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Original Research Article

INDOOR AIR QUALITY IN OFFICES AND CLASSROOMS IN PUBLIC UTILITY BUILDING - A CASE STUDY

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A b s t r a c t

A microbiological analysis of indoor air quality in offices, lecture rooms, and hallways in a public utility building has been carried out in the Lubuskie Voivodship (Poland). In one of the storage rooms, the presence of fungi on the building partition was found in the place of water infiltration as a result of a technological failure in the building. A total of 17 non-residential interiors were examined. The total number of psychrophilic and mesophilic bacteria and the total number of fungi were sampled by the collision method with the air sampler. A qualitative analysis has been performed of fungi present in the indoor air and from building partition of the studied interiors. A total of 11 species of fungi have been specified. Relative humidity and air temperature were measured with a hygrometer. The studies showed that the number of psychrophilic bacteria in indoor air was in the range 0-730 CFU/m^3, while the number of mesophilic bacteria was slightly higher (0 - 896 CFU/m^3). A high level of contamination and a large number of fungi (734 CFU/m^3) were found in the indoor air of storage room, where the problem of biodeterioration of building partitions occurred. In the remaining rooms, the level of microorganisms was low or moderate. Microbiological tests of the outdoor air (background) did not reveal an excessive number of microorganisms in the air.

Keywords: indoor air quality, bioaerosol, microorganisms, fungi

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1. INTRODUCTION

Indoor air quality (IAQ) gains the attention of an increasing number of scientists aiming to improve the comfort, as well as the quality of life and health of indoor users. It is estimated that people spend circa 90% of their time in both private and public interiors such as homes, gyms, schools, workplaces, transportation vehicles, etc. [3]. Indoor air quality constitutes a very important factor impacting human comfort and work efficiency in offices [11]. Low indoor air quality may result in reduced work efficiency [12].

The chemical and biological composition of indoor air depends on many factors: room equipment, used finishing materials, amount of dust or plants in an interior, quality of the ventilation and air conditioning system, as well the person present and the activities they perform. Fungi spores, allergens, or bacterial spores suspended in the air may additionally release mycotoxins, endotoxins, etc. [20]. Excessive amounts of these substances may pose a risk to humans due to their toxic or carcinogenic properties. One of the most important issues concerning indoor air quality consists in maintaining a low concentration of microorganisms in residential and public utility interiors (workplaces, schools, universities).

In the Lubuskie Voivodship, Poland, bioaerosol microbiological tests in offices, lecture rooms, and hallways of a public utility building have been carried out in order to assess the indoor air quality. The conducted research concerned the total number of psychrophilic and mesophilic bacteria as well as fungi in the indoor air. A qualitative analysis of fungi in the air of the studied interiors has been carried out, and the fungi from building partitions with visible fungi growth (storage room) were also identified.

2. MATERIALS AND METHODS

Air samples for microbiological tests were collected from 17 interiors of a 2-storey building including utility rooms in the basement. These were: laboratory rooms (2 rooms), lecture rooms (4 rooms), staff rooms (5 rooms), hallway (3 rooms), secretary's office (1 room), social room (1 room), and a storage room (1 room). Samples have been collected during the winter (January 2019).

Samples were taken with closed windows and doors (air still). No users of the rooms were present in the tested rooms during the sampling. The research was carried out after the end of classes and work (3:00 p.m.). The wall-mounted air conditioners in rooms 12, 13, 15 were turned off during the research.

Additionally, outdoor air samples have been collected in the building's vicinity as a background for microbiological tests. A hygrometer HYGROPEN, Tanel has been used to perform air humidity and ambient temperature measurements. Samples of fungi for qualitative tests were additionally collected

from a wall in the storage room, from a location with visible mould growth. The description of the sampling sites is presented in Table 1.

Table 1. Description of the sampling sites for microbiological tests

No.	Type of interior	Number of places in the room	Building floor	Type of ventilation in the room /air conditioner	Air humidity [%]	Room temperature [°C]
1.	laboratory	15	level -1 (basement)	gravitational /lack	31	24
2.	laboratory	15	level -1 (basement)	gravitational /lack	28	24
3.	staff room	3	level -1 (basement)	gravitational /lack	32	25
4.	storage room	-	level -1 (basement)	gravitational /lack	48	23.5
5.	hallway	-	level -1 (basement)	gravitational /lack	28	23.5
6.	social room	10	level -1 (basement)	gravitational /lack	43	25
7.	lecture room	60	ground floor	gravitational /lack	28	25
8.	staff room	2	1st floor	gravitational /lack	29	24.5
9.	staff room	2	1st floor	gravitational /lack	28	24.5
10.	hallway	-	1st floor	gravitational /lack	27	23.5
11.	lecture room	60	1st floor	gravitational /lack	29	25
12.	lecture room (seminar)	30	1st floor	gravitational /is	29	25
13.	lecture room	120	1st floor	gravitational /is	27	24
14.	staff room	2	1st floor	gravitational /lack	27	24.5
15.	secretary's office	5	1st floor	gravitational /is	35	25
16.	hallway at the secretary's office	-	1st floor	gravitational /lack	32	23.5
17.	lecture room	30	2nd floor	gravitational /lack	43	25
18.	outdoor air (background)	-	building's external surroundings	-	88 (outside the building)	1 (outside the building)

