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Microbiological Risk in Rooms with Mechanical Ventilation

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ABSTRACT

The condition of air quality depends on many external (the amount of pollutant emissions, intensity and type of physico-chemical changes taking place in the atmosphere and large-scale movement of air pollutant masses) as well as internal factors (such as finishing materials, room equipment, heating systems, ventilation systems, and the presence of the humans themselves). As a result, there are various risks related to air quality, including the most important ones related to microbial contamination. For this reason, it was decided to analyze the quality of internal air in terms of microbiological contamination that may occur in university lecture halls with mechanical supply and exhaust ventilation. The analysis also took into account the impact of mechanical ventilation on physical parameters such as temperature, relative humidity as well as the concentration of PM10 and PM2.5 particulate matter pollutants, thus determining the impact of the tested parameters on human health and well-being. All the obtained results were compared with the applicable permissible standards and conclusions were drawn regarding the improvement of the quality of the indoor air microclimate.

Keywords: mechanical ventilation, microbiological pollution, dust pollution, air quality, bioaerosol.

INTRODUCTION

Nowadays, 87% of time during the day is spent on various forms of indoor activities, for example at home, school, university, work [Teleszewski et al. 2019; WHO 2005]. As a result, air quality is the main factor influencing the comfort and well-being of a person staying indoors. The composition of indoor air depends on many external and internal factors, such as finishing materials, room equipment, heating systems, ventilation systems, as well as the presence of humans themselves. One of the elements that have a significant impact on air quality is the presence of microbiological contaminants in it, forming the so-called bioaerosol. It accounts for 5 to 34% of indoor air pollutants [Asikainen et al. 2016; Gołofit-Szymczak et al. 2005]. It includes, among others, bacteria, bacterial endotoxins, fungi and their spores, viruses, dust pollen and allergens. As biological particles are of different sizes, i. e. bacteria (0.1–0.2 μm), fungal spores (1–100 μm), viruses (0.01–1 μm), they form the so-called dispersed phase in the air [Chmiel et al. 2015]. The bioaerosols smaller than 5 μm remain suspended in the air, while larger ones deposit on the surface [Wilson et al. 2018]. It should also be remembered that the most dangerous fraction for health is the respirable fraction of microorganisms, because it consists of biological particles <7 μm. Such particle that enter the upper and lower respiratory tract, causing various types of diseases (the smaller the particle, the more dangerous it is to human health) [Basińska et al. 2016]. The importance of this problem may be proven by the fact that according to some sources e. g. in Poland, 30% of the professionally active population performs office work, and thus may be exposed to this type of pollution. Despite this, practically no systematic measurements/controls of the microbiological purity of air are performed [Kaiser et al. 2007]. Office workers, schoolchildren and students spending more time in closed rooms are exposed to biological factors that may affect their well-being (e.g. headaches, lack of concentration, fatigue) [Gładyszewska-Fiodorczuk et al. 2019; Wilson et al. 2018]. One of the solutions aimed at improvement of the indoor air quality is the presence of mechanical ventilation systems in buildings. According to the principle of operation of ventilation, used air should be replaced with fresh air from outside. At the same time, it should be remembered that the outside air also contains various types of pollutants that can infiltrate through ventilation ducts or accumulate in the area of filters and get into the interior of rooms/buildings with the supplied air. Currently, the basic indicator that allows assessing the proper operation of ventilation is the level of indoor air humidity. The lower the humidity, the lesser the chance of mold and fungi development. On the other hand, too low level of humidity will result in faster deposition of particles and dust, and with them biological particles, on the surfaces of e.g. furniture or equipment/devices located in a given room. According to the Polish PN-78/B-03421 standard, in closed spaces, the correct air humidity should be 30–65%, while humans feel best at 40–60% [PN-78/B-03421]. Therefore, in this article it was decided to test and evaluate the impact of mechanical supply and exhaust ventilation on the level of dust and microbiological pollutants in a lecture hall at a university located in Lodz in central Poland, in Central and Eastern Europe. Measurements also took into account the impact of ventilation on physical parameters such as relative humidity and temperature.

