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Bacterial and Fungal Aerosols in Air-Conditioned Office Buildings in Warsaw, Poland—The Winter Season

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The microbial quality of the working environment was assessed in winter in air-conditioned office buildings in Warsaw. The average indoor concentrations of bacterial and fungal aerosols were low (<10^3 cfu·m^{-3}), below Polish proposals for threshold limit values in public service buildings. Even during cold months, if the air-conditioning system works properly, people remain the main source of bacterial aerosol in offices, whereas infiltration of outdoor air remains a major mechanism responsible for their fungal contamination. An analysis of the bioaerosol size distribution showed that microbial propagules that reach both the upper and lower respiratory tract may evoke numerous adverse health effects from irritation and asthmatic reactions to allergic inflammation. A comparative analysis of viable and total airborne microbial counts showed that viable micro-organisms accounted for up to 0.3% of the total number of microbial propagules. Hence, a comprehensive hygienic assessment of office workplaces should include an efficient control of both these elements.

indoor air quality office buildings bacterial and fungal aerosols size distribution

1. INTRODUCTION

During the past decade, there has been a rapid development of office buildings and a substantial increase in the number of people working in such spaces in Poland. Comprehensive time–activity studies show that an adult person spends 87–89% of time indoors, of which ~18–25% is spent at work [1, 2, 3]. According to epidemiological data no less than 30% of office workers complain about their health problems, linking them with bad air quality. Because of the energy crisis in the 1970s, new buildings with limited access to fresh ambient air are still relatively common [4]. In this type of indoor environment, an air-conditioning (AC) system is practically the only technical solution used to both improve the air quality and provide employees with proper working conditions. The atmospheric air, which is delivered into the building through the AC system, should be free from most common pollutants and ensure an ideal temperature and moisture. Unfortunately, bad maintenance of AC systems or their low efficiency can often lead to unintentional contamination of office spaces.

The quality of air in office buildings depends on numerous physical, chemical and biological factors. Regarding microbial pollutants, among their typical indoor reservoirs are people, plants, animals, to some extent soil and water as well as human-made materials. In this type of work environment, biological agents (i.e., bacteria, fungi, cell fragments, structures and compounds they produce including allergens, endotoxins, glucans, mycotoxins or volatile organic compounds) can cause adverse health effects

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when transported in the air as bioaerosols [5, 6]. Although the air is not conducive to the growth and survival of micro-organisms (no nutrients and usually low moisture content), it is the most important medium for carrying and spreading of biological agents [7].

Biological particles suspended in the air can be present in viable (culturable and nonculturable) as well as nonviable forms. They can either exist as individual entities or create aggregates of biological structures. They can be also attached to dust particles formed from inorganic matter or to water or saliva droplets. The range of aerodynamic diameters of particulates in biological aerosols varies from submicron values up to ~200 μm. Their aerodynamic sizes determine the depth of penetration and subsequent deposition in the human respiratory system, which in turn determines possible health effects [8, 9, 10, 11]. Such inhalation exposure can initiate numerous immunopathogenic reactions including allergies, infections, toxic reactions and other unspecified symptoms like the sick building syndrome [5, 12, 13, 14].

The aim of this study was to assess the level of bacterial and fungal contamination in air-conditioned office buildings in Warsaw, Poland. As energy conservation measures (such as air tightness of the building envelope and ventilation deficits) are key factors during the cold months in the temperate climate zone, winter was chosen to study the microbial quality of the air and surfaces (office spaces and ventilation ducts) in this type of work environment.

2. MATERIALS AND METHODS

2.1. Building Characteristics

Four office buildings equipped with AC systems were selected for this study. They were

- building 1: built in 2006, total office surface: 2800 m^2, number of employees: 120;
- building 2: built in 2000, total office surface: 5600 m^2, number of employees: 200;
- building 3: built in 2003, total office surface: 12537 m^2, number of employees: 270;
- building 4: built in 2004, total office surface: 7400 m^2, number of employees: 120.

All these buildings had fully automatic AC systems, comprising electronic adjustment of the temperature, humidity, the amount of fresh air (supplying the volume of circulated air) and the volume of the air stream itself.

