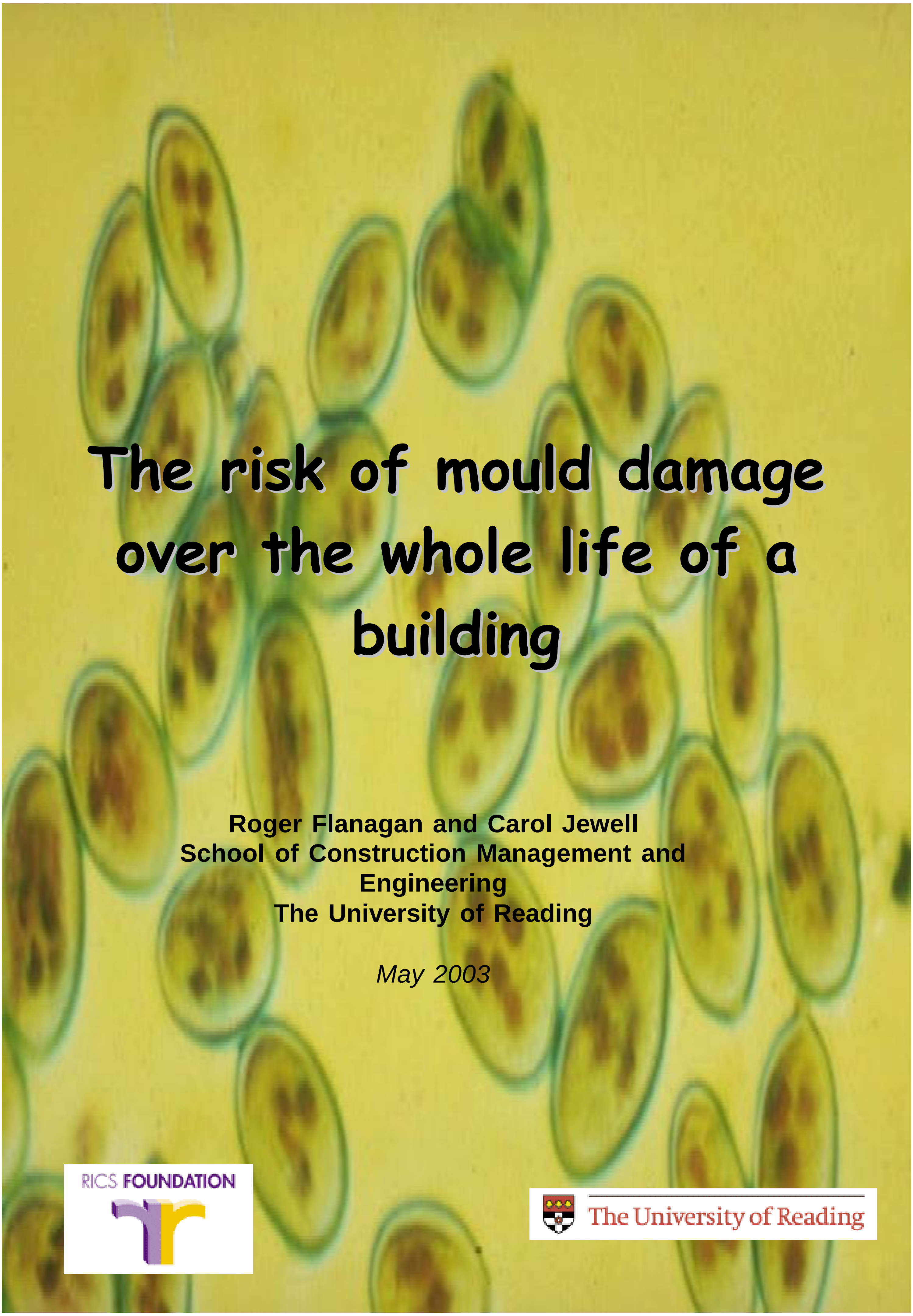

The risk of mould damage over the whole life of a building

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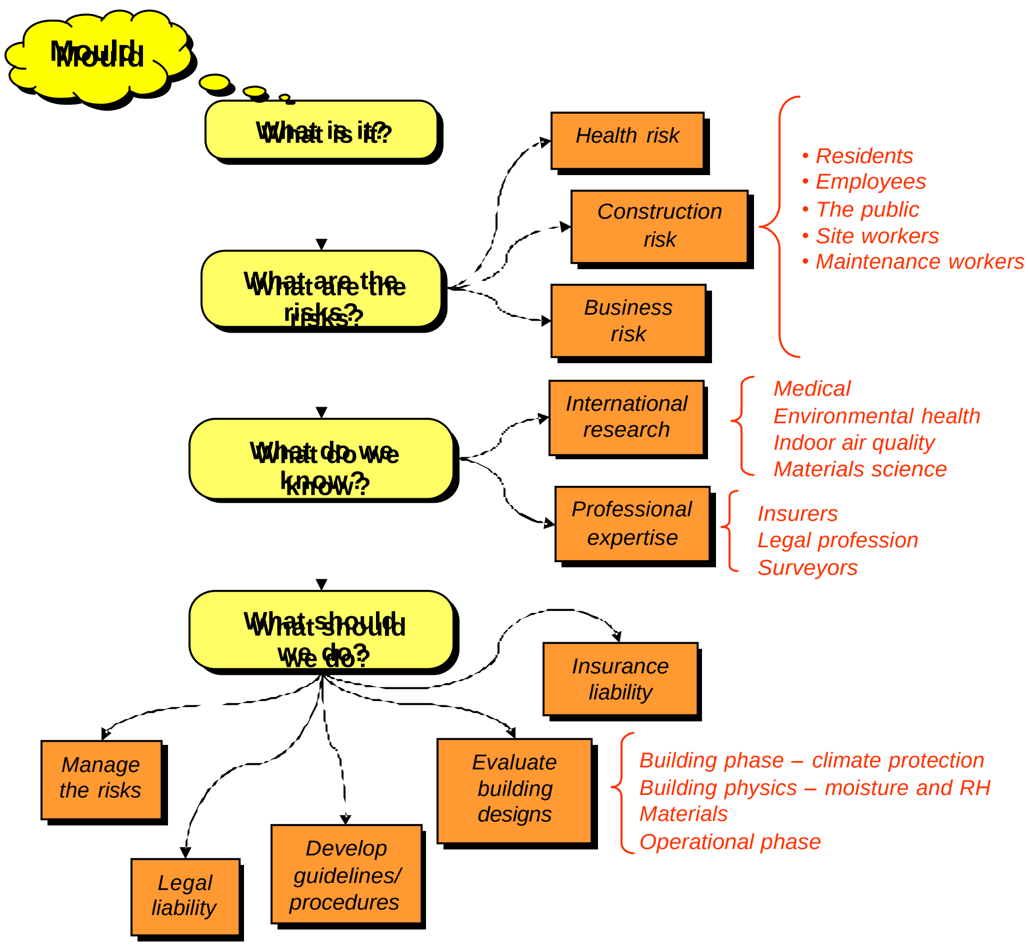
Introduction

