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Toxic Moulds and Indoor Air Quality

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Key Words

Toxic mould · Building mycology · Indoor air quality · Health effects

Abstract

Indoor air quality issues associated with exposure to moulds and their metabolites, mycotoxins, are becoming of increasing importance. There are believed to be about 1.5 million species of fungi of which more than 1000 species have evolved to exploit the built environment. Sexually mature fungi produce large numbers of spores that when airborne can be inhaled and deposited on the mucosal surface of the upper airways and in the eyes. Occupants of buildings may be affected in any of a number of ways. Fungi and moulds can contribute to the sick building syndrome or other building related illnesses and some people can have an allergic response. Such exposure to moulds and the other fungi and their spores indoors is unavoidable except when the most stringent air filtration or other environmental measures are observed. The repeated exposure to large amount of particular fungal propagules is an important risk factor for the development of specific allergic reactions. There are also a large number of toxic mould metabolites which can have a range of biological activities. Black Mould (*Stachybotrys chartarum*), in particular has been implicated in illnesses associated with living in damp houses. Reactions may be severe as in recent reports of idiopathic pulmonary haemorrhage in very young children in Cleveland, Ohio. Although some governmental agencies have published guidelines on mould assessment and remediation most are very general in nature and most focus on Black Mould as the major concern.

Introduction

There are believed to be about 1.5 million species of fungi that mostly live on decaying organic matter or in a symbiotic relationship with lichens or have a mycorrhizal association. More than 1000 species have evolved to exploit the man-made spatial ecosystems of our built environment [1,2]. Many of these found in buildings are known as moulds which is the common term for multicellular fungi that grow as a mat of intertwined microscopic filaments (hyphae). Fungi produce large numbers of spores that when airborne can be inhaled, some are small enough to be respirable, by occupants and deposited on the mucosal

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surface of the upper airways and in the eyes. Repeated exposure to large amounts of particular fungal propagules risks the development of specific allergic reactions.

Exposure to moulds and the other fungi and their spores indoors is unavoidable except when the most stringent air filtration or other environmental sanitation measures are observed. Generally, in the indoor environment there is some dampness and condensation. Fungi can manipulate such a microclimate and find ecological niches in our buildings where they feed on a variety of substrates. Since in Britain and western Europe, on average we spend 80–90% of our time indoors, any adverse interaction with fungi in the indoor environment may influence our health, comfort and, in the workplace, productivity. Occupants of buildings may be affected in the following ways.

- Effects can manifest as the sick building syndrome (SBS) [3].
- There may be other building related illnesses [3].
- Some people can have an allergic response and there may be associated environmental health problems (AEHP) [4–7].
- The sum of these can result in psychological and psychosomatic issues.

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. The economic importance of this is considerable. Many days of work are lost through absenteeism, lack of concentration or not feeling well at the workstation. A significant amount of absenteeism is attributed to SBS, building related illnesses and AEHP, which can lead to low morale and affect the ability to concentrate, produce eye strain and poor productivity.

The identification and risk management of moulds and related indoor air quality problems in buildings particularly when these produce a situation hazardous to health is complex [8]. It requires a multi-disciplinary integrated approach, which combines the skills of material scientists, environment monitoring and health specialists, occupational hygienists, toxicologists, engineers and architects.

In domestic housing the most common building health problems relate to dampness and condensation that has resulted in mould growth, an increase in the number of house dust mites and a range of other fungal and insect pests [9]. These can colonise building materials, structures, services, contents and furnishing and finishes. Any and all of these can aggravate respiratory problems and allergies in susceptible individuals. House dust mite faeces, fungi and yeasts are potent sensitisers and they become abundant in an environment of high relative humidity and low ventilation. In fact allergens from the faecal particles of the house-dust mite are the most important extrinsic cause of asthma world-wide. Allergic disease caused by inhalation of airborne material is known as perennial allergic rhinitis. This is most commonly associated with allergens from the house dust mite, domestic pets and, in the workplace, dusts, vapours and fumes. The latter are more likely to cause occupationally related perennial rhinitis than asthma. The house dust mite itself is <0.5 mm in size, invisible to the naked eye and is found in dust throughout the house, particularly in older, damp dwellings. They depend for nourishment upon desquamated human skin scales and are found in abundance (4,000 mites per gram of surface dust) in human bedding.

