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Exposure to Bacterial and Fungal Aerosol in the University Library – A Case Study

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ABSTRACT

The state of microbiological air quality in indoor environments is an important factor influencing the health and well-being of occupants. In the case of library collections, it determines their durability. The aim of this study was to assess the exposure of employees and users of the university library in the building of the Faculty of Environmental Engineering of the Lublin University of Technology to bacterial and fungal aerosols. The studies were conducted during period of six months from September to February. The air samples were collected using two methods: sedimentation and impaction. Obtained results allowed for the preparation of a microbiological profile of indoor air pollution. The average concentration of bacteria in the air ranged from 0 to 990 CFU/m^3 and fungi from 0 to 1736 CFU/m^3, which show no air contamination. The highest concentration of bacterial microflora was recorded in October and December, and in the case of fungi, it was September and October. In the indoor air of the university library, the most common bacteria in all the examined samples were gram-positive cocci and gram-positive bacilli. In the case of fungi, Cladosporium, Penicillium and Aspergillus were the most common.

Keywords: bioaerosols, indoor air quality, university library, sanitary safety.

INTRODUCTION

Libraries and reading rooms, whether municipal, school or located at universities, are microenvironments with a specific purpose and use. Despite the progressive digitization of data and the popularity of books and textbooks in electronic form, many people still use the traditional resources of the book collection. University libraries are also places frequently visited by students as part of their own work or breaks between classes. Book storage and exhibition requires maintaining a specific microclimate in the range of appropriate temperature, relative humidity and lighting [Drougka et al., 2020]. It provides readers with comfort of work and at the same time prevents the destruction and decomposition of paper printouts. Unfortunately, most libraries do not constantly monitor air quality parameters. The exceptions are places where very valuable and old heritage books of national or international importance are exhibited [Flannigan et al., 2011]. Most university libraries are places intended not only for the collection of textbooks, scientific journals or grey literature, but also a study space for students. Hence, they are high occupied [Wu et al., 2018; Yang, 2017]. Despite this state of affairs, there are no law regulations regarding the microbiological air quality standards in such spaces. This is in contradiction with the generally available scientific knowledge that indoor air quality has a proven impact on health, well-being, productivity and learning [WHO, 2009; Baeza-Romero et al., 2022]. This is also confirmed by the small amount of research available on the air quality in libraries. In addition, they are dominated by the works devoted to the assessment of the occurrence of chemical pollutants (formaldehyde, Total Volatile Organic Compounds, carbon dioxide) [Fantuzzi et al., 1996; Günes et al., 2015; Günes et al., 2022; Zhang, 2019], particulate matter [Gunes et al., 2002; Li et al., 2017] and the assessment of compliance with hydrothermal standards affecting the condition of the book collection (temperature and relative humidity) [Sahu and Gurjar, 2019; wu et al., 2018; Yang, 2017]. The

sanitary condition of the air in libraries is practically not monitored, as there are no legal regulations or guidelines in this regard [Fekadu and Melaku, 2014; Hizrri et al., 2015; Kalwasińska et al., 2012; Landry et al., 2018]. Despite the fact that air is not a favorable habitat for reproduction of microorganisms, bacterial and fungal bioaerosols as well as viruses are a natural component of air. Among the bioaerosols, there are also pathogenic microorganisms [Hess-Kosa, 2019]. The importance of controlling their concentration in rooms was demonstrated by the SARS-CoV-2 virus pandemic. The main source of bioaerosols in libraries corresponds to readers and employees. Outdoor air introduced by infiltration or opening windows is responsible to a lesser extent for the bioaerosol concentration. The concentration of bioaerosols in library rooms also depends on the efficiency of the ventilation systems [Flannigan et al., 2011]. Natural ventilation predominates in the majority of smaller libraries. Only large buildings, due to the valuable collections of books, are air-conditioned. Hence, in the absence of sufficient fresh air, there is a risk of health exposure of readers and staff to both chemical and biological agents. Due to their composition, the bioaerosols contained in the indoor air can cause many adverse disease symptoms. Some microorganisms, especially indoor bacteria and fungi, can cause asthma, hay fever, bronchitis, chronic lung failure, lung cancer, cardiovascular disease, gastroenteritis, tuberculosis, allergic reactions, acute viral as well as sinus infections and conjunctivitis. Microbial metabolites, i.e. endotoxins and mycotoxins, play a significant role in inflammatory responses and contribute to the deterioration of lung function as well as induce other infections [Flannigan et al., 2011; Mandal and Brandl, 2011]. Bearing in mind the above information, there is a need to fill the gaps in knowledge about the concentration as well as quality profiles of bacteria and fungi in the air during the hours of using the library premises. The aim of this study was a quantitative and qualitative assessment of the state of air pollution by bacterial and fungal aerosol in the university library room over a period of 6 months.