THE INFLUENCE OF MICROORGANISMS ON HUMAN HEALTH

Due to the lack of nutrients, air is not a favorable environment for the development of microorganisms. It is only a transitional environment for them, and the main target are organisms in which they can reproduce. Various diseases may develop as a result of human contact with microbes. Microorganisms, especially bacteria and fungi, can cause hay fever, sinusitis, conjunctivitis, bronchitis, lung cancer or diseases of the cardiovascular system, and in the case of weakened immunity, they may even contribute to the development of sepsis [Flanningan et al. 2017; Wong et al. 2008]. In the studies conducted in Poland in Upper Silesia in the houses with a high level of humidity, it was shown that the most frequently isolated microorganisms from the air were fungi of the genus *Aspergillus*, *Cladosporium*, *Penicillium* and their level varied from 800 cfu/m^3 to 17000 cfu/m^3.At the same time, it was noticed that in the houses where the mold problem did not occur, the amount of bacteria was greater in relation to the amount of fungi. The concentration of bacteria was 1000cfu/m^3, while fungibout 60 cfu/m^3. Among the bacteria, the most often isolated were *Micrococcus* and *Staphylococcuse pidermidis*, constituting 14% of all bacteria grown [Pastuszka, 2000]. On the other hand, the research on the air inside office buildings carried out in the United States and Brazil showed that the most frequently isolated microorganisms were fungi of the genus *Aspergillus*, *Penicillium* and *Cladosporium*, and among the bacteria *Bacillus* and *Micrococcus* [Gołofit-Szymczak et al. 2005]. Studies carried out in various countries often indicate exceeded standards of indoor pollution [Cabral 2010; Gładyszewska-Fiodoruk et al. 2016; Zhu et al 2003]. Particular attention should be paid to the bacteria of the *Staphyloccocus* genus, especially *S. aureusmannitolo-positive and S. epidermidis mannitolo-negative*. *S. ureus,* which are pathogens resistant to various antibiotics, are therefore very difficult to cure. They can cause diarrhea, vomiting, drop in blood pressure and even lead to death. *S. epidermidis* is considered a harmless pathogen found in the nasal mucosa and on the skin of humans. At the same time, more and more studies show that this bacterium can lead to serious diseases in the people with weakened immunity, with cancer or after transplant [Madsen et al. 2018]. Therefore, it is very important to regularly monitor the state of indoor air pollutants in order to eliminate this type of pollutants from the air as quickly as possible.

MATERIAL AND METHODS

The measurements were carried out in a lecture hall with mechanical supply and exhaust ventilation, located on the second floor of a four-storey university building (Lodz University of Technology, Fig. 1). The test consisted in measuring the following parameters: PM10 and PM2.5 particulate matter concentration, relative humidity, air flow velocity and the number of microorganisms. At the same time, during internal measurements, the air quality condition and meteorological conditions outside the building were also analyzed. All parameters were tested in five variants:

1. Before classes with the mechanical ventilation turned off with gravitational ventilation applied (30 minutes before classes).
2. Before classes with mechanical ventilation turned on (15 minutes before classes).
3. During classes with mechanical ventilation turned off with gravitational ventilation applied (15 minutes).
4. During classes with mechanical ventilation turned on (15 minutes).
5. After classes (15 minutes after classes).

Measurements were performed at three points in the room. There were two extreme points under the air inlet 3 and exhaust 1, and in the center of the room as the middle point of distance between the air inlet and exhaust. The arrangement of measuring points and the dimensions of the room are shown in Figure 1.

Particulate matter measurements were carried out with the Scentroid DR 1000 measuring device, humidity and temperature were measured with the Davis Vantage Pro 2 weather station, air velocity was measured with the µAS vane anemometer with a measurement accuracy of 0.5%, while microbiological measurements were made using the impact method. The obtained results were analyzed, owingto which the amount of microorganisms in 1 m^3 of air, expressed in the number of colony-forming units, was determined (cfu/m^3).

In order to detect microorganisms, the collision method was used, which consists in the mechanical separation of pollutants from the collected air sample. Air sampling was performed using a Merck MAS-100 Eco sampler. Inside the sampler there are petri dishes with special media: nutrient agar, Sabourda agar and Mannitol salt agar. The sampler was placed at a height of 1 meter on a bench at each measuring point. During the measurement, air enters the sampler through special holes, along with impurities, which remain on the dishes as a result of collision with the surface of the dishes. In this way, at each measuring point, 3 samples with a volume of 50 liters of air were taken for 30 seconds for each agar. After the specified time, the dishes were placed in an incubator for 3 daysunder the conditions of 37°C for bacteria and for 5 days at 25°C for fungi. After this time, the grown colonies were counted and identified. Then the amount of mannitolo-negative bacteria, fungi and staphylococci per 1 m^3 of air was calculated according to formula 1.

