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REVIEW ARTICLE

Retrospective Study on Indoor Bioaerosol - Prospective Improvements to Architectural Criteria in Building Design

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ABSTRACT:

Introduction: Indoor bioaerosol is one of the factors of sick building syndrome that needs to be controlled for the health of building occupants. Control of bioaerosols is a daily obligation for occupants, but can be alleviated through a building design approach, so that the potential negative effects of bioaerosols are minimized. This study aims to fill the criteria for controlling bioaerosols at the building design stage, in addition to the operational use of the building.

Methods: This literature study on indoor bioaerosols uses the Mendeley Reference Manager platform with the search phrase indoor bioaerosols. The selection of literature based on open access journals, in English, excluded the indoor production process.

Results: In the perspective of the building infrastructure design, the ventilation system is an opening facility between indoor and outdoor, as a mechanism for air flow and quality balance between the two spaces. The implementation can be in the form of fixed openings in walls, openings that can be opened and closed manually or mechanically, including windows and doors. Effective reduction of bioaerosol concentration needs to sit up the type of ventilation that is adapted to the function of indoor use and occupancy load. The ventilation method is supported by a chemical method, which is appropriate for control in food service rooms and sanitation services.

Conclusion: The bioaerosol control strategy can start from the design of the building by the designer and continue to the implementation and maintenance of the building by the occupants.

Keywords: *Bioaerosol, Building Design, Control Methods, Indoor*

Introduction

The time of daily human activities is much longer indoors than outdoors. Meanwhile, indoor materials and facilities produce a lot of substances that are released into the indoor air. Among the substances released into the indoor air, aerosols are collections of fine particles, which can serve as carriers of chemical and biological substances and spread to indoor air spaces (Sarah, 2017; Martin et al., 2019). Many indoor aerosol measurement studies have included the content of volatile organic compounds (VOCs), formaldehyde (CH_2O), nitrogen dioxide (NO_2), and carbon dioxide (CO_2), and other toxic gases as described in previous papers (Samudro, Samudro, and Mangkoedihardjo, 2022; Samudro and Mangkoedihardjo, 2021). Although the relationship between the concentration of these chemicals and the concentration of microbes is not yet known, living organisms can grow in their distribution through indoor air in conditions that support life (Yu, Mui, and Wong, 2018; Rocha-Melogno et al., 2020). Under these conditions, bioaerosols as aerosols containing living organisms (Cox et al., 2020; Tang et al., 2018; Nazaroff, 2016; Sudharsanam et al., 2012) need to receive important attention in indoor air quality, because they have potential health effects (Douglas et al. 2018; Jiayu et al. 2019). Understanding the properties of indoor bioaerosols is critical to the health and well-being of building occupants.

The removal of bioaerosols in the indoor environment of a building requires operational control of the occupants but can be minimized through a building design approach. There is an architectural strategy for controlling indoor bioaerosols by using a ventilation system approach and occupancy loads (Hospodsky et al. 2012; Meadow et al. 2014). The strategy is based on the premise that the indoor bioaerosol community is influenced by the outdoor bioaerosol community, but the most bacteria are from occupants. Meanwhile, ventilation affects the composition of the indoor bacterial community. Thus, these two variables, ventilation and occupants can be used as a building design approach.

By the time the building has been completed and used, it is possible that the concentration of bioaerosol indoors will exceed the concentration outside. Occupants can indicate the presence of pre-sick building syndrome, such as smelly and musty rooms (Samudro, Samudro, and Mangkoedihardjo, 2022). In such conditions, occupants can operate the ventilation system through various means available in the building, such as opening windows (Elbayoumi, 2018). If there is mechanical ventilation, it can be operated longer or more frequently than usual. All of which are efforts to increase the ventilation rate (Pegas et al., 2010). In addition to ventilation, occupants can also spray anti-bacterial on indoor materials and equipment, which has now become accustomed to the new normal as a health protocol to prevent disease transmission.

The study of indoor bioaerosols has progressed so far, and this paper presents the status of indoor bioaerosols, with the aim of improving architectural strategies in the design of a building. This study focuses on preventive control in aspects of building design, which facilitates bioaerosol control by occupants. This output can be used for the development of sustainable healthy building-oriented architecture, and operational control for buildings that are being used by their occupants.

Methods

Literature on research results was collected from the Mendeley Reference Manager platform with the search phrase indoor bioaerosol. The literature selection used the following criteria: journal document types and online publications, in English, empirical research, related to aerosols, excluded indoor production process, with no time limit for publication. The number of literatures obtained was 736 publications from 2013 to 2022. By screening according to the selection criteria, 44 publications were obtained which were the core of this study.

The addition of some literature outside the platform is carried out to strengthen the findings of the selected empirical papers. In this addition, several search phrases related to bioaerosol sources, health effects, control methods, indoor and environmental conditions. Search sources are directly on online journals and Google Scholar. Using the same selection criteria as the core literature, an additional 19 literatures were obtained.

The problem analysis is based on important findings from each selected literature, which are explored through abstracts, results, and conclusions. The identification of specific methods is focused on being able to propose a bioaerosol control strategy. This strategy starts from the building design phase to its operation and maintenance.

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Results

Effects and Microbes

There is ample evidence of health effects on occupants caused by microbes in bioaerosols (Chen and Yao, 2018; Núñez and García, 2022; Dashti et al., 2021). The evidence includes acute allergies and infectious diseases (Brągoszewska et al. 2018; Happo et al. 2014). Among them are symptoms of acute dry eye from indoor air caused by bioaerosols containing thousands of colonies per cubic meter (Idarraga et al., 2020). Likewise, there is evidence of health effects for school and office users (Dick and Wekhe 2020; Gholampour et al. 2020).