Mould is not a new problem. There is no shortage of technical knowledge, with extensive research being undertaken into the science of mould growth, moisture, and the degradation of the materials. However, there is a gap between the science/research into the problems of moisture in buildings, and the application of this knowledge on site, at the design stage, during the construction phase, and in the occupancy phase. The many perspectives of the problem from scientific and health issues, to the practical solutions of mould problems, mean that the research and information can be found in many disciplines, not all readily available to design and construction professionals. Figure 1 outlines the process of a risk assessment of mould.

Figure 1 A risk assessment of mould



Mould can be found almost anywhere. Spores are present in both indoor and outdoor air and cannot be seen by the naked eye. These spores need nutrition, moisture and the right temperature in order to begin growing. Many of today's building practices and building usage have increased one or other of these factors and the mould problem has become a problem that cannot be ignored. Nutrition, moisture and temperature/relative humidity are the critical factors in the control of mould and the adjustment of any of these can reduce the risk considerably. The production, storage and construction of organic materials such as wood and plasterboard need to be evaluated. An operational risk evaluation technique is needed to minimise the risk exposure arising from mould growth and its impact upon health.

The risk of mould needs to be managed by:

- Developing an operational risk procedure for managing the risk of mould.
- Designing out mould by making the design and construction team more aware of the risks of mould.
- Re-think materials – their supply, storage and use to minimize the problem of moisture. Look at alternatives and set 'standards' in co-operation with materials suppliers.
- Produce guidelines for site workers and maintenance teams on the handling of mould problems.
- Use commercially available simulation tools and models to test the design and construction for the likelihood of mould growth.
- Be aware of existing built assets that are at risk of mould.
- Review HVAC systems to minimize the risk of mould.
- The construction sector needs to pool the existing knowledge and provide a focus for continued research and development in the subject area.

Observations from the international literature survey

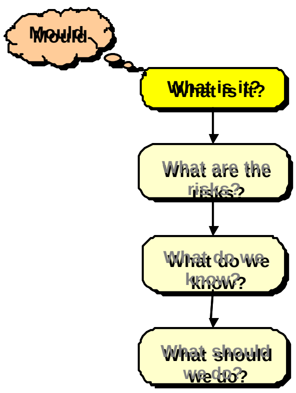
An international literature review was undertaken and listed below are some of the observations about mould growth:

- The problem is not new. It is well understood by the scientific and research community, but there is a gap between this knowledge and those involved in the construction process. There is also a gap between the knowledge of specific materials, their characteristics in certain positions and conditions, and in the way that the design community incorporates the materials into a design.
- There is a gap in knowledge about moisture and mould growth between site management and the operatives who face the day -to-day challenges of meeting deadlines and operating in harsh site conditions.
- The mould problem has increased significantly as we have moved from heavy construction to the use of lightweight materials, and to high levels of insulation and air tightness, and air conditioning.
- The concern about mould growth and its affects is widespread in many developed countries. The Indoor Air Quality Association says that the single most important indoor air quality issue is moisture, mould and other forms of microbial contamination of buildings (2000).
- Mould-related health risks are allergic reactions; respiratory infections; and the response to fungal metabolites (eg. VOC and mycotoxins) related to Sick Building Syndrome (SBS).

- Asthma and allergies are the most chronic diseases overall in the developed world. There has been a rapid increase in the illnesses in the past 15 years; the rate has doubled. The illness rate in the USA and Japan has climbed by 75%. Mould and moisture are known to play a major role in the exacerbation of asthma.
- Building codes and standards do not disregard the problems of moisture and mould, but they do not adequately deal with all the issues. We found no regulations or standards for airborne mold contaminants.
- Designers often assume a perfect world; they disregard the practical implications of constructing in a harsh site environment.
- The site workforce is not trained to understand the science of mould growth, and the necessity for the protection of materials during the production phase specifically to prevent mould growth.
- The building materials manufacturers and suppliers transfer the risk of mould growth to the contractor, by providing installation instructions and adding caveats that the material must be kept dry at all times.
- The legal frameworks are not well developed to cope with the effects on health of mould growth. However, increasing claims for ill health by building occupants and owners are leading to a growing body of knowledge in the legal community.
- Insurance premiums for many forms of liability are increasing. There is nervousness in the insurance industry about the implications of mould growth on health.
- The risk of mould growth can be minimised with the right knowledge, technology and training across the manufacture, design, production and operation phases.

The site workforce is not trained to understand the science of mould growth

Mould – what is it?



Moulds and mildew are fungi that grow on the surfaces of objects, within pores, and in deteriorated materials. A source of fungal spores is always present in indoor air (*Adan, 1994*). There are more than 100,000 species of mould. The commonly found species in mould-infested buildings are: *Penicillium, Aspergillus, Stachybotrys, Altenaria and Chaetomium* – see Table 1. They can cause discoloration and odour problems and deteriorate building materials.

Toxic moulds are those capable of producing mycotoxins – the natural organic compounds that are capable of initiating a toxic response in vertebrates. The conditions that cause mycotoxin production are not yet fully understood.

