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Indoor Biological Contaminants In The Built Environment

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Abstract

Occupants of buildings spentmost of their time indoors and posed themselves to the indoor biological contaminants (i.e. bacteria and fungi) in the built environment. However, the factors that influenced the prevalence of suspended bacteria and fungi in the air of the built environment are not well recognised. Authorities must take the growth of biological contaminants seriously to prevent serious health effects among occupants of buildings. This review summarises the factors (i.e.outdoor air, dust, ventilation problems, humidity/moisture surface problems and human occupancy) of indoor biological contaminants and their species in buildings that could worsen the indoor air quality.Bacteria species could exist in various indoor buildings (i.e.schools, cafeterias, mosques, faculties, child day-care centres, hospitals, dwellings, educational buildings, homes, elderly care centres, libraries, restaurants, and factories). The dominant bacteria were *Bacillus* spp. (24.1 %), *Staphylococcus* spp. (20.7 %), and *Micrococcus* spp. (20.7 %) whereas for fungi species were *Penicillium* spp. (25 %), *Cladosporium* spp. (21.9 %), and *Aspergillus* spp. (21.9 %).

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Introduction

In the last few decades, the problems of air borne bacteria and fungi in indoor environments have significantly increased worldwide.[1] The quality of the living spaces and occupants' health and well-beingcan be influenced directly or indirectlyby microbes in buildings.[2-6] The problems of indoor microbes in the built environment have been taken seriously into account by biologists in collaboration with building designers.[7,8] Kembel *et al*. summarised the three essential concerns associated with indoor microbes. Firstly, indoor bacteria and fungi interact with one another and with the environment in the complex ecosystem of the built environment.[10-12] Secondly, people in the built environment have significant potential contact with indoor bacteria and fungi.[13,14] Thirdly, many cases show that indoor bacteria and fungi affect human health.[15-17]

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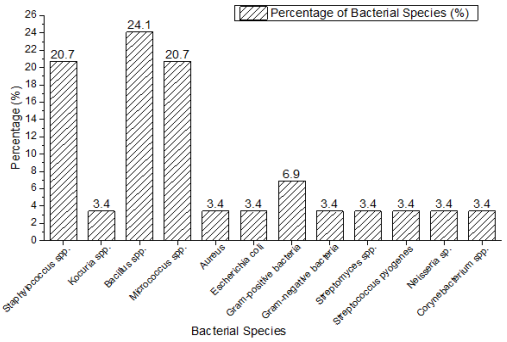

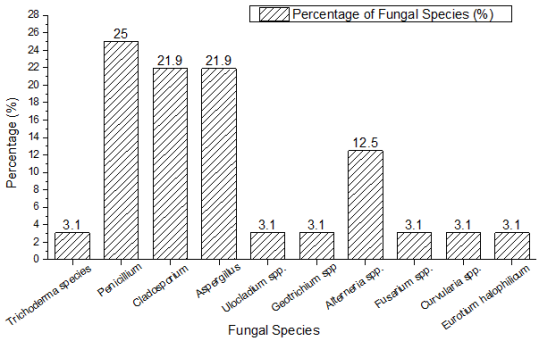

Numerous studies on airborne bacteria and fungi in the built environment conducted in different countries, including Korea, China, Ethiopia, Iran, Italy, Portugal, Jordan, France, Egypt, Malaysia, Pakistan, Greece and Finland with varying indoor locations.[15, 17-28]

Table 1 provides the details (i.e. country, location, finding, and genera) of the studies on indoor airborne conducted worldwide. *Micrococcus*, *Staphylococcus*, *Bacillus* and Pseudomonas are the most common bacteria found indoors.[5]

Table 1: Details of studies on indoor airborne conducted worldwide

No.	Country	Location	Finding	Dominant Genera	References
1.	Finland	School buildings	Fungal was influenced by hidden excess moisture and mould growth of other fungi	Fungal: Trichoderma species (i.e.Mycoparasitic and mycotrophic T. atroviride)	28
2.	Greece	Primary school	Green Roof System tend to improve indoor air quality, hence enhanced the students' comfort and performance.	Fungal: *Penicillium*, *Cladosporium*, and *Aspergillus*	17
3.	Pakistan	Cafeterias of a university campus	The outdoor fungal and bacterial concentrations were higher than that in indoor	- Fungal: 46% of *Cladosporium* spp., 8.6% of *Geotrichium* spp., 8.5% of *Ulocladium* spp., 7.9% of *Alterneria* spp., 6.6% of *Fusarium* spp., 3% of *Curvularia* spp., 2.4% of *Aspergillus* spp. and 1.3% of *Penicillium* spp. - Bacterial: *Staphylococcus* spp., *Kocuria* spp., *Bacillus* spp. and *Micrococcus* spp.	27
4.	Malaysia	Mosques	The bacterial and fungal counts and the average of PM_{10} concentrations were higher in air conditioning mosques compared to non -air conditioning mosques	Bacterial: *Staphylococcus* spp., *Bacillus* spp. and Micrococci spp. Fungal: *Aspergillus* niger.	26
5.	Egypt	Public buildings: libraries, faculties, schools,	- The microbes contaminate the hospitals' operation - Temperature has no signi-ficance in bacterial growth - Particulate matter and	- Bacterial: *Bacillus subtilis* and *Bacillus atrophaeus* - Fungal: *Aspergillus*, *Alternaria*, *Penicillium*, and *Cladosporium*	25