Indoor and outdoor bioaerosols have different abundances and taxa compositions (Leung et al., 2018). Indoor bioaerosols are generally dominated by *Actinobacteria* (e.g. *Saccharopolyspora spp*., *Mycobacterium spp*., *Nocardia spp*., etc.) (Schäfer, Jäckel, and Kämpfer, 2010), Firmicutes, Proteobacteria and Ascomycota, as well as potentially infectious and pathogenic bacteria (Núñez and García, 2022). There is the presence of various potentially pathogenic microbial communities, especially the genera *Mycobacterium, Bacillus, Cupriavidus, Hyphomicrobium,* and *Mesorhizobium* (Sibanda et al., 2021). The indoor bacterial community includes *Staphylococcus spp*, *Bacillus spp*, *Enterobacteria spp* and *Flavobacterium spp*. Meanwhile, the fungal community includes *Aspergillus spp*, *Penicillium spp*, *Fusarium spp,* and *Mucor* spp. (Sarah, 2017).

Source Indicators

As mentioned above, there are differences in the abundance of microbes between indoor and outdoor bioaerosols. In addition, indoor bioaerosols are characterized by an abundance of bacteria, while outdoor bioaerosols are characterized by fungi. This is confirmed by research results of on the presence of fungi in indoor bioaerosols which are influenced by outdoor bioaerosols and season (Bartlett et al., 2004). These distinctive differences lead to indicators of the origin of bioaerosols.

The first is the bacteria/fungi ratio (B/F), which shows the concentration ratio, or density, between the number of bacterial colonies and the number of fungal colonies in the same unit volume of air. The B/F ratio is greater than one, it indicates the bioaerosol comes from an indoor source. The B/F ratio is less than one, it indicates an outdoor source.

The second is the indoor/outdoor (I/O) ratio, which shows the ratio of the concentration, or density, between the number of indoor microbial colonies and the number of outdoor microbial colonies in the same unit volume of air. The I/O ratio is greater than one, it indicates the bioaerosol comes from an indoor source. The I/O ratio is less than one, it indicates an outdoor source. The use of the I/O ratio can be used at the building design stage and the building use stage. At the building design stage, controlling the outdoor bioaerosol becomes one of the designer's tasks, for example proposing the placement of a facade to reduce the amount of outdoor bioaerosol. At the building use stage, it is the responsibility of the occupants to control indoor bioaerosols, for example by minimal flushing and closing of toilets, so that toilet bioaerosols do not spread to other indoor spaces. Both uses are expected to control the I/O ratio as low as possible.

In general, the concentration of indoor bioaerosol is higher than that of outdoor (Sarah, 2017). This was confirmed by the results of other studies (Pegas et al. 2010; Jo and Seo 2005), and research on bioaerosols in indoor classrooms shows that the density of fungi and bacteria is approximately 2-3 times that of outdoor bioaerosols. The density varies with the physical conditions of the classroom and the density of students (Mirhoseini, Ariyan, and Mohammadi, 2019), the worse the physical condition and the more students, the greater the density of bioaerosols. Under conditions of I/O ratio of more than 1 indicates that indoor substances may a negativly effect on occupants and indoor life.

Indoor Conditions

Physical conditions of temperature and relative humidity have an influence on the existence of the bioaerosol community (Sarah 2017; Walls et al. 2017; Brągoszewska and Pastuszka 2018). The presence of an air conditioning system is beneficial for thermal comfort for occupants but has potential health effects due to the accumulation of bioaerosols (Sibanda et al., 2021). In addition, the use of air handling units (AHUs) can spread bioaerosols containing respiratory viruses throughout indoor spaces (Bandaly et al., 2019).

ISRAA UNIVERSITY JOURNAL OF APPLIED SCIENCE

Volume 6 :Issue1, October, 2022 | ISSN: 2523-0522

Daily activities in a building, at a certain time there is a breakdown of the wastewater piping system and/or the use of plumbing equipment, such as toilets and kitchen laundry. These events produce bioaerosols, containing potentially pathogenic microbes suspended in the gas stream from wastewater vapor to the ambient indoor air (Gormley, Aspray, and Kelly 2021). Sanitary services in toilets also produce bioaerosols containing fungi and bacteria at the scale of thousands of colonies per cubic meter of air (Sarah 2017; Dick and Wekhe 2020). Apart from sanitation services, indoor bioaerosols are generally in the dust particulates, and originate from the presence of solid waste (Siebielec et al. 2020). The presence of particulates can be a microbial carrier medium and prolong the existence of bioaerosols (Frka et al. 2012; Ciglenečki et al. 2021).

Likewise, there is damage to building parts due to water, the place becomes a source of fungi (Vornanen-Winqvist et al. 2020; Afanou et al. 2014) in addition to *Actinobacteria* and *Actinomyecetes*, which enrich the bioaerosol community (Schäfer, Jäckel, and Kämpfer 2010; Shoemaker, House, and Ryan 2013). The age of the building increases the potential for deterioration of building materials which produces dust particles, which can prolong the presence of microbes in the indoor environment (Wlazło et al. 2020). For indoor activities that are used as a group of people, several research results showed the similarity of bioaerosol content. Rooms with the function of sports activities have the potential to produce bioaerosols containing *Staphylococcus* (Małecka-Adamowicz et al. 2019). Also, activities in the school environment such as classrooms, libraries and cafeterias produce many bacteria and fungi on a scale of thousands of colonies per cubic meter of air (Elbayoumi, 2020). The classroom produced bioaerosols containing mainly *S. aureus*, followed by *S. xylosus, S. haemolyticus* and *S. saprophyticus* (Małecka-Adamowicz, Koim-Puchowska, and Dembowska 2020).

