www.czasopisma.pan.pl PAN POLSKA AKADEMIA NAUK www.journals.pan.pl

Archives of Environmental Protection
Vol. 50 no. 4 pp. 43–50

PL ISSN 2083-4772
DOI 10.24425/aep.2024.152894

Assessment of indoor environmental comfort for individuals wearing face masks of different thickness

Łukasz Jan Orman[1]*, Luiza Dębska[1], Lidia Dąbek[1], Stanislav Honus[2], Stanisław Adamczak[3]

[1]Faculty of Environmental Engineering, Geodesy and Renewable Energy, Kielce University of Technology, al. Tysiaclecia P.P.7, 25-314 Kielce, Poland

[2]Faculty of Mechanical Engineering, VSB – Technical University of Ostrava, 17. listopadu 2172/15, 708 00 Ostrava-Poruba, Czech Republic

[3]Faculty of Mechanical Engineering, Kielce University of Technology, al. Tysiaclecia P.P.7, 25-314 Kielce, Poland

* Corresponding author's e-mail: orman@tu.kielce.pl

Keywords: Questionnaire study, environmental comfort, indoor environment

Abstract: The present paper experimentally analyses the subjective assessment of indoor environment comfort based on a questionnaire survey conducted in a climate chamber located at Kielce University of Technology (Poland), if two types of face masks are worn by the respondents: thin (medical) and thick (cotton-made) masks. Air temperature and relative humidity in the chamber ranged from around 19 to 28oC and 20 – 70%, respectively. Precise measurement of the microclimate parameters was obtained with a microclimate meter, which recorded air temperature and relative humidity at the moment of completing the questionnaires. The respondents were of similar age (22 – 31 years old) and wore two types of clothing during the experiments: summer and winter, which differed by thermal resistance. This value amounted to 0.5 clo for the summer outfit and 0.8 clo for the winter one. In total 960 questionnaires were analysed in the study. The results indicate that the increase in air temperature led to poorer overall comfort, while the largest comfort sensation was recorded for the most favourable thermal sensation range. In general, thicker masks provided lower overall comfort than thinner masks for all relative humidity values.

Introduction

The COVID pandemic, which started in 2020, changed the lives of almost every person and community. The need to protect the population against the virus led to the introduction of various safety measures, including the widespread use of face masks. While primarily employed during the pandemic to reduce the release of the virus from infected individuals and protect uninfected individuals from inhaling the virus, face masks also serve as protection against various non-viral threats both outdoors (Starzomska and Strużewska 2024) and indoors (Frączek et al. 2023). Prolonged mask usage, however, often result in discomfort for individuals in enclosed spaces, such as residential rooms, offices, shops, and etc.). Although overall comfort is a subjective sensation unique to of each person, it can be anticipated that wearing face masks influences the perception of indoor environment.

Experimental studies of comfort in enclosed spaces are typically conducted in actual rooms within various types of buildings (Amanowicz et al. 2023, Dudkiewicz et al. 2021, Ratajczak et al. 2023), while tests in climate chambers are less common. This is likely because climate chambers are expensive to buy and maintain, requiring costly and frequent servicing. For instance, Zhang et al. (2019) conducted tests in a climate chamber, in which ambient temperature ranged from 20 to 32°C, and relative humidity varied from 50 – 70%. Their finding indicated a neutral temperature of approximately 27°C. Similarly, Soebarto et al. (2019) explored the influence of age on thermal responses in a climate chamber, concluding that no significant differences were observed between older and younger participants. On the other hand, Chen et al. (2023) found in their study of the elderly that the neutral and preferred temperatures were 26°C. and 26.5°C, respectively.

Ahmad et al. (2022) investigated thermal preferences in a climate chamber with air temperatures ranging from 19 to 29°C, determining that the value of 23°C was the most preferred. They also reported a linear relationship between overall thermal comfort and thermal sensations, a finding not corroborated by experimental data from actual rooms (Majewski et al. 2020)). Orman et al. (2024) compared environmental comfort levels in rooms and climate chambers, and concluded that chambers typically provided more comfortable sensations. Notably, the most preferable air temperature in the chamber was 1.5°C lower than in rooms, with 22.3°C being the optimal temperature. The authors also found a strong relationship between environmental comfort and indoor air quality. Interestingly, respondents in the climate chamber preferred slightly cool conditions, while in actual rooms, comfort was associated with neutral to slightly warm environments. On the other hand, the experiments performed in a climate chamber in China (Dong et al. 2022) indicate that the most favorable air temperature in a climate chamber was 26°C for local participants. Upadhyay et al. (2023) identified a comfort range of 25.7 to 32.9°C, though this study examined the sensations of individuals from a sub-tropical climate, which likely influenced the results. Climate chamber studies can also involve participants performing various types of activities there. For example, Jiang et al. (2023) recently found that walking men experienced improved thermal comfort under summer conditions when exposed to higher air flow velocity. This improvement was attributed to enhanced cooling due to increased heat transfer coefficient values.

The studies on human thermal sensations discussed above were conducted without the use of face masks. Due to a short period of time during which face masks were widely adopted, data collected on thermal comfort with face masks are scarce and challenging to find in the open literature. Zhang et al. (2021) conducted research on thirty subjects wearing face masks in a climate chamber, determining the neutral temperature to be between 24 and 25°C. Moreover, they emphasized that breathing discomfort increased with rising air temperature. Lin and Chen (2019) analyzed two types of face masks and observed differences in thermal sensations depending on the type of mask. On the other hand, Liu et al. (2022) suggested that thermal sensations of individuals wearing and not wearing masks were similar in the air temperature range of 22 to 28°C. However, a more recent study by Seo et al. (2024) conducted in a climate at 20°C, 22°C and 24°C found that thermal sensations with face masks often exceeded the comfort range and had more sensitive variations. It was also reported that an indoor temperature of 24°C or higher significantly affected the individual's thermal comfort when wearing masks.