Some species of fungi, including some moulds, may produce secondary metabolites, or mycotoxins which can have an adverse effect on health. *Stachybotrys chartarum* and many fungi for example species of *Aspergillus*, *Penicillium*, *Fusarium*, *Trichoderma* and *Memnoniella* can produce potent mycotoxins [10]. Although some of these find valuable clinical use, e.g., penicillin, cyclosporine, other mycotoxins have been shown to be toxic to man and for these reasons certain fungi are treated as a hazard in the indoor environment. Because of the variety of fungi and moulds and the varied conditions under which they may grow; mould growth in buildings may affect the health of occupants in many ways. In the workplace some believe they are responsible for, or at least contribute to, SBS and more generally they may contribute to other building related illnesses as well as producing allergic responses and other health problems.

Heavy and extensive exposure to fungal contamination may occur in certain agricultural settings or to the professional working in the business of renovation/cleaning/mould assessment may put people at risk of developing organic dust toxic syndrome (ODTS) [11,12] or hypersensitivity pneumonitis commonly known as Farmer's lung disease which is an immune response in the lung involving microbial antigens found in mouldy hay [12,13].

Health Effects

Most fungi generally are not pathogenic to healthy humans but moulds and other fungi may adversely affect

human health through 3 processes: allergy; infection; and toxicity. They do so through the production of spores, mycotoxins and VOC emissions. While infection and toxicity are extremely important when they occur, the most general and certainly the commonest problem is allergy. I make no apologies, therefore, for concentrating in this article on discussing allergic reactions in buildings, their signs and symptoms, types of allergies, the variety of indoor allergens and their management [14–21].

Allergy

Allergic reactions are generally confined to rhinitis, eye irritation, cough and aggravation of asthma but related to these is hypersensitivity pneumonitis or Farmer's lung caused by a number of organisms including actinomycetes. Allergies are caused by several organisms from a number of fungal classes including members of the Ascomycetes and Basidiomycetes classes.

In the most common allergic conditions the biological particles, for example fungal spores, are largely respirable and generally have a diameter greater than 5 μm. This includes spores of most commonly occurring moulds such as the followings; *Alternaria alternata*, *Botrytis cinera*, *Cladosporium herbarum*, *C. macrocarpum*, *Drechslera* spp. and *Epicoccum purpurascens*. Moulds of particular allergenic importance include *Botrytis*, *Rhizopus* and *Trichoderma*. Certain yeasts, unicellular fungi that reproduce by budding or fission, are allergenic and have considerable clinical importance, notably Candida.

Allergy and Environmental Illnesses

Allergy in the workplace environment is a growing concern for employers and it is a complex issue, which requires a multidisciplinary integrated approach. The incidence of the problem is increasing at an alarming rate. Exposure to indoor allergens is a risk factor for susceptible individuals. Should they develop allergic reactions this will reflect on their health, comfort and productivity. A basic understanding of the problem is needed and a solution sort through close dialogue between employees and those responsible for human resources including facilities managers and health and safety officers. In established buildings it is essential to consult with architects, engineers and building health specialists in order to identify, evaluate, monitor and remedy the conditions responsible for allergic reactions suffered.

The Problem of Damp

Buildings which suffer from dampness (rising or penetrating dampness) or other moisture problems, whether chronic due to condensation, or acute following fire fighting or flood damage, experience significantly higher numbers of micro-organisms in their indoor environment. This creates problems for atopic people who work in the buildings. Acute dampness problems can be solved by drying out the building fabric, although this may not be an easy task to do as saturated building fabric takes years to dry out naturally. Chronic dampness is quite different. It has to be remembered that a prolonged residual moisture problem may also cause troubles for non-allergic people, who may nevertheless develop several of the mucosal and general symptoms of the allergy sufferers.