Control Methods

From the perspective of the building infrastructure designer, the ventilation system is an opening facility between indoor and outdoor, as a mechanism for airflow and quality balance between the two spaces. The implementation can be in the form of wall and/or ceiling ventilation arrangement, use of ventilated window and door designs, placement of ventilation facilities in spaces that produce a lot of bioaerosols.

Many studies have been conducted regarding the effectiveness of ventilation, and the results support each other that ventilation systems are important and necessary in the control of bioaerosols (Dick and Wekhe 2020; Oh, Ma, and Kim 2020). Natural or manual passive ventilation by opening a window for two hours does not significantly reduce the indoor microbial community, which may be caused by mixing with outdoor bioaerosol (Núñez and García 2022). This finding indicates that natural or manual ventilation is not a variable for bioaerosol reduction. The results are reinforced by the investigation on the content of indoor bioaerosols, which showed that indoor ventilation is necessary, but its type has no significant effect on the presence of bioaerosols. In addition, the presence of fungi was from outdoor, while indoor sources were bacteria. Therefore, indoor generation sources and ventilation systems are factors that determine the presence of bioaerosols (Myers et al. 2021). However, there are specific conditions that allow for optimal functioning of bioaerosol ventilation, which are provided in Table 1.

Table 1. Specific Conditions of Optimal Bioaerosol Ventilation

Specific conditions	References
Mechanical ventilation is more effective than natural ventilation and increasing ventilation rates reduced bioaerosol concentrations.	(Bartlett et al. 2004; Pegas et al. 2010)
There are differences in the size and concentration of bioaerosols on the type of ventilation. A room with air conditioning contains a larger size of bioaerosol than a room with natural ventilation, while the concentration of bioaerosol is the opposite.	(Brągoszewska et al. 2018)
The function of ventilation is to dilute and remove indoor bioaerosol. Opening windows and doors is good for increasing ventilation rates.	(Zhu et al. 2020)
The use of mechanical ventilation and air conditioning contributes to the transport and dispersion of bioaerosols in the indoor environment of a building. Even the virus can pass through the filter and still be infectious for 10 hours. The use of air filters is considered effective for the elimination of viruses, which are attached to dust particles. A similar method of using an air purifier can also eliminate viruses and bacteria, which arise from the occupants' activities.	(Bandaly et al. 2017; Vyskocil et al. 2021; Brągoszewska and Biedroń 2021)
Air exchange rate is not effective in reducing the concentration of continuously exposed aerosols. However, aerosol reduction is effective for door position and movement. Similarly, ventilation can reduce the concentration of bioaerosols.	(Pegas et al. 2010; Grosskopf 2013)
About 80% of people stay indoors using mechanical ventilation systems such as air conditioning and fans, which are common in the tropics.	(Wu, Rong, and Luhung 2018)

The interaction between the air and the ventilation system can change the quality of the bioaerosol. It was identified, the ventilation system is a way of spreading bioaerosol from its source to all indoor areas of a building. However, space design, materials, indoor microclimate, and periodic cleaning of ventilation can reduce the concentration of bioaerosols.	

From the findings of ventilation characteristics in Table 1, The approach that must also be considered is the selection of the type of ventilation based on the occupant load, namely the number of people during the time they stay in the room. Assume a house inhabited by a couple with a normal 8-hour rest time, and the remaining time is used for various indoor and outdoor activities which are less than the indoor rest time. Certainly, the bedroom is the room with the highest occupancy load compared to other rooms. In this case, the bedroom is worth using mechanical ventilation.

In addition to ventilation control, from the perspective of building users, of course, the operation and maintenance of existing facilities determines the control of bioaerosols. The control status of bioaerosols in the operation and maintenance of indoor facilities is presented in Table 2.

Table 2. Chemical Control for Bioaerosol

Chemical control	References
Chemical treatment using gentamicin, levofloxacin and rifampicin are effective for *Staphylococcus aureus, S. xylosus, S. haemolyticus* and *S. saprophyticus*.	(Małecka-Adamowicz et al. 2019; Małecka-Adamowicz, Koim-Puchowska, and Dembowska 2020)
There was a peak generation of bioaerosols with a concentration of 3 CFU/cm^3 from tracer microbe *Pseudomonas putida*, when the toilet was flushed 1.2 L. The number of particles was reduced, including microbial concentration, with a reduction in the flushing volume of the toilet.	(Gormley, Aspray, and Kelly 2021)
During the COVID-19 pandemic and beyond, the use of disinfectants is a chemical treatment to eliminate microbes, in addition to cleaning building materials and their contents regularly. Control by chemical treatment using chlorine dioxide gas (ClO_2) is carried out for cafeterias in Taiwan. The frequency of disinfection is once and twice, and in general, the effectiveness of the chlorine gas concentration against bacteria is two times greater than against fungi. Curcumin and Azadirachtin are capable of inactivating bacterial bioaerosols.	(Hsu and Huang 2013; Nandini, Shilpashree, and Venkatashamaiah 2020)

