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INDOOR ENVIRONMENT, LIGHTING CONDITIONS AND PRODUCTIVITY IN THE EDUCATIONAL BUILDINGS

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Abstract

The main aim of the research is to assess the light intensity and its impact on the productivity of research participants in educational buildings. The research was carried out in 18 rooms in teaching buildings in Poland and involved over two hundred volunteers. The tests were carried out with the following climate parameters: air temperature ranged from 20 to 25.1 °C, relative humidity from 18.16 to 50.9 %, and the concentration of carbon dioxide from 509 to 1634 ppm. The light intensity in the tested rooms ranged from 17.3 to 1095.1 lux. The parameters of the room temperature, carbon dioxide concentration, relative humidity and light intensity were recorded using a microclimate meter. The study participants were asked to answer questions about overall well-being, lighting quality, and productivity in each room. The results show that the air temperature has an effect on the productivity of the participants with the most preferable range of about 22 – 24 °C. It was also observed that productivity increased with improved well – being of the respondents. The analysed research also made it possible to check whether the users were satisfied with the light intensity. 74 % of respondents assessed that with the prevailing lighting, their productivity is normal, and they also felt best in rooms where the light intensity was 200 - 400 lux.

Keywords:

Thermal comfort;
Productivity;
Lighting conditions;
Indoor environment;
General sensation vote.

1 Introduction

As the most important of the internal environment for humans, air has a huge impact on health, well-being and productivity. Unfortunately, with poor indoor air quality, various symptoms, such as headaches, fatigue, eye, nose and throat irritation we can be experienced. Improper lighting conditions can also have an influence. Indoor air quality depends on many factors: the amount of pollutant emissions in the rooms, the cleanliness of the ventilation ducts and the frequency of replacing air filters. The internal environment of buildings affects human health, comfort, work efficiency and self-esteem. Looking at today's work environment, we spend more and more time in buildings and schools. The right quality of the indoor environment can improve the quality and efficiency of work. Each person wants to feel comfortable in the room they are in. This means that people do not want to feel either too hot or too cold indoors.

In terms of thermal comfort in buildings, modern systems are based on existing models. First of all, it is the Fanger model [1], which determines the PMV (Predicted Mean Vote) index to determine thermal comfort. The PMV index does not take into account, inter alia, the concentration of carbon dioxide and physiological characteristics, such as age, BMI (Body Mass Index) or gender. Recent studies by Yeom and Delogu [2] show that the variables for estimating thermal comfort for optimal productivity may also be the local skin temperature. The authors performed experiments on 50 participants at six temperatures from 18 to 28 °C (2 °C step). The authors also showed that the gender difference can have a significant impact on thermal sensation and productivity. Other authors [3] conducted studies in air-conditioned offices comparing the differences between the sexes and environmental satisfaction. The results showed that women are less satisfied with the prevailing climate. Indoor environmental quality is a measure of how occupants perceive comfort. Failure to ensure appropriate climatic conditions will certainly affect the quality of work performed by building users. Duran and Lomas [4] conducted research in British office buildings that require modernization. The research methodology takes into account the improvement of thermal comfort, which will affect the productivity of employees. The influence of discomfort on the decline in productivity is also shown. Research in office buildings was also carried out by Kaushik et al. [5]. The authors showed that temperature and humidity had the greatest impact on the efficiency of users' work. Carbon dioxide, according to the authors, ranks fourth in terms of its impact on productivity.