Liu et al. (2020) examined different types of face masks and their impact on the occurrence of sick building syndrome (SBS) symptoms, such as headache, reduced concentration, and breathing difficulties. Their study found that the KN95 face mask proved to be the least comfortable. The issue of SBS symptoms was also explored by Krawczyk et al. (2023). Health-related problems linked to face mask usage become more pronounced when masks are worn for prolonged periods of time, a situation often caused by market shortages or insufficient stockpiles, as discussed by Jimenez – Garcia et al. (2022). In order to mitigate issues associated with wearing masks, such as the accumulation of carbon dioxide and humidity, Huo and Zhang (2021) proposed a new ventilated mask design incorporating additional HEPA filters. These ventilated masks provided better protection against airborne particles and significantly improved wearing comfort. Another innovative approach, presented by Zhang et al. (2022), involved covering the filter material of face masks with a cardboard support frame with openings. This modification improved filtration efficiency, increased oxygen content, and enhanced breathing comfort compared to other mask types included in the study. Moreover, the new mask increased the as well as the.

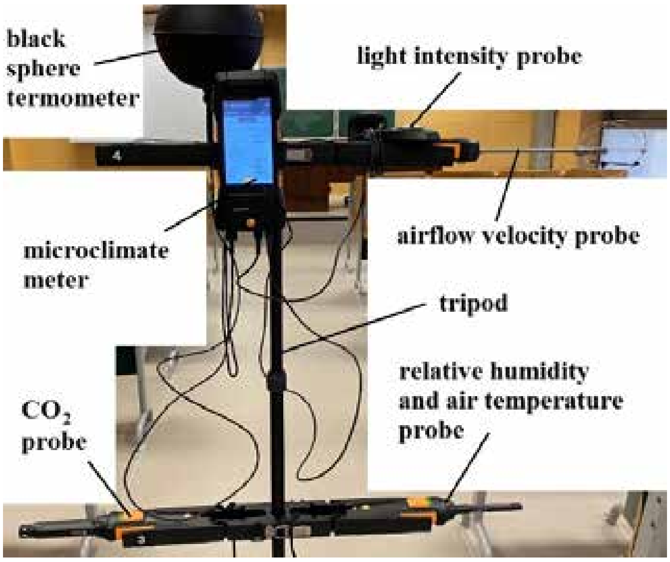

Fig. 1. Measuring station: meter with the probes.

Studies on the thermal comfort of people wearing face masks have also been conducted outdoors in urban environments. It was recently reported (Hu et al. 2024) that wearing masks outdoors while walking leads to higher thermal sensations accompanied by lower thermal comfort. Moreover, people wearing face masks were found to be more prone to thermal stress.

Due to a very short period of time during which face masks have been used, few studies in literature address the subjective sensations experienced by people wearing them. Limited information is available on the relationships between indoor environmental parameters and overall comfort of respondents using various face masks. Existing data are scarce, and the few studies available do not thoroughly or meticulously explore this issue. This paper aims to fill this gap by providing valuable insights and fostering a better understanding of this phenomenon. The practical implications are significant: if pandemic conditions were to return and face masks became mandatory again in daily life, understanding indoor thermal sensations could inform more accurate adjustments to heating, ventilation, and air conditioning systems.

Experimental method and measurements

The measurements in this study involve collecting data on selected air parameters within a climate chamber, as well as the respondents' sensations, which are recorded through anonymous questionnaires. These questionnaires were printed and filled out manually by each participant. Figure 1 presents the measuring station used in the tests, consisting of a Testo 400 microclimate meter mounted on a tripod and equipped with appropriate probes.

The meter can simultaneously measure many environmental parameters, however, in the present study, only air temperature and relative humidity were considered due to their profound