2.2. Sampling Strategies

The bioaerosol sampling was carried out in four air-conditioned office buildings. The measurements were performed during the winter season defined as 6 months from October until March, when the average outdoor air temperature was below 10 ºC for at least 7 consecutive days. Viable bioaerosol samples were simultaneously taken inside and outside of the buildings using both a six-stage Andersen impactor (model WES-710, Westech Instrument, UK) and a single-stage MAS impactor, (model 100Eco, Merck Eurolab, Switzerland). The flow rates and sampling times were 28.3 $L \cdot min^{-1}$ and 5 min for the Andersen impactor, and 100 $L \cdot min^{-1}$ and 1.5 min for the MAS impactor [15, 16, 17]. Additionally, indoor bioaerosol samples were also taken using a Button personal inhalable aerosol sampler (SKC, UK) to determine the total (viable and nonviable) number of both bacteria and fungi. The flow rate and sampling time were 4 $L \cdot min^{-1}$ and 30 min, respectively.

In each building, bioaerosol samples were taken in five randomly selected offices. They were collected twice a day: in the morning at the beginning of work (to establish the so-called indoor background), and at noon (after 4–5 h of work). All sampling instruments, i.e., Andersen and MAS impactors as well as the Button sampler, were placed 1–1.5 m above the floor (indoor measurements) or above the ground (outdoor measurements) to simulate aspiration from the human breathing zone.

To assess the level of microbial pollution in AC systems, settled dust samples were taken from the inner surfaces of ventilation ducts using sterile cotton swabs (FL-Medical, Italy). The sampled surface was 100 cm^2 with a 10 × 10 cm sterile template limiting the investigated area.

2.3. Colony Counting and Microbiological Analyses

Impactor samples were collected on agar media. Standard Petri dishes filled with blood trypticase soy agar (TSA, 51044, bioMérieux, France) and malt extract agar (MEA, CM-59, Oxoid, UK) were used for bacterial and fungal sampling, respectively. After aspiration, the plates with blood TSA were incubated for 1 day at 37 ºC, then for 3 days at 22 ºC followed by 3 days at 4 ºC. The MEA plates were incubated for 4 days at 30 ºC followed by another 4 days at 22 ºC. Afterwards, the number of bacterial and fungal colonies growing on respective agar media was counted and recalculated as colony forming units per cubic meter of the air (cfu·m^{-3}). The actual colony count per each culture plate was corrected using the positive hole correction table [18].

All isolated microbial colonies were subsequently classified at the genus and/or species level on the basis of their morphology, microscopic structure and biochemical reactivity. Bacterial and yeast strains identification was supplemented with API tests (bioMérieux, France). Filamentous fungi were identified on the basis of their macro- and micromorphology with several taxonomic keys [19, 20, 21, 22].

The total number of micro-organisms was estimated with the CAMNEA method [23]. In short, the micro-organisms were sampled onto a 25-mm gelatin filter with a pore size of 3 μm (SKC, USA) housed in the inlet section of the Button sampler. After sampling, the filter was removed from the holder of the sampler and dissolved in sterile water containing 0.01% Tween 80 (Merck, Germany). The obtained suspension was treated with formaldehyde (37%) (POCH, Poland). The resulting fluid was stained with acridine orange (Sigma-Aldrich Chemie, Germany), then filtered through a black polycarbonate filter with a pore size of 0.4 μm (Whatman, UK) and, finally, the dyed micro-organisms were counted under an epifluorescence microscope (model Eclipse E200, Nikon, Japan).

After settled dust sampling, to extract the collected micro-organisms, the cotton swabs were vortexed for 10 min using a programmable rotator-mixer (model Multi RS-60, Biosan, Latvia) in 2 ml of distilled water. The spread method was used to qualitatively identify isolated; 0.2 ml of the resulted suspension was spread evenly over the same media as in bioaerosol sampling and, after incubation, it was identified to the genus and/or species level in the same way as airborne microbes.

Due to a nonparametric distribution of the collected data (analysed with the Shapiro–Wilk test), all results were analysed with the Kruskal–Wallis and Mann–Whitney tests with Statistica version 7.1.