It turns out that the colour of the walls also affects the productivity of the work. The authors [6] conducted research on the influence of wall colour on user performance. The research was carried out on 23 people, aged 23 - 32, for two temperatures and three colours of the walls. The results showed that the most advantageous wall colour is white, while red has a negative impact on the users' ability to work. Tsay et al. [7] conducted a study in Taiwan on participants aged 20, where the most comfortable conditions for the respondents were in the temperature range of 25.4 - 27.4 ^{o}C. However, the optimal temperature in terms of productivity for women is 25 ^{o}C, and for men it turned out to be higher - 27 ^{o}C. In the study [8], the highest efficiency was achieved for the temperature of 24 ^{o}C, in which 9 women and 12 men participated. Faheem et al. [9] carried out studies in neutrally ventilated buildings in warm and humid climatic regions. The author justified his conclusions on the basis of 2028 questionnaires collected on students. It should therefore be noted that the comfort range in warm regions will be greater, from 26.1 to 32.8 ^{o}C. Schellen et al. [10] performed research on 10 women and 10 men aged 20 to 29. Research results show differences between PMV and survey results, and that women felt more uncomfortable than men. Providing the right thermal conditions is a difficult task. The authors [11] discussed the assessment of productivity in office buildings based on a study carried out on 940 users. The authors explained that of the 32 variables relating to the climatic environment, user preferences, thermal sensation and acceptability have the greatest emphasis on performance.

Despite many analysed articles, it is difficult to choose the right climatic conditions so that users have the greatest possible work efficiency, and thus feel good indoors. The aim of the article is to analyse and discuss the indoor environment in the educational buildings of Kielce University of Technology (Poland) with the view to assess general sensations of the students and determine whether lighting conditions and the air temperature can influence student performance.

2 Materials and methods

The research was conducted at Kielce University of Technology in four teaching buildings from June 2021 to April 2022 – two of them (“Energis” and “D” building) have been shown in Fig. 1.

a) b)

Fig. 1: Educational buildings of Kielce University of Technology: a) “Energis”, b) “D” building.

The research consisted in carrying out microclimate measurements in classrooms, where there were students aged between 20 and 29 years, as well as 5 academic lecturers aged between 37 and 52 years. In the studied teaching rooms, the windows were located on the east and west side, depending on the rooms. A Testo 400 meter was used to measure the actual microclimate parameters. Using probes, the meter measured air temperature (with an accuracy of +/- 0.3 °C), relative humidity (+/- 2 %), carbon dioxide concentration (+/- 50 ppm), as well as illuminance (+/- 0.1 lux). The picture below shows a photo of the probes, Fig. 2. In addition, the meter also measured the air velocity. Its measurement error is +/- 0.03 m/s.

Fig. 2: Probes for collecting information on: CO_2 concentration (red circle), air temperature and humidity (blue circle) and light intensity (yellow circle).

People in the classrooms completed anonymous questionnaires. The questionnaires included questions about the general assessment of their well-being, the quality of lighting and the assessment of productivity in each room. Additionally, the questionnaire included a question about physical activity during the 30 minutes before coming to that room. For this reason, five questionnaires were rejected because the respondents ticked the answer concerning moderate physical activity. Surveys were carried out in 18 teaching rooms. During the measurements with the microclimate meter, the participants filled in the questionnaires. The measurement of parameter stabilisation lasted 15 minutes. After this time, the parameters were recorded and the questionnaires were collected, which are discussed in the next chapter. The study involved 210 participants, of which 205 questionnaires were taken for analysis.

3 Results and discussion

The collected results from the meter showed that the air temperature in the 18 rooms ranged from 20 to 25.1 ^{o}C, relative humidity from 18.16 to 50.9 %, and carbon dioxide concentration from 509 to 1634 ppm. Fig. 3 shows the discussed indoor climate parameters.