Table 1. Characteristics of the tested room. Source: own preparation

Object	Area [m^2]	Room height [m]	Number of seats	Number of people present
Lecture hall	59	2.50	36	11

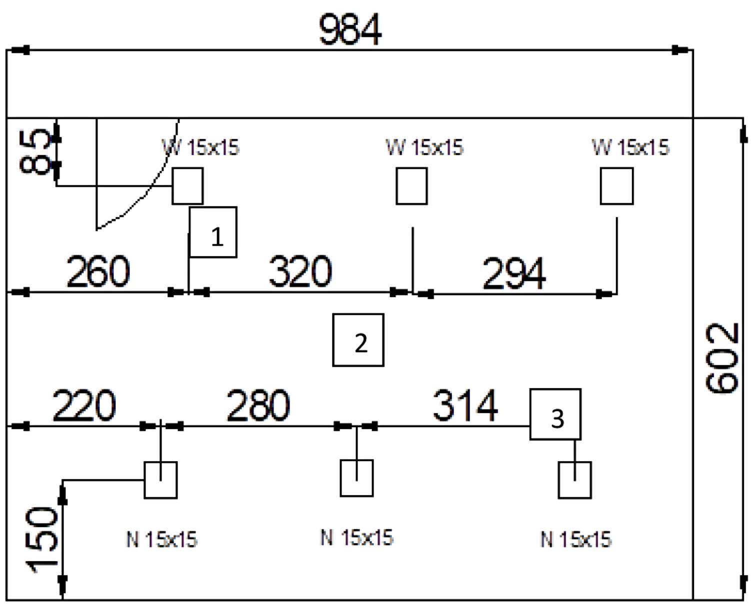

Fig. 1. The diagram shows the dimensions of the measuring room and the distributed measuring points marked with numbers 1, 2, 3. Source: Own preparation

$$x = \frac{a \times 100}{(v \times t)} \quad (1)$$

where: x – number of colony-forming units (cfu/m^3); a – average number of colonies; t – exposure time (min); v – the volume of the sample taken in one minute (100 l/min).

The advantage of the collision method is the speed of sampling and the known volume of air, while the disadvantage is the risk of a decrease in the viability of microorganisms as a result of a collision with the agar.

RESULTS

The obtained results constitute the basis for the analysis of air pollution inside the lecture hall. For each measurement point, the results of measurements of the tested parameters of temperature, humidity, air velocity and the number of bacteria, fungi and manitollo-negative staphylococci that were present in 1 m^3 of air were presented. On the other hand, the results of the concentration of PM10 and PM2.5 particulate matter were presented as the μg/m^{3}concentration during all measurements. Fig. 2 presents a comparison of the average number of microorganisms before class, without mechanical ventilation with gravitational ventilation applied and with mechanical ventilation turned on, while in Fig. 3 a comparison of the average number of microorganisms during the classes with mechanical ventilation turned on and mechanical ventilation turned off with the applied gravitational ventilation. In addition, for the purpose of comparison, the parameters of the outside air were also measured, which is shown in Figure 4. While analyzing the obtained results of measuring the number of microorganisms in the

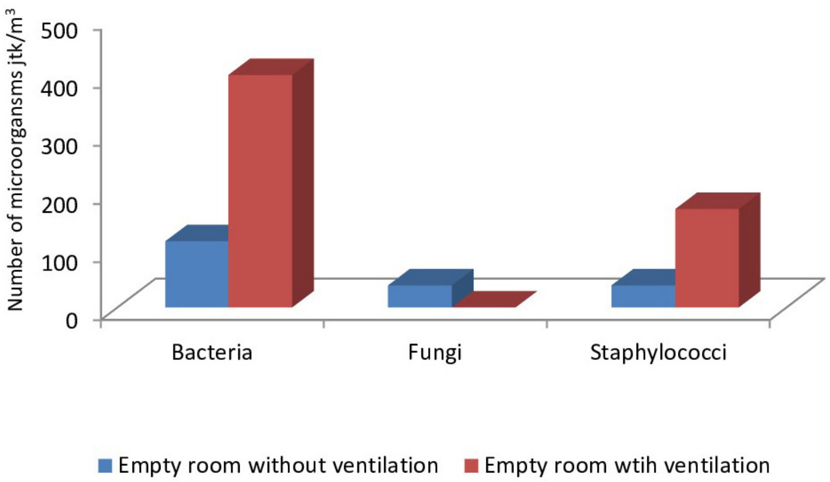

Fig. 2. Comparison of the average number of microorganisms before class without mechanical ventilation with gravitational ventilation applied and with mechanical ventilation turned on