		child daycare centres and hospitals	relative humidity influential in fungal growth		
6.	France	Hospitals	The bacterial growth has no relationship with the sampling sites.	- Fungal: *Penicillium*, *Alternaria*, *Cladosporium* - Bacterial: *Staphylococcus Aureus, Escherichia coli*	[24]
7.	Jordan	Dwellings and educational building	The PAHs metabolite, which is active and carcinogenic products could influence the human	- Bacterial: Gram-positive bacteria, Gram-negative bacteria,Fungal: *Penicillium*/ *Aspergillus* spp.	[23]
8.	Portugal	Homes, child day -care centres, primary schools, and elderly care centres	- The cause of the highest indoor bacterial and fungal concentrations in the user activities and density and the lack of ventilation.	Fungal: *Penicillium and Cladosporium*	[22]
9.	Italy	Library	The white efflorescence appeared in the book caused by the lack of ventilation system, a dusting programme, air-conditioning, and the hygroscopic behaviour of materials used in the book.	Fungal: *Eurotiumhalophilicum* behaved as a pioneer species	[21]
10.	Iran	Hospital	The outdoor bioaerosol influenced indoor hospital air quality	- Bacterial: *Bacillus* spp., *Micrococcus* spp., *Streptomyces* spp., and S*taphylococcus* spp. were the dominant bacteria indoors and outdoorson regular and dust event days.	[20]
11.	Ethiopia	Library university	Most bacterial and fungal isolated could cause sick building syndromes with significant allergy, rhinitis, asthma, and conjunctivitis.	- Bacteria: *Micrococcus* sp., S*taphylococcus* aureus, *Streptococcus pyogenes*, *Bacillus* sp., and *Neisseria* sp. - Fungal: *Cladosporium* sp., *Alternaria* sp., *Penicillium* sp., and *Aspergillus* sp.	[15]
12.	Hong Kong, China	Restaurants located on the hillside at The Chinese University of Hong Kong	Researcher's identified the bacteria species in the skin and respiratory tract of humans and from the soil.	Bacterial: Gram-positive bacteria in which *Micrococcus* and *Bacillus* species were the most abundant	[19]

13. Korea	Factories	- The environmental factors have a significantly positive relationship with the vitality of indoor airborne microorganisms.	- Bacterial: S*taphylococcus* spp., *Micrococcus* spp., *Corynebacterium* spp. and *Bacillus* spp. - Fungal: *Cladosporium* spp., *Penicillium* spp. and *Aspergillus* spp.	[18]

Certain bacteria and fungi species tend to dominate various indoor spaces in buildings. These include schools, cafeterias, mosques, faculties, child day-care centres, hospitals, dwellings, educational buildings, homes, elderly care centres, libraries, restaurants, and factories. The bacteria species were *Bacillus* spp. (24.1 %), *Staphylococcus* spp. (20.7 %), and *Micrococcus* spp. (20.7 %), Gram-positive bacteria (6.9 %), *Kocuria* spp. (3.4 %), *Aureus* (3.4 %), *Escherichia* coli (3.4 %), Gram-negative bacteria (3.4 %), *Streptomyces* spp. (3.4 %), *Escherichia* coli (3.4 %), Gram-negative bacteria (3.4 %), *Streptococcus pyogenes* (3.4 %), *Neisseria* spp. (3.4 %), and *Corynebacterium* spp. (3.4 %). Meanwhile, fungi species were *Penicillium* spp. (25 %), *Cladosporium* spp. (21.9 %), *Aspergillus* spp. (21.9 %), *Alterneria* spp. (12.5 %), *Trichoderma* spp. (3.1 %), *Ulocladium* spp. (3.1 %), *Geotrichium* spp. (3.1 %), *Fusarium* spp. (3.1 %), *Curvularia* spp. (3.1 %), and *Eurotiumhalophilicum* (3.1 %).

