis building (Faculty of Environmental Engineering, Geodesy and Renewable Energy). This smart building dates back to 2012 and has mechanical ventilation, and a BMS (Building Management System) that manages the entire building. The building has 22 classrooms, staff offices, and laboratories for research. The building in question is shown in Photo 1.

Photo 1. Department of Environmental Engineering, Geodesy and Renewable Energy at Kielce University of Technology

The research involved analysing the subjective assessment of thermal sensations, acceptability and preferences, productivity, lighting and air quality in eleven rooms. The research was carried out using two methods, i.e. measuring microclimate parameters using specialised equipment, the Testo 400 meter and its probes, and conducting and analysing anonymous surveys completed by respondents during the research. 110 users assessed thermal comfort. Photo 2 below shows the Testo 400 microclimate meter with probes.

Photo 2. Testo 400 microclimate meter with probes: light intensity (yellow circle) and air temperature and humidity (blue circle)

3. Results and Discussion

3.1. Thermal sensations and preferences

The results obtained from the questionnaire surveys allowed the respondents to assess the thermal sensations in the examined rooms. First, the respondents were asked about their feelings (TSV - Thermal Sensation Vote), which are on a seven-point scale following the (ASHRAE Standard 55 2017) and the international standard (ISO Standard 7730 2005). On the x-axis, these values mean: 0 – comfortable, 1 – pleasantly warm, 2 – too warm, 3 – too hot, -1 – pleasantly cool, -2 – too cool and -3 – too cold. The question was: "How could you rate your thermal sensation now?". Figure 1 below shows a chart showing the frequency of responses regarding thermal sensations felt by the respondents.

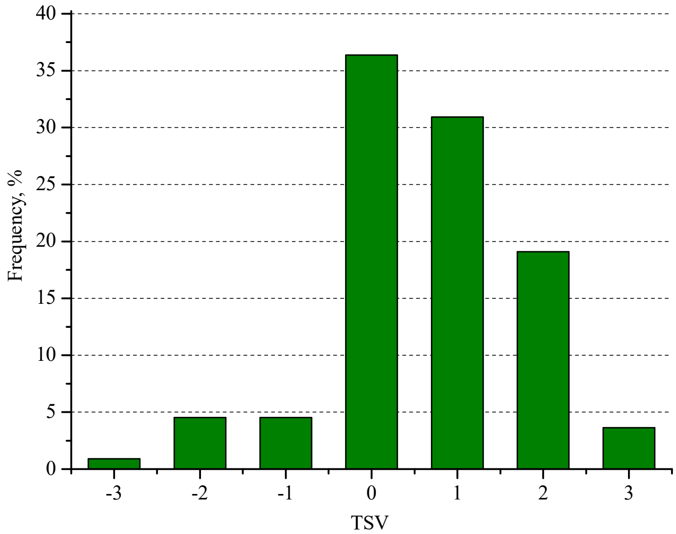

Fig. 1. Frequency of response given by respondents regarding thermal sensations

Using questionnaires, the students expressed their opinion on the thermal sensations (how they felt). The figure shows the results for the eleven analysed rooms. Zero means a comfortable and most favourable state, while the positive values (1, 2, 3) describe that the person feels warmth (1) or strong heat (3), while negative (-1, -2, -3) is the opposite (cool and then cold). In general, it can be noted that respondents indicated that the rooms were warm (positive TSV values). It is probably due to the prevailing temperature in the rooms, which most often ranged from 21.5°C to 25.5°C. In the presented diagram, it was noted that the answer comfortable was the most frequently given. It amounted to more than 36.36% of all the answers provided. Then, the students chose pleasantly warm and too warm, which were 30.91% and 19.09%, respectively. Almost 5% answered pleasantly cool and too cool. The least chosen option was the answer too hot, which amounted to 4.0%. Less than 5% chose the answer too cold and too hot. The next graph of Figure 2 shows the relationship between TSV (Thermal Sensation Vote) and air temperature (AT) in the surveyed rooms.

