

Article

Influence of Masks Protecting against SARS-CoV-2 on Thermal Comfort

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Abstract: Due to the spread of the SARS-CoV-2 virus, most countries have tightened their public health policies. One way to limit the spread of the virus is to make mouth and nose cover compulsory in public spaces. The article presents the impact of wearing masks on the perception of thermal comfort. The following masks were analysed: FFP2, cotton, medical, PM2.5, half-face protective shield plastic and full-face protective shield plastic. The research was carried out for two scenarios of an ambient temperature: -20 and 30 °C. A thermal manikin was used for the tests. In the case of when a temperature equals 20 °C, the dry masks increase comfort, both general and local, while wet masks reduce comfort. On the other hand, at 30 °C, only wet masks do not increase discomfort. In addition, moist masks require less heat flux to achieve a certain skin temperature. However, it should be remembered that it is not advisable to wet the masks from the health point of view.

Keywords: thermal comfort; SARS-CoV-2; health



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1. Introduction

In order to contain the spread of the SARS-CoV-2 virus, most countries around the world have decided to tighten their public health policies [1]. The restrictions were introduced, requiring the mouth and nose to be covered in public spaces.

The analysis of various sources concerning the filtration rate of masks shows that their effectiveness ranges from 20–95%, depending on the type of material used [2].

As the WHO (World Health Organization) notes in its advice on the use of masks in the context of COVID-19, the use of a mask alone is not sufficient to provide an adequate level of protection against the spread of respiratory viral diseases [3]. The fact is that masks are a preventive measure against the spread of pathogens by droplets, but the real effectiveness of wearing masks by the users and the consequences they may have should be analysed. Numerous studies have pointed to the validity of wearing face masks as a way to reduce COVID-19 transmission. Guy et al. noted in their analysis that mandating the wearing of masks, closing restaurants and bars, and stay-at-home orders reduced the rates of increase in cases of disease and the rate of increase in mortality [4]. Bo et al. presented in their analysis various configurations of nonpharmaceutical interventions implemented in 190 countries between 23 January 2020 and 13 April 2020. They found that face mask, isolation, social distance, and restriction of movement can reduce the spread of COVID-19 [5]. Theoretical mathematical models described by Eikenberry et al. [6] and Li et al. [7] suggest that the use of face masks may contribute to the control of the COVID-19 pandemic. As Howard et al. note in their review of the evidence on the effectiveness of wearing masks in public places, there is a lack of randomized controlled trials (RCTs) on the effect of wearing masks on community transmission of respiratory infections during a pandemic. Conclusions based on studies that were informative and on predictions

based on theoretical simulations showed a significant effect of mask use on the spread of COVID-19 [8]. However, the authors [4,5,8] point out that there are difficulties in clearly determining the effect of wearing masks on reducing the spread of COVID-19 due to the simultaneous implementation of other personal protective measures such as hand washing, distancing, quarantine, etc. It should be indicated whether the possibility of airborne virus transmission was taken into account when performing the tests on the filtration of masks, as mentioned by Morawska and Cao [9] and many others [10,11]. The SARS-CoV-2 virus with a size of 65–125 nm will easily pass through most of the materials used in the production of masks. The pore size for the N95 mask considered to be the best is around 300 nm [12]. This fact was also noticed by the Canadian Center for Occupational Safety and Health, which, in response to a question about protection using face masks, stated that: The filtering material of surgical masks does not retain or filter out submicron particles, surgical masks do not protect the wearer from inhaling small particles that may remain in the air for a long time and surgical masks are not designed to eliminate air leakage around the edges [13]. The last statement raises another point that needs attention regarding the effectiveness of the wearing of masks. The most popular face masks used by the public are often characterised as loose fitting and generate air leaks along the cheeks, on the nose, and along the bottom edge of the mask below the chin [14]. As a result, loosely fitted masks, despite their high filtering capacity, have a low protection index [15]. If the fit is not sufficient, contaminated air will leak around the mask and unfiltered air will be inhaled [16]. Surgical masks are not subject to any US-based NIOSH (National Institute for Occupational Safety and Health) fit assessment standards; therefore, the assessment of their effectiveness cannot be based on the filtration index [15]. It should be noted that even such a significant factor, which reduces the effectiveness of the use of masks in society, is not the most important, because the incorrect wearing and use of face masks can do more harm than good. The mask may not completely cover the mouth and nose, and the users should avoid touching the face and outer surface of the mask. Observational studies involving 12,588 people in five Brazilian cities showed that only 45.1% of the population wore face masks correctly [17]. In contrast, in another study conducted among the public in Japan, which included 2141 people, 80.9% of participants reported wearing a face mask, but only 23.1% used it in accordance with the WHO guidelines [18]. WHO has issued recommendations on how to properly use masks, which advise:

- Carrying out hand hygiene before putting on the mask,
- Correctly covering the mouth and nose when putting the mask on, so that there are no gaps between the mask and the face,
- Avoiding touching the mask and, if it happens, washing hands or disinfecting them,
- Removing the mask using the appropriate technique,
- Replacement of the mask with a new one as soon as it becomes wet,
- Not re-using the disposable mask after use,
- Throwing the used mask into a closed container, and in the case of material masks, handling it in such a way as not to contaminate other objects,
- Sanitizing hands again after removing the mask [3].

Researchers from the University of Hong Kong noted that the correct use of masks is crucial, and their inappropriate use may increase the risk of virus transmission [19]. In order to clarify the effectiveness of wearing masks on the face, all the above factors should be taken into account in the research.

The order to cover the mouth and nose in case of shortages in the supply of medical masks or N95 masks, concerns about side effects and discomfort associated with long-term use, and high costs of using the masks, led to the public use of various solutions, such as home cotton masks and bandanas. However, the type of face mask used makes a big difference. As shown by randomized research that compared the effectiveness of cloth masks with medical ones in healthcare workers, performed on 1607 participants in 14 hospitals in Vietnam, the penetration of cloth masks was almost 97%, and the penetration

of medical masks was 44%. The results also indicate that moisture retention, reuse of cloth masks, and poor filtration may increase the risk of infection [20].

The time of using the mask depends on its type. For example, FFP2 can be used for a couple of hours, FFP3 for several hours, provided that they are disinfected, e.g., by UV radiation, before each reuse. On the other hand, disposable medical masks should not be used after they become wet [21]. It is recommended by the WHO [3] to change masks because they can become wet after several minutes. Especially when the human activity is increased.

Other dangers that arise when wearing masks include: Difficulty breathing, causing headaches and reducing the amount of oxygen in the blood. A study involving 158 health-care professionals found that 81% of them developed headaches associated with wearing face masks. Some with pre-existing headaches have experienced an increase in headaches when wearing a mask [22]. Similarly, in randomized controlled trials in Japan, the group wearing face masks was more likely to experience headaches than the control group without masks [23]. On the other hand, during the examination of 53 surgeons who had blood oxygen levels measured before the surgery and at the end of it, a significant decrease in the blood oxygen level was shown. The decrease of the blood oxygen level was also dependent on the length of wearing the mask [24]. Hypoxia causes a decrease in immunity [25] as well as many other threats to the proper functioning of the body, which may result in the intensification of other health problems [26].

In the context of the widespread use of masks made of various materials, there is insufficient research taking into account not only the filtration efficiency, but above all, the effectiveness of protection against getting infected with the respiratory disease. In fact, the comparative studies of N95 masks and medical masks are not sufficient to univocally conclude that the N95 mask, despite its greater filtration and fitting capacity, is a better barrier against infections [27]. The reason for the reduction in effectiveness of N95 masks seems to be the greater frequency of touching the facial area by people wearing N95 masks compared to people wearing medical masks. As shown by the research conducted by Scarano et al. [28], which consisted of observing participants wearing N95 masks and medical masks for an hour, people wearing N95 masks touched it 25 times while tilting the mask, and people wearing medical masks performed this gesture 8 times. A significant influence on this behaviour is probably the discomfort caused by the mask, connected with high airflow resistance. Similar behaviour is observed when wearing other types of masks, which is caused, among others, by frequent correction of a mismatched mask. This behaviour leads to the spread of respiratory infections from contaminated hands. The heat stress that occurs when wearing personal protective equipment negatively affects the performance, safety and well-being of the mask users. The results of various studies have shown that wearing the masks increases the temperature of the facial skin, which influences the thermal sensation of the whole body. It is because the impulses of the facial skin receptors are more sensitive than the receptors from other regions [28,29].