MATERIALS AND METHODS

Sampling sites description

The measurements for this research were carried out in the library of the Faculty of Environmental Engineering of the Lublin University of Technology, Poland. It is a room located on the 4th floor of the building, with an area of 55 m^2 and a cubic volume of 200 m^3. The book collection consists of ca. 4500 books and periodicals. The resources are placed on wooden shelves. The floor of the room is covered with a carpet. Walls are painted white with emulsion paint. There are 6 desktop computers and a laser printer in the room. Additional equipment of the library is a drinking water dispenser and a fan heater, which is used periodically. The service is provided by one employee of the Lublin University of Technology Library. The room has no mechanical ventilation, only natural. Fluorescent lamps are used for lighting. Smoking, eating and wearing outerwear is strictly prohibited in the room. The library is open Monday through Friday for 8 hours a day, and 4 hours on Saturdays. The library has not been renovated since it was put into use in 2002. The exception is a minor repair work related to removing the effects of flooding with rainwater from the leaky roofing. Due to the area of the room, four measuring points for the assessment of microbiological air quality were established. One of the air sampling points was on the desk of a library worker. The other three were placed on tables for students. The library room has a symmetrical arrangement of furniture, i.e. there is a passage in the middle, and bookshelves with books and tables for readers are located on the right and left sides. Average values of airborne bacteria and fungi concentrations were calculated and marked in Tables 1-6 as P1 for point 1 and 2 and P2 for points 3 and 4, respectively. The library staff and cleaning staff were asked not to open the windows while the measurements were in progress. Every morning before opening, the floor in the library was vacuumed.

Sampling procedure and quantification

Sampling of indoor air for microbiological analysis was performed with application of two methods: Koch sedimentation and impaction. A six-stage Andersen cascade sampler (MAS-6 SKC Biostage, US) equipped with 400, 0.25-mm holes, and a pump drawing air at a constant flow rate of 28.3 L/min through the impactor was used. Additionally, as a background concentration for bacteria and fungi, their presence in outdoor air was tested with sedimentation

method. Both methods used Petri dishes with a diameter of 90 mm. The impactor has aerodynamic diameter cut points as follows: 0.65–1.1; 1.1–2.1, 2.1–3.3, 3.3–4.7, 4,7–7.0, and >7.0 μm. This allows for the determination of various fractions of bioaerosols penetrating individual sections of the human respiratory system. Particles smaller than 0.65 μm reach the alveolar region. Particles with diameters in the range of 0.65–1.1 μm are retained in the pulmonary bronchioles; 1.1–2.1 μm will be retained in the terminal bronchioles; 2.1–3.3 μm are deposited in the area of secondary bronchi, and particles with dimensions of 3.3–4.7 μm migrate to the primary bronchi and trachea. Particles with size of 4.7–7 μm are retained in the throat region. On the other hand, particles with an aerodynamic diameter greater than 7 μm penetrate the nasal passages. Collection time for the sedimentation method was 20 minutes and for the impact method – 10 minutes, respectively. The bacterial and fungal airborne concentrations were determined in accordance with the guidelines of the Polish standards PN-89-Z-04111/03 and PN-89-Z-04111/02, using appropriate media for the cultivation and identification of microorganisms. The conditions for the cultivation of microorganisms, reading the results and interpretation regarding the assessment of the indoor microbial pollution were carried out in accordance with the provisions contained in these standards. Each measurement was performed in three replications. TSA culture medium (Tryptic Soya Agar, Biomaxima, Poland) was used to determine the total number of bacteria, and Sabouraud agar medium with chloramphenicol for fungi / molds (Biomaxima, Poland) was used to determine the total number of fungi. The plates with medium were placed on the tables and desks of the library employees. The impactor was positioned 1.2 m above the floor in the middle of the room.

The cultivation conditions for the determined groups of indicator organisms were as follows: for bacteria, temperature 37°C and readout after 48h; temperature 26°C for fungi and readout after 7 days. For each plate, the calculation of CFU/m^3 (colony forming units per cubic meter) was obtained according to the device manufacturer guidelines. Qualitative identification was performed using biochemical API tests (Biomeriux): API Staph, API Strep, API 20NE, API 50CHB/E Medium.

The bacterial and fungal bioaerosol measurements were performed in 8 series: one in September (1), two in October (2,3), November (4,5), and December (6,7) and the last in February (8). The autumn-winter period is the most reliable for conducting a bioaerosol exposure assessment in the library due to the number of students using the library resources. On average, 15 to 30 people stay in the library per day. The largest number of students was recorded between 10 a.m. and 3 p.m. The Excel program was used to analyze the results statistically.