Discussion

Building Design

Researchers (Prussin and Marr 2015; Miletto and Lindow 2015; Lai, Lee, and Yu 2015) identified the sources of bioaerosols, namely: outdoor, deteriorated building conditions, dust resuspension, mold, ventilation, air conditioning, heating, plumbing systems, plants, the number of occupants and pets, kitchen activities. In more detail, indoor bioaerosols were dominated by *Diaphorobacter sp*., *Propionibacterium sp*., *Sphingomonas sp.,* and *Alicyclobacillus sp.,* which shows the large contribution of outdoor bioaerosols into indoor space. The number and activity of occupants and living things in the room affect the diversity and concentration of bioaerosols (Miletto and Lindow 2015). In addition, indoor bioaerosol contains *Micrococcus luteus* and *Staphylococcus spp*. for crowded living environments (Lai, Lee, and Yu 2015). Therefore, each source of bioaerosol has certain characteristics of organisms. The formation of bioaerosols is unavoidable and depends not only on the behavior of the occupants, but also on the building design that contributes to the emergence of potential bioaerosols. As a result, the source of building materials, layout, furniture, and related to the design of a building must be treated appropriately.

It is well known that ventilation of buildings is an essential facility (Table 1), and therefore ventilation control of bioaerosols needs to be adapted to the function of space use, which has been proven regarding people's indoor activities as a source of bioaerosol generation (Marcovecchio and Perrino 2021). In this regard, for example mechanical ventilation is suitable for toilets, bedrooms, and meeting rooms, where the potential for bioaerosol generation is more than in other spaces. Manual ventilation by opening and closing windows and doors is suitable for high spaces and/or large room volumes, because the room air volume can be a way of diluting bioaerosol concentrations.

Architectural Criteria

Controlling environmental factors is necessary to minimize the potential adverse effects of bioaerosols (Sarah 2017; Mbareche, Morawska, and Duchaine 2019; Moelling and Broecker 2020). Therefore, understanding of indoor bioaerosols' variability can be one of the criteria in designing healthy buildings. This study focuses on identifying building design and using variables, which can minimize exposure to bioaerosols to occupants. Primarily functional spaces for personal hygiene, including sewage, bathrooms, kitchen work, wastewater disposal, sewage treatment, and the like. Also, bioaerosols can arise from the degradation of building materials, building conditions, and indoor cleaning treatments.

Two bioaerosol indicators can be used in indoor design, namely the indoor/outdoor ratio (I/O) and the bacteria/fungal ratio (B/F). The I/O ratio is the ratio of the concentration of substances between indoor and outdoor. This ratio has two functions, the first indicates the source of the substance. If the I/O ratio exceeds one, it indicates that the substance is from an indoor source. The second can be a warning of possible potential negative effects on indoor life (Pegas et al. 2010; Samake et al. 2017).

The B/F ratio is the ratio of the concentration of bacteria and fungi in a certain indoor environment. This ratio has two functions, the first to indicate the source of origin of the bioaerosol. The B/F ratio exceeding one indicates the origin of the bioaerosol is indoor. The second can certainly be a warning about the possible negative effects on indoor life.

Both ratios are indeed more appropriate in operational control, but designers can conduct comparative studies on the designs that have been used and the potential problems that occur. Designers can use construction management control strategies through environmentally friendly building concepts (Sedayu and Mangkoedihardjo 2018; Berawi et al. 2019; Ayarkwa et al. 2022). With a control approach from the design, construction and operational phases of the building, the potential for bioaerosol generation can be minimized.

From an architectural point of view, bioaerosol control can be carried out by means of spatial layout, spatial dimensions, and selection of building materials. The criteria for spatial layout include, among others, sanitation services as close as possible to the open outdoor area, as far as possible from the spaces used by occupants to gather or rest, and the provision of an outdoor facade area (Samudro, 2020) for filtering outdoor bioaerosols. The criteria for the room dimensions include increasing the height of the space between the floor and the ceiling, for example, the use of a roof ceiling instead of a flat ceiling. The addition of room height can increase the volume of room air, which functions as a bioaerosol

ISRAA UNIVERSITY JOURNAL OF APPLIED SCIENCE
Volume 6 :Issue1, October, 2022 | ISSN: 2523-0522

dilution. Finally,the criteria for building materials include, among others, anti-bacterial and water-resistant paints.

An architect is also recommended to prepare a potential sick building syndrome certification (Samudro, Samudro, and Mangkoedihardjo, 2022). This certificate covers all types of pollutants, sources of pollutants, parameters for the occurrence of potential diseases from indoor sources. Especially for bioaerosols, the rooms that need certification are kitchens, sanitation services, and decorative plants.

Control by Occupants

Since the building has been built, occupants face difficulties in changing the spatial arrangement and/or building construction. In this condition, it is important and needs serious attention regarding the certification of potential sick building syndrome mentioned above. With this certificate, occupants are given guidance on how to use space and equipment that minimizes the potential for bioaerosol generation and its location.

However, regardless of building certification, occupants can arrange and select room equipment in addition to periodic cleaning and maintenance as well as behavior in using equipment and room. Occupants are responsible for using of the building and its equipment, such as furniture selection, kitchen equipment, infrastructure replacement, room renovation and others. In addition, occupants can adjust room conditions related to temperature, humidity, and illumination, all of which can control the bioaerosol. Concerning bioaerosol control, once again as a new normal behavior, from now on, it is necessary to continue to implement health protocols while staying indoors.