Additionally, it should be noted that the limited thermal comfort caused by the use of the masks may result in their incorrect use, and at the same time it may reduce the overall effectiveness of the widespread use of masks.

Thermal comfort is defined as “the state of mind, which expresses satisfaction with the thermal environment” [30]. According to this definition, thermal comfort is an individual feeling that indicates whether the body’s heat balance is balanced and does not feel too hot or cold. To date, many metrics have been developed with define thermal comfort and assess thermal stress. Potchter et al. [31] reviewed 110 articles that examined thermal comfort. They noted the use of 165 different indices to define thermal comfort, of which PET (physiological equivalent temperature), PMV (predicted mean vote), UTCI (Universal Thermal Climate Index), and SET (standard effective temperature) are the most commonly used. Because Predicted Mean Vote (PMV) is the only metric used in mechanically conditioned buildings (according to ISO 7730, ASHRAE 55, EN 16798-1 and ISO 17772-1 [30,32–34]), it was used to examine thermal comfort while wearing the mask in this study. The research

developed by Fanger at the Indoor Environment and Energy Laboratory at the Danish University of Technology was the basis for determining the PMV index. This index predicts the mean value of the votes of a large group of persons on the 7-point thermal sensation scale, based on the heat balance of the human body. Thermal balance is obtained when the internal heat production in the body is equal to the loss of heat to the environment [35]. The index is defined by values ranging from -3 to $+3$, where values close to -3 correspond to the feeling of cold, -2 —cold, -1 —slight cold, $+1$ —slight heat, $+2$ —heat, $+3$ —hot. The PMV index in range of $-0.5 < \text{PMV} < +0.5$ gives Predicted Percentage Dissatisfied (PPD) $< 10\%$, what is enough for normal offices [32].

Scarano et al. [28] assessed thermal comfort in two types of N95 and medical masks. They used a thermal imaging camera for the study. The assessment of thermal comfort was made on the basis of calculations and individual assessment of 20 people undergoing the analysis. Based on the analysis, they found less discomfort with the use of a medical mask. Scientists like Khattabi et al., Thapa et al., and Cheshmehzangi and Davey et al. [36–39] focused on assessing the internal environment in the face of lockdown and the stress associated with it. For comparison, the study described in this manuscript focused on objective measurements using a thermal manikin, in order to determine the thermal comfort of the users of various types of masks. The thermal manikin is often used for analysing thermal comfort (e.g., [40,41]).

2. Materials and Methods

The article presents the analysis of the thermal insulation of clothing, which included masks to protect against the SARS-CoV-2 virus, and the feel of thermal comfort. A thermal manikin (Figure 1), which is an advanced human body phantom (PT Teknik, Espergaerde, Denmark), was used for the analysis. It measures total body heat loss including convection, radiation, evaporation and conduction. The total mass of the manikin is 22 kg, and its height is 175 cm. The manikin did not have a core that could accumulate the heat and thus distort the measurement results. It only had a shell, so that all the energy needed to heat its surface was emitted to the environment. The manikin used in this study has 22 zones with microcomputer based controllers in each measurement section. The manikin is equipped with a respirator function. However, in accordance with the recommendations of the standards for measuring thermal insulation, PN-EN ISO 15831 and PN-EN 342 [42,43], the function was not used, which allowed for obtaining measures with no moving air conditions. The device-specific software was able to read the surface temperature, energy supplied, heat flux for each segment and total heat flux.



Figure 1. Thermal manikin.