Pathogenic Fungi

Although more than 100,000 species of fungi have been described only a limited number of these are known to be pathogenic to humans, for example: *Aspergillus*, *Blastomyces*, *Coccidioides*, *Cryptococcus* and *Histoplasma*. These can infect non-immunocompromised individuals producing the infections, aspergillosis, blastomycosis, histoplasmosis, cryptococcus and coccidioidomycosis. People with severely impaired immune function, e.g., cancer patients receiving chemotherapy, organ transplant patients receiving immunosuppressive drugs, AIDS patients and patients with uncontrolled diabetes, are at significant risk for more severe opportunistic fungal infection. The most common of such fungi in both adult and paediatric populations, in descending order of frequency, are *Alternaria*, *Helminthosporium*, *Cladosporium*, *Fusarium*, *Aspergillus*, *Phoma* and *Penicillium*.

Volatile Organic Compounds

Many moulds produce volatile organic compounds (VOCs) as part of their normal metabolism including, alcohols and ketones such as 3-methylbutanol, octen-3-one, octan-3-one, octan-3-ol, 2-octen-1-ol, 1-octen-3-ol and 1,10-dimethyl-trans-9-decalol (geosmin). Other compounds such as 2-methyl isoborneol and 2-methoxy-3-isopropylpyrazine are among those which contribute to the "musty", "mouldy" or "earthy" odours associated with mould growth in damp buildings. The principal volatile of moulds is ethanol in damp buildings. There is little evidence that they cause specific human health effects [9]. However the literature has many references to nasal irritation and feelings of stuffiness caused by fungal VOCs. It is not possible to be too specific about these reactions because many VOCs can have irritant effects [22] and it is difficult to apportion a fungal VOC fraction among the total VOC background.

beta-1,3-D-glucans

All fungal cell walls including spores and hyphae contain beta-1,3-D-glucans, medically significant glucose polymers that have immunosuppressive, mitogenic (i.e., causing mitosis or cell transformation) and inflammatory properties [23]. The response of pulmonary alveolar macrophages and the immune system to beta-1,3-glucans is only partially understood, but it appears that exposure causes inflammation reactions in lymphocytes affecting lymphocyte mitogenicity, affects IL-1 secretion (via T-cells) and stimulates bacterial and tumour defence. The glucans decrease the number of pulmonary alveolar macrophages and also affect phagocytosis [1,10,24,25]. Animal experiments have shown that this material also appears to act synergistically with bacterial endotoxins to produce airway inflammation following inhalation exposure in guinea pigs [4].

Mycotoxicity

Many fungi produce metabolites that are responsible for the commoner severe effects on health. Moulds and their spores may produce these biologically active molecules which are known as mycotoxins. However, the right environment must be present for a mycotoxin-producing mould to actually produce a mycotoxin. Also, there must be a route of exposure from a person to the mycotoxin. This may be direct contact with mouldy material, inhalation of airborne spores or fungal fragments or of contaminated building materials. There are several toxic reactions ascribed to mycotoxins [26]; a simple toxic reaction known as mycotoxicosis, immunological disregulation that can cause immunosuppression and can have many clinical effects, not only in the lungs but also potential neurological effects and there are other mycotoxins that are carcinogenic [1,10,24,25] of which the aflatoxins are probably the best known.

There are a large number of toxic mould metabolites produced by a diverse range of moulds in damp domestic housing, with an extraordinary diversity of chemical structure and biological activities [27]. *Stachybotrys chartarum* was originally implicated in stachybotryotoxicosis of farm animals, especially horses fed on contaminated mouldy hay, and occasionally with the people handling such hay [28]. More recently *Stachybotrys chartarum* has been implicated in illnesses associated with living in damp houses in which this very cellulolytic species can grow on wallpaper and plaster board when they have become wet.

A low concentration of the toxic mould metabolite "Satratoxin H" produced by *Stachybotrys chartarum* in damp houses can cause necrosis and haemorrhage in many organs. A recent review of the diversity of moulds associated with damp houses emphasises the importance of toxic mould metabolites (macrocyclic trichothecenes) produced by *Stachybotrys chartarum* [29]. There have been several well documented incidents of adults suffering a range of illnesses following exposures to the spores of *Stachybotrys chartarum* in damp buildings [30].