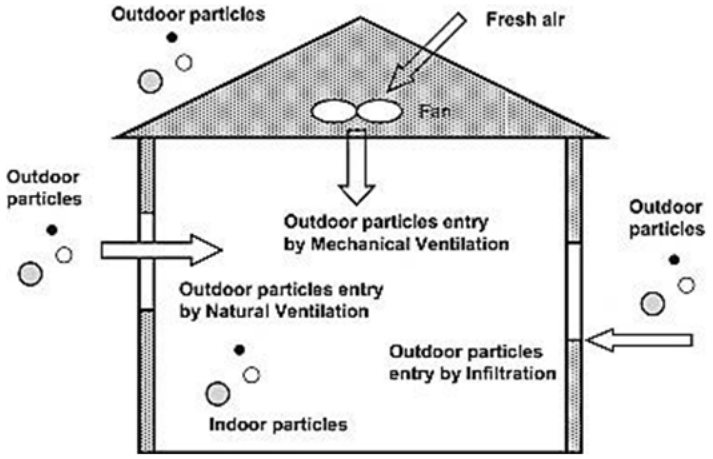

Fig.1: Air exchange in buildings through infiltration, natural ventilation, and mechanical ventilation adapted from Chen and Zhao[31]

Factors of Indoor Biological Contaminants In Buildings

Dispersal of Airborne Bacteria and Fungi by Outdoor Air

Outdoor air has become one of the main factors contributing to the complex system of indoor biological contaminants within a building.[25, 29, 30] Air exchange in the built environment is the replacement of fresh outdoor air with indoor air. A high air exchange rate from the outdoor environment with comfortable climate conditions can improve indoor air quality by reducing indoor air contaminants.[30] Outdoor air can be exchanged with indoor air through infiltration (i.e. particle penetration through the leakage paths of the wall's building), natural ventilation (i.e.doors, windows and other openings) and mechanical ventilation (i.e. fans).[30,31] Figure 1 shows the building air exchange.[31] However, indoor airborne bacteria and fungi accumulated from the dispersal from the outdoors that grew and resuspended in the built environment[29] can potentially influence the microbial community structure.[9] Table 2 lists the study cases on outdoor air with microbial problems.

Dust present in Indoor Air

The accumulated dust (i.e. particulate matter) is one factor supporting air borne bacterial and

fungal culture ability in an indoor environment.[25] Indoor airborne particles sizes in the aerodynamic diameter range of 0.1–10 µm (i.e. coarse particles ≥ 7 µm and fine particles < 2.5 µm).[30] Figure 2 shows the airborne particles that can penetrate the human respiratory system from stage 0 to stage 7 with their respective particle size distribution.[33] Pyrri *et al*.[17] found that *Aspergillus* concentration is positively correlated with the coarse fraction of PM_{10} concentration indoors. Besides, the bacterial and fungal components have contributed to the adverse health effects (i.e. inflammatory lung diseases (neutrophilic inflammation), chronic lung diseases (asthma, chronic obstructive pulmonary disorder (COPD), and lung cancer)) and environmental determinants (i.e. settled dust, floor dust, mattress dust, and from hoover dust collection bag).[34,35] Table 3 lists the study cases on dust particles with microbial problems.

Table 2: Studies on outdoor air dispersed into indoor buildings with indoor microbial problems

No.	Dispersion of outdoor air with indoor microbial problems in the built environment	Dominant genera	References
1.	From the ecological approach, fungi could be dispersed from the outdoors into the built environment when the building type is held constant.	The 100% sequence similarity of fungi in indoor air and outdoor air shows that *Epicoccum* sp., Aur*eobasidumpullulans*, *Cladosporium* sp., *Cryptococcus carnescens* and *Epicoccum* sp. are the dominant genera.	29
2.	Outdoor bioaerosol can contribute to the lower indoor air quality in hospitals.	The dominant bacteria indoors and outdoors were *Bacillus* spp., *Micrococcus* spp., *Streptomyces* spp. and *Staphylococcus* spp.	20
3.	The indoor/outdoor (I/O) ratios of airborne microorganisms at old and new book libraries are less than one, indicatingno microbial sources from indoor.	The dominant indoor bacteria from outdoors are *Bacillus pseudomycoides* and *B. subtilis,* whereas the prevalent outdoor bacteria are *B. subtilis* and *Staphylococcus aspergillus* and *Penicillium.*	30