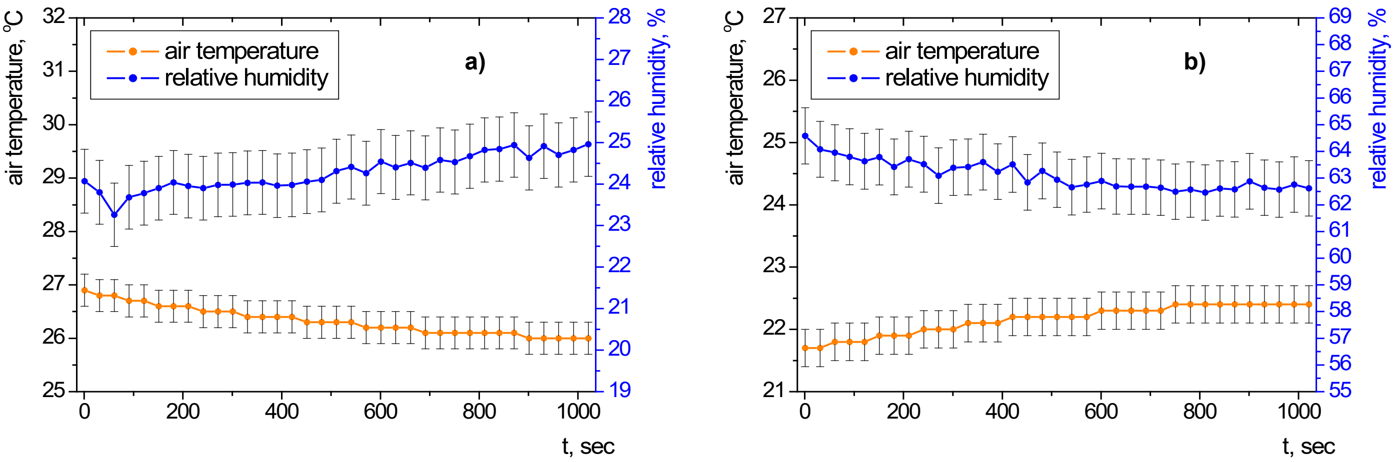

Fig. 2. Variations of air temperature and relative humidity within the chamber for: a) low humidity and high air temperature, b) high humidity and low air temperature.

impact on the volunteers' sensations. A key feature of the climate chamber is the stability of these parameters, which was verified and confirmed prior to the actual measurements. Figure 2 shows the variations in air temperature and relative humidity, along with their error bands calculated based on the manufacturer's data (Testo 2024), over a 17-minute period.

As shown, the changes in these two basic indoor air parameters within the chamber are not significant. While natural fluctuations occur, they remain almost within the error bands of the measuring system. It was observed that high air temperatures tend to decrease over time, whereas low air temperatures tend to increase. A similar trend is seen with humidity: low humidity levels rise during the measurement period, while high humidity levels decline. These variations may be attributed to heat and mass transfer with the surroundings, as the climate chamber is located in a laboratory hall. However, the changes are not substantial enough to influence the experimental results will not be considered further.

Air temperature in the chamber is increased using electric heating, while cooling is provided by a vapor compression refrigeration system, with the condenser situated outside the laboratory hall. The mean U value of the chamber walls is 0.2 W/(m^{2}K). The chamber includes a window which provides natural light, but artificial lighting is also available. The walls are not temperature-controlled. The chamber's dimensions are 4.95m x 1.80m x 2.30 m. It is situated in a large laboratory hall where the air temperature remains relatively consistent across all seasons.

The respondents were of similar age (22 – 31 years old), with an average age of 26.3 years (standard deviation: 1.51 years). The average height was 168.9 cm (standard deviation: 11.6 cm), and the average weight was 67.8 kg (standard deviation: 16.7 kg). The BMI index, calculated as weight divided by height squared, was 23.5 kg/m^2 (on average), while a standard deviation was 4.5 kg/m^2. Women comprised approximately 62% of the participants, while men made up about 38%.

The respondents wore two types of clothing: summer and winter, which differed in thermal resistance. The thermal resistance was 0.5 clo for the summer outfit and 0.8 clo for the winter one. The composition of the outfits was chosen by the volunteers, so it varied between individuals, but the total thermal resistance remained consistent in each case.

The air temperature and relative humidity in the chamber ranged from 19 to 28°C and 20 to 70%, respectively. Temperature adjustments were typically made in 1°C increments, while relative humidity was adjusted in 25% steps, however some variations occurred during the study.

The respondents, seated in the climate chamber, answered the following questions: 'What is your overall comfort rating?' and 'How do you assess your current thermal sensation?'. Anonymous questionnaires were used for the experiment, and the participants indicated their responses by marking a tick or cross next to the option that best described their current feelings. Each test involved eight participants, and the mean response to each question was calculated based on the eight independent answers. To ensure more objective results, volunteers were instructed to avoid physical activity before the tests. All participants were healthy at the time of the experiment, as any illness could have influenced their sensations.

Results and discussion

During the experiment, air temperature ranged from 19 °C to 28°C in 1°C increments, while relative humidity was set to approximately 20%, 45%, and 70%. In these environmental conditions, the respondents completed questionnaire forms assessing their subjective sensations. They wore two types of face masks: a thin medical mask and a thick cotton mask. The experiments were conducted under two clothing variants: winter and summer. One of the questions in the questionnaire was: 'What is your overall comfort rating right now?' (denoted as 'Overall comfort' in the figures below). The possible answers: very well (+2), well (+1), neither good nor bad (0), bad (-1), very bad (-2). Figure 3 shows the frequency distribution of the responses collected during the experiment across the specified range of indoor environmental parameters, typical of Polish climate conditions throughout the year.

For both types of clothing, the most common response was '0', indicating a neutral opinion of the environment. Positive