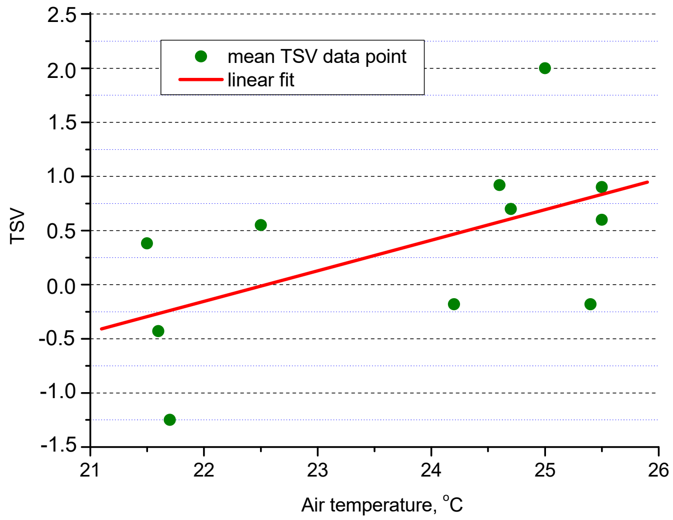

Fig. 2. Mean thermal sensation vote vs air temperature

The graph above shows the relationship between air temperature and the average results of thermal sensation voting conducted in 11 rooms. From the graph, it can be concluded that thermal sensations are in fact closely related to air temperature (although the regression coefficient was only $R^2 = 0.30$). As the air temperature increases, the average TSV value also increases. At the same time, it is worth noting that the most comfortable conditions (i.e. $-0.5<TSV<0.5$) were observed for temperatures in the range of 21.5°C to 22°C. The resulting relationship is of the following form:

$$TSV = 0.2828AT - 6.3761 \tag{1}$$

Another question related to the feeling of temperature inside rooms is about the preferences of the surveyed people (TPV – Thermal Preferences Vote).

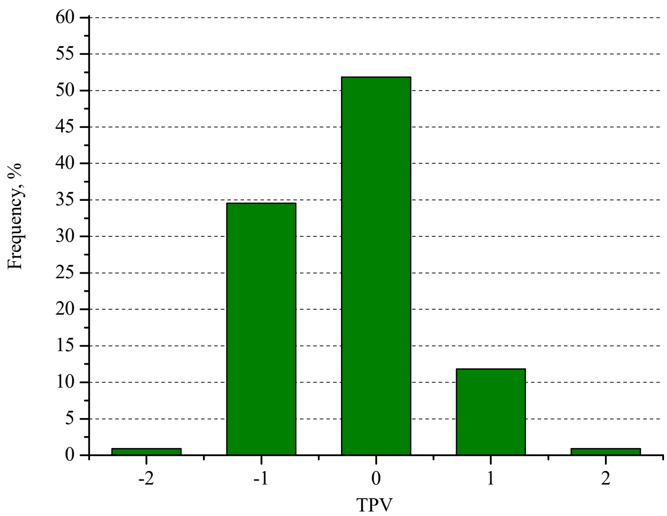

Fig. 3. Frequency of response given by respondents regarding thermal preferences

When asked about their preferences regarding a possible change in air temperatures, respondents had the following answers to choose from: -2 – definitely cooler, -1 – cooler, 0 – normal, +1 – warmer, +2 – definitely warmer. The chart shows that most respondents, i.e. 57 out of 110 people (51.82% of all respondents), admitted that they would like the room temperatures to remain unchanged. 38 people (34.55%) would like there to be cooler in the room, 13 people (11.82%) to be warmer, and one person each (about 1%) would like there to be a definitely cooler and definitely warmer. The research results are reflected in Figure 1. Since many respondents assessed the indoor environment as too warm, they would like to reduce the air temperature, which is shown in Figure 3 by a significant number of people who marked the answer (-1). Undoubtedly, TSV and TPV must be closely correlated, which is confirmed by Figure 4.