All of the following conditions are necessary for mould growth to occur on surfaces:

- Temperature range above 5°C and below 38°C
- Mould spores
- Nutrient base (most surfaces contain nutrients)
- Moisture

Moisture is considered to be one of the main reasons for deterioration in a building (*Geving, 1997*), and is the cause of an estimated 75%-95% of damage to the building envelope (*Trechsel, 1994; Bomberg & Brown, 1993*). Moisture is an important factor in the production of materials, their transport and storage, and in the construction and operational phases and poses the biggest threat to a building's fabric. One problem of designing buildings for naturally damp climates is that many parts of the construction are above the critical relative humidity level –

The problems of mould and moisture in buildings need to be designed out.

this can lead to mould growth. The solution cannot be to eradicate mould growth, but to control it within acceptable boundaries. The problems of mould and moisture in buildings need to be designed out.

Table 1 Allergenic or pathogenic fungi that may grow in moisture

Fungal species	Typical growth location	Mean dia. (um)
Acremonium	Humidifer water, fibre-glass insulation	2.5
Alternaria`	Cooling coils, filters, paint, dust, carpets	14.4
Aspergillus	Cooling coils, dust, filters, fibre-glass insulation	3.5
Aureobasidium	Building materials, painted surfaces, filters	5.0
Chaetomium	Fibre-glass insulation, filters, dust	5.5
Cladosporium	Carpet, walls, building materials, metal surfaces, dust	9.0
Cryptococcus	Floor dust	5.5
Epicoccum	Fibre-glass insulation	17.3
Eurotium	Gypsum-based finishes	5.7
Exophiala	Humidifer water, filters	1.4
Fusarium	Humidifer water, filters, dust	11.5
Mucor	Fans, filters, dust	7.5
Paecilomyces	Humidifer water	3.0
Penicillium	Air conditioners, painted surfaces, ducts, filters, dust	3.3
Phialophora	Humidifer water, filters	1.5
Phoma	Humidifer water, dust, filters, paint	3.2
Rhizopus	Fans, filters, dust	8.0
Rhodoturula	Carpet, walls, humidifier water	14.0
Scopulariopsis	Filters, dust	6.0
Stachybotris	Building materials	5.6
Trichoderma	Building materials, dust, filters	4.0
Ulocladium	Humidifier water, filters	15.0
Wallemia	Filters, dust	3.0

Moisture problems can arise from rain penetration, leakage from water or drainage systems, or water vapour produced by the normal domestic activities. Surface condensation is often claimed to be the main cause for biodeterioration in dwellings (*Garratt & Nowak, 1991*).

An average family of four can add more than 70 litres of water a week to the atmosphere in their home.

Geving (1997) presented a systematic method for hygrothermal analysis of construction by the use of simulation models. The method is applied on a design case of a wood-frame wall, evaluating the risk for mould growth within the construction. Mould growth on wooden building materials has been studied widely and analyses of the risk of rot and mould have been devised (*Nevander and Elmarsson, 2000*) – see Figure 2.

Figure 2 shows the importance of relative humidity (y-axis) and temperature (x - axis) in assessing the levels of risk. Below 0ºC and below 80% there is no risk of mould. As figure 3 shows, the higher the relative humidity, the greater the risk. The three lines indicate the change in that risk at different temperatures.

Table 2 shows the levels of risk for rot and mould in wood according to levels (by weight) and relative humidity.

