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Review

Indoor moulds, Sick Building Syndrome and building related illness

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ABSTRACT

Humans are constantly exposed to fungi, or moulds, usually without suffering harm to health. However, in some instances inhalation of sufficient numbers of mould spores can trigger symptoms of asthma, rhinitis or bronchitis. Respiratory ill health associated with the built environment is often referred to either as Sick Building Syndrome [SBS] (i.e. building related symptoms) or building related illness. For many, the difference between SBS and building related illness is unclear and the two overlap. This review examines the differences between the two and describes in more detail the role of moulds in building related illness. Using as examples the after-effects of flooding in the UK in 2007, and Hurricane Katrina in USA in 2005, methods used to investigate exposure to indoor mould contamination are described, together with strategies for remediating mould contaminated buildings.

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1. Introduction

Fungi, or moulds, are ubiquitous in the environment; therefore we are constantly in contact with them. In most cases they present no harm to human health and exposure, for example inhalation of airborne mould spores is tolerated by their physical expulsion or by their elimination by the immune system. However, for those who are immunologically sensitized, inhalation of sufficient numbers of mould spores can trigger symptoms of asthma, rhinitis or bronchitis (Husman, 1996; Fung and Hughson, 2003).

Seasonal asthma may be triggered by temporarily raised outdoor levels of mould spores at certain times of the year, while agricultural or industrial activities such as grain

handling or waste disposal can result in massive exposure leading to occupational asthma (Poulsen *et al.*, 1995; Eduard *et al.*, 2004; Heederik and Sigsgaard, 2005). However, in an increasingly urban based society people spend approximately 85–90 % of their time inside buildings (Brown, 1983; Klepeis *et al.*, 2001) therefore, aside from the above examples, the most likely means of inhalation exposure to mould spores is from mould sources within the built environment.

Respiratory ill health associated with the built environment is often referred to either as Sick Building Syndrome [SBS] (i.e. building related symptoms) or building related illness. For many, the difference between SBS and building related illness is unclear and the two overlap. This review aims to clarify the differences between the two and then to

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examine in more detail the role of moulds in building related illness, how to investigate exposure to indoor mould contamination and what to do to remediate mould contaminated buildings.

2. Sick Building Syndrome – what is it?

Sick Building Syndrome (SBS), as described in UK/European terminology, or building related symptoms as it is referred to in the United States, has been described as ‘a group of symptoms of unclear aetiology’ (Burge, 2004). In broad terms, these symptoms can be divided into mucous membrane symptoms related to eyes, nose and throat; dry skin; general symptoms of headache and lethargy. These symptoms are common in the general population. What makes them part of SBS is a temporal relation with work in, or occupation of, a particular building. Therefore, with SBS most of the above symptoms should improve within hours of leaving the problem building.

SBS is most clearly recognised in the office environment. However, similar problems could occur, and have been reported, in schools, hospitals or care homes. In Nordic countries, their definition for SBS also attributes ill health symptoms to indoor air problems in domestic dwellings, especially associated with water damage (Berglund *et al.*, 2002). In order to define SBS, Raw *et al.* (1995) developed a symptom questionnaire which, in summary, comprised the following series of questions:

- In the past 12 m have you had more than two episodes of:
 - Itchy or watery eyes;
 - blocked or stuffy nose;
 - runny nose;
 - dry throat;
 - lethargy and/or tiredness;
 - headache;
 - dry, itchy or irritated skin.
- If ‘yes’, was it better on days away from office?

3. SBS population studies and factors related to increased prevalence of SBS

A comprehensive and long term study of SBS is the ‘Whitehall II’ SBS study, which is an ongoing longitudinal health survey of UK office-based civil servants. The study commenced at baseline with a total of 10,308 male and female office staff aged between 35 and 55 y, and by the time of recent reporting of detailed findings Marmot *et al.* (2006) had a retained population of 4052 male and female participants aged between 42 and 62 y occupying 44 buildings. Participants in the study have been asked to complete a self-reported questionnaire which collates data on the following ten symptoms: headache; cough; dry eyes; blocked/runny nose; tired for no reason; rashes/itches; cold/flu; dry throat; sore throat; and wheeziness.