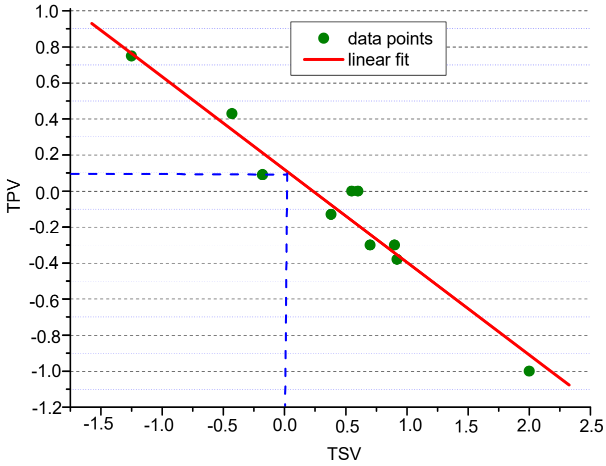

Fig. 4. Relationship between thermal sensation vote (TSV) and thermal assessment vote (TAV)

Based on the analysis of 110 surveys, the relationship between average thermal sensations and preferences was presented. Average ratings for Thermal Subjective Sensation (TSV) and Thermal Subjective Preferences (TPV) were calculated for each of the 11 rooms. It is noticeable that people who felt thermal comfort (TSV = 0) preferred no temperature changes (TPV close to 0). The linear approximation of 11 points determining the average values from the rooms turned out to be so precise that for TSV = 0, we obtain TPV = 0.1. From the above data, it is worth noting that thermal comfort was present in 7 rooms. It means that the respondents rated their well-being as comfortable and did not want any changes in the rooms examined. However, they found three rooms too cold and similarly wanted the room to be warmer. Only one room was too warm for the respondents, so they wanted the temperature in the room to be lower. The coefficient of determination for this relationship is very high and amounts to $R^2 = 0.94$, and the correlation between these two variables is strong, which is presented as:

$$TPV = -0.5151TSV + 0.1192 \tag{2}$$

3.2. Overall comfort, lighting conditions and productivity

The research asked respondents about their general well-being (GSV) in the examined rooms. When asked, "How do you feel overall?" respondents had five answers to choose from: positive values meant good and very good, "0" meant indifferent, and negative values meant bad and very bad. Below is a frequency chart (Figure 5) regarding the respondents' feelings.

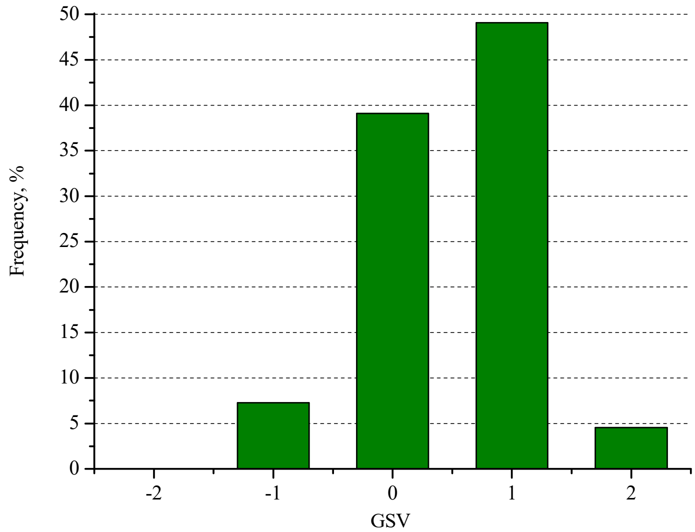

Fig. 5. Frequency of responses provided about General Sensation Vote (well-being)

Regarding temperatures and air humidity, almost 50% of respondents were satisfied with the indoor environment. Only 7.27% of respondents did not respond to the climate conditions well, and they marked the answer as bad. It may probably be related to factors other than the thermal environment. 39.09% of respondents were indifferent to indoor conditions. 4.55% of respondents felt very well.

Good lighting where we do our work or study should be necessary to perform our tasks comfortably and qualitatively. Lighting should have a positive impact on the quality of work performed. The level of light intensity can also affect concentration during school or work. Therefore, the respondents were asked to complete a survey about the lighting in the examined rooms, as illustrated in Figure 6.