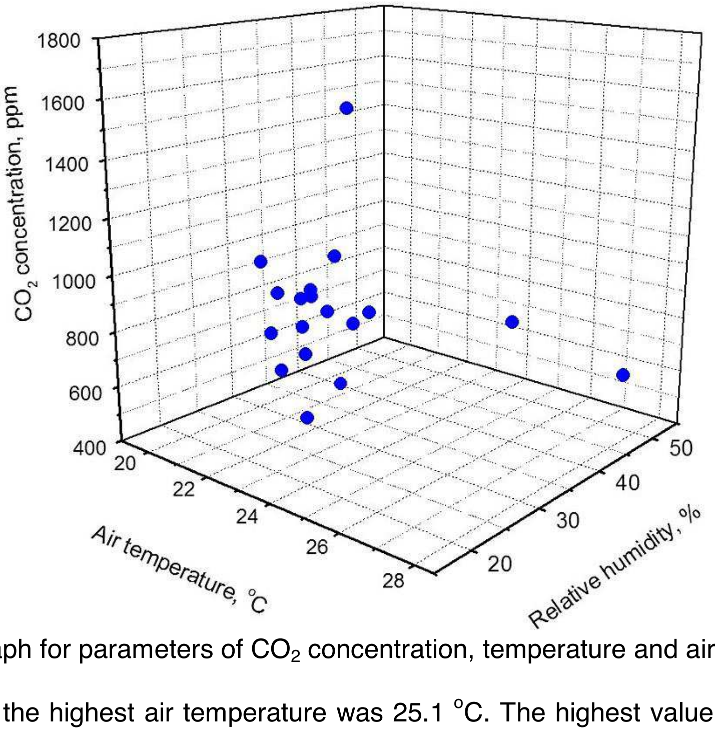

Fig. 3: Graph for parameters of CO_2 concentration, temperature and air humidity.

For 18 rooms, the highest air temperature was 25.1 ^{o}C. The highest value for air humidity was 50.9 % and for CO2 concentration - 1634 ppm. Only one room had a carbon dioxide concentration value above 1500 ppm. The maximum value of carbon dioxide concentration for category II buildings (as those analysed) is 800 ppm + carbon dioxide level in the outside air [12]. If the rooms in which people stay are poorly ventilated, people feel tired, drowsy and even get headaches.

In the conducted questionnaire research 80 women and 125 men participated. The respondents were first asked to give answers about their general well-being. They could choose between the following answers: “very good”, +2, “very bad”, -2, “good”, +1, “bad”, -1 and “indifferent”, 0. Fig. 4 shows the graph for this question.

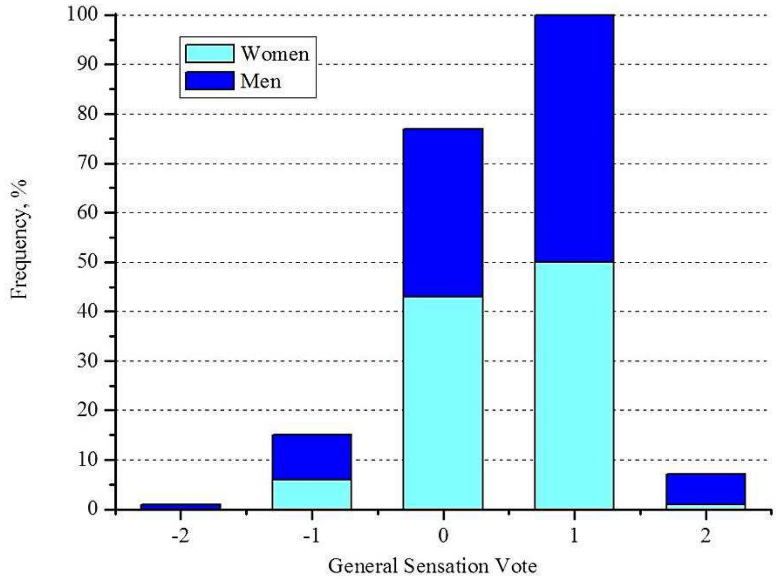

Fig. 4: Frequency of responses provided about General Sensation Vote (well-being).

For temperatures ranging from 20 ^{o}C to 25.1 ^{o}C, with an air humidity of 18.16 to 50.9 %, it can be seen that 50 % of women and 50 % of men were satisfied with the indoor environment. Only 1 % of men did not respond to the climate conditions well and they marked the answer “very bad”, “-2”. 43 % of women and 34 % of men had indifference to the indoor conditions. 6 % of women and 9 % of men felt bad in the room “-1”. Probably it may be related to factors other than the thermal environment. 1 % of women and 6 % of men felt very well. The Fig. 5 shows the assessment of the light intensity for the classrooms in question – with the possible answers: “too strong”, +1, “too weak”, -1 and “appropriate”, 0.