3. RESULTS

Table 1 presents the concentration of viable and total microbial aerosols in the office buildings. The concentrations of viable airborne microflora were low and did not exceed 10^3 cfu·m^{-3}. A comparison of microbial aerosol concentrations at selected sampling points in the offices collected with the Andersen and MAS impactors did not indicate statistically significant differences between them. Therefore, when the indoor air was microbiologically relatively clean, both samplers measured bioaerosol

TABLE 1. Concentrations of Microbial Aerosols (Bacteria and Fungi) in Office Buildings

	Microbial Aerosol (Bacteria and Fungi)		
Sampler	**Type**	**Median**	**Range**
Andersen impactor[1]	viable	84 (cfu·m^{-3})	14–494 (cfu·m^{-3})
MAS impactor[2]	viable	105 (cfu·m^{-3})	10–530 (cfu·m^{-3})
Button[3]	total	98 301 (cells·m^{3})	31 457–157 283 (cells·m^{3})

Notes. 1—model WES-710, Westech Instrument, UK; 2—model 100Eco, Merck Eurolab, Switzerland; 3—SKC, UK.

concentrations with the same accuracy. A comparative analysis of viable and total (collected with the Button sampler) microbial concentrations showed that viable organisms constituted 0.03–0.30% of the total microflora on the premises.

An analysis of microbial concentrations measured at selected workplaces showed that building 2 differed significantly from buildings 1, 3 and 4 (Kruskal–Wallis test: $p < .01$). That difference was visible mainly due to the higher (median value: 221 cfu·m^{-3}) than in other buildings (median values: 39, 42 and 123 cfu·m^{-3}) concentration of bacterial aerosol (Kruskal–Wallis test: $p < .001$). This building was the oldest one and its AC system had not been frequently comprehensively cleaned since its completion. Hence, a constant accumulation of various contaminants (suitable as sources of both nutrients and water) could contribute to higher concentrations of micro-organisms.

Table 2 shows the concentration of bacterial and fungal aerosols observed in outdoor air and in the office rooms. The concentrations of both bioaerosols were below 10^3 cfu·m^{-3}. Fungal outdoor background levels were significantly higher than those in indoor background (Mann–Whitney test: $p < .001$). These differences were not statistically significant for bacteria. A comparison of microbial concentrations between the indoor background and workplaces did not indicate significant differences for either bioaerosol constituents.

Table 3 shows all bacterial and fungal strains isolated from the air of the offices. Seventeen bacterial species from 8 genera and 12 fungal species from 6 genera were identified. The bacterial species from *Micrococcus* and *Bacillus* genera were predominant indoors. Among fungal species, the most frequently isolated strains belonged to *Aspergillus* (all species: 8.4%) and *Penicillium* (all species: 5.9%) genera. Moreover, the analysis showed that 5 bacterial (*Micrococcus luteus*, *Micrococcus* spp., *Staphylococcus warneri*, *Bacillus pumilus* and *Bacillus cereus*) and 4 fungal (*Penicillium chrysogenum*, *Penicillium citrinum*, *Aspergillus candidus* and *Rhodotorula mucilaginosa*) strains present in the air were also isolated in settled dust samples from the ducts of the AC systems. The rest of the identified microbial strains, however, were present in bioaerosol samples only. There was also a relatively high occurrence of yeasts in both the indoor air and settled dust samples from the premises.

Figure 1 presents distributions of the groups of micro-organisms identified in indoor (background and workplaces) and outdoor environments. The composition of the species of airborne microflora at workplaces was similar to that in the indoor background. The most numerous groups of micro-organisms in indoor air were Gram-positive cocci, followed by endospore-forming Gram-positive bacilli and filamentous fungi. The qualitative structure in both indoor environments, however, differed substantially from the composition of outdoor air microflora, where there was a clear domination of filamentous fungi.

Table 4 shows all isolated bacterial and fungal strains from the inner surfaces of the AC ducts. Six bacterial species from 3 genera and 8 fungal species from 6 genera were identified. A comparison of microbial representatives isolated from the air of the offices with those in settled dust samples revealed an occurrence of analogous species.