In order to determine the ambient temperature of the manikin, a device called a comfortmeter was used. It measured parameters in real time.

The tests were carried out in a climatic chamber that allowed for the maintenance of a steady state of environment conditions. When measuring the thermal insulation performance of the clothing, the thermal manikin operated in the heat transfer mode with the possibility of maintaining a constant surface temperature of 32 °C. The ambient temperature was selected at the level of 20 °C, which made it possible to obtain a temperature difference, in accordance with the recommendations of the standards for measuring thermal insulation of clothing PN-EN ISO 15831 and PN-EN 342 [42,43]. According to the guidelines, the air was not moved (the fans in the chamber were turned off).

The thermal insulation of the clothing was measured for seven cases:

- 1 Dressed manikin without face mask,
- 2 Dressed manikin with a mask of the FFP2 type,
- 3 Dressed manikin with a cotton mask,
- 4 Dressed manikin with a medical mask,
- 5 Dressed manikin with a PM2.5 mask,
- 6 Dressed manikin with half-face protective shield plastic,
- 7 Dressed manikin with full-face protective shield plastic.

The measured thermal insulation of the clothing was used to measure the thermal comfort index PMV (Predicted Mean Vote) in accordance with EN ISO 7730: 2005 [32]. The measurement of the PMV coefficient was carried out for two scenarios of ambient air parameters: Temperature of 20 and 30 °C. In each scenario, the measurements were carried out for three cases of a face without mask, dry mask, and wet mask with water in the amount corresponding to the amount of water vapour exhaled by a healthy person. Each of the measurements was repeated three times. The obtained results did not differ from each other; therefore, such a number of repetitions was considered sufficient.

The thermal insulation of clothing at 20 °C was 0.7 clo, while at 30 °C it was 0.315 clo. Activity in a sitting position for office work was assumed, hence the metabolic rate 1.2 met ($70 \text{ W}\cdot\text{m}^{-2}$). The external work was $0 \text{ W}\cdot\text{m}^{-1}$. The air velocity in the area where the dummy was present was measured and amounted to $0.2 \text{ m}\cdot\text{s}^{-1}$. The radiant temperature has been assumed equals to the air temperature. The basic clothing insulation value has been adjusted for the effect of air and body movement according to the recommendation of Appendix C, EN ISO 7730: 2005 [32] and the suggestion of d'Ambrosio Alfano and all [44]. The value of velocity due to body movement has been calculated according to the recommendation of EN ISO 7730: 2005 [32]. However, human breathing was not included due to the limited capabilities of the manikin. Investigations should be continued considering the effect of air trapped between the mask and the face.

The parameters of the protective masks used (Figure 2) are shown in Table 1.



Figure 2. The face masks.

Table 1. The parameters of the face masks.

Sample/Fabric	Permeability μm [45,46]	Thermal Insulation [clo]
FFP2	0.5 ÷ 1	0.134
cotton, 2 layers	6	0.098
medical	<1	0.111
PM2.5	2.5	0.119
half-face protective shield plastic	-	0.072
full-face protective shield plastic	-	0.063

Additionally, the energy expenditure was measured in relation to m^2 of body surface, in order to maintain the skin temperature at $32.2\text{ }^\circ\text{C}$. The measurements were made for two scenarios, the same as for the PMV indicator.

3. Results and Discussion

The subject of the analysis was the PMV value for a person wearing: Underwear, shirt, pants, socks, shoes, staying in the rooms with a temperature of $20\text{ }^\circ\text{C}$ (Figure 3a); and wearing: Underwear, shorts, sleeveless shirt, socks, light shoes in the rooms with a temperature of $30\text{ }^\circ\text{C}$ (Figure 3b).