Key findings of the ‘Whitehall’ SBS study are summarised as follows. While 25 % of men and 15 % of women reported no symptoms, 14 % of men and 19 % of women reported five or more. The physical environment, including exposure to

airborne fungi as judged against an ‘acceptable limit’ of 500 colony forming units (cfu; a measure of the numbers of cells/spores capable of growing to form a colony on agar media) per m³ air and bacteria of 1000 cfu/m³ air, was considered to have less of an effect than the psychosocial work environment. For example, the ability of an individual to exert control over the environment of their local workstation was related to a lowering of reported symptoms.

Features of the indoor office environment that were shown to have significant effect on reporting of SBS symptoms can be divided into personal and building factors. Personal factors leading to greater reporting of SBS are female gender, lower status in the organisation and working on more routine tasks. Building factors include raised levels of paper dust or office dust, extensive use of computers and the presence of cigarette smoke, although recent changes in legislation to ban smoking in indoor areas will eliminate this factor. Other building related factors include high indoor temperature, little or no outdoor air ventilation, poor individual control of temperature and lighting, air conditioning and especially its poor maintenance, poor office cleaning regimes and water damage.

4. SBS and mould exposure

Mould exposure has previously been considered as a significant factor in SBS, but from recent studies it has become clear that there is no strong evidence of a contribution (Burge, 2004). However, biological agents do contribute to human health consequences that may be described as building related disease. These include infectious disease associated with building services (e.g., Legionellosis), diseases spread from worker to worker including colds and influenza, toxic reaction to chemicals in buildings, and fungi, bacteria or their toxins present in buildings.

A fundamental question that needs to be asked relates to the role of mould exposure in buildings, and how important it is as an occupational or public health issue. Research into mould exposure indoors has been less extensive in the UK than in other European countries, with the most comprehensive data set probably available from the Nordic countries (Hyvärinen *et al.*, 2001; Meklin *et al.*, 2003; Patovirta *et al.*, 2004). This may reflect building design, with a greater emphasis on structurally tight buildings for heat and energy conservation giving rise to the potential for damp conditions that could promote mould growth. Building materials often reflect what is available locally, therefore there is a greater use of timber in construction in Nordic countries. Indoor mould exposure and ill health have been extensively researched in USA. The most recent research has indicated that dampness is more of an indicator of increased respiratory symptoms and respiratory infections (IOM, 2004; WHO, 2009). A review of lower respiratory symptoms in 80 office buildings investigated by the US National Institute of Occupational Safety and Health (NIOSH) found an association between moisture and debris in the ventilation systems and adverse respiratory health effects (Mendell *et al.*, 2003). However, a review of symptoms using the United States Environmental Protection Agency Building Assessment Survey Evaluation (BASE) study found that most office buildings have occupants

who report building related symptoms (Brightman *et al.*, 2008). Sahakian *et al.* (2009) surveyed a total of 4345 adult residents to examine potential associations between building dampness, the use of air conditioning and respiratory ill health. Significant positive association was found between workplace dampness and sickness absence attributed to respiratory symptoms. The estimated cost burden to the US economy resulting from this was put at US\$1.4 billion.

5. Causes of mould growth in buildings and contributory factors

Not surprisingly, the main factors influencing mould growth in buildings are the fundamentals of mould growth in any circumstances. Construction materials and furnishings in the indoor environment can provide nutritional requirements that may promote colonisation. Many moulds can utilise cellulose in wallpaper, or starch in wallpaper paste, the toxigenic mould *Stachybotrys* sp. can grow on the paper covering on gypsum plaster boards (Canadian Construction Association, 2004), and timber used in construction, etc. (Menetrez and Foarde, 2004). Wooden furnishings and fabrics are also susceptible to mould colonisation, augmented by organic soiling, dust and food debris. However, all of the above will only occur given the right conditions of water availability, usually relative humidity greater than 60% throughout a building or in localised areas, together with sufficient warmth to allow mould spore germination and hyphal growth. Conditions that are likely to exacerbate mould growth include inadequate ventilation, poor maintenance, water intrusion and the use of heating, ventilation and air conditioning (HVAC) systems (Kemp *et al.*, 2003).

Based on evidence gathered from investigations of mould in buildings where users have reported respiratory and other ill health complaints, the following are major factors. Ingress of rainwater, such as from a roof or drainage system leak, can rapidly lead to mould growth problems if not thoroughly remedied. In some instances, an insidious and undiscovered roof leak can cause problems. The result could be visible mould growth on surfaces, but may be less obvious such as on a wall behind wallpaper or under floor coverings. Localised damp areas can occur in the space between a wall and a large item of furniture such as a cupboard. Water damage and resulting mould growth may be obvious on the room side of suspended ceiling panels, but may be indicative of more extensive mould growth occurring behind the panels in the ceiling void. Similarly, mould growth may develop in cavity wall spaces (Sessa *et al.*, 2002; Gots *et al.*, 2003; Lugauskas and Krikstaponis, 2004; Canadian Construction Association, 2004).