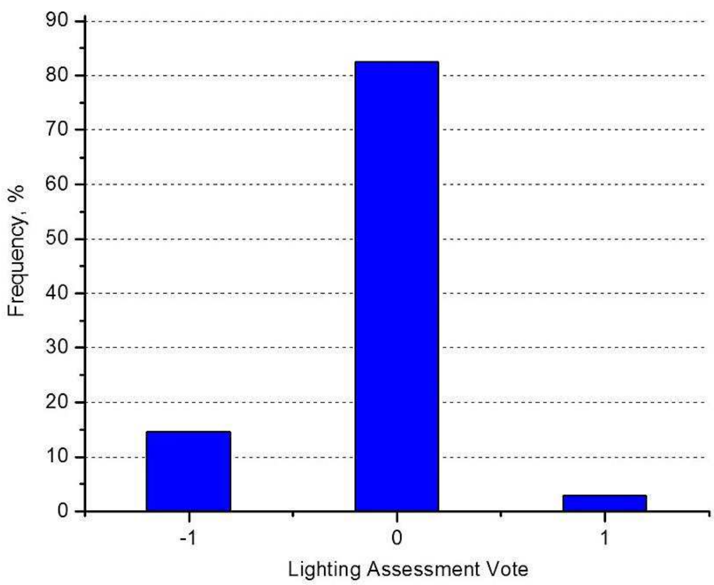

Fig. 5: Average light intensity rating for 18 rooms.

Analysing the above graph regarding the evaluation of lighting, it can be seen that 82.44 % considered it appropriate. 14.63 % of the respondents considered it too weak, while almost 3 % of the respondents considered it too strong. The level of light intensity for the 18 rooms was in the range of 17.3 to 1095.1 lux. Thus, it should be concluded that the people taking part in the research were satisfied with the quality of lighting in the teaching rooms. Fig. 6 shows the light intensity and the average evaluation of the lighting according to the respondents.

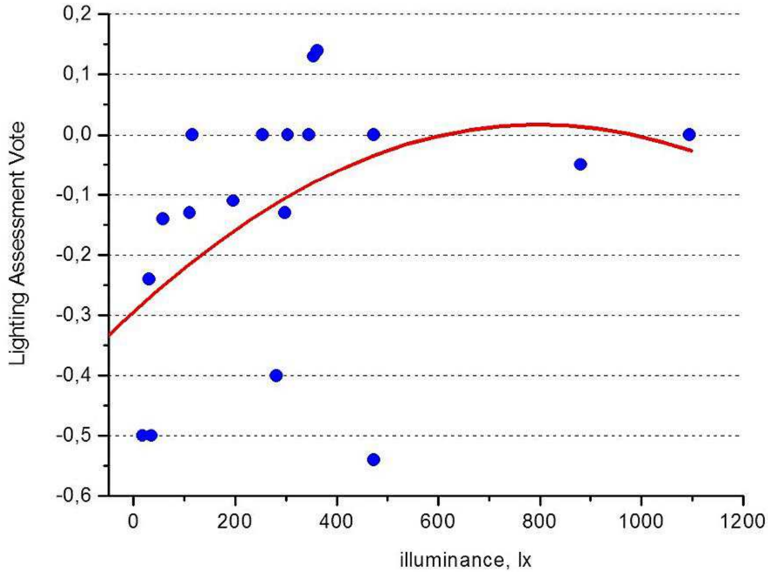

Fig. 6: Light Assessment Vote vs. lighting intensity.