RESULTS

The results of microbiological air pollution tests by bacteria and fungi have been calculated as averaged and presented in Tables 1 to 6. The location of the library room on the top 5th floor of the building, where there are no classrooms, affects the bioaerosol concentration. It can be assumed that the only source of it in the case of bacteria should be the people using library resources and the employees themselves. Due to the good condition of building partitions and the prevailing microclimate, no high concentrations of fungi were recorded. The concentration of the total number of bacteria varied in the range of 26–723 CFU/m^3 and fungi 0–943 CFU/m^3. In the case of bacteria, higher concentrations were measured in the afternoon. This can be explained by the constant presence of students and staff. The determined concentrations were much higher than the concentration of bacteria in the outdoor air. A reverse relationship was noted for fungi. Their concentrations were much higher in the outdoor air and decreased during winter, which is a normal phenomenon in temperate climates. The measured values of bacterial and fungal aerosols using the sedimentation method allow the air to be classified as clean. According to the provisions of the aforementioned standards: the air is not contaminated with bacterial aerosol (clean) when the total number of bacteria is < 1000 CFU/m^3; moderately polluted for concentrations in the range of 1000–3000 CFU/m^3 and heavily polluted for concentrations >3000 CFU/m^3. For fungi, the concentration ranges are as follows: 3000–5000 CFU/m^3 for averagely clean air, 5000–10000 CFU/m^3 for air that may have a negative impact on humans, and >10000 CFU/m^3 for polluted air.

Table 1. Total number of bacteria (CFU/m^3), sedimentation method

Series	P1		P2		Outdoor air	
	9 a.m.	3 p.m.	9 a.m.	3 p.m.	9 a.m.	3 p.m.
1	113	225	86	214	50	72
2	128	268	82	195	52	43
3	147	255	60	182	33	39
4	48	169	39	170	8	18
5	210	463	94	334	12	27
6	105	217	62	79	29	16
7	270	120	139	370	4	10
8	26	105	341	723	19	24

Table 2. Total number of fungi (CFU/m^3), sedimentation method

Series	P1		P2		Outdoor air	
	9 a.m.	3 p.m.	9 a.m.	3 p.m.	9 a.m.	3 p.m.
1	943	883	749	860	1880	2450
2	147	79	112	139	550	581
3	52	79	26	65	542	664
4	60	79	55	42	482	490
5	139	52	62	105	390	361
6	120	113	60	68	304	270
7	0	0	22	39	109	129
8	0	0	26	0	42	56

Table 3. Total number of bacteria (CFU/m^3), 3 p.m. (impaction method)

Series	1	2	3	4	5	6	Total
	>7.0 [µm]	7.0–4.7 [µm]	4.7–3.3 [µm]	3.3–2.1 [µm]	2.1–1.1 [µm]	1.1–0.65 [µm]	[CFU/m^3]
1	29	29	62	125	158	62	465
2	4	17	71	62	346	367	867
3	4	29	42	62	408	133	678
4	21	29	33	58	125	37	303
5	4	21	67	75	62	104	333
6	33	29	87	162	204	112	627
7	8	8	46	117	242	100	521
8	0	25	17	46	120	46	254

Table 4. Total number of fungi (CFU/m^3), 3 p.m. (impaction method)

Series	1	2	3	4	5	6	total
	>7.0 [µm]	7.0–4.7 [µm]	4.7–3.3 [µm]	3.3–2.1 [µm]	2.1–1.1 [µm]	1.1–0.65 [µm]	[CFU/m^3]
1	21	17	29	8	8	4	87
2	17	4	33	71	96	25	246
3	12	59	25	50	66	25	236
4	21	46	50	58	100	33	308
5	58	71	92	104	162	67	554
6	37	50	154	183	458	108	990
7	17	42	29	67	196	104	455
8	12	12	8	25	33	42	132

Table 5. Total number of fungi, (CFU/m^3), 9 a.m. (impaction method)

Series	1	2	3	4	5	6	Total
	>7.0 [µm]	7.0–4.7 [µm]	4.7–3.3 [µm]	3.3–2.1 [µm]	2.1–1.1 [µm]	1.1–0.65 [µm]	[CFU/m^3]
1	108	296	587	58	197	0	1736
2	4	4	17	67	137	17	246
3	8	8	29	124	146	12	324
4	0	0	15	71	121	8	215
5	0	0	17	21	55	8	101
6	8	0	29	87	137	4	265
7	4	0	4	17	12	8	45
8	0	0	0	8	29	0	37

Table 6. Total number of fungi (CFU/m^3), 3 p.m. (impaction method)

Series	1	2	3	4	5	6	Total
	>7.0 [µm]	7.0–4.7 [µm]	4.7–3.3 [µm]	3.3–2.1 [µm]	2.1–1.1 [µm]	1.1–0.65 [µm]	[CFU/m^3]
1	4	0	42	104	137	8	295
2	4	33	8	117	150	12	345
3	0	4	42	100	96	8	250
4	0	6	8	71	112	12	208
5	0	4	25	50	21	0	100
6	4	6	21	54	62	4	151
7	0	8	12	17	17	4	58
8	0	0	0	4	4	0	8

The sedimentation method of air sampling for the assessment of its microbiological contamination is recommended by the Polish law. However, the impaction method was used to identify the size of individual bioaerosol fractions.