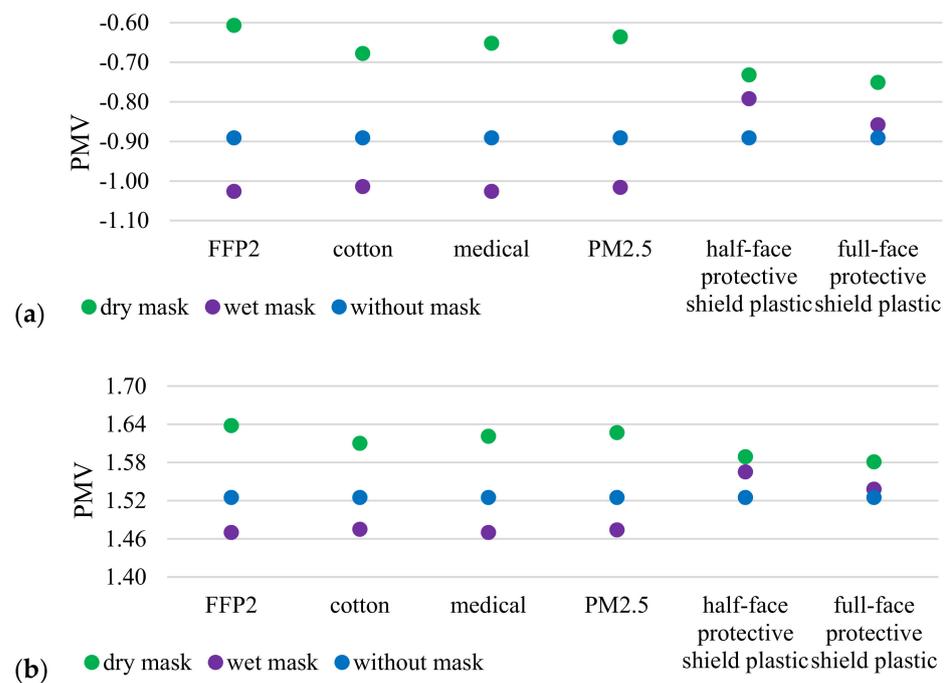


Figure 3. PMV value. (a) Human staying in the rooms with internal temperature equal to $20\text{ }^\circ\text{C}$; (b) human staying in the rooms with internal temperature equal to $30\text{ }^\circ\text{C}$.

When using a dry mask at $20\text{ }^\circ\text{C}$, regardless of the type of mask, thermal comfort is higher than without the use of a mask. On the other hand, while staying in premises with an internal air temperature of $30\text{ }^\circ\text{C}$, the use of a dry mask is associated with greater discomfort. When the masks are wet, the situation changes. At a lower temperature, a person wearing a wet mask feels less comfortable overall than without a mask. At higher temperatures, he feels more comfortable in a wet mask than without a mask. It is worth noting that we should not allow walking in wet masks due to the risk to health [3]. When comparing different types of masks, there is no significant difference in terms of thermal comfort between FFP2, cotton, medical and PM2.5 masks. On the other hand, half-face protective shield plastic and full-face protective shield plastic for a temperature of $20\text{ }^\circ\text{C}$,

when used in dry and wet conditions, provide higher thermal comfort than being without a mask, while at a temperature of 30 °C, both dry and wet use causes greater discomfort. Deviations of PMV values when using masks, in relation to PMV values when not using masks vary at 20 °C for dry masks from 15.71% to 31.87%, for wet masks from 3.7% to 15.15%. The lowest deviations are observed for full-face and half-face protective shield plastic and the highest for FFP2. At 30 °C, the deviations of PMV values when using masks, in relation to PMV values when not using masks are lower than for the temperature of 20 °C, and range from 3.67% to 7.41% for dry masks, and from 0.85% to 3.61% for wet masks. In this case also the lowest deviations are observed for full-face and half-face protective shield plastic, and the highest for FFP2. At the same time, it should be mentioned that full-face and half-face protective shield plastic do not protect enough in terms of health.

The analysis of local comfort within the face (Figure 4) showed that, regardless of the type of mask used, at 20 °C a person feels more comfortable, than without a mask, while at 30 °C feels more discomfort. At the same time, the deviations from thermal comfort without a mask are much greater at 20 °C and averaged 0.48%, while at 30 °C it is 0.02% on average.

