

TOPICAL REVIEW

Moldy buildings, health of their occupants and fungal prevention

Mihinova D¹, Pieckova E²

Department of Health Protection, Faculty of Public Health, Slovak Medical University, Bratislava, Slovakia.
 daniela.mihinova@szu.sk

Abstract: Microscopic fungi are important biological pollutants in the indoor environment, they are spread generally: on building materials, carpets, ceiling tiles, insulations, any surfaces, wallpapers, or in heating, ventilation, and air conditioning systems. Molds are able to grow on any materials, as long as moisture and oxygen are available. Exposure to fungi in indoor environments (esp. in water-damaged buildings) can cause adverse health effects, such as allergy, asthma, hypersensitivity pneumonia, mucous membrane irritation, different toxic effects, or even mycoses (in immunocompromised individuals) – alone or in combination. As serious adverse health effects could be caused antifungal prevention is an absolute need.

This review article summarizes the occurrence of fungi in the indoor environment of buildings and their contribution to occupants' health problems, and preventive measures against molds (Tab. 1, Fig. 1, Ref. 48). Full Text in PDF www.elis.sk.

Key words: microscopic fungi, indoor environment of buildings, primary causes of fungal occurrence, system of fungal prevention.

It is absolutely clear that poor quality of indoor environment in buildings can contribute to lots of health troubles. The importance of its evaluation is permanently growing. The problem of indoor environment quality is one of the most relevant public health tasks (1).

The long-lasting interest of medical authorities and technical specialists as well paid to quality of indoor environment deals with the fact that modern people spend predominant part of life in closed spaces (2).

Nowadays the modern society is exposed to many risk factors, which include various chemical substances in living and working environment. The toxic (and even carcinogenic) effects of these substances can threaten human health significantly. Besides industrial substances, some other toxic natural compounds were found to have adverse effects on the human health. These factors include toxic fungi and mycotoxins in foods and also in living and working environment. (3).

Microorganisms belong to important biological pollutants in the indoor environment (4). Toxic exposure to molds and mycotoxins in public buildings, offices, and homes is really common (5).

Exposure to microscopic fungi and mycotoxins in indoor environment

Some epidemiological studies of damp buildings have focused on health risks from indoor exposure to toxic fungi and mycotoxins

(6–8). Most of these studies have not considered assessment of such hazards in the outdoor environments (8). In Taiwan, the study began by evaluating the airborne fungal concentrations at urban and suburban areas of the city in two seasons. The geometric mean concentration for indoors was 8,946 CFU (colony forming units)/m³ in winter and 4,381 in summer, for outdoors, it was 11,464 CFU/m³ in winter and 4,689 in summer. In summer, the total fungal concentrations, both indoors and outdoors, of suburban homes were significantly higher than those of urban homes (9). O'Connor et al (10) performed a home environmental survey and measured the concentrations of culturable airborne fungi inside and outside the homes of 414 mold-sensitive children with asthma in 7 urban communities. The airborne fungi encountered indoors qualitatively generally paralleled those found outdoors. Indoor fungal concentrations were correlated with outdoor concentrations measured in the same study. The indoor concentration was an indicator of the relative moldiness of a home. The concentration of fungi in indoor air exceeded the outdoor one. The indoor-outdoor difference was significantly related to home characteristics, including dampness, having a cat and cockroach infestation.

Many studies proved isolation of *Stachybotrys* sp. (11–13) and other genera, incl. *Aspergillus*, *Penicillium*, *Cladosporium*, *Chaetomium*, *Ulocladium* and *Alternaria* (13–17) from the indoor environment of buildings. Scheel et al. (18) collected samples of the moldy ceiling tiles at the Central Middle School in Tennessee, USA. *Stachybotrys* spores were evident on their majority. Other fungal contaminants identified included the xerophilic species of the genera *Aspergillus* and *Penicillium*, both of which are known respiratory allergens that might produce mycotoxins. *Ulocladium* sp., a hydrophile that grows on cellulose material, was also identified. In the United Kingdom, Hunter et al (19) used air filtration to

¹The Department of Health Protection, Faculty of Public Health, Slovak Medical University, Bratislava, Slovakia, and ²The Department of Microbiology, Research Base, Slovak Medical University, Bratislava, Slovakia

Address for correspondence: D. Mihinova, RND, Dept. of Health Protection, SZU, Limbova 12, SK-83303 Bratislava, Slovakia

monitor 163 homes for the presence of fungi and bacteria over the period of November 1990 to December 1992. The geometric mean count was 234 CFU/m³ air for fungi. In a more intensive study of 35 of the houses, mean counts were 912 and 818 CFU/m³ air for fungi in living rooms and bedrooms. *Penicillium* spp. was the most frequently isolated fungus, found in 53 % of samples. It was followed by *Cladosporium* and *Aspergillus*. In Norway, Dotterud et al (20) found that *Penicillium* was the most common mold in homes and schools, followed by *Aspergillus*, *Cladosporium*, and *Mucor*.