The figure above shows the data for the average lighting rating (based on questionnaires) for 18 classrooms, attended by 205 people, and the results from the light intensity meter. For the 18 teaching rooms, only in 4 rooms the respondents were satisfied with the light intensity. The lowest satisfaction was found for the room at 17.3 lux and 30.5 lux. The lower the illuminance in the rooms, the more dissatisfied the people there, which may translate into the productivity of the people surveyed or into general well-being. The light intensity in most of the rooms was in the range of 200 to 400 lux. The standard EN 12464-1: 2012 [13] shows that the satisfactory light intensity is 300 lx for classrooms. Fig. 7 shows the relationship between the average well-being score and the average lighting score.

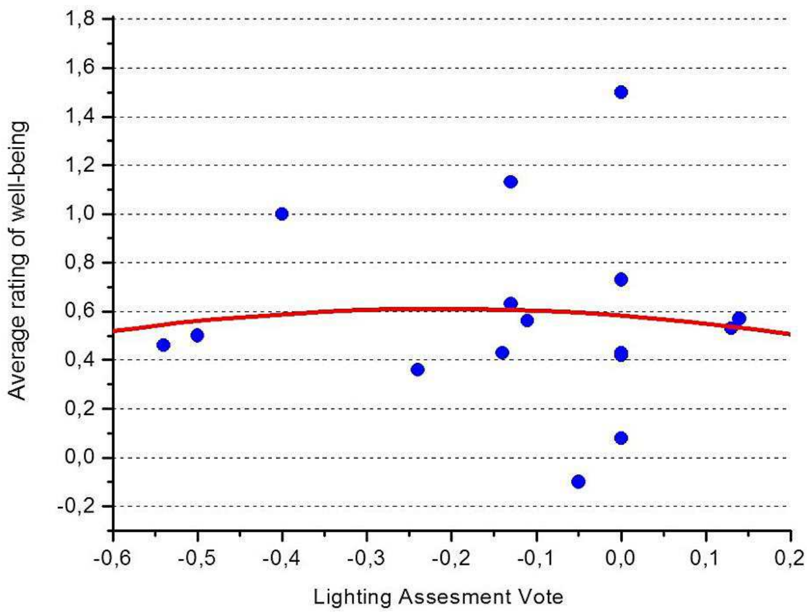

Fig. 7: The relationship between the average well-being rating and the mean lighting rating.

When comparing the average rating on lighting in the rooms studied with the rating on well-being, the study showed that there was no correlation between these factors. If lighting intensity had an impact on well-being, the average rating on lighting would have been significantly higher. For the majority of the rooms, the respondents rated the lighting as too weak. Research should therefore be conducted for more data to test this relationship. The next part of the study was to assess the productivity of the respondents, as shown in Fig. 8. When asked to rate their productivity during the class, the respondents had a choice of different answers to this question: “weak”, -1, “high”, +1 and “normal”, 0.

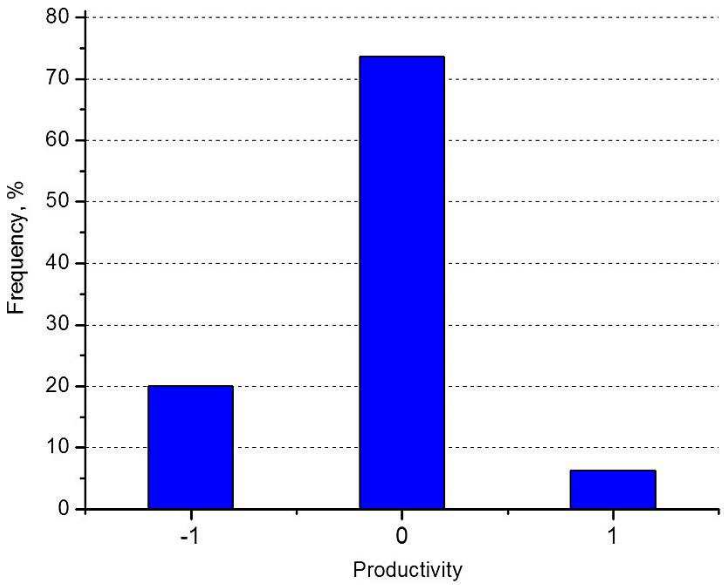

Fig. 8: Average productivity assessment in the tested rooms.