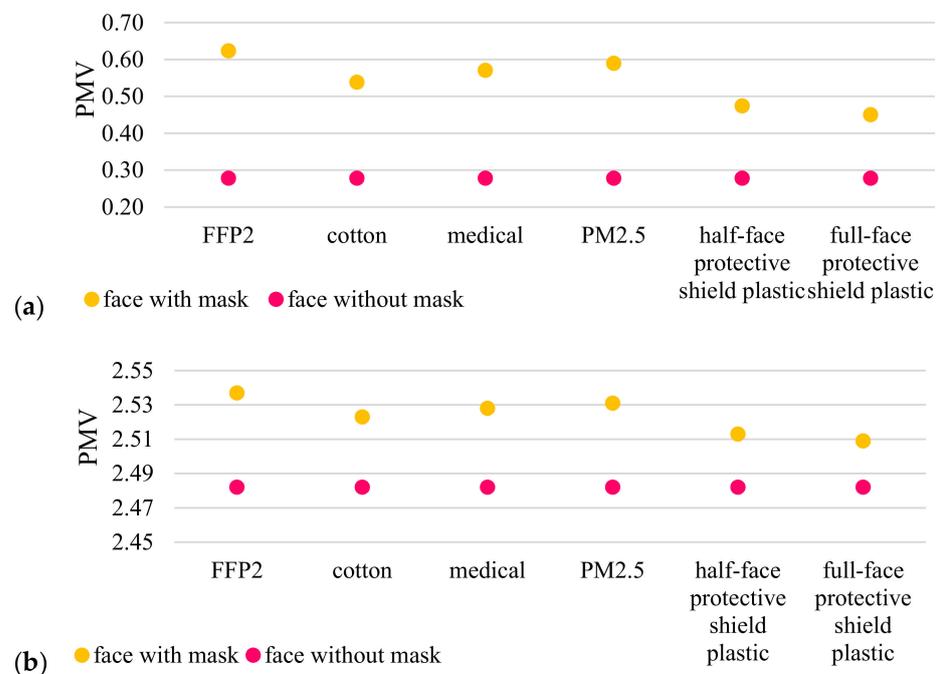


Figure 4. Local PMV value. (a) For face of human staying in the rooms with internal temperature equal to 20 °C; (b) for face of human staying in the rooms with internal temperature equal to 30 °C.

The last stage of the research was to determine the amount of heat in relation to m^2 of body surface area necessary to obtain the facial skin temperature of 32.2 °C (Figure 5).

At an ambient temperature of 20 °C, the amount of heat flux to reach the skin temperature of 32.2 °C is greater than for the temperature of 30 °C. For a lower ambient temperature, for dry masks heat flux ranges from 61.6 to 65.4 $W \cdot m^{-2}$, for wet masks from 65.4 to 72.9 $W \cdot m^{-2}$. For an ambient temperature of 30 °C, for dry masks the heat flux is within the range from 22.3 to 23 $W \cdot m^{-2}$, and for wet masks from 24.2 to 31.7 $W \cdot m^{-2}$. More heat is required for wet masks for both ambient temperatures. At the same time, in the case of use of wet masks: FFP2, cotton, medical and PM2.5 in an environment with a temperature of 30 °C, the increase in the amount of heat flux is the greatest and it amounts to 0.14% on average.

