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Occupational Exposure to Moulds in Buildings

Jagjit Singh

Environmental Building Solutions Ltd.
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Author for Correspondence
Dr Jagjit Singh
Director
Environmental Building Solutions Ltd.
Galley Cottage, Galley Lane, Great Brickhill, Milton Keynes, MK17 9AA

Telephone: + 44 (0) 1525 261922
Fax: + 44 (0) 1525 261923
Email: ebs@ebssurvey.co.uk
Web: www.ebssurvey.co.uk

Abstract

Airborne moulds are ubiquitous and have evolved to exploit the man-made spatial ecosystems of our built environment. In the enclosed environment, especially where there is dampness and condensation, they manipulate the microclimates and ecological niches of our buildings and feed on a variety of substrates. Over the last century the management of mould problems in buildings has largely relied on a misunderstanding and misdiagnosis of the biology, ecology and physiology of the causal organisms. Mould growth in buildings may affect the health of occupants in many ways and may contribute to Sick Building Syndrome (SBS) as well as allergy and other environmental health problems. The consequences of occupational exposure to moulds are gaining prominence because of demands for better working conditions. There is a need to look after and hopefully improve the health, comfort and productivity of a building's occupants.

Introduction

Airborne moulds are ubiquitous and have evolved to exploit the man-made spatial ecosystems of our built environment. In the enclosed environment of our buildings they manipulate the microclimates and exploit ecological niches. Their ecological diversity is such that no matter what number and variety of substrates are available there will some micro-organism able to feed on virtually all of them (Gravesen et al., 1994; Gravesen et al., 1999).

It is to be regretted that over the last century the management of mould problems in buildings has largely relied on a misunderstanding and misdiagnosis of the biology, ecology and physiology of the causal organisms. Mould growth in buildings may affect the health of occupants in many ways (Croft et al. 1986; CDC 1997) and may contribute to the so-called Sick Building Syndrome (SBS) as well as allergy and other environmental health problems (Malkin et al. 1998). However, microbial contamination in buildings can vary greatly, depending on the location of growing organisms, and possible exposure pathways. The presence of mould in a building does not necessarily constitute exposure.

Several studies have described health problems due to moisture and mould growth in domestic buildings (Haverinen et al. 2001; Lawton MD et al. 1998; Spengler et al. 1994; 4: Koskinen et al. 1999; Dales et al. 1991; Strachan et al. 1990; Etzel et al. 1998). The consequences of occupational exposure to moulds are gaining prominence because of demands for better working conditions. The problems of such exposure are not new but must now be addressed because of demands for better standards of living to improve the health, comfort and productivity of the occupants. In certain occupations, particularly those in the agricultural sector, high levels of moulds and fungi may constitute a particular occupational hazard (doPico, 1986; Parker et al., 1992; SNB, 1994; Adhikari 1999) Other factors include the increase in the incidence of allergic reactions in susceptible individuals (Rask-Andersen 1989; Institute of Medicine. 1993) and the need for energy conservation measures that leads to sealed buildings.

Allergy and environmental health problems in buildings have generally been neglected because the effects are mostly chronic and long-term and not directly and immediately life threatening. People are increasingly dissatisfied with the air quality in their work places and this is costing employers millions of pounds every year in loss of business. Healthy and comfortable environment requires multi-disciplinary scientific input from those involved in building construction, services and controls, design, use and maintenance of buildings.

Building Health and Occupant Health

Building health and any pollutant problems should be addressed before the building is built. There should be early consideration of the choice of construction materials and building systems and techniques. These must be integrated to minimise microbial habitats and avoid sources of particulates and other pollutants such as VOCs. There should be a clear understanding of the building's use which should direct the careful selection of furnishings and operating equipment. Once a building is commissioned and operating, proper maintenance of the air handling system, other buildings systems and structural elements is critical. In operation, housekeeping and interior design professionals must work in concert with facilities management so that, as staffing or work functions change, appropriate action can be taken.