In the surveyed rooms, the respondents assessed their productivity as normal, which amounted to almost 74 %. Less than 7 % assessed their productivity as high, and 20 % as weak. Similar results were noticed in earlier works of the authors [e.g. 14]. Many other factors can contribute to an increase or decrease in the ability to acquire knowledge (e.g. thermal environment). The Fig. 9 presents the influence of air temperature on the average productivity assessment.

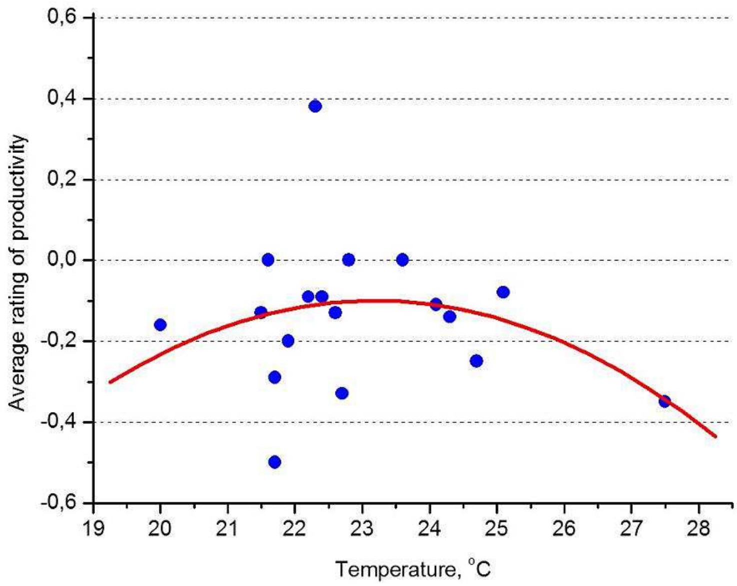

Fig. 9: Influence of air temperature on the average rating of productivity.

The figure above shows the average productivity score in the classrooms surveyed with 205 students. As can be seen air temperature can influence the productivity assessment. In the studied teaching rooms the air temperature ranged between 20 and 25.1 ^{o}C. Analysing the above graph for the 18 rooms surveyed, it can be seen that for air temperatures below 22 ^{o}C productivity generally falls. On the other hand, if the air temperature is between 22 and 24.5 ^{o}C, the respondents rated their learning ability higher. This means that this is when students learn best. In addition, below these values, respondents felt uncomfortable and therefore also had a lower learning ability. The last figure discusses the relationship between the average well-being rating and the average productivity rating, which were determined by means of questionnaires.

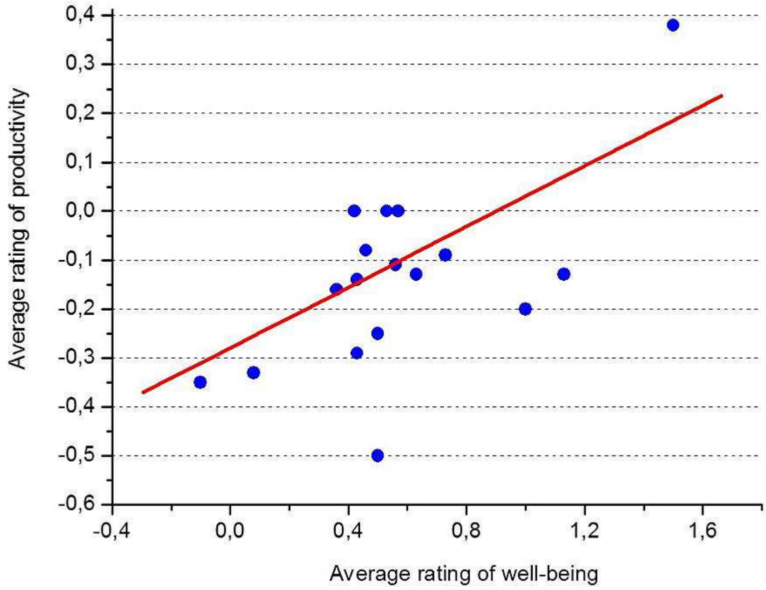

Fig. 10: Average well-being rating and average productivity rating.