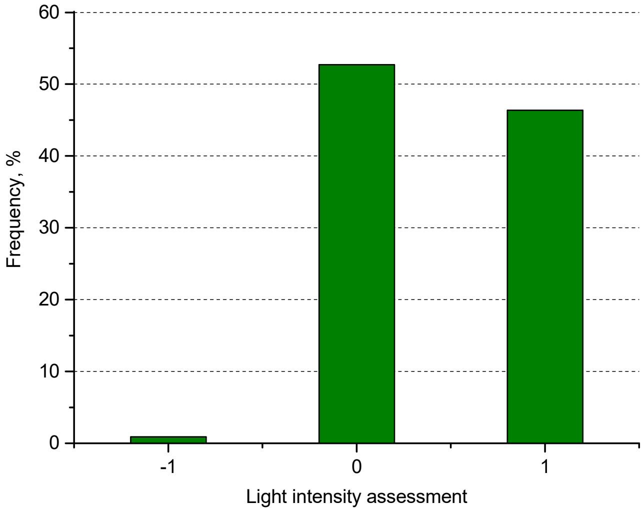

Fig. 6. Light intensity assessment (LIA) in the rooms according to respondents

According to the people survey, this chart shows the overall assessment of lighting in the Energis building. The temperature for the tested rooms ranged from 21.5°C to 25.5°C, and the light intensity ranged from 23.8 to 505lx. Respondents rated the lighting according to the scale: -1 – too weak, 0 – appropriate, 1 – too strong. The analysis of the results showed that the respondents generally rated the lighting in the room as appropriate at around 52.73%. For about 46.36%, the lighting was too strong, and for about 1%, it turned out to be too weak. However, this does not change the fact that more than half of the surveyed people rated the lighting as appropriate and were satisfied with its intensity. Figure 7 shows the relationship between the average well-being score (GSV) and the average lighting score (LIA).

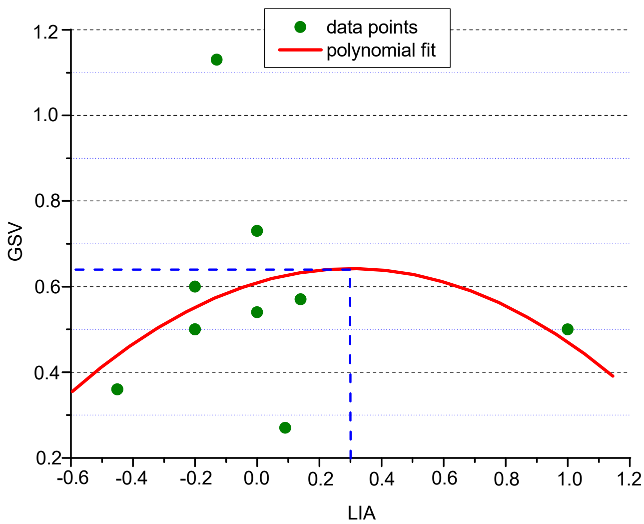

Fig. 7. Relationship between the average well-being rating and the mean lighting rating

When comparing the average rating on lighting in the rooms studied with the rating on well-being, the study showed that the range of best well-being (maximal value of GSV) is for the LIA value of 0.3. It means that the lower or higher the light intensity, the worse people feel. However, the regression coefficient is very low

(R^2 = 0.02), thus this conclusion is difficult to prove decisively. It means that people cannot accurately relate the magnitude of illumination with rating on well-being. The next figure shows the measured light intensity and the average lighting evaluation according to the respondents. One data point was removed due to a possible large error.