The holistic approach is necessary because buildings may affect the health of occupants in many ways. So may ways in fact that a terminology has developed in an attempt to classify the problems. Pre-eminent among the names is Sick Building

Syndrome (SBS) but there are also building related illnesses (BRI), and allergy and environmental health problems (AEHP). The term SBS is extremely vague and it and its connotations should be distinguished from building-related illness. In the latter a specific agent such as bacteria or moulds may be found responsible but in SBS this is rarely the case (Gots, 1998). SBS is often used to describe buildings where workers have many and varied symptoms. The sheer number of potential causes of those symptoms makes the term misleading. People complain they do not feel well and have certain symptoms and that these symptoms have a temporal relationship with the building. The implication is often that the symptoms arise because of some problem with the indoor air quality. While there may be a building-related cause, such as poor air exchange in an energy-efficient building, most often in SBS the cause will never be identified. One epidemiological study (Finnegan, Pickering, and Burge, 1984) concluded that air-conditioned buildings consistently showed more symptoms than naturally ventilated buildings. However the researchers could determine no specific cause, such as the use of humidifiers or the presence of formaldehyde or other chemicals.

BRI is usually more definite and the term is used to describe diseases ranging from mild to severe, that are due to specific, identifiable contaminants of the indoor air. For a classification of building related disease to be designated, clear and convincing evidence must exist that something in the building is causal; preferably, the agent should be known. Moreover, the disease or end point of the disorder must generally be quite clear-cut, not merely a set of non-specific complaints (Gots, 1998). In the most serious cases there may be quite definite symptoms as is the case with Legionnaires' disease. Occupational asthma may be proven by immunological studies of the patient. If a large number of the workforce are beset by symptoms such as eye and mucous membrane irritation, headaches, fatigue, and sinus congestion these may be the result of a BRI.

It remains, though, that the most common health problems in buildings relate to dampness and condensation resulting in mould growth producing respiratory problems and allergies. Not only moulds but also house dust mites, and, less commonly, amoebae can colonise building structures, furnishings and finishes with the same health consequences. House dust mites, fungi and yeasts are potent sensitisers, and they flourish in an environment of high relative humidity and low ventilation. Fragments of these organisms or their decayed material or their metabolites, becoming airborne, can be inhaled and cause allergic disease.

Moisture Saturated Dwellings

Because micro-organisms need water to grow, the presence of moisture plays a key role in many indoor air quality problems. Accumulation of moisture via leaks or broken pipes, condensation as a result of bad ventilation or poor dehumidification by HVAC systems can all lead to microbial growth. Fungi are the most common micro-organisms in a damp building because they require less moisture than bacteria to grow. A relative humidity of 75-85% is sufficient for growth. Bacteria do not begin to amplify aggressively until the humidity is very high, around 95%, or if standing water is present.

Buildings which suffer from dampness (Rising or penetrating dampness), moisture problems due to condensation, fire and flood damage can have a significantly higher number of micro-organisms in their indoor environment (Pasanen et al., 1993). However, the development of a microbiological flora depends not just on water but also on time. In the case of flooding, if the buildings are dried quickly when the water retreats there may be little increase in overall levels of both bacteria and fungi (Curtis et al. 2000). Nevertheless, in areas where flooding has occurred, prompt cleaning of

walls and other flood-damaged items with water mixed with a chlorine bleach would be a wise precaution. Another factor which should be remembered is that mould on the walls of a building is not the same as mould or spores in the air. For an exposure to present a hazard direct contact with fungal growth or inhalation of the spores is necessary. Surface contamination can lead to airborne contamination but any quantitative relationship is at best indirect.

If water has been present for a long time species of mycotoxin-producing moulds may be present, these include *Fusarium*, *Trichoderma*, and *Stachybotrys*. In addition there are other moulds of allergenic importance including for example, *Botrytis* and *Rhizopus*. These and other species create problems for allergic patients since the most common response to mould exposure may be allergy. However, a prolonged residual moisture problem may also cause troubles for non-allergic people, who may develop several of the mucosal and general symptoms. These may result from other types of health effects known to result from exposure to micro-organisms, namely: infections, irritation (mucous membrane and sensory) and toxicity.

