Moisture conditions and biodeterioration risk of building materials and structure

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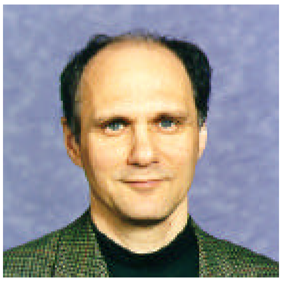

The expertise of writers are biodeterioration of building components, wood preservation and building physics. The work is also involving in consultation and training concerning conservation and reparation of buildings.

Summary

During the service life of buildings, natural ageing of materials due to different chemical, physical, and biological processes can take place. Biodeterioration is important critical factor for durability and usage of different material. Level and duration of moisture stress connected with temperature are the most critical factors for the durability and life time of building materials. Mould and decay damage in buildings is caused by moisture exceeding the tolerance of structures. The roofs, floors and lower parts of walls are most often exposed to high humidities and to attack by mould and decay fungi. A part of this growth is caused by the natural ageing of the materials, and a part of the growth and decay is caused by moisture damage. The demands on durability, energy balance and health of houses are continually rising. Modelling of mould growth and decay development based on humidity, temperature, exposure time and material will give new tools for the evaluation of life time of different building materials and structure. For mould development, the minimum (critical) ambient humidity requirement is shown to be between RH 80 and 95 % depending on other factors like ambient temperature, exposure time, quality and surface conditions of building materials. For decay development and serious problems to achieved in the buildings, moisture content combined with materials properties, temperature conditions and time are the most important factors. The moisture content for decay development is higher than that for mould growth. The risk of mould growth in the VTT model is presented as a mould growth index reflecting the amount of mould mycelium on the surface of materials. The index makes it possible to analyse the critical conditions needed for the start of growth, but it is also a tool to measure the progress of mould growth in different conditions and structures. Numerical simulation makes it possible to evaluate the risk and development of mould growth on the surface of wooden material in different structures.

1. Introduction

In this paper, biodeterioration and the requirements to numerically simulate mould growth and decay development will be presented. Some analysis about the risks of mould growth in applications with different materials and moisture load conditions are also presented.

2. Biological damages of building materials

2.1 Biodeterioration or ageing

During the service life of buildings, natural aging of materials due to different chemical, physical, and biological processes can take place (Figure 1). Ageing of the materials is often a results of different chemical reactions of the materials. The abiotic factors like water, temperature and quality of substrate (nutrients, pH, water permeability) are also the most significant for the growth of organisms. In some cases, UV radiation, air movements and gases of air have effects on the ageing, but also on microbial growth. However, the effect of these factors is often indirect. Air circulation affects humidity conditions, particle accumulation and gas composition of air and surfaces.