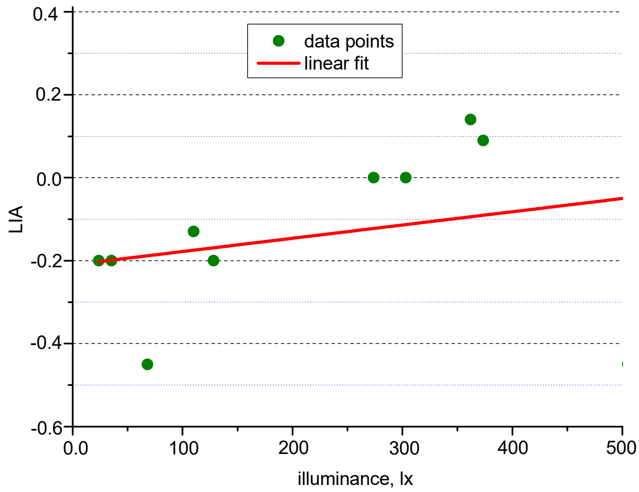

Fig. 8. Relationship between the average rating of lighting in the studied rooms and the intensity of lighting

The figure above shows data on the average lighting rating (based on questionnaires) for 10 rooms and the light intensity meter (x-axis) results. Out of the classrooms, only 2 classrooms were satisfactory regarding the light intensity, which ranged from 274lx to 303lx. The standard (EN 12464-1: 2012) indicates that the satisfactory light intensity in classrooms is 300 lx. The light intensity in most rooms ranged from 23.8 to 505lx. The equation for the LIA (Light Assessment Vote) value in Figure 8 is:

$$LIA = 0.003x - 0.20936 \tag{3}$$

where x is the illuminance value and the regression coefficient was only R^2 = 0.07. As the illuminance rose, people reported higher LIA values, which is in agreement with common sense and knowledge and proved the correctness of the experimental set-up.

The survey also asked respondents about their assessment of productivity (i.e. their subjective ability to acquire knowledge, which they determined independently), as shown in Figure 9.

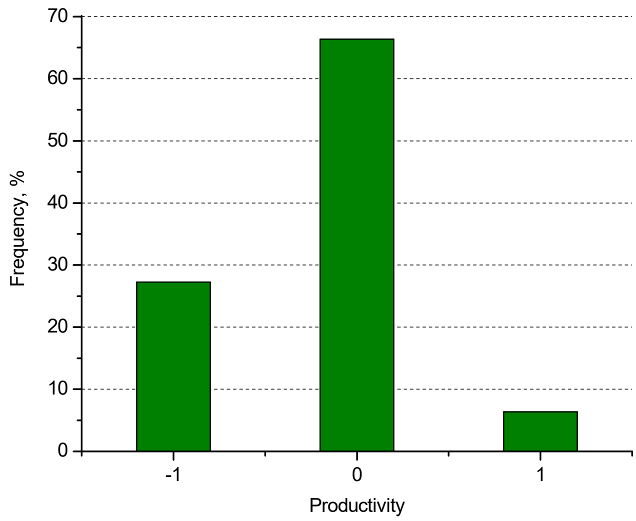

Fig. 9. Overall assessment of student productivity for the audited classrooms throughout the building

The figure presents the frequency of the answers regarding the learning productivity in the building under study, where -1 is weak, 0 is normal, and 1 is high. It can be seen in the chart that the most frequently given answer was normal, which amounted to 66.36% of all the answers. The second answer, 27.27%, was weak, while high was the least chosen answer (6.36%).

The impact of positive well-being on work efficiency is quite subjective. It requires a detailed discussion on the impact of atmospheric conditions indoors on the learning abilities of the respondents. Figure 10 shows the relationships between the air temperature in 11 different rooms and the average work efficiency results reported in the surveys.