The source of mesophilic bacteria in the indoor air of the library are employees and resource users. Thus, the obtained measurement values appear in each series at a similar level, which can be explained by a similar number of people in the room. The measurement results (<1000 CFU/m^3) indicate no bacterial contamination of the air. In two cases (series 2 in the morning and series 6 in the afternoon) the concentration of bacteria was close to normal for average air pollution. The library is only equipped with a gravity ventilation system, which has many limitations and its effectiveness depends on the weather conditions. The highest values of bacterial concentration were found for the fractions 1.1–2.1, 2.1–3.3 and 3.3–4.7µm, respectively. These are respirable and tracheal fractions. Inhalation of particles within this range size may cause respiratory infections.

In the case of the fungal bioaerosol collected with the impaction method, the highest concentrations (1736 CFU/m^3) were recorded in the 1st measurement series carried out in September, and the lowest in winter, in February (8 CFU/m^3). This is in line with the general indoor air fungal trend during these seasons in temperate climate. In the rooms with low relative humidity <35% and temperature above 22°C, high concentrations of mold spores are not observed. The library room, despite its location on the top floor of the building and previous flooding, shows no signs of problems with moisture. The cleanliness of the ventilation ducts also did not raise any objections. Higher concentrations of fungi were measured in the morning series, suggesting infiltration of the fungal aerosol from the outdoor air through the gravity ventilation system. The fungal aerosol fractions in the range 1.1–2.1 and 2.1–3.3 µm accounted for the largest share in the tested air. They are respirable fractions, therefore the most harmful to health. Overall, it can be concluded that the obtained values of fungal concentrations do not indicate mycological contamination in the library air. The sedimentation

method used in the study has its drawbacks and limitations. However, it was chosen due to the nature of the occupation of the room where the air intake was conducted and the need to reduce noise during the measurements. Selected media-grown fungal and bacterial species were identified in the bioaerosols contained in the collected indoor air samples.

In order to identify bacteria, API (Biomerieux) tests were conducted, biochemical properties were determined and the preparations stained with the Gram's method were subjected to microscopic observations. Fungi were identified according to the taxonomic key, depending on microscopic and macroscopic appearance of grown colonies. Gram-positive bacilli and gram-positive cocci were the most prevalent bacteria in the indoor air of the considered library. *Micrococcus luteus*, which belongs to the *Micrococcus* genus, constituted the most widespread cocci in the conducted studies. Furthermore, other species of this genus, namely *Kocuria kristinae* and *Kocuria rosea* were often found. *Staphylococcus* genus constituted the second most prevalent bacteria in the indoor air of the investigated library. *Staphylococcus haemolyticus* was the most abundant species. *Staphylococcus capitis, Staphylococcus epidermidis, Staphylococcus hominis,* and *Staphylococcus xylosus* were often found as well. In addition, *Staphylococcus aureus* was identified in the indoor air.

Spores of the genus *Bacillus,* which are gram-positive, were often identified during the research. These mostly included the species *Bacillus firmus* and *Bacillus pumilus*. Additionally, *Bacillus megaterium* and *Bacillus licheniformis* were observed. The studied indoor air samples also contained non-enteric gram-negative rods and bacteria of the *Rhodococcus, Brevibacterium, Propionibacterium, Arthrobacter,* and *Corynebacterium* genera. Nevertheless, gram-negative rods of the *Enterobacteriaceae* family and gram-negative cocci were absent. *Pseudomonas stutzeri* constituted the most common gram-negative rods in the analyzed air samples. *Aspergillus, Penicilliu,* and *Cladosporium* constituted the most prevalent fungi species observed in the studies. As far as the *Aspergilllus* genus is concerned, *Aspergillus versicolor, Aspergillus nigeri, Aspergillus fumigates,* and *Aspergillus flavus* species were identified. In addition, yeasts, as well as *Chaetomium, Trichoderma, Alternaria,* and *Mucor* genera were noted.

CONCLUSIONS

The results show that the determined fungal airborne concentrations indicate no mycological hazard in the library room. The concentrations of bacterial bioaerosol in the indoor air remained at a constant and similar level in all research series. No exceedances in the concentration of bacteria above 1000 CFU/m^3 were recorded, which means no sanitary hazard. Respirable fractions of tested bioaerosols in the range 1.1–2.1 μm dominated in the analyzed air samples. The gravitational ventilation system in the library room ensures adequate air exchange to maintain a safe concentration of bacterial and fungal bioaerosols.

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