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Microbial air contamination in indoor environment of a university library

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Abstract

The present study was aimed at evaluating the number of bacteria and mould fungi in the indoor and outdoor environment of Toruń University Library. The sampling sites were located in the rooms serving the functions typical of libraries (i.e. in the Main Reading Room, Current Periodicals Reading Room, Collections Conservation Laboratory, Old Prints Storeroom, in rooms serving other (non-library) functions (i.e. main hall, cafeteria, and toilet) as well as outside the library building. The analyses reveal that the concentrations of bacterial as well as fungal aerosols estimated with the use of the impaction method ranged between 10^1-10^3 CFU·m^{-3}, which corresponds to the concentrations normally observed in areas of this kind. Evaluation of the hygienic condition of the studied areas was based on the criteria for microbiological cleanliness in interiors submitted by the European Commission in 1993. According to this classification, the air was considered to be heavily or moderately contaminated with bacteria, while the air contamination with mould fungi was described as low or moderate. The air in the Old Prints Storeroom was considered the least contaminated with microbial aerosol.

Key words

microbial air contamination, indoor environment, bacteria, mould fungi

INTRODUCTION

Indoor air quality is one of the most significant factors affecting the health and well-being of people who inhale 10m^3 of the air every day, and spend between 80-95% of their lives indoors [1].

The air inhaled by people is abundantly populated with microorganisms which form so-called bioaerosol [2]. Bioaresol is a colloidal suspension, formed by liquid droplets and particles of solid matter in the air, whose components contain or have attached to them viruses, fungal spores and conidia, bacterial endospores, plant pollen and fragments of plant tissues [3].

Possible sources of biological contamination of indoor air include: people, organic dust, various materials stored in the buildings, and the air inflowing from the ventilation and air conditioning systems.

Due to their specific functional character, library rooms constitute a unique micro-environment where the possibility of air contamination with microbial organisms developing on the damp library items is high. When favourable microclimatic conditions occur, the microorganisms are likely to infect the library collections and initiate the process of their biodeterioration. Damage to paper is primarily due to microfungi (e.g. species belonging to the genera *Aspergillus, Penicilium, Trichoderma, Alternaria, Mucor, and Rhizopus*), and, to a lesser degree, to heterotrophic bacteria [4]. Bacteria rarely exist on paper and their number increases significantly only when library or archive collections are damp, flooded, or when the drying process of this type of material is too slow. Such conditions are favourable for the development of cellulolytic bacteria from the genera *Cellulomonas, Cellfalciculata, Cellvibrio* and *Cytophaga* [5, 6]. Additionally, microorganisms may affect the general health of people who work on the premises or use library resources.

The findings of epidemiological research indicate that exposure to high concentrations of microbes in the air frequently leads to allergies, asthma, hay fever [7, 8], pneumonia [9], and many other health side-effects, including infections [10]. Biological factors such as fungal spores and mites are involved in sick building syndrome, a complex situation in which occupants experience a variety of symptoms and become generally unwell, recovering only when they cease to frequent the building [4,116, 12].

In recent years, a dramatic increase in the number of allergic reactions to fungal spores has been observed. Young people, including students, constitute a large group of allergy sufferers; they experience the above-mentioned allergic symptoms throughout the year, but the symptoms intensify during spring and summer months [13, 14]. For that reason, regular monitoring of the indoor air quality in public buildings such as libraries, lecture halls, schools etc. is fully justified.

The objective of this study is was a microbiological evaluation of the indoor air quality in the University Library, based on the results of research into the concentrations of microorganisms forming bioaerosol, namely bacteria and mould fungi.

MATERIALS AND METHODS

Sampling sites. Sampling was conducted in the building of the University Library, which is a part of the building complex on the campus of Nicholas Copernicus University,

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situated in the district of Bielany in the city in Toruń. Since it opened in 1973, the University Library has gathered a vast collection of books and magazines as well as special collections of manuscripts, old printed music, graphics, old maps, documents on social life, etc. The research was conducted in the following areas:

1. Rooms serving functions typical of libraries, including the Main Reading Room, Current Periodicals Reading Room, Old Prints Storeroom, Collections Conservation Laboratory.
2. Rooms/areas serving other (non-library) functions, including the main hall, the cafeteria and toilet.
3. Outside the library building.