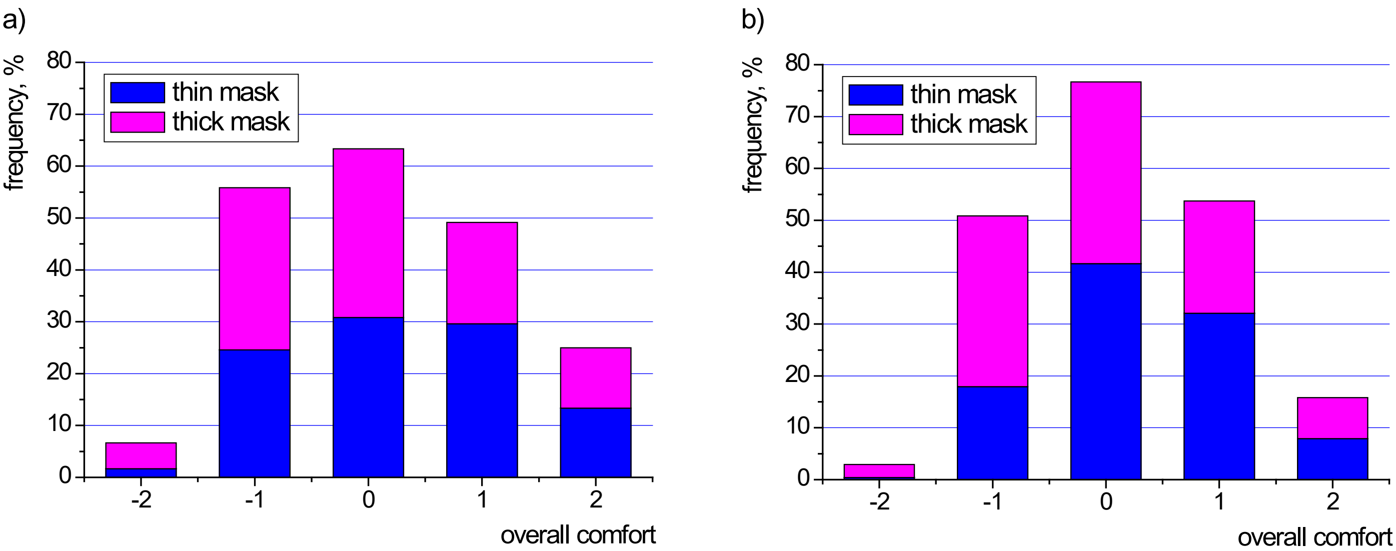

Fig. 3. Frequency count of the responses regarding the overall comfort of the respondents: a) summer clothing, b) winter clothing.

views (answers '+1' and '+2') were predominantly expressed by respondents wearing the thin mask, while negative views (answers '-1' and '-2') were more common for those wearing the thick mask. This clearly indicates that comfort was greater with the thin mask compared to the thick mask. This trend was more pronounced with winter clothing, probably due to difficulties in heat dissipation through evaporation from the lungs (thicker masks may offer greater resistance to air). On the other hand, the total share of negative responses was higher with summer clothing than winter clothing. This can be attributed to the combined effects of air and radiation temperature on thermal comfort, which, in turn, affects subjective assessments of overall comfort. Furthermore, a comparison with the results of Majewski et al. (2020), who conducted a survey of individuals not wearing face masks, shows that people wearing masks found their environment significantly less comfortable. While this finding may be expected, the exact cause of this discomfort is unclear. It may relate to breathing difficulties due to the resistance of the mask material or challenges with heat removal from the body.

A close analysis of the impact of air temperature on environmental comfort reveals that the type of face mask may have a considerable impact. Figure 4 shows the relationship between overall comfort and air temperature for two types of clothing. Each point represents the mean value calculated based on the responses of 8 participants in the study.

Typically, as air temperature increases, the level of comfort experienced by the respondents decreases. This may be related to difficulties in latent heat removal from the body (Kaniowski and Pastuszko 2021) or the presence of an additional thermal barrier provided by the mask. The highest comfort ratings were observed at around 20°C for summer clothing and 19°C for winter clothing, which is understandable given the greater need for more intense cooling when wearing winter outfit, despite the same indoor environmental parameters. Figure 4 clearly shows that thick masks provide less comfort than thin masks across the entire temperature range. The fitting equations for overall comfort (OC) as a function of air temperature (T) are as follows:

$$OC_{\text{summer, thin mask}} = -0.0207T^2 + 0.8509T - 8.0719; \; R^2 = 0.66 \quad (1)$$

$$OC_{\text{summer, thick mask}} = -0{,}0151T^2 + 0.571T - 4.8433; \; R^2 = 0.74 \quad (2)$$

$$OC_{\text{winter, thin mask}} = -0.0027T^2 + 0.0732T + 0.0949; \; R^2 = 0.28 \quad (3)$$

$$OC_{\text{winter, thick mask}} = -0.0067T^2 + 0.2396T - 1.8482; \; R^2 = 0.35 \quad (4)$$

It needs to be emphasized that the environmental comfort of the respondents wearing face masks was lower compared to when no masks were worn. The data. represented by the black dashed line in Figure 4 from the experiments by Orman et al. (2024), show a higher level of overall comfort when no masks are worn, with the only exception being winter clothing and air temperatures above 27.5°C. This anomaly could be attributed to other factors such as fitting errors or individual preferences. In the absence of face masks, the most favorable air temperature was 21°C, which is higher than the optimal temperature for wearing masks (approximately 19.1°C for the thick mask and 20.7°C for the thin one. This is understandable, because the absence of a mask allows for more effective body cooling, making higher air temperatures more tolerable. This also explains why the optimal air temperature is lower for the thick mask than for the thin one.

An additional question in the questionnaire asked, 'How do you assess your current thermal sensation?' (denoted in the figures as 'Thermal sensation vote', or 'TSV'). The possible responses were: 'too hot' (+3), 'too warm' (+2), 'pleasantly warm' (+1), 'neutral' (0), 'pleasantly cool' (-1), 'too cool' (-2), and 'too cold' (-3). Figure 5 presents the relationship between the mean overall comfort rating and the thermal sensation vote, calculated as the average value of the eight responses in each experimental session for the two types of clothing separately.