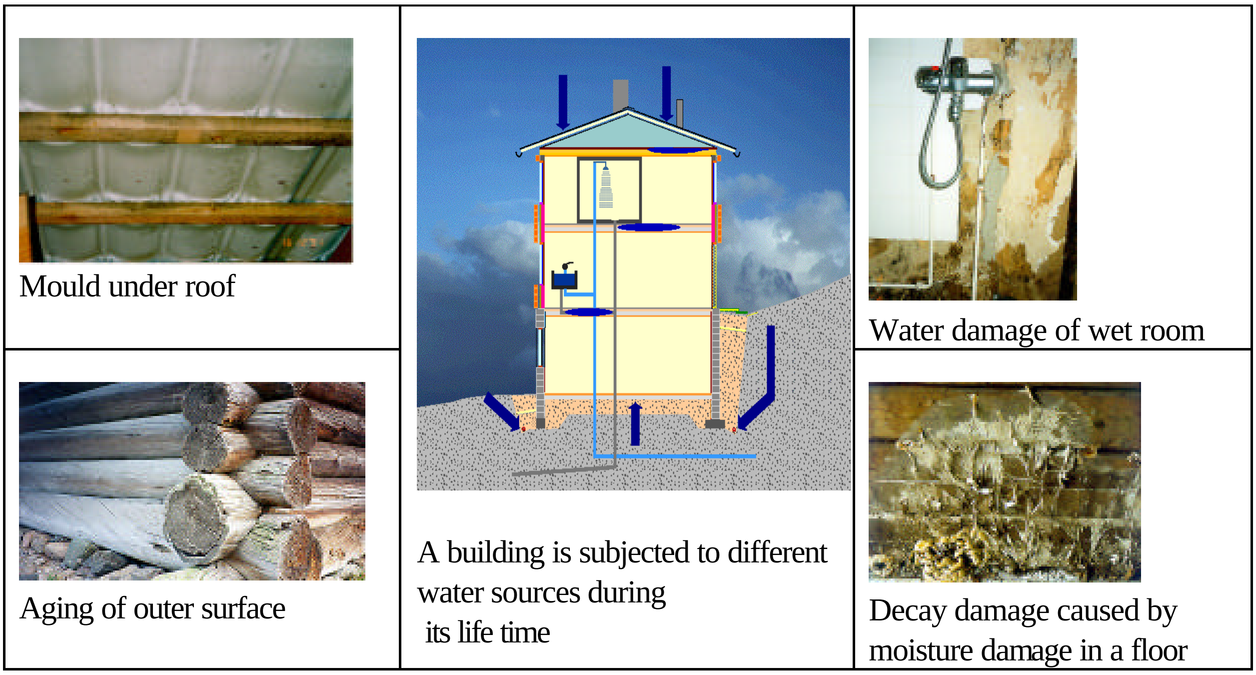

Figure 1. A building is subjected to different water sources, aging prosesses and damages during the life time.

Table 1. Organisms involving damages and defects of building components [1]

Type of organism	Damage / problem type	Humidity or moisture range (RH or MC %)	Temperature range (°C)
bacteria	biocorrosion of many different materials, smell, health problems	wet materials RH > 97 %	ca -5 to +60
mould fungi	surface growth on different materials, smell and health problems	Ambient RH > 75 %, depends on duration, temperature and mould species	ca 0 to + 50
blue-stain fungi	blue-stain of wood permeability change of wood	Wood moisture content > 25 - 120 % RH > 95 %	ca -5 to + 45
decay fungi	different type of decay in wood (soft rot, brown rot or white rot), also many other materials can be deteriorated, strength loss of materials.	Ambient RH > 95 %, MC > 25 - 120 %, depends on duration, temperature, fungus species and materials	ca 0 to +45
algae and lichen	surface growth of different materials on outside or weathered material.	wet materials also nitrogen and low pH are needed	ca 0 to +45
insects	different type of damages in organic materials, surface failures or strength loss.	Ambient RH > 65 % depends on duration, temperature, species and environment	ca 5 to +50

Biodeterioration (i.e. mould, decay and insects damage) may be a critical factor for durability and usage of different building materials. Different organisms e.g. bacteria, fungi and insects are growing and living in the building materials (Table 1). Mould and decay damage in buildings is caused by moisture exceeding the tolerance of structures. The roofs, floors and lower parts of walls are most often exposed to high humidity and to attack by biodeterioration processes.

Many building materials can support growth of microbes and mould problems are more common than decay damages. Typical mould fungi found in damaged buildings are e.g. *Acremonium*, Aspergillus species (e.g. *fumigatus*), *Aureobasidium pullullans*, *Alternaria alternata*, *Cladosporium* species (e.g. *herbarum*, *sphaerospermum*), *Mucor* species, *Penicillium* species (e.g. *brevicompactum*) and *Stachybotrus* species (e.g. *atra*). Often these fungi are also found in nature (soils, decaying materials and waste). Algae are most often found on the outer surfaces and outdoor structures.Different decay types can be detected in damage: brown rot, soft rot, and white rot. In buildings suffering by excessive moisture loading, brown rot is the most common decay type. Among the typical brown rot fungi, which cause the most serious damage in buildings in temperate climates are *Serpula lacrymans* (dry rot fungus), other *Serpula* and *Leucogyrophana* spp., *Coniophora puteana* (cellar fungus), different *Antrodia / Poria* species, *Gloeophyllum sepiarium*, *Gloeophyllum trabeum*, *Paxillus panuoides* and *Lentinus lepideus*.

2.2 Critical conditions for biodeterioration: humidity, temperature, exposure time, materials

At VTT Building and Transport, the mould and decay problems in buildings have been studied for many years. The effect of humidity, temperature and the exposure time on mould growth and decay development has been studied and modeled, especailly on wood material. For mould development, the minimum (critical) ambient humidity requirement has been shown to be between RH 80 and 95 % depending on other factors such as ambient temperature, exposure time, quality, composition and surface conditions of building materials. (Figure 2A and 2B).