Conclusions

The duration of bioaerosol emission from indoor events may be short, on a minute scale, making them difficult to detect, but repeated and frequent occurrences should receive serious attention. Apart from sources of damage to plumbing pipes and use of toilets, there are daily activities in the kitchen and various washing of materials and goods, as well as biodegradable waste bins. The nature of aerosols produced from these sources is easily carried away by airflow, so bioaerosols can spread throughout the indoor area. The bioaerosol control strategy can start from the design of the building by the designer and continue to the implementation and maintenance of the building by the occupants. From the point of view of building architecture, ventilation systems are essential, but it is necessary to select the appropriate type according to the functions of the use of room. Decreasing indoor bioaerosol concentrations can be attempted by increasing the room height to increase the air volume as a bioaerosol diluent. It can also be supported by an outdoor reduction approach by providing a facade.

It is recommended that building certification be needed, both those that have been built and those that are planned, in relation to the potential for sick building syndrome, which is sourced from bioaerosols as well as other indoor pollutants. In addition, in building architecture, it is important and necessary to conduct empirical research on relationship between room occupancy load, indoor volume, and ventilation system on room functions.

References

Afanou, K.A., A. Straumfors, A. Skogstad, T. Nilsen, O. Synnes, I. Skaar, L. Hjeljord, A. Tronsmo, B.J. Green, and W. Eduard. (2014). "Submicronic Fungal Bioaerosols: High-Resolution Microscopic Characterization and Quantification." *Applied and Environmental Microbiology* 80 (22): 7122–30. https://doi.org/10.1128/AEM.01740-14.

Ayarkwa, J., D.G. Joe Opoku, P. Antwi-Afari, and R.Y.M. Li. (2022). "Sustainable Building Processes' Challenges and Strategies: The Relative Important Index Approach." *Cleaner Engineering and Technology* 7 (April): 100455. https://doi.org/10.1016/j.clet.2022.100455.

Bandaly, V., A. Joubert, Y. Andres, and P.L. Cann.(2019). "Adenovirus Behavior in Air Handling Unit Fiberglass Filters." *Aerobiologia* 35 (2): 357–66. https://doi.org/10.1007/s10453-019-09565-3.

Bandaly, V., A. Joubert, P.L. Cann, and Y. Andres. (2017). "The Fate of Mengovirus on Fiberglass Filter of Air Handling Units." *Food and Environmental Virology* 9 (4): 464–72. https://doi.org/10.1007/s12560-017-9310-8.

Bartlett, K.H., S.M. Kennedy, M. Brauer, C.V. Netten, and B. Dill. (2004). "Evaluation and a Predictive Model of Airborne Fungal Concentrations in School Classrooms." *Annals of Occupational Hygiene* 48 (6): 547–54. https://doi.org/10.1093/annhyg/meh051.

Berawi, M.A., P. Miraj, R. Windrayani, and A.R.B. Berawi. (2019). "Stakeholders' Perspectives on Green Building Rating: A Case Study in Indonesia." *Heliyon* 5 (3): e01328. https://doi.org/10.1016/j.heliyon.2019.e01328.

Brągoszewska, E., and I. Biedroń. (2021). "Efficiency of Air Purifiers at Removing Air Pollutants in Educational Facilities: A Preliminary Study." *Frontiers in Environmental Science* 9: 709718. https://doi.org/10.3389/fenvs.2021.709718.

Brągoszewska, E., I. Biedroń, B. Kozielska, and J.S. Pastuszka. (2018). "Microbiological Indoor Air Quality in an Office Building in Gliwice, Poland: Analysis of the Case Study." *Air Quality, Atmosphere and Health* 11 (6): 729–40. https://doi.org/10.1007/s11869-018-0579-z.

Brągoszewska, E., and J.S. Pastuszka. (2018). "Influence of Meteorological Factors on the Level and Characteristics of Culturable Bacteria in the Air in Gliwice, Upper Silesia (Poland)." *Aerobiologia* 34 (2): 241–55. https://doi.org/10.1007/s10453-018-9510-1.

Chen, H., and M. Yao. (2018). "A High-Flow Portable Biological Aerosol Trap (HighBioTrap) for Rapid Microbial Detection." *Journal of Aerosol Science* 117: 212–23. https://doi.org/10.1016/j.jaerosci.2017.11.012.

Ciglenečki, I., P. Orlović-Leko, K. Vidović, and V. Tasić. (2021). "The Possible Role of the Surface Active Substances (SAS) in the Airborne Transmission of SARS-CoV-2." *Environmental Research* 198: 111215. https://doi.org/10.1016/j.envres.2021.111215.

Cox, J., H. Mbareche, W.G. Lindsley, and C. Duchaine.(2020). "Field Sampling of Indoor Bioaerosols." *Aerosol Science and Technology* 54 (5): 572–84. https://doi.org/10.1080/02786826.2019.1688759.

Dashti, M., A. Sorooshian, M. Vosoughi, S.A. Mokhtari, H. Sadeghi, and A.N. Baghani. (2021). "On the Nature of Indoor Airborne Bioaerosols at a Hospital in Iran." *Journal of Air Pollution and Health* 6 (1): 14–29. https://doi.org/10.18502/japh.v6i1.7602.

Dick, A.A., and C. Wekhe. (2020). "Bioaerosol Assessment of Selected Offices within a Polytechnic." *International Journal of Pathogen Research* 5 (1): 28–35. https://doi.org/10.9734/ijpr/2020/v5i130125.