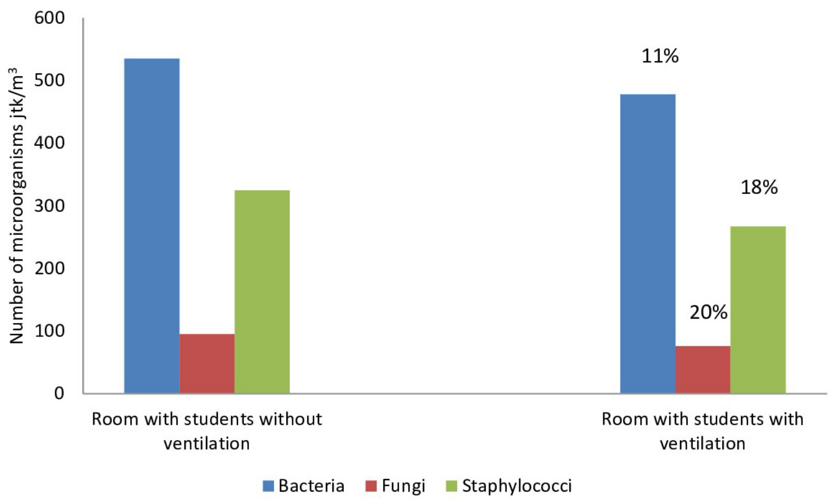

Fig. 3. Comparison of the average number of microorganisms during classes with mechanical ventilation turned on and mechanical ventilation turned off – with the gravitational ventilation applied

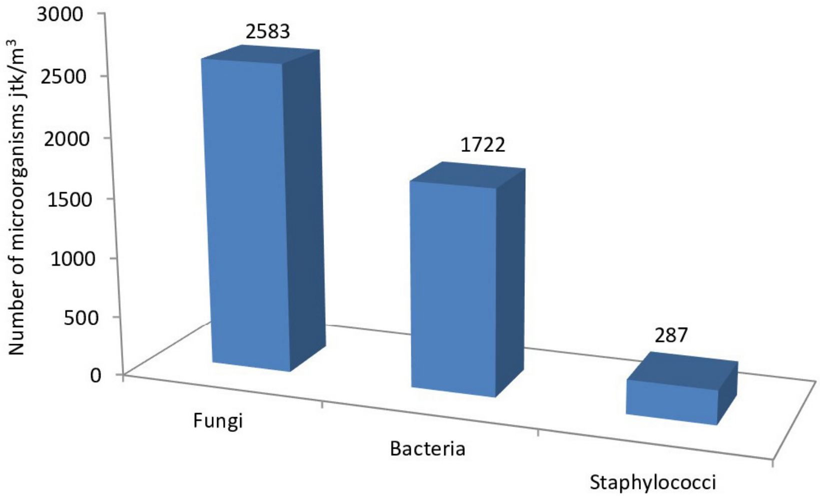

Fig. 4. The number of microorganisms outside

room with the ventilation turned on and without mechanical ventilation (Fig. 2), it can be seen that the number of bacteria, including staphylococci, is higher during the measurement with mechanical ventilation turned on. This means that the air movement caused by the activation of mechanical ventilation could cause the microorganisms accumulated on filters or in the ventilation duct to enter the room or microorganisms could accumulate at the measuring point under the exhaust air vent.

On the other hand, when analyzing the obtained results of measuring the number of microorganisms during the classes with mechanical ventilation turned on and without mechanical ventilation (Fig. 3), it can be seen that the number of microorganisms decreases during the operation of mechanical ventilation. The number of bacteria decreased by 11% compared to the measurement of the number of bacteria without mechanical ventilation turned on. Moreover, the number of fungi and staphylococci decreased by 20% and 18%, respectively, compared to the measurement without mechanical ventilation turned on. At the same time, when analyzing the measurement results before classes without mechanical ventilation and during classes without mechanical ventilation, one can see a large increase in the number of all tested microorganisms for the measurement during classes. It can therefore be concluded that the human factor is the reason for the increase in this number.