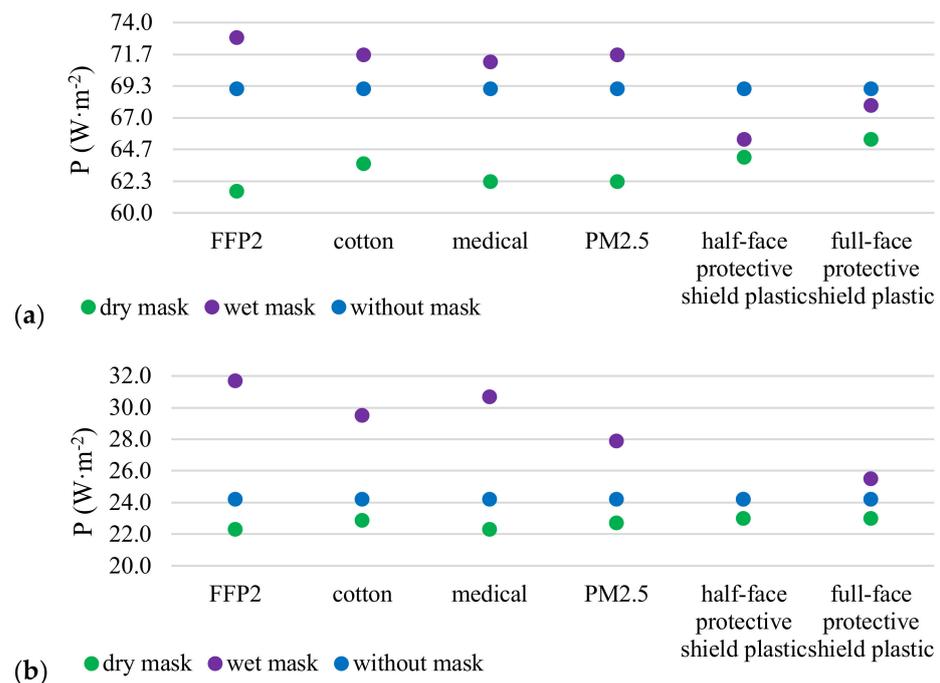


Figure 5. Amount of power needed to reach skin temperature equal to 32.2 °C. (a) Internal temperature 20 °C; (b) internal temperature 30 °C.

The obtained results may confirm the results obtained by Scarano et al. [28], who found an increase in the temperature in the area of the face with the use of masks. In our study, we showed less need for the amount of heat produced by the body in order to obtain a specific skin temperature (32.2 °C). So with the constant heat production, the temperature of the skin will be higher if the human face is wearing a dry mask.

4. Conclusions

The proper use of the masks, consisting of frequent changing of the mask, obligatory disinfection each time a reusable mask is used, appropriate disposal, and in the case of reusable masks, appropriate handling of the contaminated mask after removing it and before its disinfection, taking care of proper removal, washing or disinfection of hands after each contact with the mask, adjusting the mask to the shape of the face, ensures the protection against the spread of pathogens, including SARS-CoV-2.

The conducted thermal comfort tests showed:

- Greater general discomfort at higher temperature with a dry mask on face compared to no mask;
- Greater general comfort at a lower temperature with a dry mask on face compared to no mask;
- Greater general discomfort at a lower temperature with a wet mask on face compared to no mask;
- Less general discomfort at higher temperatures with a wet mask on face compared to no mask;
- Slight difference in the feeling of general thermal comfort when using the following masks: FFP2, cotton, medical and PM2.5;
- Greater thermal comfort at a lower temperature when using half-face protective shield plastic and full-face protective shield plastic regardless of their wetting;
- Greater discomfort at higher temperatures when using half-face protective shield plastic and full-face protective shield plastic regardless of their wetting;
- At a lower temperature, greater local comfort within the face when the mask is on the face than without it;

- At a higher temperature, local discomfort in the face when the mask is on the face is greater than without it.

The analysis of the amount of heat flux necessary in order to maintain the skin temperature at 32.2 °C showed that:

- At lower temperatures, more heat flux is needed;
- The use of dry masks requires less heat flux than the use of wet masks;
- The use of dry masks requires less heat flux than no masks;
- The use of wet masks requires more heat flux than no masks.

Despite the positive effect of moistening the masks (at an ambient temperature of 30 °C) on the feeling of thermal comfort, it should be emphasized that it is unacceptable from the point of view of health risk. Hence, only dry masks should be assessed when the recommendations for use are created. In addition, general education on the proper use of masks is necessary, with particular emphasis on the risks associated with improper use.

Not only is it not advisable to wear wet masks from a public health perspective, but also various facial coverings offer different amounts of community and personal protection benefits.

Further work is needed in order to create masks connecting ideal fit, sufficient filtration and maintenance of thermal comfort.

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