Figure 2 The relationship between relative humidity (RH) and temperature on wood

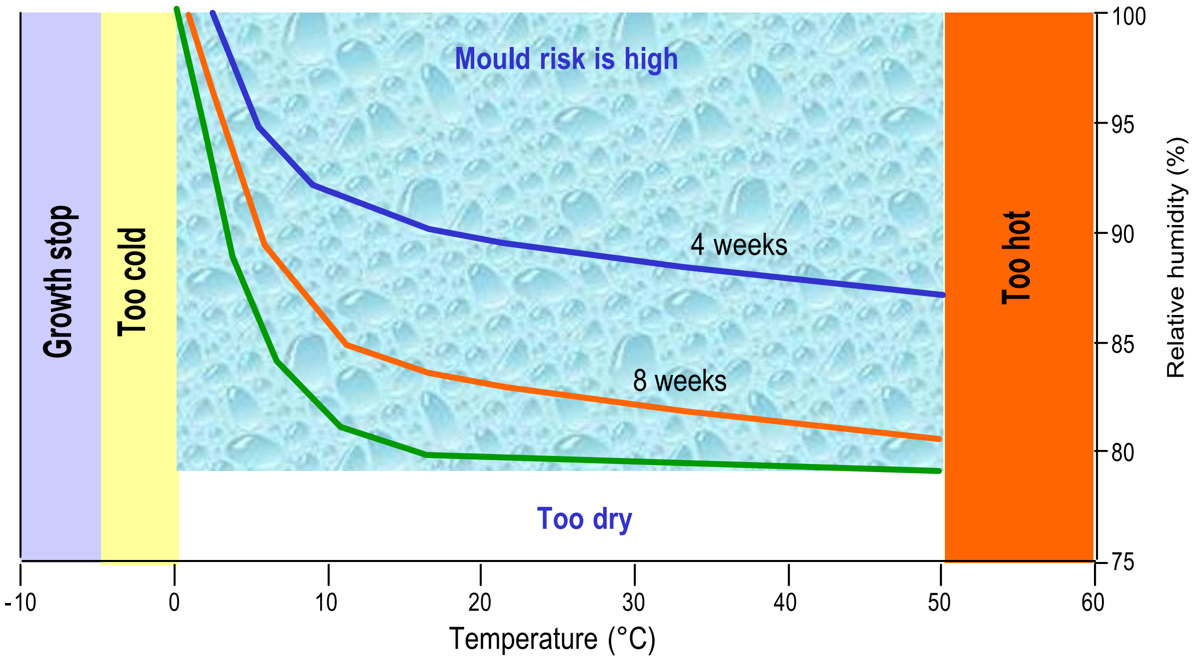


Figure 3 The relationship between risk and relative humidity

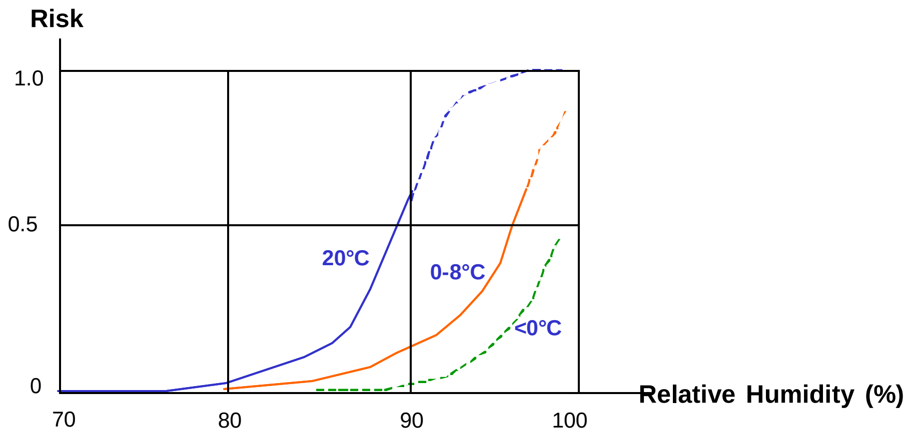


Table 2 Data from empirical observations of the risk of decay and mould on wood

Type of decay	Moisture	No risk	Low/Mod Risk	High risk
Rot	By weight (%)	<16	16-25	>25
	RH (%)	<75	75-95	>95
Mould	By weight (%)	<15	15-20	>20
	RH (%)	<70	70-85	>85

Source: Nevander and Elmarsson, 2000

Table 3 shows the widely varying ability of a building material/component to store moisture. Wood can safely store moisture until the moisture content by weight exceeds 16% - the “surface mould limit for wood”. Gypsum sheathing can only store about 1% before mould colonization occurs, whilst concrete has the largest buffer capacity of all. Thermal insulation can increase the length of time that moisture remains in the construction/component.

Table 3 Hygric buffer capacity for 186m^2 residential property

Material	Approximate capacity (litres)
Steel frame with gypsum sheathing	19
Wood frame with wood sheathing	189
Masonry wall	1892

Table 4 gives examples of the critical limits of relative humidity for various building materials.

Table 4 Critical limits of relative humidity in various building materials

Material	Critical limit value of relative humidity
Concrete	100%
Lightweight concrete	100%
PVC floor coverings	90%
Water-based adhesives under floor coverings	85-90%
Casein-containing smoothing compound (pre 1983)	85%
Type-approved smoothing compound (post 1983)	85%
Wood and wood-based materials	75%
Dust and rubbish	75%

Mould and building materials

Spores are almost always present in outdoor and indoor air, and almost all commonly used construction materials and furnishings can provide nutrients to support mould growth. Many building materials provide suitable nutrients that encourage mould to grow. Wet cellulose materials, including paper and paper products, cardboard, ceiling tiles, wood, and wood products, are particularly conducive for the growth of some moulds. Other materials such as dust, paints, wallpaper, insulation materials, drywall, carpet, fabric, and upholstery, commonly support mould growth.

Gypsum board provides a cellulose-rich medium and ensures a consistent long-term source of moisture for the non-outdoor moulds growing on the paper and deposited dust - an ideal environmental for moulds to reproduce. The use of thermal insulation reduces the heat loss from the conditioned space into the wall cavities, decreasing the temperature in the wall cavities and therefore increasing the likelihood of concealed condensation. The first condensing surface in a wall cavity in a heating climate is typically the inner surface of the exterior sheathing,

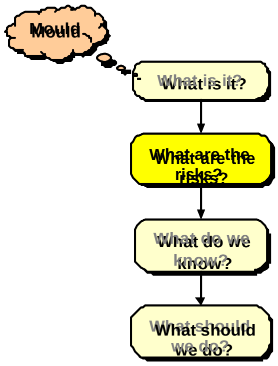
> “ I think of gypsum board as a sponge with food pasted to both sides”.

the "back side" of plywood or fibreboard. As the insulation value is increased in the wall cavities, so does the potential for hidden condensation (*Environmental Protection Agency, 2001*).

As shown in Table 3, some materials are more liable to moisture-induc ed damage such as mould. Structures with a mix of insensitive and moist sensitive materials present a risk. Small changes in the choice of materials can eliminate high-risk exposure.

What are the risks?

All moulds under proper conditions are capable of eliciting a negative health response in humans, such as inflammations, allergy or infection.



Moisture damage can originate from all the different stages in the whole life of a building (*Samuelson, 2000*):

- **Architects and designers** – specifying designs and materials unsuitable for the environment/surroundings of the building.
- **Building contractors** – lack of protection of materials on site, cheap/substandard materials, bad workmanship.
- **Owners of buildings** – lack of maintenance and damage prevention.
- **Users** – inadequate cleaning standards, cleaning agents and incorrect cleaning methods.

"Toxic Mold ... The Next Asbestos"
Lawyers Weekly, Oct. 2, 2000

The mould problem is being compared to the 'asbestos experience' two decades ago. However the problem is further complicated by its biological rather than chemical origins. Mould has the ability to grow and transform, which makes laboratory samples and site investigations far more complex.

Mould can be a health risk, a construction risk, and a business risk. It can affect buildings, the materials within them and the health of both the constructers or maintenance crew, and the users. Claims from the workers and the users of affected buildings are likely to become more prevalent because of the rapidly growing publicity, hype and litigation, involving allegations of mould damage. A number of states in the USA are involved in legal proceedings. The insurance company GeneralCologne Re (*Kingdollar, 2001*) reports that several toxic mould awards and/or settlements have exceeded US$500,000 in damages.

Health risk

There are a limited number of documented cases of health problems from indoor exposure to fungi. The intensity of exposure and health effects seen in studies of fungal exposure in the indoor environment was typically much less severe than those that were experienced by agricultural workers but were of a long-term duration. Illnesses can result from both high level, short-term exposures and lower level, long-term exposures. The most common symptoms reported from exposures in indoor environments are runny nose, eye irritation, cough, congestion, aggravation of asthma, headache, and fatigue.

In order for humans to be exposed indoors, fungal spores, fragments, or metabolites must be released into the air and inhaled, physically contacted (dermal exposure), or ingested. Whether or not symptoms develop in people exposed to fungi depends on the nature of the fungal material (e.g., allergenic, toxic, or infectious), the amount of exposure, and the susceptibility of exposed persons. Susceptibility varies with the genetic predisposition (e.g., allergic reactions do not always occur in all individuals), age, state of health, and concurrent exposures. For these reasons, and because measurements of exposure are not standardized and biological markers of exposure to fungi are largely unknown, it is not possible to determine "safe" or "unsafe" levels of exposure for people in general.