Health effects

There are more than 100,000 species of fungi and the genera and species that cause human disease include a wide array of these. The most common fungi found in both adult and paediatric populations in descending order of frequency were *Alternaria*, *Helminthosporium*, *Cladosporium*, *Fusarium*, *Aspergillus*, *Phoma* and *Penicillium* (Kuehn et.al 1992)

The most common response to mould exposure may be allergy. People who are atopic, that is, those who are genetically capable of producing an allergic response, may develop symptoms of allergy when their respiratory system or skin is exposed to mould or mould products to which they have become sensitised. Repeated exposure to large amount of fungal propagule risks the development of specific allergic reactions and the incidence of the problem is increasing at an alarming rate. It is a sad fact that every third child in many industrialised countries has an atopic disorder (ISAAC, 1998).

Indoor Allergens
The fruiting bodies of fungi produce large numbers of spores that when liberated to the indoor air of buildings may constitute a health hazard. They are part of the whole bioaerosol mix often described as organic dust (NIOSH, 1994). The most common of these micro-organisms in the indoor air are: *Cladosporium herbarum*, *Alternaria alternata, Eurotium herbariorum*, *Penicillium* spp., *Aspergillus* spp., particularly *Aspergillus versicolor*, *Aureobasidium pullulans, Mucor* spp., *Phoma* spp and *Wallemia* spp. The other micro-organisms are bacteria, viruses, Actinomycetes, yeasts and pollens and the dust also includes faecal pellets of the house dust mite and effluvia from domestic pets (birds, rodents, dogs, cats). The fungal spores can, like other types of dust, sediment on surfaces or it could be inhaled by occupants and deposited on the mucosal surface of the upper airways and in the eyes.

In an occupational setting allergy problems in buildings reflect on the health, comfort and productivity of the occupants and also increases in the rate of sickness at work places. To avoid these problems a defensive strategy is necessary from the building design stage. A close dialogue must exist between architects, designers, engineers and building health specialists in the early stages of conception and construction with later the involvement of facilities managers, health and safety officers and employees. This multi-disciplinary approach is necessary in order to identify, evaluate, monitor and remedy allergic reactions in buildings.

Allergic Reactions
Allergic reactions can range from mild, transitory responses, to severe, chronic illnesses. The Institute of Medicine (1993) estimates that one in five Americans suffers from allergic rhinitis, the single most common chronic disease. Additionally, about 14% of the American population suffers from allergy-related sinusitis, while 10 to 12% have allergically-related asthma. A very much smaller number, less than one percent, suffer serious chronic allergic diseases such as allergic bronchopulmonary aspergillosis (ABPA) and hypersensitivity pneumonitis (Institute of Medicine, 1993).

While there are thousands of different moulds that can contaminate indoor air, allergic potential has only been identified in a few of them. This means that exposed and sensitised atopic individuals may not be identified as having mould allergy. Allergy tests are highly specific and it is possible that even closely related species may cause allergy yet not be detected through challenge with the purified allergens available for tests. A negative test does not rule out mould allergy for atopic individuals.

Environmental Control of Allergens
In environmental control of allergens avoidance of exposure should be the first line of defence. In a domestic setting removal of a household pet or remediative action to remove house-dust mites can lead to a cure of rhinitis and, indeed, asthma in atopic occupants. Similarly in industry, changes in working practices such as the total enclosure of industrial processes that release sensitising agents can improve worker health.

In any environment where there is risk of exposure to a known material with a record for causing allergy, that material should be managed by the principles of substitution, containment, local exhaust ventilation and finally personal protection.

If complete avoidance is not possible other therapeutic methods exist that may be used in combination or singly, namely, pharmacotherapy, and immuno-therapy

Management of moulds in Buildings

Environmental Management
Much damage has been inflicted in last Century by dealing with the symptoms of the problems and not with the causes. By proper understanding of the courses, its repetition should be avoided in this Century. The environmental approach is beneficial to the building fabric, occupants and to the wider environment. Fungi and other bio-contaminants cannot be removed from a building but their levels should be controlled. For example, it has been hypothesised that a level of non-toxigenic and non-pathogenic organisms $\leq$300 cfu.m^{-3} should be typical for environments in which normal, non-immuno-compromised people live (Robertson, 1997).