TABLE 2. Bacterial and Fungal Concentrations (cfu·m^{-3}) in Outdoor and Indoor Air

	Bacteria		Fungi	
Environment	**Median**	**Range**	**Median**	**Range**
Outdoor background	39	35–126	140	42–432
Indoor background	42	7–262	11	0–70
Workplaces	70	14–494	21	0–176

TABLE 3. Percentage Contribution to Total Microflora of Bacterial and Fungal Strains Isolated From Workplace Air

Bacteria	Contribution to Total Microflora (%)	Fungi	Contribution to Total Microflora (%)
Gram-positive cocci	48.9	Filamentous fungi	18.7
*Micrococcus luteus**	23.4	*Penicillium* spp.	0.5
Micrococcus spp.*	14.3	*Penicillium chrysogenum* Thom*	1.5
Micrococcus roseus	0.1	*Penicillium commune* Thom	0.5
Kocuria kristinae	0.9	*Penicillium citrinum* Thom*	2.4
Staphylococcus epidermidis	0.9	*Penicillium marneffei* Thom**	1.0
Staphylococcus capitis	3.0	*Aspergillus candidus* Link*	7.0
Staphylococcus hominis	4.0	*Aspergillus terreus* Thom	0.9
Staphylococcus sciuri	1.4	*Aspergillus fumigatus*	0.5
*Staphylococcus warneri**	0.5	*Cladosporium* spp.	3.0
Staphylococcus auricularis	0.5	*Acremonium* spp.	1.1
Staphylococcus saprophyticus	0.1	*Mucor* spp.**	0.3
Endospore-forming Gram-positive bacilli	23.6	Yeasts	7.0
*Bacillus pumilus**	6.5	*Rhodotorula mucilaginosa** (Jörgensen) Harrison (synonyms: *Rhodotorula biourgei, Rhodotorula grinbergsii, Rhodotorula rubra*)	7.0
*Bacillus cereus**	17.1		
Nonsporing Gram-positive rods	1.4		
Arcanobacterium haemolyticum	0.4		
Arthrobacter spp.	1.0		
Mesophilic actinomyctes	0.4		
Rhodococcus spp.	0.1		
Streptomyces spp.	0.3		

Notes. *—micro-organisms present in settled dust samples, **—biological agents from risk group 2 (according to the classifications in Directive 2000/54/EC [24] and in the Ordinance of the Minister of Health [25].

TABLE 4. Micro-Organisms Identified in Settled Dust Samples From the Ducts of Air-Conditioning Systems

Bacteria		Fungi	
Genus	**Species**	**Genus**	**Species**
*Bacillus**	*Bacillus* spp.	*Acremonium*	*Acremonium* spp.
	Bacillus cereus	*Aspergillus**	*Aspergillus candidus*
	Bacillus pumilus		*Aspergillus* spp.
*Micrococcus**	*Micrococcus luteus*	*Penicillium**	*Penicillium citrinum*
	Micrococcus spp.		*Penicillium chrysogenum*
*Staphylococcus**	*Staphylococcus warneri*	*Mucor*	*Mucor* spp.
		Rhizopus	*Rhizopus* spp.
		Rhodotorula	*Rhodotorula mucilaginosa*

Notes. *—species from this genus were isolated in over 50% of the offices.