Immunological reactions include asthma, and allergic rhinitis. Contact with fungi may also lead to dermatitis. It is thought that these conditions are caused by an immune response to fungal agents. The most common symptoms associated with allergic reactions are runny nose, eye irritation, cough, congestion, and aggravation of asthma

A wide variety of symptoms have been attributed to the toxic effects of fungi. Symptoms, such as fatigue, nausea, and headaches, and respiratory and eye irritation have been reported. Some of the symptoms related to fungal exposure are non-specific, such as discomfort, inability to concentrate, and fatigue. Severe illnesses such as Organic Dust Toxic Syndrome (ODTS) and pulmonary hemosiderosis have also been attributed to fungal exposures. ODTS has been documented in farm workers handling contaminated material, but is also of concern to workers performing renovation work on building materials contaminated with fungi.

Only a small group of fungi have been associated with infectious disease. Aspergillosis is an infectious disease that can occur in immunosuppressed persons. Health effects in this population can be severe. Exposure to this common mould, even to high concentrations, is unlikely to cause infection in a healthy person.

Construction risk

The effects of mould on the performance of building materials and the possible exposure to mould for site workers, constitute construction risk. Construction practices and materials that have a high risk of moisture-induced damage need to be recognized and addressed.

As many as thirty different types of **wall** structures may be regularly used by any one contractor. Those structures that use plasterboard are more sensitive to moisture levels and so pose a greater risk. In a survey of one contractor, 45% of the wall structures used are considered to be in the medium risk category, 18% are low risk and 37% are high risk.

Slab structures have to be designed to reduce the prevalence of moisture. There has been extensive research and investigations into concrete slab structures, and so these carry a low risk. However, knowledge of suspended floors is less and so the risk is greater.

Floor structures such as prefabricated concrete elements represent a high risk because of the difficulty of reaching an acceptable level of relative humidity in the time available. There is also greater risk because of the sensitivity to moisture of wooden flooring on top of the concrete floor.

Basement structures are high risk because of their susceptibility to damp conditions – both soil and climatic conditions need to be assessed to estimate the risk.

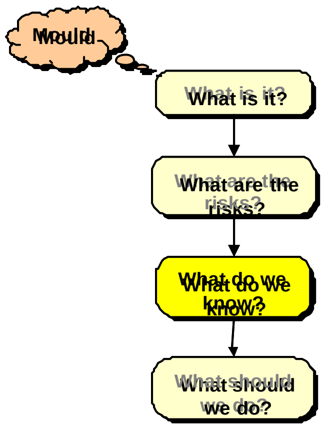
Roof structures can suffer a high risk of condensation with the trend for increased thermal insulation that does not allow the roof to be heated.

Business risk

The failure of building materials, components or structures and any likely health hazard to construction workers and users constitutes a business risk – a risk of loss of image and credibility. Legal action against the company for damage to health or property exacerbates the business risk. Knowledge and understanding of any existing or likely future mould problem, and its consequences is important to the business strategy.

The next two sections look at the breadth of available knowledge and what can be done to manage the risks.

What do we know about mould?



The problem of moulds and buildings has been around for many years. What has changed is the way that we build (using materials with cellulose such as plasterboard, ceiling tile etc.) and the increasingly stringent insulation requirements (due to environmental considerations and the oil crisis in the 1970s). The 'sealing up' of buildings leads to the increased need for heating ventilation, which can introduce breeding grounds for mould growth such as drip trays, humidifiers etc.

International research

An international literature survey was carried out of the research undertaken into the problems of mould, bacteria and moisture in buildings and the remedies. Countries all over the world have recognized the problems of mould on the occupants of buildings. The research has either considered the problem of mould in terms of:

- Indoor air quality
- Degradation of the product/system
- The design and construction of buildings to minimize moisture problems.

"HVAC units are a great breeding ground for mould."

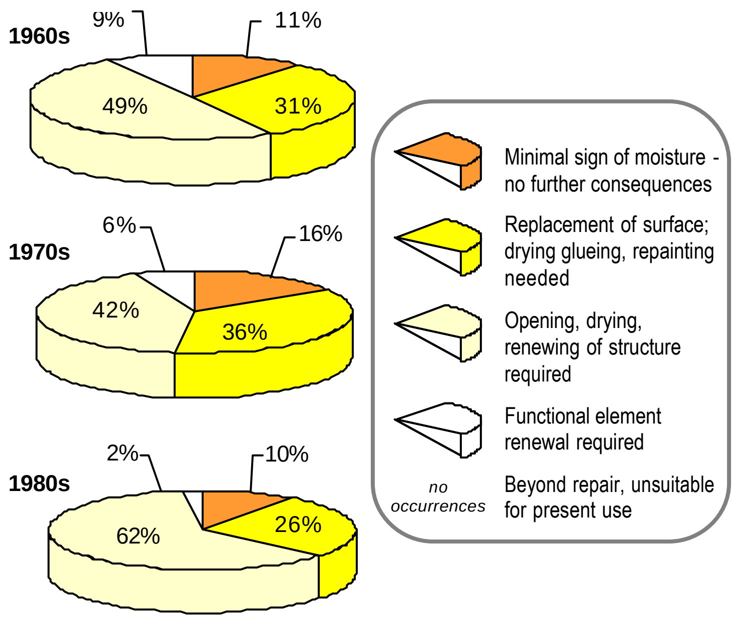
Research has involved a number of disciplines including, engineering, medicine, chemistry, biology, environmental health, design and construction. There has been considerable research undertaken by timber-related organisations. The following countries have research organisations studying the problems of mould from a number of aspects. This includes research into timber, its production, preservation and use; the effects on indoor air quality and a building's occupants; and the moisture content of buildings during their construction and operational phases.