Monitoring and Risk Assessment

To determine the type and degree of infestation by micro-organisms requires specialised equipment. A range of instrumentation is available for monitoring moulds in the environment. These may be used for continuous measurement (Stern et al. 1999) or to sample air using viable cascade impactors based on the Anderson design (Brickus, 1998) or related techniques (Bhattacharya et al., 2001). The choice of sampler requires careful consideration of the purposes of the investigation, the information required, the characteristics of the moulds in the environment being

studied and the sampling and trapping efficiencies of the available samplers. Other methods include sampling airborne allergens, airborne mycotoxins, sampling volatile metabolites and endotoxins.

SAMPLING METHODS

Determinations of the occurrence of microorganisms in buildings can only be as good as the methods used. Choice of a sampler requires careful consideration of the purposes of the investigation, the information required, the characteristics of the microorganisms in the environment being studied and the sampling and trapping efficiencies of the available samples.

During mould monitoring in buildings, often-insufficient attention is given to the followings;

- Sampling characteristics of different instruments and their limitations,
- the siting of samplers,
- the timing of samples and
- the way in which the catch is handled.

Failure to consider these factors means that much published work gives less reliable information than is often attributed to it. No one method of sampling or isolation medium is ideal for all needs.

SAMPLING VIABLE MICROORGANISMS

Settle plates, Petri dishes of agar medium exposed to the atmosphere by removing the lid for a fixed period, have been used widely in studies of the indoor environment. They are simple and easy to use but the results are difficult to interpret. Spores or cells sediment at a rate determined by the square of their aerodynamic radius, i.e. the radius of a unit density sphere sedimenting at the same rate. Consequently, small spores are effectively sampled from a much smaller volume of air than large spores and if present in the air in equal concentrations, many more of the larger particles will be collected than of the smaller. Further errors are caused by any air movement which creates a shadow with no deposition downwind of the leading edge that increases in size with wind speed until there is no deposition unless airflow becomes turbulent when deposition may become greater then expected. Much deposition may also occur in the turbulence created when the lid is removed and replaced.

Mycoflora samplers

Some modern hand-held samplers are very convenient to use but their trapping efficiency is often low and differs for different size particles, again distorting results. The Biotest RCS sampler has often been used in indoor studies. The other methods and sampler used in mould monitoring are;

- SAS sampler
- Andersen samplers to be comparable
- cascade impactor - Impaction and impinger samplers
- Settle Plates
- Automatic volumetric spore trap

A careful seletion of the sampler and observations should be made for occupational hygiene criteria of inhalable, thoracic and respirable fractions of airborne dust.

Almost all studies of the indoor air spora have involved short-period samples during periods of inactivity within the building or without reference to the amount of activity. However, numbers of airborne microorganisms may change considerably with

activity that stirs up dust and longer-term sampling would seem desirable. The most satisfactory instrument for long-period sampling is probably the multi-stage liquid impinger since, especially in the first two stages, this treats particles more gently than other liquid impingers.

Calibration of sampling instruments is essential to ensure that the correct sampling rates are being maintained.

Nutrient Media

A wide range of media have been used to determine numbers of different microorganisms in the air spora . Selective media have been used for the isolation of different group of bacteria but these are less well developed for fungi. However, it is evident from the range of fungi isolated that a medium that allows optimum growth of xerophilic fungi should often be included. ~DG18 agar is a good example of such a medium which is satisfactory for the growth of *Aspergillus*, *Penicillium* and w*allemia* spp., as well as other xerophiles. Malt extract and DG18 agars gave consistently high yields of fungi, both in terms of cf/m3 and of total number of species isolated with slit samplers and six-stage Andersen samplers and also gave best reproducibility between duplicate parallel samples with Andersen samplers. The use of at least two media is essential because some important hydrophilic fungi, like Stachybotrys atra, will not grow on DG18 activity medium. Malt extract agars containing glucose and peptone have been recommended but should not be used because the glucose encourages excessive growth of Mucorales (Lacey, 1994).