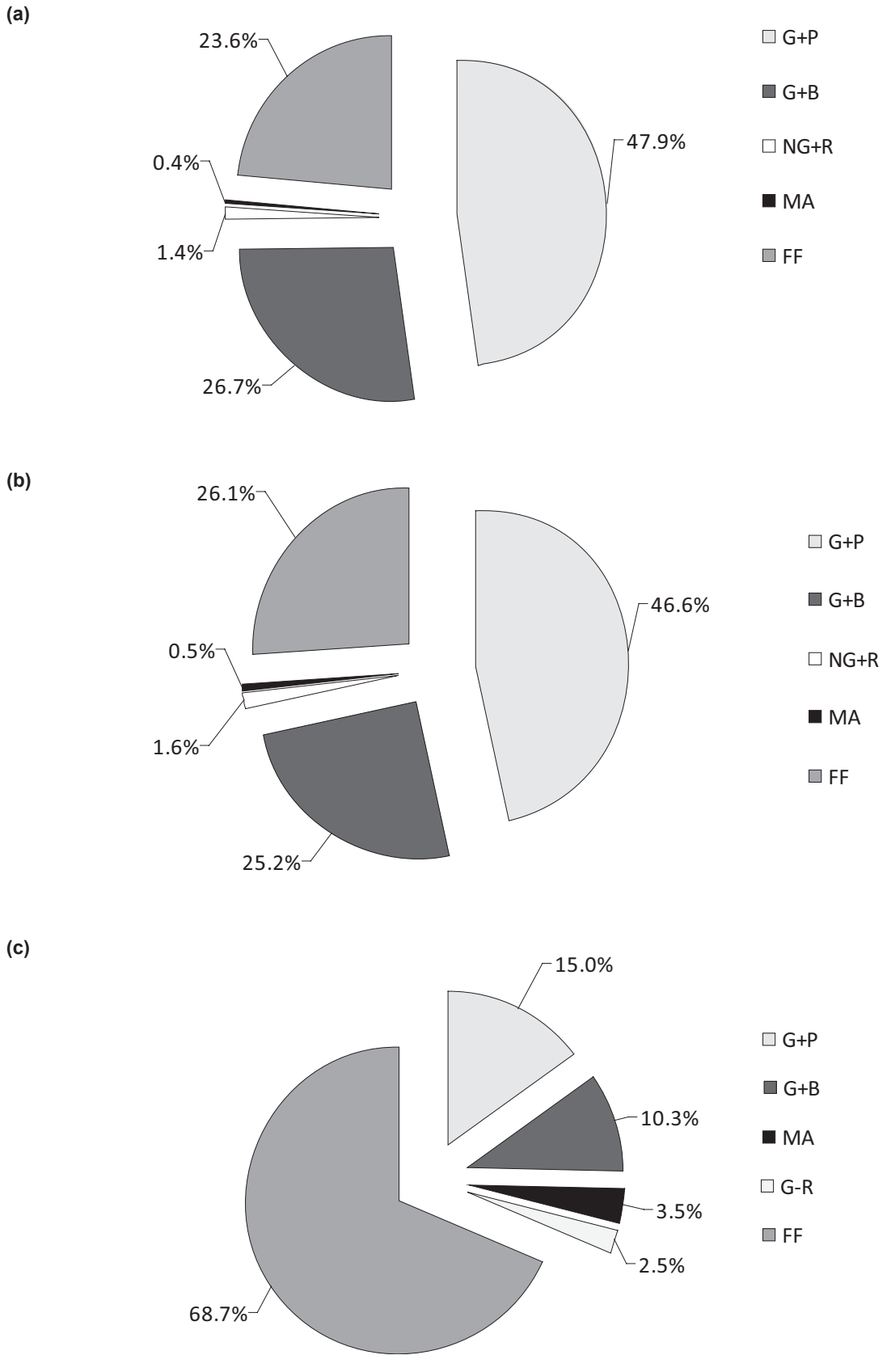

Figure 1. Distribution (%) of groups of microorganisms identified (a) at workplaces, (b) in indoor background and (c) in outdoor air. *Notes.* G+C—Gram-positive cocci; G+B—Gram-positive bacilli; NG+R—nonsporing Gram-positive rods; G-R—Gram-negative rods; MA—mesophilic actinomycetes; F—fungi.