The highest overall comfort rating occur when thermal sensations are also ideal (i.e., 'neutral': TSV ≈ 0). In fact, deviations of TSV from -0.5 to +0.5 are considered highly acceptable, and in this range, overall comfort peaks for all mask types and clothing (the regression curves reach their maximum values). For summer clothing, lower values (TSV < 0) are more favorable, while for winter clothing, the opposite is true,

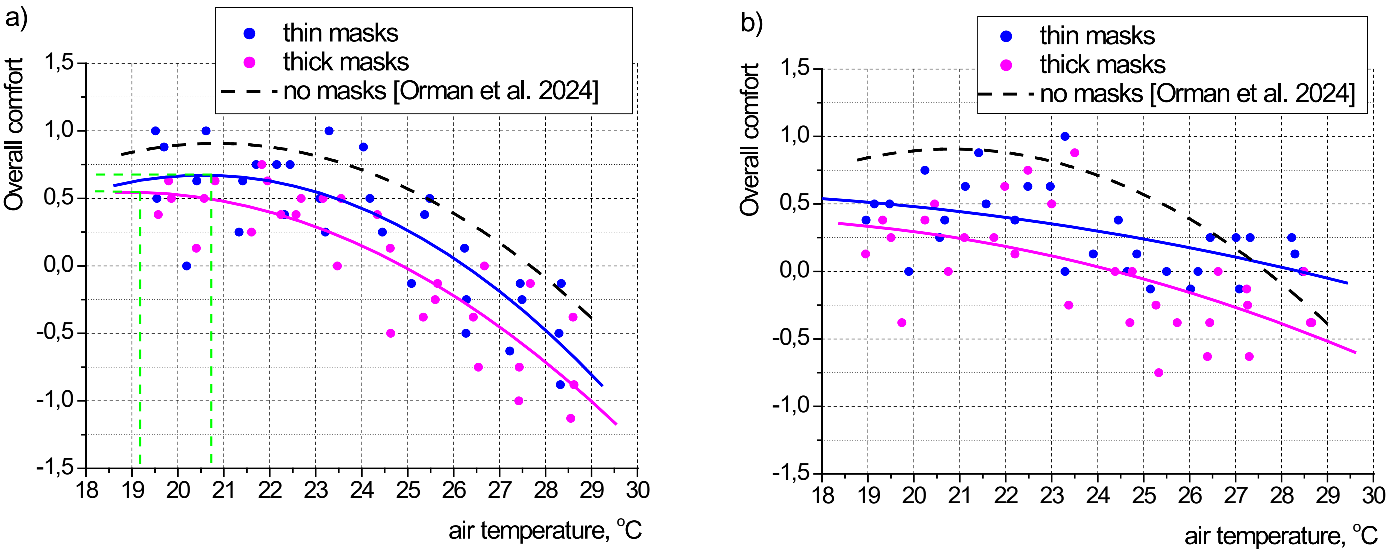

Fig. 4. Overall comfort vs. air temperature: a) summer clothing, b) winter clothing; solid colour lines represent polynomial fit of the experimental data, while the black dash line – data from (Orman et al. 2024).

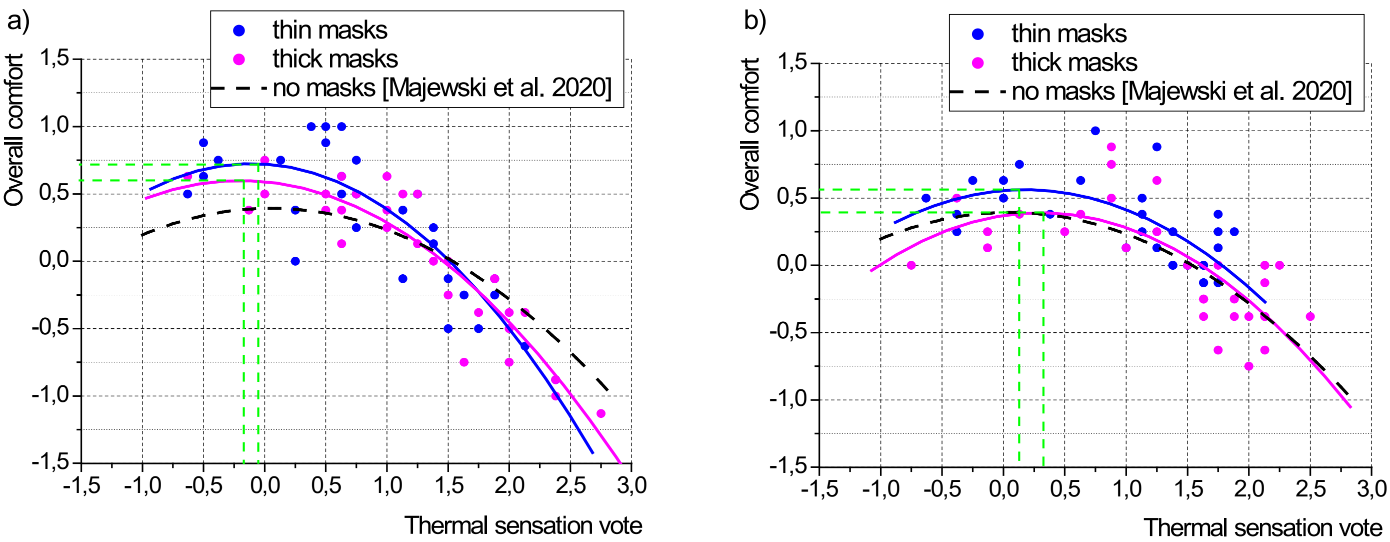

Fig. 5. Overall comfort vs. thermal sensation vote: a) summer clothing, b) winter clothing; solid colour lines represent polynomial fit of the experimental data, while the black dash line represents data from (Majewski et al. 2020).