Fig. 10 shows the average scores from the questionnaires for well-being vs. productivity for the rooms surveyed. It's worth noting that if the students felt comfortable indoors, they would be more productive. The linear fitting (red line) is quite straightforward, as can be anticipated – humans work and learn better when they are satisfied with their indoor environment. Despite a large number of factors influencing human sensations and perceptions, thermal environment and heat transfer issues might be considered as a dominant force [15-21]. However, an important element is also noise [22] and future studies might be focused on this aspect due to its possible impact on the general sensations and productivity.

4 Conclusion

The work assesses the well – being of over two hundred people, lighting conditions and productivity building users. The respondents felt the most favourable in rooms, where the range for the light intensity was 200 - 400 lux. The participants of the study in rooms below 200 lux did not feel satisfied. For 18 rooms, the temperature range was 20 - 25.1 ^{o}C, with CO_2 concentration of 509 -1634 ppm. With such parameters (recorded by the Testo 400 device), 74 % of the students assessed their productivity as normal. The results indicate that the air temperature influences productivity of the participants and its most preferable range is about 22 - 24 ^{o}C. Moreover, productivity increased with rising well – being of the respondents.

Thermal comfort and the quality of the internal environment are important for people staying in teaching rooms. Indoor environment that is appropriate and adapted to the needs of people has an impact on the productivity of users. It is worth noting that the design guidelines for teaching and office buildings should also cover user productivity. The impact on productivity is crucial for the perception of employees.

References

[1] FANGER, P. O.: Thermal Comfort, Analysis and Applications in Environmental Engineering, Danish Technical Press, Copenhagen, 1974.
[2] YEOM, D. J. – DELOGU, G.: Local body skin temperature-driven thermal sensation predictive model for the occupant's optimum productivity. Building and Environment, Vol. 204, 2021, 21 p., doi: 1016/j.buildenv.2021.108196.
[3] INDRAGANTI, M. – HUMPHREYS, M. A.: A comparative study of gender differences in thermal comfort and environmental satisfaction in air-conditioned offices in Qatar, India, and Japan. Building and Environment, Vol. 206, 2021, 15 p., doi: 10.1016/j.buildenv.2021.108297.
[4] DURAN, Ö. – LOMAS, K. J.: Retrofitting post-war office buildings: Interventions for energy efficiency, improved comfort, productivity and cost reduction. Journal of Building Engineering, Vol. 42, 2021, 12 p., doi: 10.1016/j.jobe.2021.102746.