Mold growth within homes and other buildings has been associated with varying degrees of human health problems (21). Exposure to fungi, particularly in indoor environments (in water-damaged buildings) can cause adverse health effects, such as mycoses (in immunocompromised individuals), allergy, asthma, hypersensitivity pneumonia, mucous membrane irritation, and toxic reactions – alone or in combination (21–26). Building-related illnesses due to mycotoxins have not been fully proven in the literature yet (22, 23).

Molds are common and important allergens. About 5 % of individuals are predicted to have some allergic airway symptoms from molds over their life-time (27). In the UK, Potter et al. (28) detected allergic responses to 9 different fungal allergens in a survey of 2,000 patients with allergic respiratory diseases. Also in Sweden, Wickman et al (29) found that *Penicillium*, *Alternaria*, and *Cladosporium* molds were more common in homes of children with allergies, and Neas et al (30) reported that morning lung malfunction was inversely associated with *Epicoccum* and *Cladosporium* spore concentrations amongst a panel of 108 children. Jussila et al (31) isolated spores of *Aspergillus versicolor* in moisture-damaged buildings. These spores caused dose and time dependent acute inflammation in mouse lungs. Cytotoxicity was marked only at the highest spore dose.

Allergens dispersed by airborne fungal spores play an important but poorly understood role in the underlying cause and exacerbation of asthma. Previous studies suggest that spores of *Alternaria* and *Aspergillus* release greater quantities of allergen after germination than before it. It is unknown whether this is true of other allergenic fungi. For 9 of 11 species (*Alternaria alternata*, *Cladosporium herbarum*, *Aspergillus fumigatus*, *Botrytis cinerea*, *Epicoccum nigrum*, *Exserohilum rostratum*, *Penicillium chrysogenum*, *Stemphylium botryosum*, *Curvularia lunata*, *Trichoderma viride*, *Bipolaris spicifera*), between 5.7 % and 92 % of spores released allergen before germination. Spores of other *Penicillium* and *Trichoderma* did not release detectable allergens. After germination, all spores that germinated had allergen elution from their hyphae. Eight of 11 species showed a significant increase ($p < 0.05$) in the percentage of spores eluting detectable allergen (32). Based on the results of the meta-analyses, building dampness and mold are associated with approximately 30–50 % increase in a variety of respiratory and asthma-related health outcomes (33).

Rea et al (5) studied 100 patients who had been exposed to toxic molds in their homes. The predominant molds identified were *Alternaria* sp., *Cladosporium* sp., *Aspergillus* sp., *Penicillium* sp., *Strachybotrys* sp., *Curvularia* sp., Basidiomycota, Myxomycota, *Epicoccum* sp., *Fusarium* sp., *Bipolaris* sp. a *Rhizopus* sp. The pre-

dominant signs and symptoms observed in the subjects were as follows: respiratory symptoms (sneezing, rhinorrhea, nasal stuffiness, dyspnoe and wheezing) in 64 patients, neurological symptoms (short-term memory loss, imbalance and dizziness) in 70 patients, immunological symptoms (hypersensitivity to molds, foods and chemicals) in 100 patients, gastrointestinal symptoms (bloating, gas and cramps) in 24 patients, musculoskeletal symptoms (muscle and joint aches and tenderness) in 29 patients and cardiovascular symptoms (bruising, hemoptysis, and petechiae) in 10 patients.

A majority of occupants of a newly removed historic courthouse in Calgary, Alberta, Canada, reported multiple (3 or more) health-related symptoms, and several reported more than 10 persistent ones. Most required at least a day out of the building to recover from their problems. There were identified molds that produce mycotoxins in the building, such as *Stachybotrys chartarum* and *Emmericella nidulans*, along with fungal organisms of the genera *Aspergillus*, *Penicillium*, *Cladosporium*, *Chaetomium*, *Rhizopus/Mucor*, *Alternaria*, *Ulocladium* and *Basidiomycota*. Renovations of this historic building failed to provide adequate thermal and vapour barriers, thus allowing most indoor air to migrate into the building closure, causing condensation. Mold grew on the condensation and was dispersed through the courthouse, including the furniture and files. The courthouse was closed and a few facilities were modified with low-offgassing materials, better ventilation and air filtration, and strict building maintenance to accommodate those occupants of the older building who had developed multiple chemical sensitivities (34). On the different plasters, mixtures of the spores of *Aspergillus ustus*, *A. versicolor*, *Cladosporium sphaerospermum* and *Penicillium* spp. held their vitality from 40 d to 3 months, i. e. up to the end of the experiment (35, 36).