- Australia
- Austria
- Canada
- Denmark
- Finland
- Germany
- Japan
- Norway
- The Netherlands
- USA
- European Union
- World Health Organisation

Studies have researched mould problems in existing buildings. Australia (*Godish et al, 1993*), Finland (*Hyvärinen et al, 1999; Hirvonen, 1999*) and Denmark (*Gunnarsen, 2001*) have looked at residential dwellings, whilst the USA, Finland (*Nevalainen, 1999*), Sweden (*Hilling, 1998*) and the Netherlands have studied the problems of mould in schools and other public buildings. Office buildings have been extensively studied, for example three office buildings in Sydney, Australia with histories of sick building syndrome symptoms have been investigated. A Swedish study is developing a model for mould growth in buildings as a function of temperature and water activity. A number of models of mould growth have been developed; Hens (*1996*) undertook an international review of the simulation tools available for hygrothermal analysis of buildings. There were 37 simulation tools at the time of his study. Hygrothermal analysis is not always enough to model the performance of building materials or components under various conditions as the interaction of heat and moisture with the material is not always known (*Holm & Künzel, 2000*).

Among a number of studies into moisture-induced damage in housing is one carried out in Finland by Nevalainen et al (*1998*) as part of a national Indoor Air & Environment Program. 55% of Finnish buildings (500,000 houses) were found to be in need of repair from damage caused by moisture. 450 houses (in five cities), built over several decades, were surveyed for signs of current or previous moisture problems see Figure 4. Some of the faults were due to flaws in design or construction, others because of ageing materials. It is interesting to note the high percentage of repairs needed to the 1980s-built homes with 62% of those surveyed needing to be dried out and some structural damage repaired.

Figure 4 Results of the Finnish survey of houses built in the 1960s, 1970s and 1980s



Source: Nevalainen, 1998

Reijula (*1998*) suggests that there are several reasons for this high percentage of moisture-damaged homes:

- Over 80% of all buildings have been built since the Second World War in "a relatively short time and without sufficient competence and proper materials".
- The water tightness of these post war buildings is not good, with flat roofs, especially those built in the 1970s, causing many problems.
- The energy crisis in the 1970s led to building being more tightly sealed, with a reliance on effective ventilation systems. If these systems do not work effectively then the relative humidity increases.

A study undertaken in Scotland (*Clarke et al, 1997*) generated growth limit curves for six generic mould categories based on an analysis of published data. The curves define the minimum combination of temperature and relative humidity required to sustain mould growth on indoor building surfaces.

A number of handbooks on moisture and its control have been produced. For example in the USA by the Oak Ridge National Laboratory and Lsitburek & Carmody (1998), and in Sweden (*Fukthandboken; Nevander & Elmarsson)*. These handbooks provide guidance to architects and building designers. The International Society of Indoor Air Quality and Climate have an International Task Force on "Control of moisture and mold problems in cold climates".

What should we do?

Mould is a risk that has to be identified, quantified and managed. It has an effect on the durability and performance of materials, components and structures, and it can produce adverse health effects on site workers in the construction and maintenance phases, and on the occupants. Figure 6 shows the final stage in the risk assessment diagram.

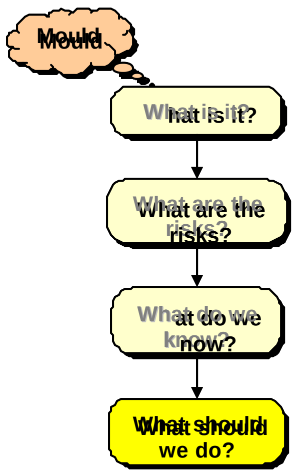
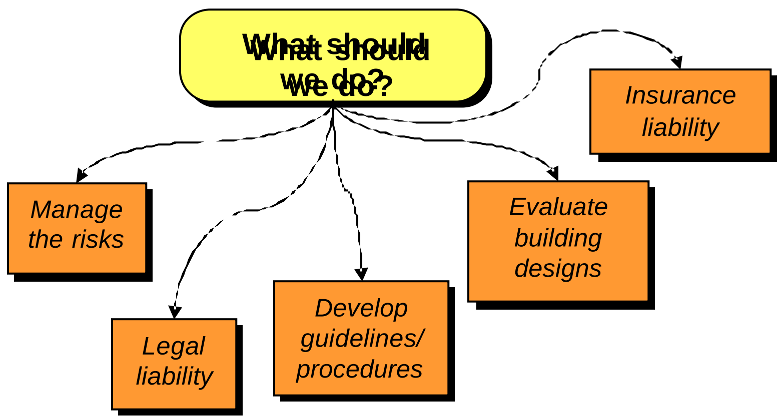


Figure 6 The final step in the risk assessment process



Insurance liability

The insurance perspective is three-fold:

1. Damage to users/occupiers' health
2. Damage to the health of the site workers, resulting from mould growth in existing and new properties.
3. Damage to property from mould growth.

The Institute for International Research has predicted that insurance premiums in the US are to rise by 40% to offset claims for mould damage. Delegates at a recent Air Conditioning Contractors of America's (ACCA) conference were told: "*Contractors should expect insurance companies to add some sort of mold exclusion in a contractor's general liability policies in the not-so-distant future*." They were also warned "*The insurance industry is looking at mold as being the next asbestos … They are looking to get an absolute exclusion*." Insurance companies are more worried about the health aspects of mould rather than property damage; this means they may exclude physical injury and offer some property damage coverage; albeit to maximum low level of liability.

Design teams have professional indemnity insurance covering them against claims resulting from any acts of negligence. Proving negligence in the case of damage from mould growth will be very difficult unless there is a glaring error. The designer would claim that the moisture has resulted from an inadequate construction process, rather than from a defective design detail.

Evaluate building designs - designing out mould

The problem of mould needs to be designed out, using materials and component combinations that minimize the risk of moisture retention. The relationship between the relative humidity, temperature and the risk of moisture-induced damage needs to be understood. That understanding has to extend across the whole value chain, from design to construction to site management to the operational phase, and include suppliers, manufacturers and especially the workforce.

Develop guidelines and procedures

Those working in areas where mould is present need guidelines on how to treat the mould and how to protect themselves from any ill effects. A number of agencies have mould control procedures with clear guidelines for those in contact with mould. The US Envi ronmental Protection Agency has guidelines for mould treatment and control. Any treatment using chemicals may have an effect on workers or building occupants and the implications need to be considered (*Watt et al, 2001*). The New York City Mould Protocol: Guidelines on Assessment and Remediation of Fungi/Mould in Indoor Environments is widely cited as being a comprehensive guide for those dealing with the effects of mould. The guidelines can be found online at http://www.ci.nyc.ny.us/html/doh/html/epi/moldrpt1.html

The problem of mould damage is raising the same set of issues faced by those involved in the asbestos scare in the early 1980s. The professionals need clear-cut industry regulation, certification, response data and standardised assessment procedures.