Detailed specifications of examined library rooms are presented in Table 1.

Table 1. Detailed specification of examined library rooms.

Location	Room specifications		
	Usable area (m^2)	Cubature (m^3)	Installations affecting climate
1. Main Reading Room	340	2,003	Heating (radiators), natural ventilation
2. Current Periodicals Reading Room	290	736	Heating (radiators), natural ventilation
3. Old Prints Storeroom	322	851	Heating (radiators), mechanical ventilation
4. Collections Conservation Laboratory	37	89	Heating (radiators), natural ventilation
5. Main Hall	388	934	Heating (radiators), natural ventilation
6. Cafeteria	93	227	Heating (radiators), kitchen, sink, natural ventilation
7. Toilet	8	22	Heating (radiators), toilet, sink, humidifier, natural ventilation

Sampling. Sampling was conducted at monthly intervals from October 2009 – March 2010, twice a day – early in the morning before the library staff started work in order to determine indoor background, and in the afternoon when the highest number of students and academic teachers used the library collections. Air samples were also collected outside the library building in order to determine outdoor background and possible migration of biological contaminants into the interiors.

Air sampling was conducted with the impaction method, with the use of MAS-100 (Merck) air sampler, based on the principle of the Andersen air sampler (corresponding to its 5th stage [15, 16], which guarantees that all particles > 1μm were collected). Air volumes were 50-100 litres (depending on expected contamination level). During the sampling, the device was placed at a height of 1.0-1.5m above the floor (one sampling site in the middle of the room) or at the ground level (for outdoor measurements) to simulate aspiration from the human breathing zone.

Petri dishes filled with a microbiological culture medium suitable for bacteria and fungi were used as the sampling surface. Trypticase Soy Agar (TSA) supplemented with cyclohexamide (which inhibits the growth of fungi) was used in order to determine the total number of bacteria. Malt Extract Agar (MEA) supplemented with chloramphenicol (which inhibits the growth of bacteria) was used in order to determine the total number of fungi. Dishes with TSA medium were incubated for 3 days at 37°C while dishes with Malt Extract Agar (MEA) medium were incubated for 7 days at 26°C. All air analyses were performed in 3 parallel repetitions. The results are expressed as colony forming units in a cubic metre of air ($CFU \cdot m^{-3}$). The airflow velocity was about 11 $m \cdot s^{-1}$ and allowed the capture of particles with size > 1μm, which play a significant role in the transmission of microorganisms.

Statistical analysis. IBM SPSS Statistics 19 software was applied to determine the likelihood of statistically significant differences between the concentrations of bacteria and mould fungi measured in the morning and in the afternoon, in the indoor and outdoor environments, as well as in the library rooms and rooms serving other (non-library) functions.

RESULTS AND DISCUSSION

Results of the research into the concentration range, arithmetic mean and standard deviation of bacterial and fungal aerosol present in the investigated rooms of the University Library in Toruń and in the air outside the library building are presented in Table 2.

Table 2. Bacterial and fungal concentration in the outdoor air and in library rooms

Environment			Bacteria			Fungi		
			Range ($CFU \cdot m^{-3}$)	Mean	SD*	Range ($CFU \cdot m^{-3}$)	Mean	SD
Outdoor air		Outdoor background	10-310	159	93	217-3750	1161	1306
Indoor air	1. Main Reading Room	Indoor background	160-453	363	109	0-393	117	141
		Site	507-1313	881	311	0-420	155	146
	2. Current Periodicals Reading Room	Indoor background	147-580	308	176	13-453	132	165
		Site	253-847	542	253	0-453	162	165
	3. Old Prints Storeroom	Indoor background	7-140	78	53	0-27	10	10
		Site	53-173	128	46	13-60	31	16
	4. Collections Conservation Laboratory	Indoor background	153-693	364	195	27-733	241	257
		Site	233-1080	573	336	40-733	281	249
	5. Main Hall	Indoor background	147-800	543	233	27-493	165	178
		Site	200-1207	876	363	27-493	180	174
	6. Toilet	Indoor background	133-3313	1191	1103	13-893	232	329
		Site	673-5673	2045	1845	40-933	302	324
	7. Cafeteria	Indoor background	440-1287	704	321	20-607	177	217
		Site	500-1667	1076	442	7-1373	413	520

* SD – standard deviation

The results indicate that the total amount of bacteria in the investigated rooms, which constituted indoor background, ranged from 7-3,313 CFU·m^{-3} of air, while the amount of bacteria at different sampling sites ranged from 53-5,673 CFU·m^{-3}. The amount of bacteria found in the outdoor air ranged from 10-310 CFU·m^{-3}.