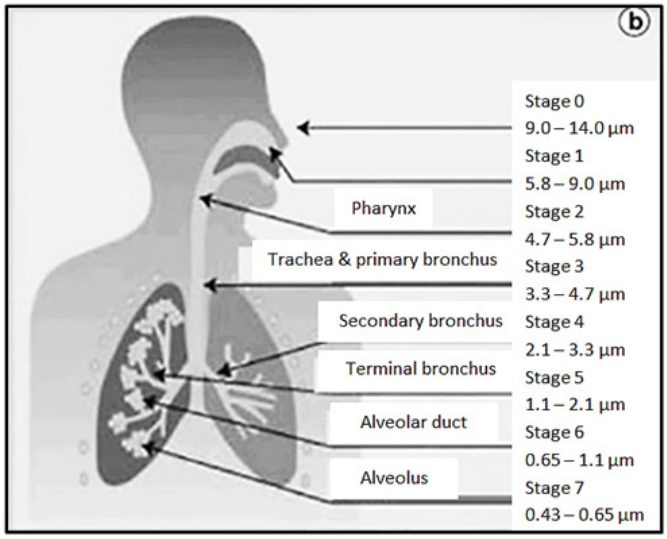

Fig. 2: Sizes of airborne particles that can penetrate the human respiratory system adapted from Andrade-Lima *et al*.[33]

Table 3: Studies on dust particles with indoor microbial problems

No.	Dust particles causing indoor microbial problems in the built environment	Dominant genera	References
1.	Concentrations of bacteria and fungi within hospital buildings are high on dusty days.	The dominant indoors and outdoors bacteria on regular and dusty days are *Bacillus* spp., *Micrococcus* spp., *Streptomyces* spp. and *Staphylococcus* sppgram-positive bacteria exhibiting higher concentrations than gram-negative bacteria.	20
2.	Polycyclic aromatic hydrocarbons (PAHs) are active and carcinogenic products that have positive correlations with floor dust which contains bacteria and fungi.	Phenanthrene in PAHs hasa moderate positive correlation withgram-positive bacteria, whereas fluoranthene and pyrene have significant positive correlations withgram-negative bacteria.	23
3.	Crawling infants tend to be exposed to floor dust resuspended from carpeted flooring, which produces a concentrated and localised cloud of microbial content.	Carpet flooring has concentrations of *Proteobacteria* and lower concentrations of *Firmicutes.*	36

Ventilation Problem

Indoor microorganism is also associated with the lack of ventilation systems, especially in air-conditioned buildings. Improperly designed or operated air-conditioning system within a building can contribute to many microorganisms in the air, which can worsen the indoor environment and threaten occupants' health.[37, 38] Lee *et al*.[39] stated that microorganisms couldbe transferred into the indoor environment due to the air-conditioning system's faulty operation during the maintenance period and the temporary malfunction of the air-conditioning system. Table 4 provides the study cases on the inefficient ventilation system with indoor microbial problems.

Table 4: Studies on inefficient ventilation systems with indoor microbial problems

No.	Inefficient ventilation systems as the cause of indoor microbial problems in the built environment	Dominant genera	References
1.	Concentrations of bacteria are usually associated with indoor CO_2 concentrations, which might be due to human occupancy and lack of a ventilation system.	he dominant indoor fungi are *Penicillium* and *Cladosporium.*	22
2.	The growth of fungi on library materials indoors is due to improper dusting, defective air-conditioning system and lack of a ventilation system.	The dominant indoor fungi on the library materials are *Eurotiumhalophilicum.*	21
3.	Microbial communities found in the Heating, Ventilation and Air Conditioning (HVAC) filter dust samples are the same in residences' surface dust.	The amount of Proteobacteria and Gram-positive bacteria present on the HVACX filter dust samples occupied residences, respectively.	40

Humidity/Moisture Surface Problems

Dampness or moisture problems are associated with the growth of indoor microorganisms (i.e. mould exposures) in buildings, with the estimates ranging from 18% to 50%, and these affect human health.[30, 41-45] The relative humidity is one of the environmental factors contributing to airborne microorganisms' vitality with higher bacteria and fungi.[18] However, humidity with a lower percentage is the limiting factor for indoor microorganisms.[46, 47] The low-moisture condition in the air affects the germination and growth conditions of some fungi rather than bacteria.[47-49] Dannemiller *et al*.[50] found that bacteria tend to grow at 100% of relative humidity. By contrast, fungi grow at ≥80% in home carpet dust, and this surrounding condition results in a significant increase in microbes' concentration. Haines *et al*.[51] also reported that fungi could grow at high relative humidity even at short periods. To prevent mould growth, the home relative humidity level must remain below 60%, and proper building maintenance is needed to save occupants' health.[51, 52]

Besides, microbial growth due to indoor dampness is always associated with building materials. Building materials with high porosity and rough surface (i.e. plasterboard and mortar) and moisture in building materials are favourable to the proliferation and growth of indoor microorganisms. They may cause high exposure to spores, spore fragments, secondary metabolites and cellular microbe components.[53,54] Generally, fungal growth always gives off an unpleasant odour indoors. Table 5 provides details onhow humidity/moisture surface problems influence indoor airborne.