Microbiological air tests

In each room, air sampling has been performed using the collision method and concerned the total number of psychrophilic and mesophilic bacteria and the total number of fungi with the use of the MAS-100 ECO air sampler, Merck, and 90 mm Petri dishes with proper substrates: TSA (Tryptone Soya Agar, SterBios), and Sabouraud Dextrose Agar, SterBios. Samples were taken three times. The MAS 100 ECO sampler was placed in the rooms at a height of 1 m from the floor. Each time, 100 l of air were taken for 1 minute. The air sampler was placed at a height of 1 m from the ground level next to the tested building for sampling outdoor air. After sampling, the dishes with microorganisms were transferred to the laboratory of the Institute of Environmental Engineering, University of Zielona Góra. The microorganism samples were placed in incubators. The temperature and incubation time for the microorganisms were respectively: fungi (26 °C/6 days), psychrophilic bacteria (22° C/72 h) and mesophilic bacteria (37 ° C/48 h). After incubation, the grown colonies were counted and the number of CFUs in 1 m^3 of air has been calculated according to sampler instruction, Merck. Due to the lack of regulations concerning indoor air quality in Poland, the results were assessed with the use of a report by a Team of Experts on Biological Factors (Table 2) and Report No. 12 concerning biological particles in an indoor environment (Table 3), [8, 9].

Table 2. Propositions for the recommended concentrations of microorganisms and endotoxin in the air of interiors, developed by a Team of Experts on Biological Factors [8, 9]

MICROBIOLOGICAL FACTOR	Acceptable concentration	
	Work interiors contaminated with organic dust	Residential and public utility interiors
Mesophilic bacteria	1.0 x 10^5 CFU/m^3*	5.0 x 10^3 CFU /m^3
Bacterium, Gram negative	2.0 x 10^4 CFU /m^3*	2.0 x 10^2 CFU /m^3
Thermophilic actinomycetes	2.0 x 10^4 CFU /m^3*	2.0 x 10^2 CFU /m^3
Fungi	1.0 x 10^5 CFU /m^3*	5.0 x 10^3 CFU /m^3

* for a respirable fraction, the proposed values should be 50% of the achieved value and amount to: 5.0x10^4 CFU/m^3 for mesophilic bacteria; 1.0 x 10^4 CFU/m^3 for Gram-negative bacteria; 1.0 x 10^4 CFU/m^3 for thermophilic actinomycetes; 2.5 x10^4 CFU/m^3 for fungi, and 100 ng/m^3 (1000EU/m^3) for bacterial endotoxin.

Table 3. Classification of microbial contamination of indoor air in homes and non-production interiors [1]

Contamination level	Total number of bacteria [CFU/m^3]		Total number of fungi [CFU/m^3]	
	Residential interiors	Non-production interiors	Residential interiors	Non-production interiors
Very low	<100	**<50**	<50	**< 25**
Low	<500	**<100**	<200	**<100**
Moderate	<2,500	**<500**	<1,000	**<500**
High	<10,000	**<2,000**	<10,000	**<2,000**
Very high	>10,000	**>2,000**	>10,000	**>2,000**

The assessment of outdoor air was based on the following standards: PN-89/Z-04111/02 and PN-89/Z-04111/03 [16, 17].

Sampling from a moldy wall surface

The samples were collected directly at the site of occurrence and transferred onto Petri dishes which contained the following media: MEA (Malt Extract Agar) and Czapek-Dox, BTL. The samples were taken in three repetitions. The mycological analysis was performed in accordance with the methodology given by CBS (Centraalbureau voor Schimmelcultures), [22]. According to this method, small fragments of the material infested with fungi are transferred or spread onto Petri dishes containing the culture media [10].

Identification of fungi to species

The cultivation of microorganisms has been carried out in a laboratory of the Institute of Environmental Engineering, University of Zielona Góra. In order to identify the fungi to species (from the air and from building partitions), the individual strains were passaged to specific growth substrates (MEA, Czapek-Dox, BTL). The isolated fungi species were incubated in a cultivating interior, covered with a white cloth at a room temperature of 18° - 22°C, maintaining a daily day and night pattern. The time of screening, cultivation, and observation for an isolated species was circa 21 days [18]. The isolated strains were subjected to identification tests with the use of keys for taxonomic determinations [6, 19, 13, 22, 23].