The concentration of mould fungi in the indoor air was lower than the concentration of bacteria and ranged from 0-893 CFU·m^{-3} in the early morning, but fluctuated between 0-1,373 CFU·m^{-3} in the afternoon (depending on the sampling site). The concentration of mould fungi which constituted outdoor background ranged from 217-3,750 CFU·m^{-3}.

Comparison between bioaresol concentrations determined during the investigations carried out on the premises of the University Library in Toruń and the results obtained by other researchers investigating the library environment, may present some difficulty due to the small number of available publications and some methodological limitations. The majority of tests were conducted using the sedimentation method which, in view of recent studies, can be used for qualitative rather than quantitative assessment of the presence of microorganisms in the air [17, 18, 19, 20].

Studies conducted by Górny and others in 2005 [21] in library storage rooms, as well as studies conducted by Wlazło and others in 2008 [20], who investigated the exposure of library workers to bioaraesols in 17 libraries in the Silesian Province, as well as research by Karbowska-Berent and others [22], show that the concentrations of bacterial and fungal bioaerosols measured with the use of the impaction method usually range from 10^1-10^3 CFU·m^{-3}. From the comparison with the above data it can be concluded that the concentrations of bacterial and fungal bioaerosols determined during the investigations in the University Library in Toruń fall within the range normally observed in such areas.

Table 3 presents the results of statistical tests for determining significant differences between the amounts of the studied groups of microorganisms present in the air of the University Library in the morning (indoor background) and in the afternoon. The results seem to suggest that the concentrations of bioaerosols identified in the studied areas in the afternoon were higher than the values established in the morning for the indoor background – the concentrations of both mesophylic bacteria and fungal aerosol were higher ($p < 0.05$) in the afternoon. Furthermore, the concentrations of bacterial aerosol inside the library premises were higher than the concentrations measured outside the library building ($p = 0.002$).

In the case of fungal aerosol, an inverse relationship was established ($p = 0.108$). The observed regularities are consistent with the current state of knowledge about the sources of bioaresols. For bacterial aerosol, the most important and continuously active sources of its emission in the environment are people and animals [23]. The most significant sources of fungal aerosol, however, are found in the outdoor environment, and include the soil, water, plants, etc. Regular outside air inflow into interiors is the main process resulting in biological contamination of the indoor environment [14].

Table 3. Statistic differences (t - test) between bacterial and fungal concentrations in air of the University Library in Toruń

		Afternoon		Outside building		Other rooms	
		Bacteria	Fungi	Bacteria	Fungi	Bacteria	Fungi
Morning	Bacteria	0.026					
	Fungi		0.029				
Inside building	Bacteria			0.002			
	Fungi				0.108		
Library rooms	Bacteria					0.003	
	Fungi						0.102

Analyses conducted in this research indicate that statistically significant differences are observed between the concentrations of bacterial aerosol at the sampling sites located in the rooms serving functions typical of libraries, i.e. in the Main Reading Room, Current Periodicals Reading Room, Old Prints Storeroom and Collections Conservation Laboratory, and in the rooms serving other (non-library) function, such as the main hall, cafeteria and toilet. The data presented in Table 3 reveal that the concentration of bacteria in the rooms of the latter type was higher ($p = 0.003$) than in the rooms serving typical library functions. However, no statistically important differences were determined during the research into the amounts of mould fungi than at the sites serving other (non-library) functions.

Relatively high concentrations of bacteria observed in the main hall (where a large cloakroom is located), cafeteria and toilet are entirely understandable and confirm the observations of other researchers [24]. Remarkably, air contamination reached the highest level in areas characterised by a large circulation of people. In the toilet, these were the toilet bowl, washbasin and humidifier, apart from the people who produce large amounts of microorganisms in the air. In the cafeteria, directly connected to the kitchen, tiny particles which may form a suspension in bioaerosols are released into the air during different stages of food preparation. Stairs located nearby leading to the Main Reading Room constitute an additional source of air contamination since they are responsible for large amounts of dust entering the bar.