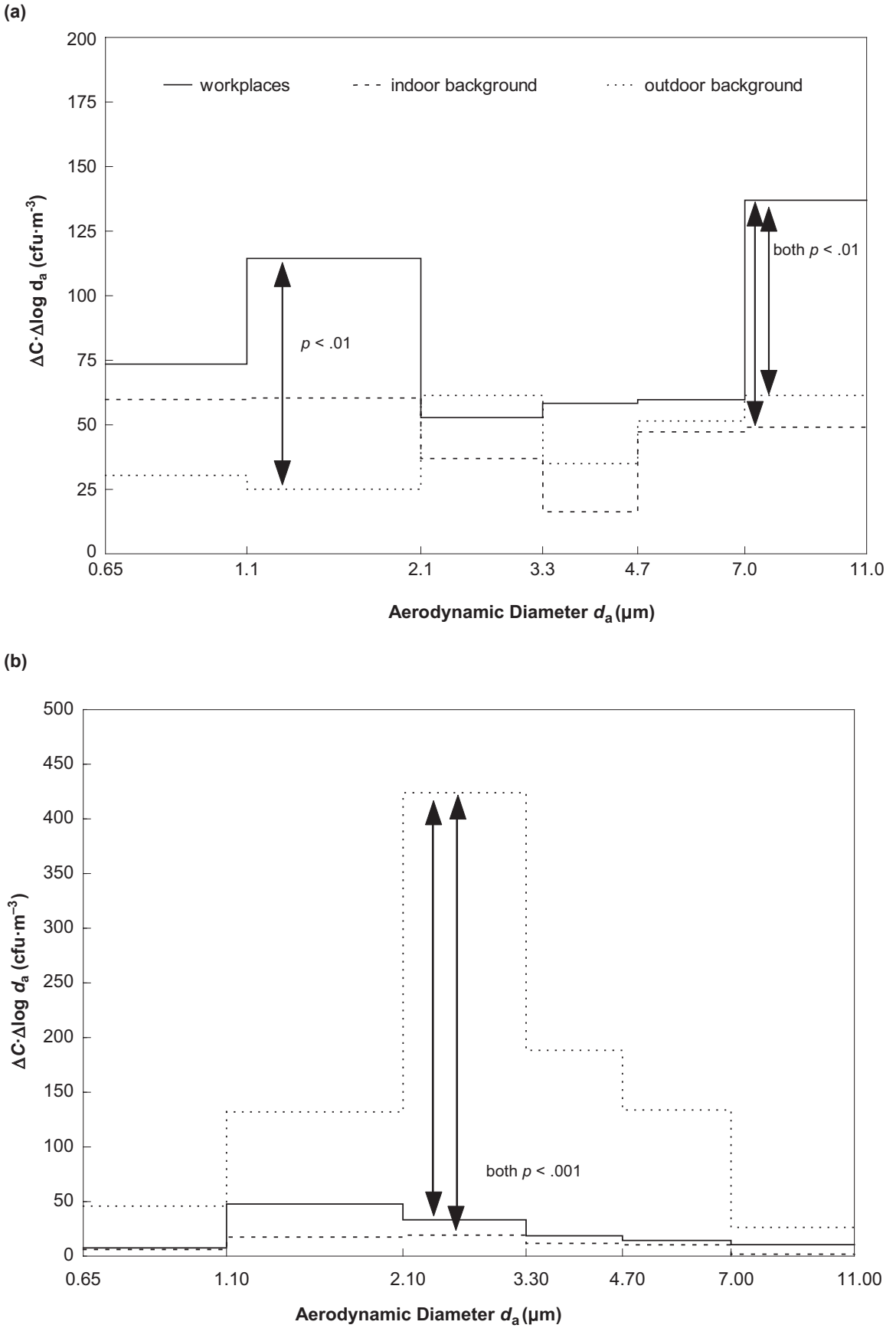

Figure 2. Size distribution of (a) bacterial and (b) fungal aerosols in outdoor (background) and indoor (workplaces) environments.

The Andersen impactor made it possible to divide bioaerosol particles into six fractions according to their aerodynamic diameters (Figure 2). The *x* axis ends at 11 μm because the settling velocity for such coarse particles is very high (i.e., it fluctuates from a few minutes to a few seconds) and practically prevents their massive penetration into the human respiratory tract [26, 27]. The analysis of the size distribution of bacterial aerosol at workplaces revealed that peak concentrations were observed in size ranges between 1.1 and 2.1 μm and above 7 μm. This indicates that bacteria were present in the offices as single cells or large aggregates consisting of bacterial cells and/or bacterial and dust particulates. A comparison of size distributions of bacterial aerosol at workplaces with those in indoor background and outdoor air suggests that employees' activity is a major process contributing to a statistically significant increase in the emission of bacterial aerosol at workplaces ($p < .01$ for workplaces versus indoor background when particles are bigger than 7 μm, and for workplaces versus outdoor air within both the aforementioned size ranges). In contrast, an analysis of the size distribution of airborne mycoflora indicated that fungi were observed at workplaces mainly as naturally dispersed spores 1.1–3.3 μm in diameter and infiltration of outdoor air was a major process contributing to the observed levels of indoor contamination ($p < .001$ for outdoor air versus both indoor background and workplaces).