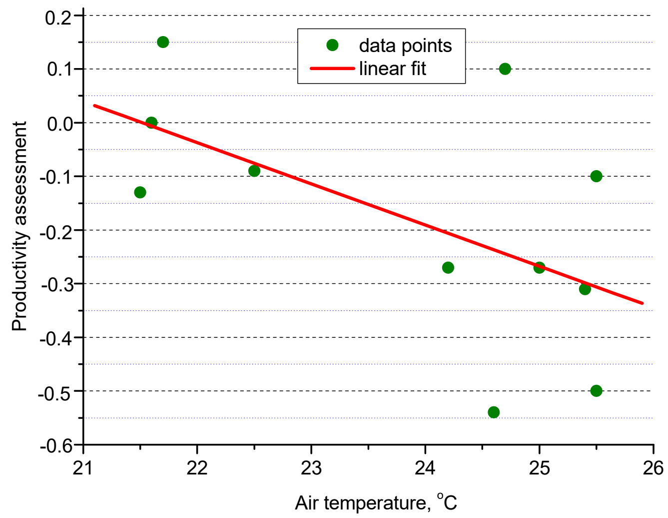

Fig. 10. The average productivity assessment in the rooms and air temperature

From the chart above it can be concluded that the temperature from 21°C to 22°C provides highest productivity. However, looking at the downward trend, the productivity above 24°C will be lower. The figure shows that the best learning productivity occurs at the temperature of 21.5°C. It means that students learn best because they are warm enough. The resulting linear fit formula is:

$$\text{Productivity} = -0.0772\text{AT} + 1.662 \tag{4}$$

where x – air temperature. The regression coefficient turned out to be $R^2 = 0.33$. The data show that the higher the air temperature, the lower the quality of learning. The next chart (Figure 11) shows the relationship between the average productivity and well-being ratings.

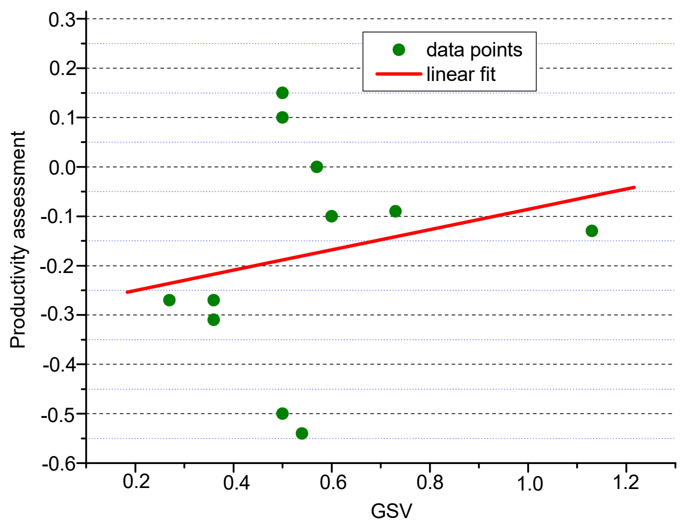

Fig. 10. Relationship between the average productivity rating in rooms and the average general well-being

The diagram illustrates the mean survey ratings, comparing the relationship between well-being and productivity in the examined rooms. It is important to highlight that when individuals experience a sense of comfort indoors, their productivity increases. As expected, the linear regression line (depicted in red) follows a logical pattern – people demonstrate enhanced work and learning capabilities when they are content with their indoor surroundings. The linear fit equation takes the following form:

$$\text{Productivity} = 0.216\text{GSV} - 0.2972 \quad (5)$$

and the regression coefficient amounts to $R^2 = 0.05$. Upon scrutinising the graph above, one can observe that an improvement in well-being might correlate with an elevation in productivity, although the regression coefficient is very low. People work more efficiently when they feel satisfied and happy.

4. Summary and Conclusions

The respondents were generally satisfied with their indoor thermal conditions. A relation between thermal sensation and air temperature was confirmed. Similarly, a strong correlation between thermal sensations and thermal preferences was observed.

The investigation conducted within a building revealed that 53% of individuals expressed contentment with the lighting conditions. Specifically, students clearly prefer lighting ranging from 200 to 400 lux, with the most favourable conditions perceived at 300 lux.

In a broader sense, the overall light intensity was deemed appropriate, although a few respondents found it excessively bright. Productivity levels were generally considered normal. It was inversely proportional to air temperature and proportional to the well-being of the students. It underscores the importance of conducting further research to ascertain whether the relationships among the tested variables will become more pronounced.

The work in the paper was supported by the project: "REFRESH – Research Excellence For Region Sustainability and High-tech Industries, (VP2), (Reg. No.: CZ.10.03.01/00/22_003/0000048) co-funded by the European Union".

References

Aghniaey, S., Lawrence, T.M. (2017). Cooling season demand response and the real world, *ASHRAE Journal*, *59*, 68-70.