6. Investigations of flood damage and mould contamination in buildings

In the summer of 2007, abnormally heavy rainfall led to flooding in several areas of the UK. In one instance, this flooding affected a Government department occupying the building and personal documents from members of the public held by the department. Under normal circumstances, flood damaged paperwork would be disposed of, but in this instance

it was not appropriate. A strategy therefore was needed to retrieve, remediate and recover documents firstly potentially contaminated by sewage contaminated water, and secondly paper materials that were wet and in the warm conditions likely to become rapidly colonised by mould growth. Guidance or advice was limited at the time, although subsequently the UK Environment Agency issued information on their website (Environment Agency, 2009). Practical advice provided by Health and Safety Laboratory included personal protection for workers handling the contaminated documents to limit exposure to bacteria associated with sewage in the water, and rapid action to separate the documents to facilitate drying and so prevent mould colonisation. Other options were considered, such as freezing the documents to halt mould contamination whilst a recovery strategy was planned.

On a much greater scale was the devastation caused in New Orleans and surrounding areas of USA by Hurricane Katrina in 2005. Buildings that survived intact were still likely to have been affected by heavy rainfall and flooding; leading to gross colonisation of wall coverings by mould growth and more insidious colonisation of the building fabric (Figs 1–4). One set of studies found that moderately to heavily contaminated homes had an airborne culturable mould concentration of 67,000 cfu/m³ as a geometric mean (Rao *et al.*, 2007; Riggs *et al.*, 2008). The predominant moulds identified were *Aspergillus niger*, *Penicillium* spp., *Trichoderma*, and *Paecilomyces*. One investigation, which looked at the remediation of homes after the hurricanes, found culturable mould concentrations ranging from 22,000 to 515,000 cfu/m³ (Chew *et al.*, 2006). *Aspergillus*, *Paecilomyces*, and *Penicillium* were the predominant genera. Another study looked at the aerosolisation of mould from flood contaminated bedding, linoleum, rugs, and carpets in a laboratory setting using a fungal spore source tester (Adhikari *et al.*, 2009). The investigators found that the level of airborne mould concentration aerosolised from these materials ranged from below the analytical limit of detection to 260,000 cfu/m³ (Adhikari *et al.*, 2009). *Aspergillus*, *Penicillium*, and *Cladosporium* were the predominant genera.

Health consequences from exposure to these moulds have been reported (CDC, 2006; Cummings *et al.*, 2008). The US Centers for Disease Control and Prevention (CDC) in conjunction with the Louisiana Department of Health and Hospitals conducted a survey in New Orleans and the surrounding communities to look at the degree of mould contamination and use of personal protective equipment (PPE) in the water-damaged homes (CDC, 2006). They found that the majority of respondents who were classified as remediation workers (72/76 [95%]) believed mould could make people sick and that respiratory protection (65/76) should be used while remediating mould. Cummings and associates conducted a random study of residents in post-hurricane New Orleans to look at respiratory symptoms and PPE usage (Cummings *et al.*, 2008). The study was conducted 6 m after the hurricanes using administered questionnaires. Respiratory symptoms were positively correlated with exposure to water-damaged homes and that PPE usage (respirators) reduced symptoms when worn while in the water-damaged homes. Three hundred sixty (65%) of the 553 participants reported at least one upper respiratory symptom (UPS) and 245 (44%) reported at least one lower respiratory symptom



Fig. 1 – Mould damage in a domestic dwelling affected by Hurricane Katrina.

(LRS). The most commonly reported symptoms were nasal symptoms (URS) and cough (LRS). Three hundred fifteen respondents reported using either a mask or respirator during clean-up. In October 2005, the CDC Mold Work Group

published guidelines entitled “Mold prevention strategies and possible health effects in the aftermath of hurricanes and major floods” that addressed potential health effects, clean-up, and PPE issues (Brandt *et al.*, 2006).