4. DISCUSSION

Epidemiological studies have shown that a few hundred million people around the world are exposed to biological agents. Unfortunately, there are no quantitative health-based guideline values or thresholds for acceptable levels of microbial contamination. This is so because

- a dose–response relationship for most biological agents has not been determined yet and is controversial in many aspects;
- it is not possible to identify individual species of micro-organisms or other specific biological agents (except for some common allergies) responsible for health effects;
- susceptibility to a specific biological agent is an individual feature of each organism;
- source data on environmental and occupational concentrations of biological agents are still insufficient; and finally
- sampling methods (samplers) and experimental procedures (commonly approved criteria for assessing exposure to biological agents) have not been standardized yet.

That is why, the Expert Group for Biological Agents of the Interdepartmental Commission for Maximum Admissible Concentrations and Intensities for Agents Harmful to Health in the Working Environment at the Central Institute for Labour Protection – National Research Institute (CIOP-PIB) has proposed a different approach to this problem. The assumption was that if a solid link could not be established between the concentration of the investigated parameters and the resulting adverse health effect, then on the basis of the measurements of the concentration of the biological agent, reference values should make it possible to evaluate the quality of the environment and to determine what is typical and acceptable, and what is atypical or unacceptable for a specific type of setting [28, 29]. On that basis the commission drafted proposals for threshold limit values in occupational and nonoccupational environments for several microbial agents, which can be present in the air as bioaerosol components (Table 5) [30].

Data resulting from this study showed that the concentrations of both viable bacterial and fungal aerosols in all examined office rooms did not exceed 10^3 cfu·m^{-3}. The low levels of microbial contamination suggest that, in most cases, efficient and regularly maintained AC systems ensure proper hygienic conditions of office workplaces.

The concentrations of viable bioaerosols recorded in the examined office buildings in Warsaw were similar to those published in other reports. For example, the average concentrations of micro-organisms in office rooms in Upper Silesia, Poland, were 225 cfu·m^{-3} for bacteria and 201 cfu·m^{-3} for fungal spores [31]. Data

TABLE 5. Polish Proposals of Threshold Limit Values for Bioaerosols

Bioaerosol Component	Industrial Settings Polluted With Organic Dust	Public Service and Residential Buildings
Mesophilic bacteria	100 000 cfu·m^{-3}*	5 000 cfu·m^{-3}
Gram-negative bacteria	20 000 cfu·m^{-3}*	200 cfu·m^{-3}
Thermophilic actinomyces	20 000 cfu·m^{-3}*	200 cfu·m^{-3}
Fungi	50 000 cfu·m^{-3}*	5 000 cfu·m^{-3}
Microbial agents from risk groups 3 and 4	0 cfu·m^{-3}	0 cfu·m^{-3}
Bacterial endotoxin	200 ng·m^{-3} (2 000 EU·m^{-3})*	5 ng·m^{-3} (50 EU·m^{-3})

Notes. *—for respirable fraction the proposed limits should be twice as low, i.e., 50 000 cfu·m^{-3} for total mesophilic bacteria, 10 000 cfu·m^{-3} for both Gram-negative bacteria and thermophilic actinomycetes, 25 000 cfu·m^{-3} for fungi, and 100 ng·m^{-3} (1 000 EU·m^{-3}) for bacterial endotoxin; EU–endotoxin unit.

from the Building Assessment Survey and Evaluation (BASE) study showed that mean concentrations of airborne bacteria in 100 large office buildings were below 10^2 cfu·m^{-3} [32]. In Wong, Mui, Hui, et al.'s study, the average levels of airborne bacteria and fungi in air-conditioned offices in Hong Kong were 249 and 42 cfu·m^{-3}, respectively [33].

The quantitative analysis of microbial contamination showed that the concentrations of bacterial aerosol were higher indoors than outdoors. For fungi, the relationship was opposite. The observed dependencies are in good agreement with data on the sources of bioaerosol. People are the main active source of bacterial aerosol indoors. A great number of those micro-organisms are emitted into the air during talking, coughing, sneezing or peeling of the epidermis, whereas fungal aerosol particulates (such as intake spores and mycelium fragments) can be released into the air from colonies growing on dead organic matter, plants, soil as well as other organic and inorganic substrates [34, 35, 36]. Hence, an infiltration of outdoor air into the building envelope can be the major mechanism responsible for fungal contamination in offices.