The most recent reports of idiopathic pulmonary haemorrhage in very young children in Cleveland, Ohio, USA have really put the spotlight on this group of moulds [31]. *Stachybotrys chartarum* is a complex mould species and seems to contain at least 2 distinct phylogenetic species [32]. There is no correlation between genetic characteristics and geographical distribution [33]. Both chemotypes have been described, 1 characterised by the production of cytotoxic macrocyclic trichothecenes and the other by the production of a group of diterpenoid metabolites known as atranones. These induce inflammation and may occur in damp buildings which makes it difficult to determine cause and effect, a difficulty compounded by the ability of these moulds to produce several other toxic metabolites under these conditions [31].

Indoor air quality issues associated with exposure to mould and related substances (e.g., mycotoxin) are becoming of greater importance. A few governmental agencies have published guidelines on mould assessment and remediation but most are very general in nature [34–36]. These guidelines mostly focus on Black Mould (*Stachybotrys chartarum*) as the major concern [37]. Most of the mould genera encountered are "toxic" and allergenic [34,35], and can be considered to constitute a serious problem.

Environmental Exposure and Assessment

Inhalation exposure to very high concentrations of fungal spores leading to hypersensitivity pneumonitis, lower levels of exposure to conidia also have consequences, for atopic and non-atopic individuals. In addition to allergic effects that they may have on atopics, such exposures apparently produce a variety of non-allergic effects on lung function, particularly interference with pulmonary alveolar macrophage cells. A variety of undesirable effects occur if sufficient numbers of these cells are damaged when a variety of biochemical changes occur. Unusual exposure to fungal spores, alone and in combination with biotic and abiotic factors can be

expected to promote viral and bacterial disease and decrease general well being.

Indications of a possible mould problem affecting the inhabitants rather than the structure of a building can include rhinitis (sneezing attacks, nasal discharge or blockage) which maybe seasonal (Hay Fever or Allergic Rhinitis) or experienced throughout the year (Perennial Rhinitis). Seasonal rhinitis is the most common of all allergic diseases. Nasal irritation and sneezing are the most common symptoms but many also suffer from itching of the eyes. A common fungal cause is *Cladosporium herbarum* the spores of which can be found virtually all year round although many fungi can produce allergic responses [38]. Understanding the aerobiology of fungal spores is an important part of understanding human atopy due to moulds. The allergic responses are generally due to the inhalation of spores rather than mycelia-derived material [39–41].

Work has shown that the spores and not just the vegetative mycelium of many toxigenic moulds, contain mixtures of the toxins which are known to be produced by the species. For example, the conidia of number of toxigenic moulds including: *Fusarium graminearum* (DON), *F. sporotrichioides* (T-2), *F. moniliforme* (fumonisin), *Stachybotrys chartarum (atra)* (satratoxins), *Penicillium expansum* (citrinin), *P. chrysogenum* (roquefortine C), *P. brevicompactum* (mycophenolic acid), *Aspergillus versicolor* (sterigmatocystin), *A. flavus*, *A. parasiticus* (aflotoxins) [1,10,24,25]. One of the most dangerous moulds that may be encountered in the built environment is *Stachybotrys chartarum (atra)*. This is a greenish black fungus that grows on material with a high cellulose and low nitrogen content, such as wallboard, gypsum board, paper and other materials found in buildings that are chronically moist or have been water damaged due to excessive humidity, water leaks, condensation, water infiltration or flooding as described above.

Environmental Control of Allergens

Environmental control of allergens consists of 3 possible treatment methods that can be used singly or in combination: avoidance; pharmacotherapy; and immunotherapy. For example, elimination of allergen reservoirs, control of humidity, exposure to heat or cold and air filtration. Air filtration and vacuum cleaning have long been recommended for control of dust mites but their efficacy is variable. If filtration is recommenced then high-efficiency particulate air (HEPA) filters are probably most effective.

Pharmacotherapy of allergic diseases due to living in the built environment deals with the patient not the cause. The first step should be avoidance – if possible – of identified allergens and, failing this, immunotherapy including specific hyposensitisation and pharmacotherapy.

Monitoring

A range of instrumentation is available for monitoring physical, biological and chemical pollutants in buildings including moulds, bacteria and house dust mites. The choice of sampling equipment requires careful consideration of the purposes of the investigation, the information required, the characteristics of the biological pollutants in the environment being studied and the sampling and trapping efficiencies of the available samplers. Methods available also include equipment for sampling airborne allergens, airborne mycotoxins, volatile metabolites and endotoxins.

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