Other media and incubation temperatures found satisfactory for isolating microorganisms from the air include;

- tryptone soya agar at 37°C for total bacteria,
- half-strength nutrient agar at 25 and 40°C for total bacteria and actinomycetes,
- half-strength tryptone soya agar + 0.2% casein hydrolysate at 55°C for thermophilic actinomycetes,
- violet red bile glucose agar at 37°C for Gram-negative bacteria,
- Columbia agar base + half-strength staphylococcus selective supplement at 37°C for Gram-positive cocci and
- 2% malt extra t agar + dichloran rose Bengal, chloramphenicol agar at 25 and 40°C for fungi (Lacey 1994).

SAMPLING TOTAL MICROORGANISMS

Culturing reveals only those viable microorganisms that will grow on the media used under the selected incubation conditions and can often give a misleading impression of the total numbers of cells in the air. However, even non-viable organisms may be important in allergic reactions and in carrying endotoxins and mycotoxins. Direct counting methods have to be used to estimate the total microorganisms concentration in the air. Method used have included cascade impactors and filtration with polycarbonate or cellulose ester membrane filters in aerosol monitors. A four-stage cascade impactor has been used widely (Lacey 1994) in studies of occupational environments. Filtration, using aerosol monitors loaded with polycarbonate filters and operated with personal sampler pumps as above, allows scanning electron microscopic assessment or acridine orange staining and epifluorescence microscopy of the catch while cellulose ester filters cleared with glycerol triacetate allow light microscopy.

SAMPLING AIRBORNE ALLERGENS

Not all allergens are microbial in origin and while microbial allergens can be assessed using the methods described above, non-microbial allergens require different methods. Filtration has been used most commonly, with high volume samplers drawing up to 1 m3 /min through 20x30 cm glass fibre filter paper or, more recently, with 3 cm diameter glass fibre filters sampling at 17 1/m min or 25 mm glass fibre filters sampling at 2 1/min (Lacey 1994). Cascade impactors and multistage liquid impingers have been used to collect and size allergenic particles. Better recovery of scampi allergen was obtained with a Litton-type large volume filtration and this has been confirmed in a model system using egg albumin (Lacey 1994). Radioallergosorbent test (RAST) inhibition assay (ELISA) to detect lgG antibodies. ELISA is probably no more sensitive than RAST and has been used to detect house-dust mite allergen in samples collected on personal sampler filters. ELISA also allows the assay of specific component using monoclonal or polyclonal antibodies.

SAMPLING MYCOTOXINS

Glass fibre filters and a high-volume sampler have been used to sample airborne aflatoxins and were subsequently found more satisfactory or sampling such aerosols than cotton filters, a RCS sampler, an Andersen sampler loaded with Teflon (Dupont) discs instead of agar and liquid impinger . Similar sampling methods could be used for other mycotoxins with detection and quantification by immuno-assay, using monolclonal antibodies.

SAMPLING VOLATILE METABOLITIES

Fungal volatiles were sampled by Miller et al, (1988) by passing 2001 of air filtered to 0.22 μm through clean stainless steel cartridges packed with Tenax GC support (60/80 mesh). The cartridges had been conditioned at 300°C, with a helium gas flow of 20 ml/min for 6 h and a baseline record for each cartridge determined by gas chromatography-mass spectroscopy (GC-MS) after transferring the cartridges to a desorption unit (Chemical Data System 320) interfaced to a GC-MS system (Finnigan MAT 312).

The cartridges were kept sealed into glass tubes before and after sampling. As soon as possible after sampling, the cartridges were thermally desorbed and analysed.

SAMPLING ENDOTOXINS

Endotoxins have generally been collected by filtration through cellulose acetate or polyvinyl chloride, either directly with sampling rates of 1-2 1/min or using a vertical elutriator. But an Andersen sampler, depositing onto glass fibre filters, and a cascade impactor have also been used. After exposure and weighing the filters are shaken with pyrogen-free water and endotoxin is quantified with a *Limulus* ameobocyte lysate (LAL) assay.

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