Douglas, A., F. Torpy, N. Surawski, and P. Irga.(2018). "Mapping Urban Aerosolized Fungi: Predicting Spatial and Temporal Indoor Concentrations." *Human Ecology Review* 24 (2): 81–104. https://doi.org/10.22459/HER.24.02.2018.05.

Frka, S., J. Dautović, Z. Kozarac, B. Ćosović, A. Hoffer, and G. Kiss. (2012). "Surface-Active Substances in Atmospheric Aerosol: An Electrochemical Approach." *Tellus B: Chemical and Physical Meteorology* 64 (1): 18490. https://doi.org/10.3402/tellusb.v64i0.18490.

Gholampour, A., A. Biglaric, V. Barzeghar, and N.Z. Firouzsalari. (2020). "Assessment of Airborne Bacterial and Fungal Communities in Different Wards of Educational Hospitals: A Case Study in Urmia, Iran." *Journal of Air Pollution and Health* 5 (4): 209–22. https://doi.org/10.18502/japh.v5i4.6442.

Gormley, M., T.J. Aspray, and D.A. Kelly. (2021). "Aerosol and Bioaerosol Particle Size and Dynamics from Defective Sanitary Plumbing Systems." *Indoor Air* 31 (5): 1427–40. https://doi.org/10.1111/ina.12797.

Grosskopf, K.(2013). "P396: Balancing Ventilation and Energy Use in Hospitals: A Case Study of Bioaerosol Transport in Healthcare Environments." *Antimicrobial Resistance and Infection Control* 2 (S1): P396. https://doi.org/10.1186/2047-2994-2-s1-p396.

Happo, M.S., O. Sippula, P.I. Jalava, H. Rintala, A. Leskinen, M. Komppula, K. Kuuspalo, et al. (2014). "Role of Microbial and Chemical Composition in Toxicological Properties of Indoor and Outdoor Air

Particulate Matter." *Particle and Fibre Toxicology* 11 (1): 60. https://doi.org/10.1186/s12989-014-0060-6.

Hospodsky, D., J. Qian, W.W. Nazaroff, N. Yamamoto, K. Bibby, H. Rismani-Yazdi, and J. Peccia. (2012). "Human Occupancy as a Source of Indoor Airborne Bacteria." *PLOS ONE* 7 (4): e34867. https://doi.org/10.1371/journal.pone.0034867.

Hsu, C.S., and D.J. Huang. (2013). "Disinfection Efficiency of Chlorine Dioxide Gas in Student Cafeterias in Taiwan." *Journal of the Air and Waste Management Association* 63 (7): 796–805. https://doi.org/10.1080/10962247.2012.735212.

Idarraga, M.A., J.S. Guerrero, S.G. Mosle, F. Miralles, A. Galor, and N. Kumar.(2020). "Relationships between Short-Term Exposure to an Indoor Environment and Dry Eye (De) Symptoms." *Journal of Clinical Medicine* 9 (5): 1316. https://doi.org/10.3390/jcm9051316.

Jiayu, C., R. Qiaoqiao, C. Feilong, L. Chen, W. Jiguo, W. Zhendong, C. Lingyun, R. Liu, and Z. Guoxia. (2019). "Microbiology Community Structure in Bioaerosols and the Respiratory Diseases." *Journal of Environmental Science and Public Health* 3 (3): 347–57.

Jo, W.K., and Y.J. Seo. (2005). "Indoor and Outdoor Bioaerosol Levels at Recreation Facilities, Elementary Schools, and Homes." *Chemosphere* 61 (11): 1570–79. https://doi.org/10.1016/j.chemosphere.2005.04.103.

Lai, K.M., K.M. Lee, and W. Yu. (2015). "Air and Hygiene Quality in Crowded Housing Environments - A Case Study of Subdivided Units in Hong Kong." *Indoor and Built Environment* 26 (1): 32–43. https://doi.org/10.1177/1420326X15600042.

Leung, M.H.Y., X. Tong, J.C.K. Tong, and P.K.H. Lee. (2018). "Airborne Bacterial Assemblage in a Zero Carbon Building: A Case Study." *Indoor Air* 28 (1): 40–50. https://doi.org/10.1111/ina.12410.

Małecka-Adamowicz, M., B. Koim-Puchowska, and E.A. Dembowska. (2020). "Diversity of Bioaerosols in Selected Rooms of Two Schools and Antibiotic Resistance of Isolated Staphylococcal Strains (Bydgoszcz, Poland): A Case Study." *Atmosphere* 11 (10): 1105. https://doi.org/10.3390/atmos11101105.

Małecka-Adamowicz, M., T. Kubera, E. Jankowiak, and E. Dembowska. (2019). "Microbial Diversity of Bioaerosol inside Sports Facilities and Antibiotic Resistance of Isolated Staphylococcus Spp." *Aerobiologia* 35 (4): 731–42. https://doi.org/10.1007/s10453-019-09613-y.

Marcovecchio, Francesca, and Cinzia Perrino. (2021). "Bioaerosol Contribution to Atmospheric Particulate Matter in Indoor University Environments." *Sustainability (Switzerland)* 13 (3): 1149. https://doi.org/10.3390/su13031149.

Martin, R.V., M. Brauer, A. Donkelaar, G. Shaddick, U. Narain, and S. Dey. (2019). "No One Knows Which City Has the Highest Concentration of Fine Particulate Matter." *Atmospheric Environment* X (3): 100040. https://doi.org/10.1016/j.aeaoa.2019.100040.