The number of fungi and the total number of bacteria in the outside air (Fig. 4) is much higher than inside and amounts to 1722 cfu/m^3 for fungi and 2583 cfu/m^3 for bacteria, respectively. These numbers, however, do not exceed the permissible air pollution standards. On the other hand, the number of staphylococci is 287 cfu/m^3, which proves that the limit of 50 cfu/m^{3}is exceeded five times.On the other hand, the results of the analysis of temperature and relative humidity at specific measuring points were also compared, depending on whether the mechanical ventilation was on or off.The tested parameters of relative humidity and temperature indicate higher values of the parameters tested in the room during the measurement without mechanical ventilation turned on – with the use of gravitational ventilation both before classes and during classes. The temperature range before the classes without mechanical ventilation ranged from 24 to 25°C, and the humidity level ranged from 26 to 28%. On the other hand, with the mechanical ventilation turned on, the temperature ranged from 23 to 24°C, and the humidity was 23 to 24%. Only in the measuring point no. 2 there was an increase in humidity to 32%, because at this point there was no movement of air masses.

The next part of the analysis were the measurements of the concentrations of PM10 and PM2.5 perticulate matter inside the room (Fig. 5) and it was an important parameter in the analysis, because particulate matter can be a carrier of various types of pollutants.

The concentration of PM2.5 and PM10 particulate matter during all measurements inside the room ranged from 20 μg/m^3 to 25 μg/m^3 for PM10 and from 19 μg/m^3 to 24 μg/m^3 for PM2.5. The lowest concentration of PM2.5 and PM10 particulate matter, 15 μg/m^3 for PM2.5 and 16 μg/m^3 for PM10, was recorded during the measurement before classes with mechanical ventilation

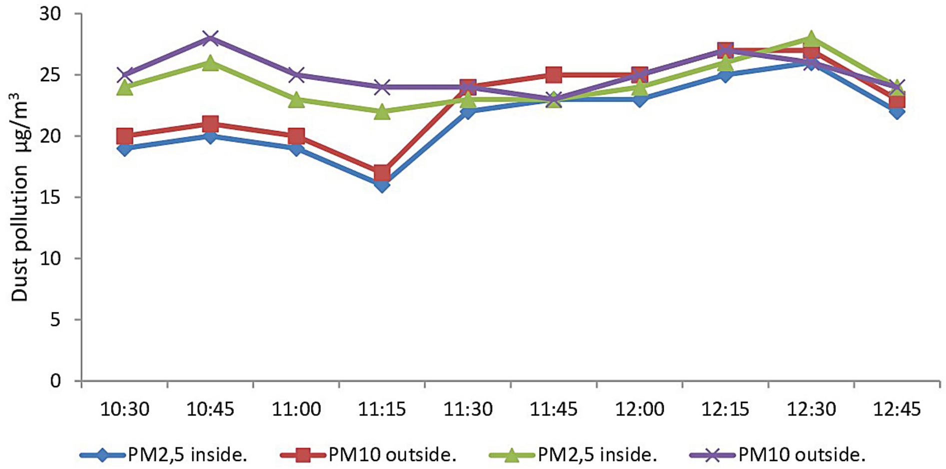

Fig. 5. The concentration of PM10 and PM2.5 particulate matter inside and outside the room during all measurements

turned on, while the highest during the measurement during classes with mechanical ventilation turned on. The measurements taken after the end of the classes showed a decrease in the concentration of PM2.5 and PM10 particulate matter to the value of 23 μg/m^3. This proves that secondary particulate matter, brought by people, appeared in the room during the classes.