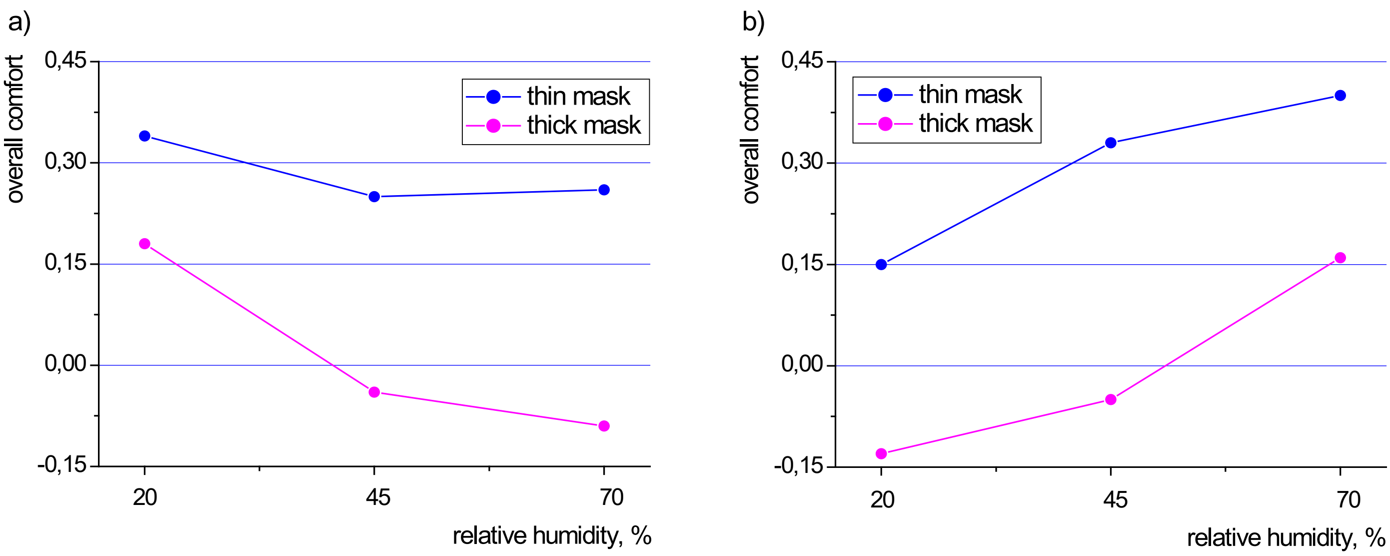

Fig. 6. Mean overall comfort of the respondents for various relative humidity values: a) summer clothing, b) winter clothing.

though the differences are minimal. The data from Majewski et al. (2020), obtained without face masks, show similar trends, with the most favorable TSV in the range of 0 to 0.5. However, the slopes of the curves are less steep, indicating that changes in overall comfort are more gradual without masks. This may be related to the fact that face masks become less tolerable when indoor air parameters are at the extremes.

The fitting equations for the overall comfort (OC) as a function of thermal sensation vote (TSV), are presented in Figure 5 and take the following form:

$$OC_{summer,\ thin\ mask} = -\ 0.2763TSV^2 - 0.0582TSV + 0.722;\ R^2 = 0.74 \quad (5)$$

$$OC_{summer,\ thick\ mask} = -\ 0,2179TSV^2 - 0.0851TSV + 0.5908;\ R^2 = 0.85 \quad (6)$$

$$OC_{winter,\ thin\ mask} = -\ 0.218TSV^2 + 0.0764TSV + 0.555;\ R^2 = 0.43 \quad (7)$$

$$OC_{winter,\ thick\ mask} = -\ 0.2265TSV^2 + 0.137TSV + 0.3701;\ R^2 = 0.55 \quad (8)$$

The influence of thermal environment on overall comfort sensation votes is quite obvious and understandable. However, the impact on air humidity remains unclear. It is generally accepted, and aligns with common sense, that relative humidity affects human well – being, with discomfort occurring when it is too dry (typically below about 20%) or too humid (above approximately 70%). The use of face masks introduces another factor: the presence of excess water vapor in the space between the face and the mask, which accumulates due to vapor released from the lungs during breathing. While the mask naturally allows some vapor to pass through the material, mass transfer may not be fully efficient, leading to higher relative humidity in the space between the face and mask. Moreover, some of the vapor may condense on the mask material, reducing the mass flow rate and causing further accumulation of vapor. Figure 6 shows the mean overall comfort ratings for two types of clothing and two types of masks at various relative humidity levels. Each dot represents the mean rating from the questionnaires (completed by 8 participants) for all ten temperature values, resulting in an average from 80 measurements.

Both figures clearly show that thick masks provided poorer overall comfort than thin masks across all relative humidity levels, with differences ranging from 0.16 to 0.38. When respondents wore summer clothing, overall comfort decreased as humidity rose, while the opposite occurred when winter clothing was worn. It appears that thinner clothing (Fig. 6a) facilitated better cooling through evaporation of water from the skin surface at 20% humidity, resulting in a higher overall comfort rating. In contrast, thicker clothing (Fig. 6b) created a more challenging barrier for water vapor to escape from the body at the lowest humidity. However, the true nature of this phenomenon is not easily explained and may also involve factors such as metabolic rate. It is important to note that evaporation primarily occurs mostly from the surface of the skin, which was covered by clothing, not the mask. The study did not account for the clothing coverage area as a factor, so a more in-depth analysis of this phenomenon is not possible. According to the study by Orman et al. (2024), overall comfort in respondents not wearing masks increased with rising air humidity (up to 70%), a trend that was more apparent in the climate chamber experiments than in those conducted in educational building rooms. However, due to the spread of experimental data, solid conclusions could not be drawn. Nevertheless, it is clear that relative humidity influences human sensations in closed spaces.