Mbareche, H., L. Morawska, and C. Duchaine. (2019). "On the Interpretation of Bioaerosol Exposure Measurements and Impacts on Health." *Journal of the Air & Waste Management Association* 69 (7): 789–804. https://doi.org/10.1080/10962247.2019.1587552.

Meadow, J.F., A.E. Altrichter, S.W. Kembel, J. Kline, G. Mhuireach, M. Moriyama, D. Northcutt, et al. (2014). "Indoor Airborne Bacterial Communities Are Influenced by Ventilation, Occupancy, and Outdoor Air Source." *Indoor Air* 24 (1): 41–48. https://doi.org/10.1111/ina.12047.

Miletto, M., and S.E. Lindow. (2015). "Relative and Contextual Contribution of Different Sources to the Composition and Abundance of Indoor Air Bacteria in Residences." *Microbiome* 3: 61. https://doi.org/10.1186/s40168-015-0128-z.

Mirhoseini, S.H., F. Ariyan, and S. Mohammadi.(2019). "Quantitative and Qualitative Monitoring of Airborne Bacteria and Fungi and Their Relationship with Environmental Parameters in Two Selected Primary Schools." *Journal of Arak University of Medical Sciences* 22 (6): 242–51. https://doi.org/10.32598/jams.22.6.5931.1.

Moelling, K., and F. Broecker. (2020). "Air Microbiome and Pollution: Composition and Potential Effects on Human Health, Including SARS Coronavirus Infection." *Journal of Environmental and Public Health* 2020 (May): e1646943. https://doi.org/10.1155/2020/1646943.

Myers, N.T., L. Calderón, B. Pavilonis, Z. Wang, Y. Xiong, Mary Ann Sorensen-Allacci, Deborah Plotnik, et al. (2021). "Presence and Variability of Culturable Bioaerosols in Three Multi-Family Apartment Buildings with Different Ventilation Systems in the Northeastern US." *Indoor Air* 31 (2): 502–23. https://doi.org/10.1111/ina.12743.

Nandini, N., M.K. Shilpashree, and T. Venkatashamaiah. (2020). "Herbal Hand Sanitizer for Management of Indoor Bioaerosol and Touch Surfaces." *Journal of Pharmacognosy and Phytochemistry* 9 (3): 1171–75.

Nazaroff, W.W. (2016). "Indoor Bioaerosol Dynamics." *Indoor Air* 26 (1): 61–78. https://doi.org/10.1111/ina.12174.

Núñez, A., and A.M. García. (2022). "Effect of the Passive Natural Ventilation on the Bioaerosol in a Small Room." *Building and Environment* 207 (B): 108438. https://doi.org/10.1016/j.buildenv.2021.108438.

Oh, H.J., Y. Ma, and J. Kim. 2020. "Human Inhalation Exposure to Aerosol and Health Effect: Aerosol Monitoring and Modelling Regional Deposited Doses." *International Journal of Environmental Research and Public Health* 17 (6): 1923. https://doi.org/10.3390/ijerph17061923.

Pegas, P.N., M.G. Evtyugina, C.A. Alves, T. Nunes, M. Cerqueira, Mariana Franchi, Casimiro Pio, Susana Marta Almeida, and Maria Do Carmo Freitas. (2010). "Outdoor/Indoor Air Quality in Primary Schools in Lisbon: A Preliminary Study." *Quimica Nova* 33 (5): 1145–49. https://doi.org/10.1590/S0100-40422010000500027.

Prussin, A.J., and L.C. Marr. (2015). "Sources of Airborne Microorganisms in the Built Environment." *Microbiome* 3: 78. https://doi.org/10.1186/s40168-015-0144-z.

Rocha-Melogno, L., O. Ginn, E.S. Bailey, F. Soria, M. Andrade, M.H. Bergin, J. Brown, G.C. Gray, and M.A. Deshusses. (2020). "Bioaerosol Sampling Optimization for Community Exposure Assessment in Cities with Poor Sanitation: A One Health Cross-Sectional Study." *Science of the Total Environment* 738: 139495. https://doi.org/10.1016/j.scitotenv.2020.139495.

Samake, A., G. Uzu, J.M.F. Martins, A. Calas, E. Vince, S. Parat, and J.L. Jaffrezo. (2017). "The Unexpected Role of Bioaerosols in the Oxidative Potential of PM." *Scientific Reports* 7 (1): 10978. https://doi.org/10.1038/s41598-017-11178-0.

Samudro, H. (2020). "Landscape Intervention Design Strategy with Application of Islamic Ornamentation at Trunojoyo Park Malang, Jawa Timur, Indonesia." *Journal of Islamic Architecture* 6 (1): 41–47. https://doi.org/10.18860/jia.v6i1.4383.

Samudro, H., and S. Mangkoedihardjo. (2021). "Indoor Phytoremediation Using Decorative Plants: An Overview of Application Principles." *Journal of Phytology* 13: 28–32. https://doi.org/10.25081/jp.2021.v13.6866.

Samudro, H., G. Samudro, and S. Mangkoedihardjo. (2022). "Prevention of Indoor Air Pollution through Design and Construction Certification: A Review of the Sick Building Syndrome Conditions." *Journal of Air Pollution and Health* 7 (1): 81–94. https://doi.org/10.18502/japh.v7i1.8922.