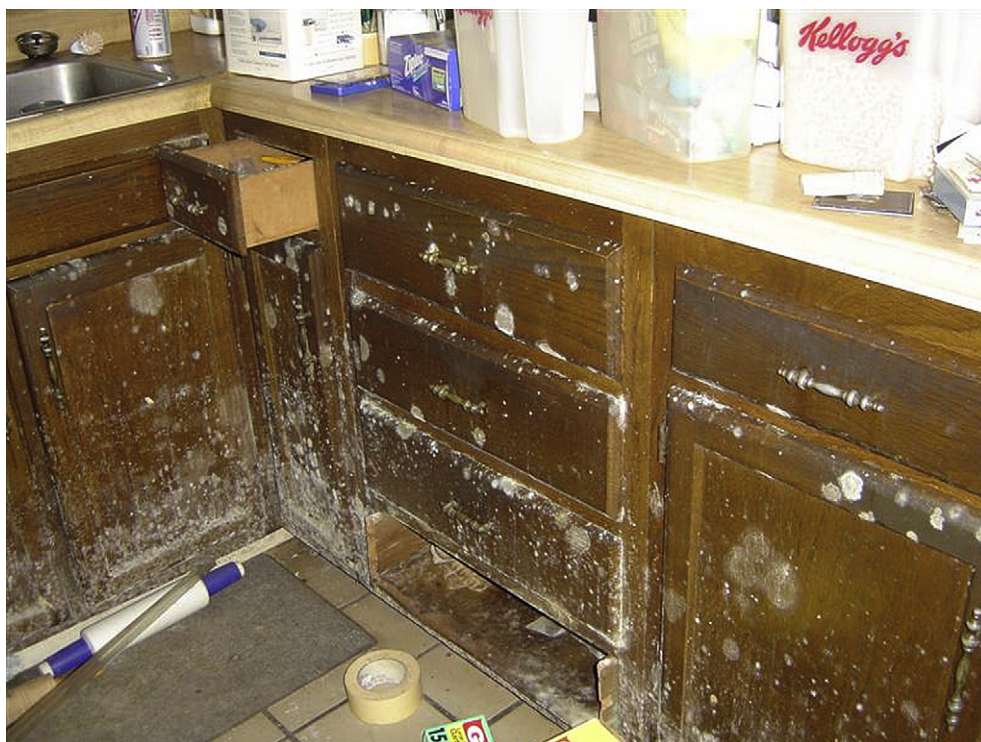


Fig. 2 – Mould damage in a domestic kitchen affected by Hurricane Katrina.



Fig. 3 – Mould damage in a domestic living room affected by Hurricane Katrina.

7. Intervention and investigation strategies in mouldy buildings

In most instances, investigations of buildings related human exposure and reported ill health are dealing with more insidious mould colonisation than may be found after flood damage. This therefore requires methods for measuring representative exposure levels and a point of reference to establish whether the exposure levels are atypical, given that some airborne moulds will always be present. Various guidance limits or action levels have been proposed. For example, Switzerland has determined that a level greater than 1000 cfu/m³ represents a probable contamination source (SUVA, 2005). In Europe, EC guidelines state that greater than 500 cfu/m³ may be considered an intermediate level of exposure for a building occupant, whereas >1000 cfu/m³ is a high level of exposure in indoor non-industrial workplaces. Investigation and possible remediation are required when indoor mould levels exceed 500 cfu/m³ and when there have been health complaints such as headaches, fatigue and cough (Baubiologie Maes, 2008; CEC, 1993). However, it is acknowledged that levels in excess of these guidelines do not necessarily imply unsafe or hazardous conditions. In the United States, there are no exposure levels for airborne concentrations of mould (OSHA, 2003). Sampling for mould is usually conducted in support of a scientific hypothesis. Frequently, no sampling is conducted; the source of the moisture is addressed; and the mould growth remediated. In some 'non-complaint' buildings, i.e. where occupants have not expressed health concerns associated with the quality of the indoor air, airborne mould concentrations may exceed

500 cfu/m³, and may even exceed levels detected in buildings with complaints of non-specific health symptoms. As well as determining the number of airborne cfu/m³, identification of predominant moulds is important to evaluate properly the hazard to workers. Mould concentrations may also vary between geographic location and in different seasons, therefore comparison of levels in non-complaint and complaint buildings collected at the same time may aid the evaluation (Gots *et al.*, 2003; Bartlett *et al.*, 2004).