Akimoto, T., Tanabe, S., Yanai, T., Sasaki, M. (2010). Thermal comfort and productivity - Evaluation of workplace environment in a task conditioned office. *Building and Environment*, *45*(1), 45-50. https://doi.org/10.1016/j.buildenv.2009.06.022

Allah, M.Z., Kamar, H.M., Hariri, A., Wong, K.Y. (2023). Investigating adaptive thermal comfort in office settings: A case study in Johor Bahru, Malaysia. *Case Studies in Chemical and Environmental Engineering*, *8*, 100466, https://doi.org/10.1016/j.cscee.2023.100466

Amanowicz, Ł., Ratajczak, K., Dudkiewicz, E. (2023). Recent Advancements in Ventilation Systems Used to Decrease Energy Consumption in Buildings-Literature Review. *Energies*, *16*(4), 1853. https://doi.org/10.3390/en16041853

ANSI/ASHRAE Standard 55 (2017). Thermal environmental conditions for human occupancy, Atlanta: American Society of Heating, Ventilation and Air-conditioning Engineers Inc.

Dudkiewicz, E., Fidorów-Kaprawy, N., Szałański, P. (2022). Environmental Benefits and Energy Savings from Gas Radiant Heaters' Flue-Gas Heat Recovery. *Sustainability*, *14*, 8013. https://doi.org/10.3390/su14138013

Dudkiewicz, E., Laska, M., Fidorów-Kaprawy, N. (2021). Users' Sensations in the Context of Energy Efficiency Maintenance in Public Utility Buildings. *Energies, 14*, 8159. https://doi.org/10.3390/en14238159

Elbellahy, S., Alotaibi, B.S., Abuhussain, M.A. (2024). Field measurements of post-operation evaluation of daylighting and thermal comfort in hot and arid climates: A pilot study of three educational buildings on the Najran University campus in Saudi Arabia. *Journal of Building Engineering*, *82*, 108174. https://doi.org/10.1016/j.jobe.2023.108174

EN 12464-1 (2012). Light and lighting – Lighting of workplaces – Part 1: Indoor workplaces.

Homod, R.Z., Mohamed Sahari, K.S., Almurib, H.A.F., Nagi, F.H. (2012). RLF and TS fuzzy model identification of indoor thermal comfort based on PMV/PPD. *Building and Environment*, *49*(1), 141-153. https://doi.org/10.1016/j.buildenv.2011.09.012

Hu, X., Li, N., Gu, J., He, Y., Yongga, A. (2023). Lighting and thermal factors on human comfort, work performance, and sick building syndrome in the underground building environment. *Journal of Building Engineering*, *79*, 107878. https://doi.org/10.1016/j.jobe.2023.107878

ISO Standard 7730 (2005). 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; Geneva, Switzerland, 2005.

Kim, J., De Dear, R. (2018). Thermal comfort expectations and adaptive behavioural characteristics of primary and secondary school students. *Building and Environment*, *127*, 13-22.

Koshlak, H., Pavlenko, A. (2020). Mathematical model of particle free settling in a vortex apparatus. *Rocznik Ochrona Środowiska*, *22*, 727-734.

Kotrys-Działak, D., Stokowiec, K. (2023). Temperature Distribution Analysis on the Surface of the Radiator: Infrared Camera and Thermocouples Results Comparison. *Rocznik Ochrona Środowiska*, *25*, 37-44. https://doi.org/10.54740/ros.2023.005

Kramer, T., Garcia-Hansen, V., Omrani, S., Zhou, J., Chen, D. (2023). Personal differences in thermal comfort perception: Observations from a field study in Brisbane, Australia. *Building and Environment*, *245*, 110873. https://doi.org/10.1016/j.buildenv.2023.110873

Krawczyk, N., Dębska, L., Piotrowski, J.Zb., Honus, S., Majewski, G. (2023). Validation of the Fanger Model and Assessment of SBS Symptoms in the Lecture Room. *Rocznik Ochrona Środowiska*, *25*, 68-76. https://doi.org/10.54740/ros.2023.008