3. RESULTS

Table 4 presents the obtained quantitative results concerning bacteria in the air. The tested interiors included psychrophilic bacteria in the number from 0 to 730 CFU/m^3, while mesophilic bacteria ranged from 0 - 896 CFU/m^3. The largest number of bacteria in the air was found in rooms 4, 6, and 17. The number of bacteria in the outdoor air (background) was in the range of 707 - 1791 CFU/m^3, which according to the standards indicates uncontaminated air.

Table 4. Summary of test results concerning the total number of mesophilic and psychrophilic bacteria in the tested interiors

No.	**Psychrophilic microorganisms** [CFU/m^3]	**Contamination level∗**	**Mesophilic bacteria** [CFU/m^3]	**Contamination level∗**
1	66	low	0	-
2	132	moderate	33	very low
3	33	very low	33	very low
4	0	-	663	high
5	166	moderate	132	moderate
6	663	high	896	high
7	33	very low	33	very low
8	166	moderate	33	very low
9	33	low	0	-
10	132	moderate	66	low
11	365	moderate	464	moderate
12	398	moderate	531	high
13	0	-	33	very low
14	132	moderate	0	-
15	265	moderate	99	low
16	66	low	265	moderate
17	730	high	730	high
18. background	1791	uncontaminated air∗	707	uncontaminated air∗

∗according to table 3

Fungi in the air

Table 5 presents the quantitative and qualitative results concerning fungi in the air of the researched interiors and in the outdoor air (background).

Table 5. Fungi species isolated from indoor air

No.	The number of fungi [CFU/m^3]	Contamination level	Fungi species isolated from the air of the tested interiors
1	52	low	***Aspergillus niger,*** *Acermonium strictum*
2	26	low	*Penicillium chrysogenum*
3	79	low	*Cladosporium herbarum, Acermonium strictum*
4	**734**	**high**	*Cladosporium herbarum, Chromelosporium fulvum*
5	79	low	*Acremonium charticola, Cladosporium herbarum,* ***Aspergillus versicolor****, Penicillium chrysogenum*
6	157	moderate	*Aspergillus ochraceus,* ***Aspergillus versicolor****, Chromelosporium fulvum,* ***Stachybotrys chartarum***
7	52	low	*Cladosporium herbarum, Acremonium charticola*
8	26	low	*Acremonium charticola*
9	79	low	*Cladosporium herbarum, Penicillium chrysogenum*
10	104	moderate	*Acremonium charticola, Cladosporium herbarum, Penicillium chrysogenum*
11	52	low	*Acremonium charticola, Cladosporium herbarum, Aspergillus versicolor*
12	26	low	*Cladosporium herbarum, Penicillium chrysogenum, Ulocladium chartarum*
13	26	low	*Acremonium charticola*
14	26	low	*Penicillium chrysogenum*
15	104	moderate	***Aspergillus versicolor****, Cladosporium cladosorioides, Cladosporium herbarum, Penicillium chrysogenum*
16	79	low	*Acremonium charticola, Chromelosporium fulvum*
17	26	low	*Penicillium chrysogenum*
18	1258	uncontaminated air*	*Acermonium strictum* ***Aspergillus niger Aspergillus ochraceus****,* ***Aspergillus versicolor*** *Cladosporium herbarum, Cladosporium cladosorioides, Chromelosporium fulvum, Penicillium chrysogenum,* ***Stachybotrys chartarum,*** *Ulocladium chartarum*

* according to PN-89/Z-04111/03[17]
species of fungi hazardous to human health **in bold**

Fungi were present in the concentration of 26 to 734 CFU/m^3. The largest number was found in the air of interior no. 4. This is due to the visible fungi on the storage

room's partition wall as well as the room's increased humidity. 11 fungi species belonging to 7 genera have been specified. The fungi species in the outdoor air were similar to the indoor air species. The number of fungi in the outdoor air according to PN-89/Z-04111/03 [17] indicates uncontaminated air.

Fungi on building partitions

In the storage room (no. 4), the microbiological analysis revealed a large number of fungi species: *Cladosporium herbarum* and *Chromelosporium fulvum.* These species have also been found in the air.

Results of humidity and meteorological tests

Measurements made with the hygrometer showed air humidity in the building in the range of 27-48%. The temperature in the rooms was 23.5-25° C, respectively. The tests were carried out in the winter season (January), at an outdoor temperature of 1° C and high air humidity of 88% (Table 1).