[5] KAUSHIK, A. – ARIF, M. – TUMULA, P. - EBOHON, O. J.: Effect of thermal comfort on occupant productivity in office buildings: Response surface analysis. Building and Environment, Vol. 180, 2020, 9 p., doi: 10.1016/j.buildenv.2020.107021.
[6] LATINI, A. – GIUSEPPE, E. Di. - D'ORAZIO, M. – PERNA, C. Di.: 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, Vol. 253, 2021, 18 p., doi: 10.1016/j.enbuild.2021. 11508.
[7] TSAY, Y. S. – CHEN, R. – FAN, CH. CH.: Study on thermal comfort and energy conservation potential of office buildings in subtropical Taiwan. Building and Environment, Vol. 208, 2022, 13 p., doi: 10.1016/j.buildenv.2021.108625.
[8] GENG, Y. – JI, W. – LIN, B. – ZHU, Y.: The impact of thermal environment on occupant IEQ perception and productivity. Building and Environment, Vol. 121, 2017, pp. 158-167, doi: 10.1016/j. buildenv.2017.05.022.
[9] FAHEEM, M. – BHANDARI, N. – TADEPALLI, S.: Adaptive thermal comfort in naturally ventilated hostels of warm and humid climatic region, Tiruchirappalli, India. Energy and Built Environment, In Press, Corrected Proof, 2022, 13 p., doi: 10.1016/j.enbenv.2022.04.002.
[10] SCHELLEN, L. – LOOMANS, M. GLC. - DE WIT, M. H. – OLESEN, B. W. - VAN MARKEN LICHTENBELT, W. D.: 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. Physiology & Behavior, Vol. 107, Iss. 2, 2012, pp. 252-261, doi: 10.1016/j.physbeh.2012.07.008.
[11] MUÑOZ, J. S. – KELLY, M. T. - FLORES-ALÈS, V. - CAAMAÑO-CARRILLO, CH.: Recognizing the effect of the thermal environment on self-perceived productivity in offices: A structural equation modeling perspective. Building and Environment, Vol. 210, 2022, 12 p., doi: 10.1016/j.buildenv.2021.108696.
[12] CEN Standard EN 16798-1, 2019 Energy Performance of Buildings—Ventilation for Buildings—Part 1: Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics—Module M1-6; European Committee for Standardisation: Brussels, Belgium.
[13] EN 12464-1, 2012, Light and lighting - Lighting of workplaces - Part 1: Indoor workplaces.
[14] BIAŁEK, A. – DEBSKA, L. – KRAWCZYK, N.: Assessment of light intensity and productivity in the intelligent building case study. E35 Web Conf., Vol. 336, 2022, 5 p., doi: 10.1051/e3sconf/ 2022336 00011.
[15] KRAWCZYK, N. - SURMAŃSKA, S.: Analysis of thermal comfort in a single-family house in Poland. Civil and Environmental Engineering, Vol. 16, Iss. 2, 2020, pp. 396-404, doi: 10.2478/cee-2020-0040.
[16] DĄBEK, L. – KAPJOR, A. – ORMAN, Ł. J.: Boiling heat transfer augmentation on surfaces covered with phosphor bronze meshes. MATEC Web Conf, Vol. 168, 2018, 6 p., doi: 10.1051/ matecconf/201816807001.
[17] PONECHAL, R. – CHABADA, M.: The impact of ventilation and shading control on the result of summer overheating simulation. Civil and Environmental Engineering, Vol. 17, Iss. 1, 2021, pp. 327-334, doi: 10.2478/cee-2021-0034.
[18] ORMAN, Ł. J.: Boiling heat transfer on single phosphor bronze and copper mesh microstructures. EPJ Web of Conferences, Vol. 67, 2014, 4 p., doi: 10.1051/epjconf/2014 6702087.
[19] ORMAN, Ł. J.: Boiling heat transfer on meshed surfaces of different aperture. AIP Conference Proceedings, Vol. 1608, 2014, pp. 169-172, doi: 10.1063/1.4892728.
[20] SINACKA, J. – SZCZECHOWIAK, E. – ŻABICKA, P.: Influence of usage profile on energy needs for heating and cooling in a building with thermally activated building systems. Instal, Vol. 10, 2019, pp. 34-37.
[21] SINACKA, J. – SZCZECHOWIAK, E.: An experimental study of a thermally activated ceiling containing phase change material for different cooling load profiles. Energies, Vol. 14, 2021, 16 p., doi: 10.3390/en14217363.
[22] ARGALASOVA, L. – KIMAKOVA, T. – PANULINOVA, E. – FILOVA, A. – PULTZNEROVA, A. – JURKOVICOVA, J.: Sleep disturbance and noise annoyance and environmental noise exposure in residents of two major Slovakian cities. Civil and Environmental Engineering, Vol. 17, Iss. 2, 2021, pp. 690-697, doi: 10.2478/cee-2021-0068.