Latini, A., Giuseppe, E., Di. D'Orazio, M., Perna, C. Di (2021). Exploring the use of immersive virtual reality to assess occupants' productivity and comfort in workplaces: An experimental study on the role of walls colour. *Energy & Buildings*, *253*, 111508. https://doi.org/10.1016/j.enbuild.2021.111508

Nogaj, K., Turski, M., Sekret R. (2017). The influence of using heat storage with PCM on inlet and outlet temperatures in substation in DHS. *Proc of Int. Conf. on Advances in Energy Systems and Environmental Engineering* (ASEE17), Wrocław, Poland, July 2-5, 2017, *E3S Web of Conferences*, *22*, 00124. https://doi.org/10.1051/e3sconf/20172200124

Orman, Ł.J. (2014). Boiling heat transfer on meshed surfaces of different aperture. *Proc of Int. Conf. on Application of Experimental and Numerical Methods in Fluid Mechanics and Energetics (Slovakia), AIP Conference Proceedings*, *1608*, 169-172. https://doi.org/10.1063/1.4892728

Orman, Ł.J., Chatys, R. (2011). Heat transfer augmentation possibility for vehicle heat exchangers. *Proc. of 15th Int. Conf. "TRANSPORT MEANS" (Kaunas, Lithuania)*, 9-12.

Pavlenko, A., Szkarowski, A. (2018). Thermal insulation materials with high-porous structure based on the soluble glass and technogenic mineral fillers. *Rocznik Ochrona Środowiska*, *20*, 725-740.

Singh, M.K., Kumar, S., Ooka, R., Rijal, H.B., Gupta, G., Kumar, A. (2018). Status of thermal comfort in naturally ventilated classrooms during the summer season in the composite climate of India. *Building and Environment*, *128*, 287-304.

Stokowiec, K., Wciślik, S., Kotrys-Działak, D. (2023). Innovative Modernisation of Building Heating Systems: The Economy and Ecology of a Hybrid District-Heating Substation. *Inventions*, *8*, 43. https://doi.org/10.3390/inventions8010043

Su, X., Yuan, Y., Wang, Z., Liu, W., Lan, L., Lian, Z. (2023). Human thermal comfort in non-uniform thermal environments: A review. *Energy and Built Environment*. https://doi.org/10.1016/j.enbenv.2023.06.012

Taib, N.S.M., Zaki, S.A., Rijal, H.B., Razak A.A., Hagishima, A., Khalid, W., Ali, M.S. M. (2022). Associating thermal comfort and preference in Malaysian universities' air-conditioned office rooms under various set-point temperatures. *Journal of Building Engineering*, *54*, 104575. https://doi.org/10.1016/j.jobe.2022.104575

Tsay, Y.S., Chen, R., Fan, Ch.Ch. (2022). Study on thermal comfort and energy conservation potential of office buildings in subtropical Taiwan. *Building and Environment*, 208, 108625. https://doi.org/10.1016/j.buildenv.2021.108625

Turski, M., Sekret, R. (2017). A method of determining the thermal power demand of buildings connected to the district heating system with usage of heat accumulation. *Proc. of Int. Conf. on Advances in Energy Systems and Environmental Engineering* (ASEE17) Wrocław, Poland, July 2-5, 2017, *E3S Web of Conferences*, *22*, 00180. https://doi.org/10.1051/e3sconf/20172200180

Wang, Z., de Dear, R., Luo, M., Lin, B., He, Y., Ghahramani, A., Zhu, Y. (2018). Individual difference in thermal comfort: A literature review. *Building and Environment*, *138*, 181-193. https://doi.org/10.1016/j.buildenv.2018.04.040

Xie, K., Lee, M., Khalid, R., Zakka, V.G. (2023). The impact of personal environmental control on the performance of thermal systems: Building energy consumption, occupant thermal comfort, and productivity. *Energy & Buildings*, *298*, 113552. https://doi.org/10.1016/j.enbuild.2023.113552

Yang, B., Olofsson, T., Wang, F., Lu, W. (2018). Thermal comfort in primary school classrooms: A case study under subarctic climate area of Sweden, *Building and Environment*, *135*, 237-245. https://doi.org/1010.1016/j.buildenv.2018.03.019