In the United Kingdom, Platt et al (37) examined the relationship between fungal spore counts and self-reported symptoms amongst the occupants of almost 600 homes. They were associated with an elevated prevalence of reported wheeze and fever in children, and high blood pressure, and breathlessness in adults.

Gray et al (38) in their study investigated multiple health difficulties following the exposure to various molds in 209 persons in water-damaged buildings. The authors concluded that exposure to mixed molds and their associated toxins had led to multiple health problems involving the central nervous and the immune systems, in addition to pulmonary difficulties and allergies. Mold exposure also initiates inflammatory processes. The authors propose the term „mixed mold mycotoxicosis“ for the multisystem illness observed in these persons.

Until now, the ciliostatic activity of sterigmatocystin „in vitro“ has been proven, that is the carcinogenic mycotoxin produced by *A. versicolor* and *Chaetomium* spp., even it belonged to the most active fungal secondary metabolites tested (39, 40). Kelman et al (41) tried to model a maximum possible dose of mycotoxins that could be inhaled in 24 hrs of continuous exposure to a high concentration of aflatoxins B1 and B2, satratoxins G and H, fumitremorgens B and C, verruculogen, and trichoverrols A and B. These calculated doses are compared to effects' data for the same mycotoxins. None of the maximum doses modelled were sufficiently high to cause any adverse effect.

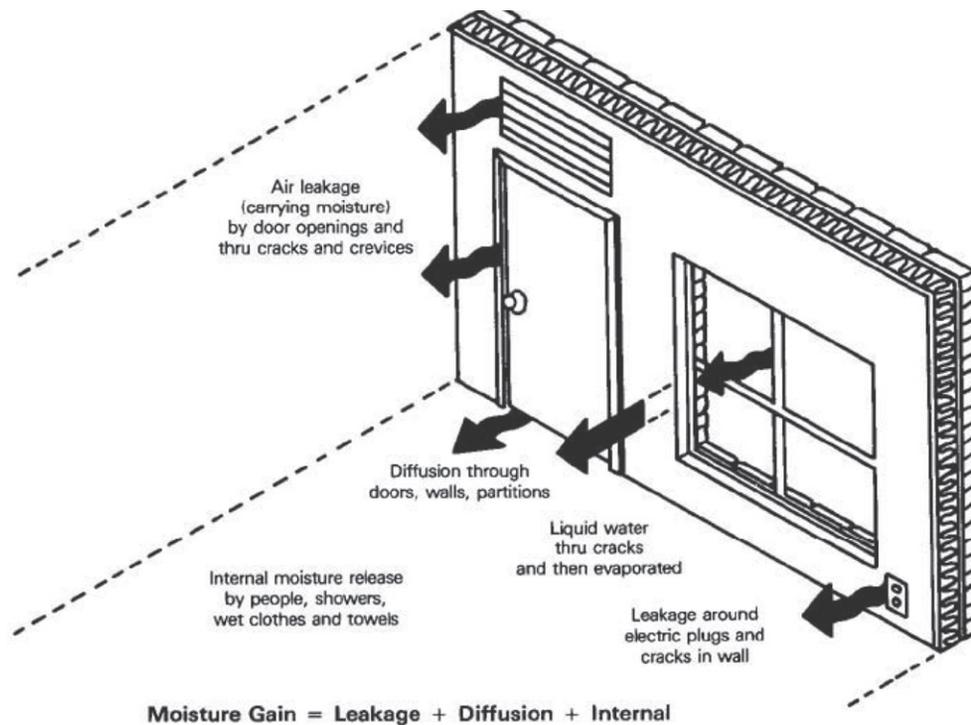


Fig. 1. Moisture gain in buildings (42).

Conditions enabling the growth of indoor microscopic fungi

Molds are found almost everywhere in our environment, both outdoors and indoors. They can grow on just about any substances, as long as moisture and oxygen are available. Mold growth may occur when excessive moisture accumulates in building or on building materials, including carpets, ceiling tiles, insulation, paper, wallboard, wood, surfaces behind wallpaper, or in heating, ventilation, and air conditioning systems (HVAC). It is impossible to eliminate all molds and mold spores in the indoor environment. However, moisture control is the most important strategy for reducing indoor mold growth (42, 43).