Naturally, caution should be exercised when directly applying the results obtained in the climate chamber to actual rooms in various types of buildings, where different heating and ventilation systems are used (Nogaj et al. 2017; Nogaj et al. 2018; Stokowiec et al. 2023). While the nature of the phenomenon is expected to remain the same, additional variables and uncontrollable parameters in real rooms may influence the results.

Another, but equally important issue for environmental engineering is the recycling of the waste in the form of face masks. While they can be effectively reused as fuel (Mutiara Sari et al. 2022), other methods may also be developed to manage this kind of waste. The limitations of this study primarily stem from the relatively narrow age range of the volunteers (22 – 31 years old) and the focus only one type of physical activity in the chamber. However, both parameters are typical and commonly used in subjective comfort studies, making comparisons with other researchers more straightforward.

Conclusions

The results of the experimental study led to the following conclusions:

1. The frequency count of the responses indicated that the neutral (0) overall comfort rating was generally similar for both types of masks and clothing. The most negative assessments (-2) were typically observed with thick masks.
2. An increase in air temperature resulted in lower overall comfort, probably due to difficulties in heat dissipation from the body via water evaporation from the lungs.
3. The highest overall comfort was recorded within the most favorable thermal sensation range (TSV between -0.5 to +0.5).
4. In general, thick masks provided lower overall comfort than thin masks across all relative humidity values.

Acknowledgement

This work 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".

Bibliography

Ahmad, R.I., Norfadzilah, J. & Raemy, M.Z. (2022). Human Responses to the Thermal Comfort in Air-Conditioned Building: A Climate Chamber Study, *Int. J. Integrated Engineering,* 14, 1, pp. 287-295. DOI:10.30880/ijie.2022.14.01.027

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. DOI:10.3390/en16041853

Chen, M., Farahani, A.V., Kilpeläinen, S., Kosonen, R., Younes, J., Ghaddar, N., Ghali, K. & Melikov, A.K. (2023). Thermal comfort chamber study of Nordic elderly people with local cooling devices in warm conditions, *Building Environment*, 235, 110213. DOI:10.1016/j.buildenv.2023.110213

Dudkiewicz, E., Laska, M. & Fidorów-Kaprawy, N. (2021). Users' Sensations in the Context of Energy Efficiency Maintenance in Public Utility Buildings, *Energies*, 14, 23, 8159. DOI:10.3390/en14238159

Dong, Y., Shi, Y., Liu, Y., Rupp, R.F. & Toftum, J. (2022). Perceptive and physiological adaptation of migrants with different thermal experiences: A long-term climate chamber experiment, *Building Environment*, 211, 108727. DOI:10.1016/j.buildenv.2021.108727

Frączek, K., Bulski, K. & Chmiel, M. (2023). Assessment of exposure to fungal aerosol in the lecture rooms of schools in the Lesser Poland region, *Archives of Environmental Protection*, 49, 4, pp. 95–102. DOI:10.24425/aep.2023.148688

Hu, R., Liu, J., Xie, Y., Su, Y., Fang, Z., Diao, Y. & Shen, H., Influencing assessment of mask wearing on thermal comfort and pleasure during outdoor walking in hot summer region, *Urban Climate*, 54, 101854, 2024. DPOI:10.1016/j.uclim.2024.101854.

Huo, S. & Hang, T.T. (2021). Ventilation of ordinary face masks, *Building and Environment*, 205, 108261. DOI:10.1016/j.buildenv.2021.108261

Jiang, H., Cao, B. & Zhu, Y. (2023). Thermal comfort of personal protective equipment (PPE) wearers in different temperatures and activity conditions, *Journal of Building Engineering,* 78, 107609. DOI:10.1016/j.jobe.2023.107609

Jiménez-García, S., De Juan Pérez, A., Pérez-Cañaveras, R.M. & Vizcaya-Moreno, F. (2022). Working Environment, Personal Protective Equipment, Personal Life Changes, and Well-Being Perceived in Spanish Nurses during COVID-19 Pandemic: A Cross-Sectional Study. *International Journal of Environmental Research and Public Health*, 19, 4856. DOI:10.3390/ijerph19084856

Kaniowski, R. & Pastuszko, R. (2021). Boiling of FC-72 on Surfaces with Open Copper Microchannel, *Energies*, 14, 7283. DOI:10.3390/en14217283

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, pp. 68-76. DOI: 10.54740/ros.2023.008

Lin, Y-C. & Chen, C-P. (2019). Thermoregulation and thermal sensation in response to wearing tight-fitting respirators and exercising in hot-and-humid indoor environment, *Building and Environment*, 160, 106158. DOI: 10.1016/j.buildenv.2019.05.036

Liu, C., Li, G., He, Y. Zhang, A. & Ding, Y. (2020). Effects of wearing masks on human health and comfort during the COVID-19 pandemic, IOP Conf Ser: Earth Environ Sci, 531, 012034. DOI: 10.1088/1755-1315/531/1/012034

Liu, T., Shan, X., Deng, Q., Zhou, Z., Yang, G., Wang, J. & Ren, Z. (2022). Thermal Perception and Physiological Responses under Different Protection States in Indoor Crowded Spaces during the COVID-19 Pandemic in Summer, *Sustainability*, 14, p. 5477. DOI:10.3390/su14095477