After the analysis of the obtained results, the presence of fungi, bacteria and manitollo-negative staphylococci *S.epidermidis* was found in the tested room and outside. The number of bacteria, including staphylococci before the classes at each measurement point, was higher during the operation of mechanical ventilation. This number is 401 cfu/m^3 for the total number of bacteria during the operation of mechanical ventilation, and 171 cfu/m^3 for staphylococci. The exception are fungi, the presence of which was not found during the operation of mechanical ventilation. However, without the mechanical ventilation turned on with the gravitational ventilation applied, the obtained result indicates the total number of bacteria 114 cfu/m^3, fungi 38 cfu/m^3 and staphylococci 38 cfu/m^3. The obtained data may indicate the ingress of pollutants from the outside to the inside through air inlets or the fact that microorganisms have accumulated on the filters and during the activation of mechanical ventilation they infiltrate with the blown air. The argument supporting such a conclusion is the number of microorganisms in point 3 under the air inlet, which is higher for the measurement before classes during the ventilation operation. Comparing the data on the analysis of the results of the number of microorganisms before classes and during classes without mechanical ventilation turned on - with the gravitational ventilation applied, a clear increase in the number of microorganisms during classes can be seen. This increase fluctuates in the range for the total number of bacteria from 114 cfu/m^3 to 535 cfu/m^3, for fungi from 38 cfu/m^{3}to 95 cfu/m^3 and for staphylococci from 38 cfu/m^3 to 325 cfu/m^3. This proves that there is a clear influence of the human factor on the growth of microorganisms in the air. The number of bacteria and fungi is within the applicable standards, while the number of staphylococci is significantly exceeded. However, when comparing the influence of mechanical ventilation on the number of microorganisms during the classes, a clear decrease of this number can be seen during the operation of ventilation. The total number of bacteria during the operation of mechanical ventilation decreased by 11%, fungi by 20% and staphylococci by 18%. Despite this decrease, the number of staphylococci is still exceeded five times above the legal limit, the upper limit of which is 50 cfu/m^3[14]. Therefore, measures were taken to eliminate staphylococci from the internal environment as effectively as possible. The analysis of the influence of mechanical ventilation on the tested parameters of relative humidity and temperature shows that mechanical ventilation reduces their values both during measurements before class and during classes.

On the other hand, the measurements of particulate matter indicate an increase in the concentration of PM10 and PM2.5 during classes and a decrease in particulate matter concentration after the end of classes. In the case of PM2.5, the highest measurement recorded was 25 μg/m^3 [12, 18] and it was the limit value in relation to the acceptable standard for the quality of the outside air. This measurement was recorded during classes without mechanical ventilation turned on with gravitational ventilation applied.

CONCLUSIONS

Microbiological air pollution is not only limited to causing various diseases, but can also affect our well-being and work comfort. The tests carried out with the use of the collision method did not show any exceeded standards of bacteria and fungi in the internal air, both when mechanical ventilation is turned on and when mechanical ventilation is turned off with the use of gravitational ventilation. The exception is the number of staphylococci, which exceeds the permissible level inside and outside five times. However, the number of fungi and bacteria, both inside and outside, is within the set standards. The exceeded limit for staphylococci inside may indicate the possibility of bacteria penetrating inside the rooms through the air ducts or their accumulation on filters and being forced in with the air stream during the operation of mechanical ventilation or the carrier may be a human factor. Nevertheless, the results show that the air condition is good both inside and outside. *Staphylococcus aureus* has not been reported in the air. Only the number of *Stapylococcusepidermidis* exceeded the acceptable limits and in terms of mannitollo-negative staphylococci, the air condition is heavily polluted both inside and outside. On the basis ofthe obtained data, it can be concluded that the influence of mechanical ventilation on the tested parameters of temperature and relative humidity is also favorable. In view of the presented data, it is true that mechanical ventilation has a positive effect on the reduction of the number of microorganisms in the indoor air and parameters such as temperature or relative humidity, but only if it is properly performed, maintained and controlled, and, if necessary, additionally cleaned.

The analysis of the parameters studied in this article shows the influence of the type of air exchange on the state of microbiological air quality, and therefore it can be useful both for the managers of this type of facilities and for other researchers who analyze the state of air pollution inside rooms/lecture halls by multiparameter analysis.