Codes and standards

ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers developed standards in 1989 addressing ventilation, resource management and air cleaning that were intended to be used to achieve an acceptable indoor air quality. Since the growth of mould is affected by humidity and air circulation, the society established standards for ventilation design, operation and maintenance. The society also defines what is acceptable air quality, although the definition is dependent on the minimum indoor air-quality standard set by governmental agencies. The society's standards have been incorporated into some state and local building codes in the USA. There are no known building codes addressing the prevention, remediation or repair of mould-infested buildings. Current codes address only the deficiencies that allow water to enter the building in the first place.

The 1999 OSHA Technical Manual (Directive No. TED 1-O.ISA; Section III: Chapter 2 Indoor Air Quality Investigation) addresses indoor air quality investigations generally and identifies fungi as an indoor air contaminant. The European standard for “Ventilation in Buildings” - PrEN 13779 – takes into account the mould as a result of poor ventilation. A number of standards are available for the testing of fungal resistance, namely BS1982 and BS 3900 (British Standard); ASTM G21-70 and ASTM D3273-86 (American Society for Testing of Materials); IEC68-2-10 (International Electrotechnical Commission) and IIPEC2.6.1 (Institute for Interconnecting and Packaging Electronic Circuits).

Legal liability

The amount of legislation on mould damage is limited. California’s Toxic Mold Protection Act (SB732) is one of the first and it has directed the Californian Department of Health Services (DHS) to convene a Task Force to develop and adopt standards for mould exposure limits for indoor mould environments by July 2003. Another Bill passed into law was AB 284 Public Health: Fungal Contamination in Indoor Environments.

Litigation

Legal action concerning mould damage or injury is increasing rapidly, particularly in the USA. Where public buildings are involved, the numbers of people ‘affected’ can be large and so defence against any lawsuit is expensive. Plaintiffs have alleged property damage, bodily injury and business interruption due to exposure to allegedly toxic mould. Contractors, sub-contractors, construction managers, property managers, architects, construction component suppliers and building owners have all been targeted in toxic mould litigation.

US$32.1 million worth of damages has been awarded to the Ballard family in Dripping Springs, USA. They claimed that the mould, that had spread through their home following a badly repaired water leak, had damaged their health – they had originally sought US$100 million!

Some examples of litigation

· About 100 workers employed at the Visalia County, California courthouse filed suit alleging that exposure to toxic molds in the courthouse caused a variety of adverse health affects (*Saddler v. County of Tulare*). Injuries alleged include respiratory ailments, skin rashes, headaches, nausea, vertigo and memory loss. The suit, which alleges that various **contractors negligently developed, designed, planned, and built the courthouse, also maintains that the county failed to properly maintain the building**.

· A Washington schoolteacher filed suit against the general contractor, construction manager, and architect of the Woodward Middle School in Bainbridge Island School District alleging exposure to toxic mold in her classroom and other places in the school caused her personal injuries (*Fulgham v. Merit Construction Co.).* The plaintiff alleges **certain construction defects in that the school's windows walls and roof do not repel and shed moisture as they should**.

- Teachers and students from Riverside High School, in Washington filed suit against the Riverside School District and its Superintendent of Schools, as well as **the contractors and architect of an addition built onto the school** (*Mielke v. Riverside School District*). The suit includes **allegations of construction defects, faulty design of the ventilation system, and faulty design of the windows used in the building**. The defendants have countersued each other and have **also sued other subcontractors as third party defendants including construction component suppliers**.
- Three Maryland office workers filed a lawsuit seeking $3 million for personal injuries arising out of exposure to toxic mold (*Eddy v. Fegan*). The suit alleges that mold and fungi "were allowed to flourish" within the **building's 30 years old heating, ventilation and air conditioning system. Defendants are the current and former building owners, the current and former property managers and the on-site building supervisor**. The plaintiffs' injuries include asthma and reactive airways disorder.

Managing the risks

Mould detection

For facilities already been built the detection of mould becomes important. If the fungal exposure is being related to adverse health effects then exposure studies should involve carefully chosen case and control buildings. If toxic health effects are being studied, a different sampling approach is required, such as air sampling of mycotoxins. The detection of mould can be carried out using three main techniques:

- Sampling the air from within wall cavities
- Reviewing the water damage history of a building
- Detecting volatile organic compounds (VOCs) with chemical techniques or a mould dog.

Review HVAC systems

Air conditioning units are prime sites for mould growth because of water in drip trays and humidifiers. A US company promotes the control of indoor mould commonly found in typical HVAC systems by using small, controllable amounts of ozone applied directly in the HVAC system – a method tested and developed in the food industry and Purdue University. The theory is that ozone oxidizes the molecules on the surface of the mould cell. Most moulds grow from the tip as elongating filaments. As the mould grows, new cell membrane and cell walls are produced at the tip. Oxidation of the cell membrane components destroys their biological function. Large-scale oxidation of membrane components by high ozone concentrations would be lethal to the mould.

Materials – transport, storage and use

The way in which materials are transported, stored and used needs to be investigated to reduce the risk of moisture-induced damage. It is important to know the moisture content of materials and how that varies according to the construction process, climate and use. Alternative materials need to be investigated. For example there are several substitutes for gypsum board that are mould resistant:

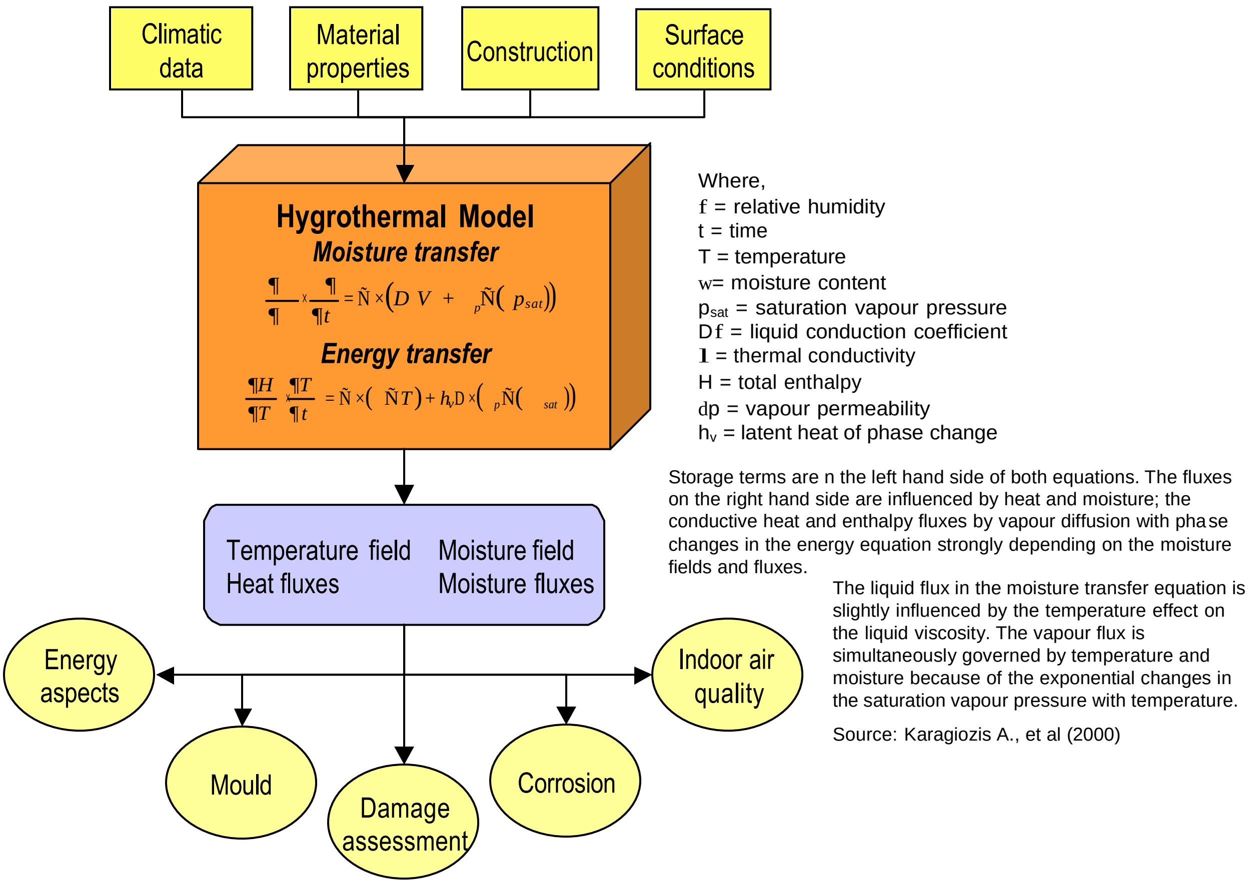
- Glass-fibre reinforced concrete
- Precast concrete
- Fibre reinforced polymers
- Epoxy concretes

Co-operation with materials suppliers could achieve better information about the moisture content of materials and their recommended storage and use. There may be scope for working with suppliers to achieve low moisture content materials.

Simulation models and tools

Simulation models are a useful way of testing a design for any moisture/mould related problems. Figure 5 shows the typical software architecture of a hygrothermal model. The model shows the number of varying factors that make up the input to the model as well as the post process considerations.

Figure 5 Typical format of a hygrothermal model



Source:Non-isothermal moisture transfer in porous building materials (Holm & Künzel, 2000).

Those creating models and other simulation tools need to consider further development in three main areas:

- The integration of hygrothermal modeling of single building components into a whole building simulation system – the interaction between indoor climate, user and surface conditions cannot be neglected.
- Introduction of chemical reactions, ageing functions and salt transport processes into the models.
- Implementation of stochastic methods because of the number of factors that affect hygrothermal conditions in a construction such as outdoor and indoor climate, and material properties.

Examples of simulation tools/models

- **Development of a model for mold growth in constructions as a function of temperature and water activity history** (FORMAS- funded research in progress). Wadso, L. (Lund University) and Bjurman, J. (University of Gothenburg)
- **Development of a simulation tool for mould growth prediction in buildings** (Clark, J.A., Johnstone, C.M., Kelly, N.J., McLean, R.C. and Nakhi, A.E., 1996, Energy Systems Research Unit, University of Strathclyde, Glasgow, UK). A prototype design tool has been developed for the prediction of the likelihood and extent of mould growth for a given combination of climate conditions, building construction and usage pattern. Such a tool can be applied to proposed designs, in order to correct any inherent defects prior to construction, or to existing buildings with mould problems in order to appraise the effectiveness of potential engineering solutions.

Conclusions

Mould is not a new phenomenon. What is happening is that buildings are better-insulated and more airtight because of greater environmental awareness and energy efficiency requirements. Buildings are being heated to higher levels and modern lifestyles are creating more moisture in homes in the developed world. Many modern construction methods and materials do not cope well with moisture. There is a greater awareness of health risk from mould for both occupants and workers.

The litigation emanating from mould and its effects is substantial in the USA; the number of cases against designers, contractors, maintenance firms and local authorities is increasing.

Mould can be a risk across the whole life of a facility, from construction, to operation and even at the demolition stage. The health risk can affect site workers, residents, employees, the public and maintenance personnel. Mould can also lead to property damage.

As the risk assessment diagram showed (see Figure 1) the risks first need to be identified. Second, the extent of the knowledge base either within the company, industry, or on an international basis needs to be established. This information then informs the "what should we do" step which is the basis of a risk management exercise.

A source of fungal spores is always present in indoor air, and with more than 100,000 species of mould, it is easier to control the factors that allow growth - temperature, food, and moisture – than control the spores themselves. This can be achieved in a number of ways:

- The effects of mould damage can be minimised at the design stage, by a greater understanding of building physics.
- Selective use of materials in different climates and environments can reduce the risk.
- Education, training and clear guidelines are needed for site personnel to inform them of the importance of keeping materials dry during storage and construction, and the need for proper drying-out procedures.
- Workers should be alerted to the health risks of mould. Remediation work needs to be understood and undertaken promptly

A clear understanding and awareness of the problem at all stages of the construction and operation of a facility is important. Operational risk management systems are valuable. Although many would not agree that mould is the “new asbestos”, the construction sector cannot afford to ignore the issue.

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