4. DISCUSSION OF RESULTS

A total of 17 interiors have been examined, along with external air constituting a background. The conducted research shows that an increased number of psychrophilic and mesophilic bacteria was present in rooms 4, 6, and 17 (storage room, social room, and lecture hall on the second floor). Rooms 6 and 17 constitute interiors where in a rotational manner the most people stay during working hours and classes. The highest number of fungi in the air was recorded in room 4. Fungi was visible on a damp building partition wall, hence the fungi spores released into the air. The number of fungi in the air was high (734 CFU/m^3). Air quality tests and samples from the wall showed the following species: *Cladosporium herbarum* and *Chromelosporium fulvum*. These are moulds that can cause, for example, allergies. *Ch. fulvum* may also cause asthma, allergic alveolitis and ODTS (*Organic Dust Toxic Syndrome*), [14]. *C. herbarum* is a mould that occurs in housing construction with a high frequency, while *Ch. fulvum* occurs in building partitions less frequently. The occurrence of fungi on building partitions is a significant problem. Fungi, apart from biodeterioration of technical materials, significantly reduce the sanitary condition of the rooms used [18]. Therefore, it is important to microbiological control of the air in the building where the phenomenon of fungi contamination of building partitions occurs.

Excessive number of fungi in the indoor air may contribute to the development of the SBS (*Sik Buildin Syndrome*) phenomenon, which, together with chemical, physical and psychological factors, may have a negative impact on human health [4, 5].

In the remaining tested interiors, the level of fungi was low to moderate (Table 5). A total of 11 species of fungi have been identified. In rooms 1, 6 and 15, three species of fungi hazardous to health have been identified: *Stachybotrys chartarum* and two species of the genus *Aspergillus*: *Aspergillus versicolor and Aspergillus niger*. They are mycotoxigenic moulds. *S. chartarum* is dangerous due to the possibility of synthesizing e.g. macrocyclic trichothecenes [15], while *A. versicolor* can synthesize sterigmatocystins that possess hepatocarcinogenic properties [2]. *A. niger* can cause tuberculosis-like lung disease. It synthesizes, among others malformin and many other toxins harmful to health [22]. The premises where dangerous species have occurred are the laboratory, break room and secretary's office, where a large number of people are present during working hours (Table 1). There are numerous green areas in the vicinity of the building under study. The research shows that the marked species of fungi in the building were also present in the outdoor air.

Air humidity measurements showed increased humidity in the storage room (48%). This is due to the presence of damp walls as a result of a technological failure (the damaged gutter caused rainwater to enter the building). In the remaining interiors, humidity measurements showed values in the range of 27-43%.Wall mounted air conditioners are installed in three interiors (12, 13, and 15). During the tests they were inactive due to the season (winter), therefore they had no impact on the tests. There is gravity ventilation in the rooms.

It is known from reference literature that air constitutes the most important medium for transferring and spreading biological agents, although it does not work in favour of the growth and survival of microorganisms due to the lack of nutrients and low moisture content [7]. Biological particles can cause various diseases in humans. They have been called in general as BRI - *Building Related Illness* and may include, for example: rhinitis, sneezing, conjunctivitis and lacrimation, asthma, "humidifier fever" with the following symptoms: fever, chills, muscle aches, malaise, extrinsic allergic alveolitis, atopic allergic dermatitis [4, 21].

Microorganisms constitute typical components of bio-aerosols. Quantitative and qualitative tests of biological particles of confined spaces are essential for verifying the quality of inhaled air. In Poland, there is a lack of standards concerning permissible concentration of microorganisms in indoor air [8, 9]. On the other hand, increasingly more science-research institutions and companies are searching for solutions to improve interior the air quality. It is important to control the air quality in public utility buildings due to possible health hazards of room users.

5. CONCLUSIONS

1. The number of psychrophilic bacteria in indoor air was in the range 0-730 CFU/m^3. The highest number was in rooms 6 and 17.
2. High levels of mesophilic bacteria were determined in the following rooms: storage room (663 CFU/m^3), administrative (social) staff room (896 CFU/m^3), one of the lecture rooms (730 CFU/m^3). These are the rooms where the most employees and students stay in a rotating manner during the working day.
3. The highest number of fungi in the air (734 CFU/m^3) can be found in interior number 4 (storage room), due to fungi formation on building partitions. In the remaining rooms, the level of fungi contamination was low and moderate. The high level of fungi proves that systematic inspections inside buildings and further research are needed to help identify biological factors that may affect the quality of health of people staying in public spaces.
4. Qualitative analysis of fungi revealed 11 species, three of which are dangerous to human health: *Stachybotrys chartarum*, *Aspergillus versicolor and Aspergillus niger*.
5. Two species of fungi were marked on building partitions in room 4: *Cladosporium herbarum* and *Chromelosporium fulvum.* These species have also been found in the storage room air in large numbers.
6. The number of psychrophilic and mesophilic bacteria and the number of fungi in the outdoor air indicates uncontaminated air (according to standards).
7. The measured humidity in the building under study was in the range 27-48%. The highest value was recorded in room 4.

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