REFERENCES

1. Asikainen A., Carrer P., Kephalopoulos S., de Oliveira F.E., Wargocki P., Hänninen O. 2016. Reducing burden of disease from residential indoor air exposures in Europe (HEALTHVENT project), Environmental Health, 15(1).
2. Basińska M., Michałkiewicz M. 2016. Airpollution and itsimpact on humanhealth. Rynek Instalacyjny, 4, 90–93.
3. Cabral J.P.S. 2010. Can we use indoor fungi as bioindicators of indoor air quality? Historical perspectives and open questions, 15, 408(20), 4285–4295. DOI: 10.1016/j.scitotenv.2010.07.005
4. Chmiel M.J., Frączek K., Grzyb J. 2015. Problems of monitoring the microbiological pollution of air. (ITP. (I–III).T.15.Z.1(49).
5. Flannigan B., SamsonR.A., Miller J.D. 2017.Microorganisms in Home and Indoor Work Environments, 539, 92.
6. Gładyszewska-Fiedoruk K. 2019. Indoor Air Quality in the Bedroom of a Single-Family House – a Case Study, Proceedings, 16(1), 38.
7. Gładyszewska-Fiedoruk K., Nieciecki M. 2016. Indoor Air Quality in a Multi-car Garage, Energy Procedia, 95, 132–139.
8. Gołofit-Szymczak M., Skowroń J. 2005. Comparison of the composition of the air microflora of office rooms in a building with air-conditioning systems with a building without air conditioning. BromatChemToksykol, 38(4), 407–412.
9. Kaiser K., Wolski A. 2007.Control of microbiological air purity. Cooling technology and air conditioning, 4, 158–162.
10. Laska M., Dudkiewicz E. 2017. Research of CO_2 concentration in naturally ventilated lecture room, E3S Web of Conferences, 22, 00099.
11. Madsen A.M., Moslehi-Janabian S., Zohorul M.D., et al. 2018.Concentrations of *Staphylococcus* species in indoor air as associated with other bacteria, season, relative humidity, air change rate, and *S. aureus-positive* occupants. https://doi.org/10.1016/j.envres.2017.10.001
12. https://powietrze.gios.gov.pl/pjp/content/annual_assessment_air_acceptable_level.
13. Nantka M.B. 2011. Ventilation with air conditioning elements., Wydawnictwo Politechniki Śląskiej, Gliwice.
14. PN-78/B-03421.Ventilation and air conditioning. Calculation parameters of indoor air in rooms intended for permanent human habitation.
15. PN-89/Z-0411/02,Air purity protection. Microbiological testing. Determination of the number of bacteria in the atmospheric air during sampling with the sedimentation and aspiration method.

16. PN-89/Z-0411/03,Air purity protection. Microbiological testing. Determination of the number of microscopic fungi in the atmospheric air (immission) during sampling with the sedimentation and aspiration method.
17. Ryńska J. 2019. Anti-smog airfilters for mechanicalventilation - recuperators and airhandlingunits. Rynek Instalacyjny, 5, 69–74.
18. Sulewska M.J., Gładyszewska-Fiedoruk K. 2018. Analysis of the results of empirical research and surveys of perceived indoor temperature depending on gender and seasons. Environmental Science and Pollution Research, 25(31), 31205–31218.
19. Teleszewski T.J., Gładyszewska-Fiedoruk K. 2019. The concentration of carbon dioxide in conference rooms: a simplified model and experimental verification. International Journal of Environmental Science and Technology, 1–10.
20. Tringe S.G, Zhang T., Liu X. et al. 2008.The airbonemetagenome in an indoor urban environment. PLoS ONE. https://doi.org/10.1371/journal.pone.0001862.
21. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005. Summary of riskassessment.
22. Wichmann J., Lind T., Nilsson M.A.M., Bellander T. 2010.PM2.5, soot and NO_2 indoor-outdoor relationships at homes, pre-schools and schools in Stockholm, Sweden. AtmosEnviron. 44, 4536–4544. https://doi.org/10.1016/j.atmosenv.2010.08.023.
23. Wilson S., Ross T.B., Blaskovich M.A.T., Ziara Z.M. 2018. Antimicrobiol silver In Medicinal and consumer aplications: a patent review of the Post Decade (2007–2017). Antibiotics. https://dx.doi.org/10.3390%2Fantibiotics7040093
24. Witczak T., Walusiak J., Pałczyński C. 2001. Sick buildingsyndrome – a new problem in occupational medicine. Med. Pr., 52(5), 369–373.
25. Wong L.T., Mui K.W., Chan W.Y. 2008. An energy impast assessment of ventilation for indorairbone bacteria exposure risk In air-conditioned Office. Building and Environment, 43, 1939–1944.
26. Zabiegała B. 2009. Indoor air quality - volatile organic compounds as an indicator of indoor air quality. Monografie Komitetu Inżynierii Środowiska PAN, 59(2), 303–315.
27. Zhu H., Phelan P., Duan T., Raupp G., Fernando H.J.S. 2003. Characterizations and relationships between outdoor and indoorbioaerosols in an office building. China Particuology, 3, 119–123.