A comparison of microbial aerosol concentrations in selected sampling points in investigated offices measured with the Andersen and MAS impactors did not indicate statistically significant differences between the samplers. The six-stage Andersen impactor collects bioaerosol particles with the aerodynamic diameter from above 7 to 0.65 μm. This impactor has high collection efficiency from 60% (for particles 0.65–2.5 μm) to 90% (for particles greater than 4 μm). The MAS impactor has the collection efficiency from 10% (for particles greater than 1 μm) to 60% (for particles 3–7 μm) [37, 38]. Nevertheless, when indoor air is microbiologically relatively clean, both samplers measure bioaerosol concentrations with the same accuracy.

A comparative analysis of viable (measured with Andersen and MAS impactors) and total (measured with the Button sampler) microbial concentrations showed that viable micro-organisms accounted for 0.03–0.30% of the total airborne microflora on the premises that were studied. Hence, the use of only one measurement method does not give a comprehensive characteristics of bioaerosol contamination in the examined environment. In this type of hygienic assessment, two measurement methods need to be used, e.g., sampling to determine viable bioaerosol components (done with an impactor) should be supplemented with an assessment of the total concentration of micro-organisms (done with a filter sampler).

A qualitative analysis of microbial flora provided additional information about exposure to bioaerosols in air-conditioned office rooms. The most numerous bacterial species in the air were Gram-positive cocci, mainly from genus *Micrococcus*, and endospore-forming Gram-positive rods from genus *Bacillus*. These species are usually the most prevalent indoors [5, 13, 21]. *Micrococcus* as saprophytic and

nonpathogenic species are ubiquitous in soil, water, dust, on human skin and animals. Then, *Bacillus* endospores have an unusual resistance to chemical and physical agents. This feature makes them predominant in the soil habitat and explains their aerial distribution and subsequent occurrence in many indoor environments, including office spaces.

Among the most common fungal species were those from genera *Aspergillus* and *Penicillium,* which are broadly present in nature, including soil, cereal grains, hay and other plant material or foodstuff. Exposure to these molds has been associated with a variety of adverse health outcomes including respiratory, hematological, immunological, and neurological system disorders and/or diseases [5, 21]. Two of the species found in the offices (*Aspergillus fumigatus* and *Penicillium marneffei*) are classified as risk group 2, i.e., as possibly responsible for allergic effects and potentially hazardous to workers' health [24, 25].

To assess and control the quality of indoor air, not only data on bioaerosol concentrations are important. The size and distribution of bioaerosol particles should also be taken into account as both those parameters determine their deposition in the respiratory system [34]. The analysis of the size distribution of the bacterial aerosol at the studied workplaces revealed that peak concentrations were recorded in the size ranges between 1.1 and 2.1 μm and above 7 μm, whereas fungal propagules dispersed in the air were concentrated within the 1.1–3.3 μm size range. Thus, bioaerosols present in the studied office buildings, which penetrate the human respiratory tract, may be deposited in the oral and nasal cavities, secondary bronchi and bronchioles and be responsible for a wide variety of adverse health effects from nose and eye irritation to asthmatic reactions to allergic inflammation [8, 10].

5. CONCLUSIONS

1. This study showed that average concentrations of bacterial and fungal aerosols in all examined office buildings did not exceed 10^3 cfu·m^{-3} and were thus below the Polish proposals for threshold limit values for bioaerosols in this type of working environment. The recorded low contamination levels of viable airborne microflora suggest that efficient and regularly maintained AC systems ensure a proper hygienic quality of office buildings.
2. The quantitative analysis of microbial contaminants confirmed that during the winter season, the concentrations of bacterial aerosol were higher indoors than outdoors, while the relationship was opposite for airborne fungi. Even during the cold months, if AC systems worked properly, people remained the main active source of bacterial aerosol in the office environment, whereas infiltration of outdoor air (through draughtiness in the building envelope) remained a major mechanism responsible for contamination of indoor spaces with fungi.
3. An analysis of bioaerosol size distribution in the office buildings revealed that microbial propagules, when penetrating the human respiratory tract, may be deposited in the oral and nasal cavities, secondary bronchi and bronchioles and thus be responsible for a variety of adverse health effects.
4. A comparative analysis of viable and total airborne microbial counts showed that viable micro-organisms constituted no more than 0.3% of the total microbial propagules. Hence, a comprehensive hygienic assessment of office workplaces should include an efficient control of both of those elements.

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