For new buildings, prevention measures proposed to reduce the potential for development of mould contamination include:

- Minimise exposure of interior building products to exterior.
- Monitor and maintain integrity of building impermeable envelope.
- Check material delivered clean and dry – reject wet or mouldy material.
- Protect stored materials from moisture.
- Minimise moisture accumulation during construction.
- Balance HVAC systems to control thermal comfort and humidity.

(European Agency for Safety and Health at Work European Risk Observatory Report, 2007)

For problems arising in existing buildings, strategies for investigation or assessment have been published (US EPA, 1991; AIHA, 2006). In summary, these comprise:

- Walk-through inspection of the premises including HVAC system.



Fig. 4 – Mould damage to walls and ceiling in a domestic dwelling affected by Hurricane Katrina.

- Documentation of history of water damage.
- Measurement of temperature, relative humidity and air movement.
- Check for visible mould, mould odours.
- Check for hidden mould (intrusive inspection behind wall-paper/panels, under carpets, in ceiling or wall cavities).
- Perform air, surface sampling if necessary.

(European Agency for Safety and Health at Work European Risk Observatory Report, 2007; Prezant *et al.*, 2008)

Environmental assessments can include physical removal of building materials, furnishings or water from HVAC systems for microbiological analysis, swab or wipe sampling of surfaces to collect moulds for analysis, or air sampling to assess the impact of mould colonisation of buildings on indoor air quality. Numerous air sampling methods exist, the most frequently used being agar plate impaction methods or collection by filtration. Each method has its advantages and limitations, as have been described in detail previously (Muilenberg, 2003; Lee *et al.*, 2004a,b; Prezant *et al.*, 2008). For example, impaction directly onto agar plates may maximise survival of culturable organisms, while filtration devices are adaptable enough to enable air samples to be taken from wall cavities or roof spaces to pinpoint foci of contamination. Samples collected on filters can also be observed and enumerated by direct microscopy.

Other assessment methods for mouldy buildings can include the use of smoke pencils to assess air movement, as stagnation points can lead to localised areas of raised humidity and possible foci of mould growth. Using humidity meters to check moisture levels in air and in building materials are also important to identify locations potentially at

risk and in need of intervention. Temperature assessments are also useful tools to identify comfort issues which are also tied into building environmental quality.

Fundamental to an investigation of mould problems in buildings is not only an awareness of typical numbers of airborne moulds, or action levels for remediation, but also typical species and their predominance. This assists in knowing whether the airspora within a building is atypical. A study by Gravesen *et al.* (1997) revealed that typical predominance of moulds in materials taken from water-damaged buildings was as shown in Table 1.

Once a mould problem has been identified and the need to remediate established, an action plan can be followed (US EPA, 2001; OSHA, 2003; NYCDHMH, 2008; Prezant *et al.*, 2008), in summary:

Table 1 – Predominant mould species in water-damaged buildings (from Gravesen *et al.*, 1997).

Mould species	Percentage frequency of isolation in air samples (%)
<i>Penicillium</i>	68
<i>Aspergillus</i>	56
<i>Chaetomium</i>	22
<i>Ulocladium</i>	21
<i>Stachybotrys</i>	19
<i>Acremonium</i>	14
<i>Mucor</i>	14
<i>Paecilomyces</i>	10
<i>Alternaria</i>	8
<i>Verticillium</i>	8
<i>Trichoderma</i>	7

- Notify people working or living in the building about the problem and remove people from exposure before remediation starts.
- Identify and fix the underlying moisture problem.
- Minimise spread of contamination which can include sealing off of ventilation systems, use of negative pressure ventilation, use of plastic sheeting in entrances and exits of the work area, and cleaning of pathways.
- Protect remediation workers from exposure using PPE.
- Remove affected porous materials.
- Clean mould growth with soap and water.
- Chemically treat remaining materials if necessary.
- Dispose of mouldy materials in sealed heavy-duty plastic bags.

8. Conclusions

Sick Building Syndrome is a complex spectrum of ill health symptoms associated with the indoor environment, but there is little evidence that microbial exposure, itself, is a significant factor. However, other building related illnesses exist that are associated with microbial exposure, including mould exposure. Poor maintenance of buildings or water damage can result in accelerated mould growth and associated exposure which can in turn lead to health problems, mainly respiratory allergies. A significant social and economic cost has been identified. Monitoring of indoor air reveals a wide range of mould species, some of which are naturally present in low numbers, but their presence in large numbers or in altered predominance is indicative of a source of colonisation within the building. Aggressive remediation may therefore be needed to prevent developing or continued problems where such colonisation is indicated.

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