Table 5: Studies on humidity/moisture surface with indoor microbial problems

No.	Humidity/moisture surface problems causing indoor microbial issues in the built environment	Dominant genera	References
1.	The airflow with moisture intrusion in the wall cavities	The fungal spores are dominated by *Aspergillusversicolor, Cladosporiumcladosporioides and Penicilliummelinii.*	30
2.	The increase of respiratory symptoms, asthma and rhinitis and decrease of remission caused by the dampness and mould at home and workplace building	Not available	55

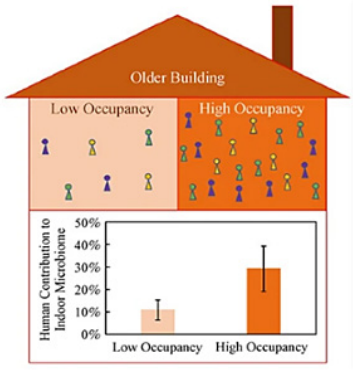

Fig. 3: The higher indoor biological contaminants in the higher levels of human occupancy in the older building adapted from Cao *et al*.[63]

Human Occupancy and Activities

Human occupants are also a prominent source of indoor biological contaminants in the built environment.[14, 22, 30, 56-59] Al-Hunaiti *et al*.[23] stated that bacterial and fungal concentrations are lower in the dwelling with a fewer number of occupants and the most recently built. Noris *et al*.[40] reported a high proportion of gram-positive bacteria in ahigh group of occupants. Indoor biological contaminants can spread in the built environment through natural shedding, which includes particles directly coming from human bodies (i.e. skin, respiratory tract,hair and nostrils) and clothing[2, 19, 58, 60, 61] and through resuspension of spores from the room surfaces, whereby the microbial materials that previously settled onto or colonised indoor materials are

disturbed by occupants' movements.[58, 62] Meadow *et al*.[14] also found that microbes' transmission to indoor surfaces possibly occurs through direct and indirect contact. Cao *et al*.[63] found that the high indoor biological contaminants in the high occupancy (30 %) compared to low occupancy (10 %) of the older building as shown in Figure 3. Table 6 describes how human occupancy and activities influence indoor microbial problems.

Table 6: Studies on human occupancy and activities with indoor microbial problems

No.	Human occupancy and activities causing indoor microbial problems in the built environment	Dominant genera	References
1.	High human occupancy in diverse space types (i.e. classroom) is associated with several bacterial taxa,the human microbiome. By contrast, low human occupancy in various space types influenced by outdoor environments.	*Lactobacillus* and *Staphylococcus* are the dominant indoor bacteria, whereas methylobacteriumis the dominant outdoor bacterium.	9
2.	The potential interactions between high occupancy and occupant activity with microbial communities in a hospital environment.	Not available	59
3.	Occupancy increases the total aerosol mass and bacterial genome concentration in the particulate matter.	All bacteria in samples of indoor air (17%), floor dust (20%) andventilation duct supply air (17.5%) are associated with human taxa, which Proprioni-bacterineae, *Staphylococcus, Streptococcus*, dominate *Enterobacteriaceae* and *Corynebacterineae.*	2

Conclusion

The potential factors that can contribute to the growth of bacteria and fungi (i.e. outdoor air, dust, ventilation problems, humidity/moisture surface problems and human occupancy) should be observed clearly in a building's characteristics and environment. The dominant bacteria species found worldwide in various indoor buildings (i.e.schools, cafeterias, mosques, faculties, child day-care centres, hospitals, dwellings, educational buildings, homes, elderly care centres, libraries, restaurants, and factories) was*Bacillus* spp. (24.1 %), *Staphylococcus* spp. (20.7 %), and *Micrococcus* spp. (20.7 %) whereas for fungi species were *Penicillium* spp. (25.0 %), *Cladosporium*spp. (21.9 %), and *Aspergillus* spp. (21.9 %). Buildings free from bacteria and fungi issues can contribute to a safe environment and protect occupants from poor indoor air quality.

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Conflict of Interest

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare absence of conflicting interests with the funders.

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