Majewski, G., Orman, Ł.J., Telejko, M., Radek, N., Pietraszek, J. & Dudek, A. (2020). Assessment of Thermal Comfort in the Intelligent Buildings in View of Providing High Quality Indoor Environment, *Energies,* 13, 8, 1973. DOI:10.3390/en13081973

Mutiara Sari M., Inoue, T., Septiariva, I.Y., Suryawan, W.K., Kato, S., Harryes, R.K., Yokota, K., Notodarmojo, S., Suhardono S. & Ramadan, B.S. (2022). Identification of face mask waste generation and processing in tourist areas with thermo-chemical process, *Archives of Environmental Protection*, 48, 2 pp. 79–85. DOI:10.24425/aep.2022.140768

Nogaj, K., Turski, M. & Sekret R. (2017). The influence of using heat storage with PCM on inlet and outlet temperatures in substation in DHS, *E3S Web of Conferences*, 22, 00124. DOI:10.1051/e3sconf/20172200124

Nogaj, K., Turski, M. & Sekret R. (2018). The use of substations with PCM heat accumulators in district heating system, *MATEC Web of Conferences*, 174, 01002. DOI:10.1051/matecconf/201817401002

Orman, Ł.J., Siwczuk, N., Radek, N., Honus, S., Piotrowski, J.Z. & Dębska, L. (2024). Comparative Analysis of Subjective Indoor Environment Assessment in Actual and Simulated Conditions, *Energies*, 17, 656. DOI:10.3390/en17030656.

Ratajczak, K., Amanowicz, Ł., Pałaszyńska, K., Pawlak, F. & Sinacka, J. (2023). Recent Achievements in Research on Thermal Comfort and Ventilation in the Aspect of Providing People with Appropriate Conditions in Different Types of Buildings—Semi-Systematic Review, *Energies*, 16, 17, 6254. DOI:10.3390/en16176254

Seo, R., Rhee, K-N. & Jung, G-J. (2024). Impact of wearing indoor masks on occupant's thermal comfort under different room temperature conditions in winter, *Indoor and Built Environment*, DOI:10.1177/1420326X241286888

Soebarto, V., Zhang, H. & Schiavon, S. (2019). A thermal comfort environmental chamber study of older and younger people, *Building Environment*, 155. DOI:10.1016/j.buildenv.2019.03.032

Starzomska, A. & Strużewska, J. (2024). A six-year measurement-based analysis of traffic-related particulate matter pollution in urban areas: the case of Warsaw, Poland (2016-2021), *Archives of Environmental Protection*, 50, 2 pp. 75–84. DOI:10.24425/aep.2024.150554

Stokowiec, K., Wciślik, S. & Kotrys-Działak, D. (2023). Innovative Modernization of Building Heating Systems: The Economy and Ecology of a Hybrid District-Heating Substation, *Inventions*, 8, 1, 43. DOI:10.3390/inventions8010043

Testo (2024), www.testo.com (28.06.2024)

Upadhyay, K., Elangovan, R. & Subudhi, S. (2023). Establishing thermal comfort baseline in a sub-tropical region through a controlled climate chamber study, *Advances in Building Energy Research*. DOI:10.1080/17512549.2023.2258884

Hang, R., Liu, J., Zhang, L., Lin, J. & Wu, Q. (2021). The distorted power of medical surgical masks for changing the human thermal psychology of indoor personnel in summer, *Indoor Air*, 31, pp. 1645–1656. DOI:10.1111/ina.12830

Zhang, T.T., Zhang, T. & Liu, S. (2022). A Modified Surgical Face Mask to Improve Protection and Wearing Comfort, Buildings, 12, 663. DOI:10.3390/buildings12050663

Zhang, Z.; Zhang, Y. & Khan, A. (2019). Thermal comfort of people from two types of air-conditioned buildings - Evidences from chamber experiments, *Building Environment*, 162, 106287. DOI:10.1016/j.buildenv.2019.106287

Ocena komfortu środowiska wewnętrznego przez ludzi noszących maski o różnej grubości

Streszczenie. Artykuł dotyczy analizy eksperymentalnej komfortu cieplnego środowiska wewnętrznego w oparciu o anonimowe ankiety przeprowadzone w komorze klimatycznej Politechniki Świętokrzyskiej w Kielcach dla dwóch wariantów masek ochronnych na twarz: cieńszych (medycznych) i grubszych (bawełnianych). Temperatura powietrza i wilgotność względna w komorze wynosiły odpowiednio 19 – 28oC i 20 – 70%. Pomiary parametrów mikroklimatycznych zostały wykonane z wykorzystaniem miernika mikroklimatu, który rejestrował temperaturę powietrza i jego wilgotność względną w czasie wypełniania kwestionariuszy. Ankietowani byli w podobnym wieku (22 - 31 lat) i podczas badań mieli na sobie dwa rodzaje odzieży: letnią i zimową, różnice się oporem cieplnym. Wartość ta wynosiła 0,5 clo i 0,8 clo odpowiednio dla ubioru letniego i zimowego. W sumie uzyskane i przeanalizowano 960 kwestionariuszy. Wyniki dowodzą, że wzrost temperatury powietrza prowadził do zaniżenia oceny komfortu, podczas gdy najwyższy poziom zadowolenia ankietowani odnotowali przy najbardziej korzystnym zakresie wrażeń termicznych. Generalnie, grubsze maski ochronne zapewniały niższy poziom komfortu niż maski cieńsze dla wszystkich wartości wilgotności względnej