Sarah, A.A. (2017). "Indoor and Outdoor Concentrations of Bioaerosols and Meteorological Conditions of Selected Salons in Four Areas of Ibadan North Local Government Area." *International Journal of Environmental Monitoring and Analysis* 5 (3): 83–90. https://doi.org/10.11648/j.ijema.20170503.13.

Schäfer, J., U. Jäckel, and P. Kämpfer. (2010). "Development of a New PCR Primer System for Selective Amplification of Actinobacteria." *FEMS Microbiology Letters* 311 (2): 103–12. https://doi.org/10.1111/j.1574-6968.2010.02069.x.

Sedayu, A., and S. Mangkoedihardjo.(2018). “Performance Evaluation of Housing Contractor by Applying the Principles of Environmentally Friendly Infrastructure.” *International Journal of Civil Engineering and Technology* 9 (4): 1014–22.

Shoemaker, R.C., D. House, and J.C. Ryan. (2013). “Vasoactive Intestinal Polypeptide (VIP) Corrects Chronic Inflammatory Response Syndrome (CIRS) Acquired Following Exposure to Water-Damaged Buildings.” *Health* 05 (03): 396–401. https://doi.org/10.4236/health.2013.53053.

Sibanda, T., R. Selvarajan, H.J. Ogola, C.C. Obieze, and M. Tekere.(2021). “Distribution and Comparison of Bacterial Communities in HVAC Systems of Two University Buildings: Implications for Indoor Air Quality and Public Health.” *Environmental Monitoring and Assessment* 193 (47): 1–15. https://doi.org/10.1007/s10661-020-08823-z.

Siebielec, S., M. Woźniak, A. Gałązka, and G. Siebielec. (2020). “Microorganisms As Indoor And Outdoor Air Biological Pollution.” *Postępy Mikrobiologii - Advancements of Microbiology* 59 (2): 115–27. https://doi.org/10.21307/pm-2020.59.2.009.

Sudharsanam, S., S. Swaminathan, A. Ramalingam, G. Thangavel, R. Annamalai, R Steinberg, K Balakrishnan, and P Srikanth.(2012). “Characterization of Indoor Bioaerosols from a Hospital Ward in a Tropical Setting.” *African Health Sciences* 12 (2): 217–25. https://doi.org/10.4314/ahs.v12i2.22.

Tang, K., Z. Huang, J. Huang, T. Maki, S. Zhang, A. Shimizu, X. Ma, et al. (2018). “Characterization of Atmospheric Bioaerosols along the Transport Pathway of Asian Dust during the Dust-Bioaerosol 2016 Campaign.” *Atmospheric Chemistry and Physics* 18 (10): 7131–48. https://doi.org/10.5194/acp-18-7131-2018.

Vornanen-Winqvist, C., K. Järvi, M.A. Andersson, C. Duchaine, V. Létourneau, Orsolya Kedves, László Kredics, Raimo Mikkola, Jarek Kurnitski, and Heidi Salonen. (2020). “Exposure to Indoor Air Contaminants in School Buildings with and without Reported Indoor Air Quality Problems.” *Environment International* 141: 105781. https://doi.org/10.1016/j.envint.2020.105781.

Vyskocil, J.M., V. Létourneau, M.W. St–Germain, J.G. Turgeon, and C. Duchaine. (2021). “Challenge of Mechanical and Antimicrobial Filters against Infectious Phages Artificially Agglomerated with Inorganic Dust with a Known Particle-Size Distribution.” *Aerosol Science and Technology* 55 (2): 194–204. https://doi.org/10.1080/02786826.2020.1834073.

Walls, H.J., J.H. Kim, R.W. Yaga, L.A. Harvey, L.G. Haines, D.S. Ensor, S.V. Hering, S.R. Spielman, and N. Kreisberg. (2017). “Long-Term Viable Bioaerosol Sampling Using a Temperature- and Humidity-Controlled Filtration Apparatus, a Laboratory Investigation Using Culturable E. Coli.” *Aerosol Science and Technology* 51 (5): 576–86. https://doi.org/10.1080/02786826.2017.1286290.

Volume 6 :Issue1, October, 2022 | ISSN: 2523-0522

Wlazło, T., M. Kasela, B. Nowakowicz-Dębek, M. Ossowski, and A. Malm. (2020). "Bioaerosols in an Underground Tourist Trail." *Polish Journal of Environmental Studies* 29 (5): 3865–72. https://doi.org/10.15244/pjoes/116607.

Wu, Y., J. Rong, and I. Luhung. (2018). "Influence of Air Conditioning and Mechanical Ventilation (ACMV) Systems on Indoor Microbial Aerosols Influence of Air Conditioning and Mechanical Ventilation (ACMV) Systems on Indoor Microbial Aerosols." *Kexue Tongbao/Chinese Science Bulletin* 63 (10): 920–30. https://doi.org/10.1360/N972017-01114.

Yu, H.C., K.W. Mui, and L.T. Wong. (2018). "Numerical Simulation of Bioaerosol Particle Exposure Assessment in Office Environment from MVAC Systems." *Journal of Computational Multiphase Flows* 10 (2): 59–71. https://doi.org/10.1177/1757482X17746919.

Zhu, S., S. Jenkins, K. Addo, M. Heidarinejad, S.A. Romo, A. Layne, J. Ehizibolo, et al. (2020). "Ventilation and Laboratory Confirmed Acute Respiratory Infection (ARI) Rates in College Residence Halls in College Park, Maryland." *Environment International* 137: 105537. https://doi.org/10.1016/j.envint.2020.105537.