The study shows that the lowest microbiological air contamination was noted in the Old Prints Storeroom. This can be explained by the fact that this area is well isolated from the influences of the outdoor environment. There are no windows in the room, which is visited only on rare occasions due to the fact that old prints are available only for scientific purposes after obtaining the consent of the manager. All items must undergo microbial disinfection with ethylene oxide or parachlorometacresol before they are brought into the room. A valuable collection of old books and prints, alongside detailed catalogues, are stored here, in the room where specific requirements must be fulfilled, particularly those related to appropriate microclimate. The Old Prints Storeroom is the only place in the library which is efficiently ventilated (ventilation system installed in the 1980s). Numerous studies emphasise the fact that rooms with efficient ventilation or air conditioning systems and guaranteed air tightness are less contaminated than rooms where air-conditioning was not installed [5, 20, 25].

A quantitative interpretation of the results describing the air quality in the library is difficult due to the lack of widely accepted normative and reference values. Universally applicable standards defining an acceptable level of indoor air contamination with microorganisms have not yet been established. Evaluation of the air quality in the designated areas on the premises of the University Library in Toruń was based on the sanitary standards for non-industrial premises formulated by the European Commission in 1993 (Tab. 4).

Table 4. Evaluation of air quality in the designated areas of the University Library in Toruń according to the sanitary standards for non-industrial premises (CEC, 1993)

Group of microbes	Range of values (CFU/m³)	Pollution degree	Sites						
			Main Reading Room	Current Periodicals Reading Room	Old Prints Storeroom	Collections Conservation Laboratory	Main Hall	Toilet	Cafeteria
Bacteria	< 50	very small	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	50-100	small	0.0	0.0	16.7	0.0	0.0	0.0	0.0
	100-500	medium	0.0	50.0	83.3	50.0	16.7	0.0	0.0
	500-2000	high	100.0	50.0	0.0	50.0	83.3	100.0	100.0
	> 2000	very high	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fungi	< 25	very small	16.7	16.7	16.7	0.0	0.0	0.0	16.7
	25-100	small	16.7	33.3	83.3	33.3	50.0	16.7	0.0
	100-500	medium	66.7	50.0	0.0	50.0	50.0	50.0	50.0
	500-2000	high	0.0	0.0	0.0	16.7	0.0	16.7	33.3
	> 2000	very high	0.0	0.0	0.0	0.0	0.0	16.7	0.0

According to this classification, the air in the Main Reading Room, the main hall, the cafeteria and the toilet was highly contaminated with bacteria. The air in the Current Periodicals Reading Room and in the Collections Conservation Laboratory showed a similar level of contamination with bacteria – half of the air tests indicated moderate bacterial contamination, while the other half indicated high bacterial contamination. The lowest bacterial contamination was detected in the Old Prints Storeroom where a majority of air samples showed a low level of contamination.

The results of the research into the concentration of mould fungi on the premises of the University Library indicate that a high level of fungal contamination was determined in 33.3 % of air samples collected in the cafeteria and in 16.7 % of air samples taken in the Collections Conservation Laboratory. At both sampling sites, half of the air tests indicated moderate air contamination. The same level of contamination was also observed in more than half of the air tests conducted in the Main Reading Room and in the toilet, and in half of the air tests conducted in the Main Hall and in the Current Periodicals Reading Room. The lowest level of air contamination with fungal aerosol was noted in the Old Prints Storeroom where 66.7 % of the air samples indicated a low level of contamination.

CONCLUSIONS

Concentrations of bacterial as well as fungal aerosols in the indoor environment of the university library, estimated with the use of the impaction method, ranged between 10^1 - 10^3 CFU·m^{-3}, which corresponds to concentrations normally observed in areas of this kind.

According to the criteria for microbiological cleanliness in the interiors submitted by the European Commission in 1993, the air was considered heavily or moderately contaminated with bacteria, while the air contamination with mould fungi was described as low or moderate.

The air in the Old Prints Storeroom was considered the least contaminated with microbial aerosol due to the specific features of this library room.

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