Water enters buildings both as a liquid and as a gas (water vapour). Water, in its liquid form, is introduced intentionally in bathrooms, kitchens, and laundries and accidentally by way of leaks and spills. Some of that water evaporates and joins the water vapor that is exhaled by building occupants as they breathe or that is introduced by humidifiers. Water vapour also moves in and out of the building as part of the air that is mechanically introduced or that infiltrates and exfiltrates through openings in the building shell. A lesser amount of water vapour diffuses into and out of the building through the building materials themselves. Figure 1 illustrates locations of moisture entry (42).

The dampness of substrate is one of the basic conditions of mold's life. Their optimal water activity in substrate ranges between 0.60 and 0.99 and their optimal relative humidity of air fluctuates between 80 and 100 %.

Other significant parameter related to humidity of building materials is the dew point temperature. The condensation of water vapour appears due to cooler air around the material surface that is below the temperature of dew point. Dew points – actually, critical temperature to develop mold growth – on inner wall surfaces under different thermal and humidity conditions in an apartment in Bratislava, Slovakia, are illustrated in Table 1 (44).

The building materials under given atmospheric conditions contain certain amounts of so-called steady moisture, which is absorbed from surrounding air. The quantity of this absorbed humidity is dependent on temperature, relative humidity, porosity of material and contents of hygroscopic salts. The building material becomes the source of humidity, when its humidity is higher than steady moisture. In this instance, moisture of building can be high even at low relative humidity of the air.

The main sources of moisture in buildings are:

- capillary action of moisture – imperfections in hydroisolation of building subsoil and inadequate reduction of moisture causing wetness on construction of building subsoil;
- raining in building – in roof constructions and through breaches in circumferential walls consisting of pieces;
- leaking in sanitary installations – at uncaulking joints of sanitary distribution system, banged up outlet baths, washbasin and kitchen sink;
- condensation of water on internal surfaces of construction – in

Tab. 1. Dew points on inner wall surfaces in a flat (44).

Air temperature (°C)	Relative humidity (%)	Relative humidity calculated for 20 °C, atmospheric pressure 2336.7 Pa (%)	Dew point calculated for relative humidity 80 % (°C)
18	50	44.1	10.74
19	50	47.0	11.68
20	50	50.0	12.62
21	50	53.2	13.57
22	50	56.5	14.51
23	50	60.1	15.45
24	50	63.8	16.40
25	50	67.7	17.34

places with lower surface temperature under temperature of dew point;

– activities of occupants of buildings – an excessive amount of flowers, aquariums, vaporizes, washing and airing laundry, cooking, and an excessively sealed windows.

The molds can not exist without occurrence of appropriate breeding ground – substrate. Primary nutrients included are organic compounds coating carbon and nitrogen (proteins and saccharides) and minerals for occurrence of hint of organic compounds. The most convenient environment for life of molds is the acidic one. The optimal pH value ranges between 5 and 7 in dependence on their species. The molds need oxygen, possibly carbon dioxide, but they do not need light (3).

System of mold and mycotoxin prevention in living and working environment

There is a high need to control moisture in both new and existing constructions because of the significant health consequences that can result from dampness and mold. Dampness and mold in buildings is undoubtedly a significant public health problem with substantial economic impact (45).

Preventive measures against molds consist of:

- assignment of suitable air circulation by periodical ventilation (ventilation system, exchange air by opening windows),
- reparations, adjustments, constructions of spaces and buildings to eliminate all sources of humidity,
- periodical building maintenance,
- employment of suitable impermeable materials for flooring,
- adjustment of climate conditions of building by right regulation of fumigation and humidity (relative humidity maintain below 60 %, ideally 30–50 % , if possible),
- adjustment of right function of vaporizer in kitchen, regular defrosting, washing and disinfection of refrigerator and freezer,
- performance of periodical cleaning of spaces (use suitable cleaners and disinfectants, regular disposal of waste),
- respect to the right principles of storage of materials (e. g. not to store objects directly at the walls),
- performance of periodical control of occurrence of molds (3, 42, 43, 46, 47).

Conclusion

Up to recently, the direct and indirect relationship between presence of microscopic fungi in buildings and health status of their occupants has not been exactly proven. Monitoring of exposure to fungi in the indoor environment is complicated, due to the absence of standardized practical methods to evaluate relations among the indoor microclimate in buildings, their outdoor environment and microscopic fungi (39, 40, 48). This problem requires strong attention not only in public health, but needs an integrated approach through the large spectrum of sciences.

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