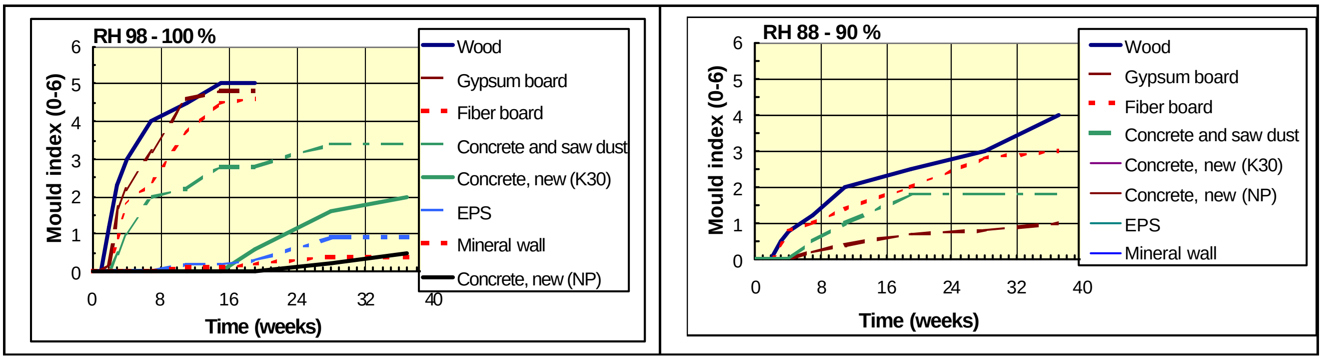

Figure 2. Mould growth on different building materials at RH 98 - 100 % (A) and at RH 88 - 90 % (B), at 22 C. [2, 3]

VTT has developed a mould growth index [4]. The risk of mould growth in the VTT mould model is based on the mould index reflecting the possible growth of different mould fungi on the surface of pine sapwood (Figure 3A). The model is based on mathematical relations for growth rate of mold index in different conditions including the effects of exposure time, temperature, relative humidity and dry periods. The model is based on laboratory work and it is purely mathematical in nature and as mold growth is only investigated with visual inspection, it does not have any direct connection to the number of living cells of organisms. The correct way to interpret the results is that the mold index represents the possible activity of the mold fungi on the wood surface.

The model on decay development is based on laboratory research with *Coniophora puteana* and other brown rot fungi like *Serpula lacrymans* (Figure 3B). The model is based on weight loss of wood reflecting to the growth and activity of fungus [5]. The model will explain the critical conditions for the early stage of decay. For decay development and other serious problems that may occur in a building, the critical moisture content is higher than that for mould growth. It has been shown by many authors and practice that a brown rot attack on wood has no practical significance if the wood moisture content is less than 30 %. The brown rot fungi are growing best at wood moisture contents between 30 and 70 %. The dry rot fungus has caused serious damages in buildings due to effective water transport system of its mycelium. Fungus can transport water from moisture source towards dry wood, if no evaporation is possible. The water transport activity of mycelium of dry rot fungus (*Serpula lacrymans*) connected with the advanced growth and decay is not included in the model.

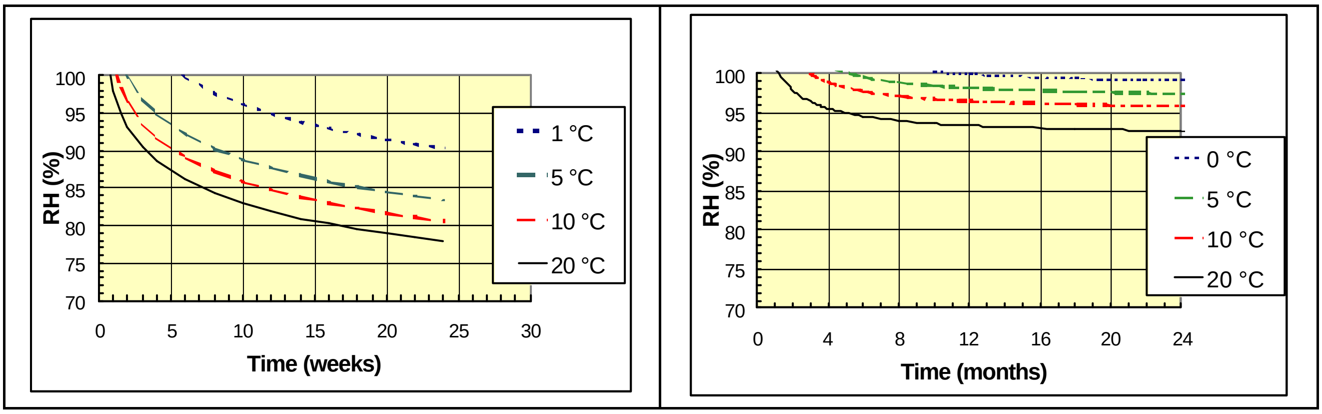

Figure 3. Critical humidity (RH %), time (weeks / months) and temperature needed for the start of mould growth (A) and early stage of brown rot development (B) in pine sapwood [4, 5].

The mould index provides the possibility to analyse the critical conditions needed for the start of growth, but it is also a tool for measuring the progress of mould growth in different conditions and structures. A risk to mould growth is high at high humidity RH > 95 % at temperatures between +20 and +40 °C on wood based materials. At low temperatures (below +5 °C), growth of mould fungi is slower even at high RH (Figure 4a and 4B). A certain **duration** of suitable exposure conditions is required before fungal growth will start or reach a certain grade. The response times proved to be short (from a few days to a few weeks) in conditions favourable to the growth of mould fungi and long (from a few months to a year) in conditions close to the minimum moisture or temperature levels (Figure 4C and 4D).

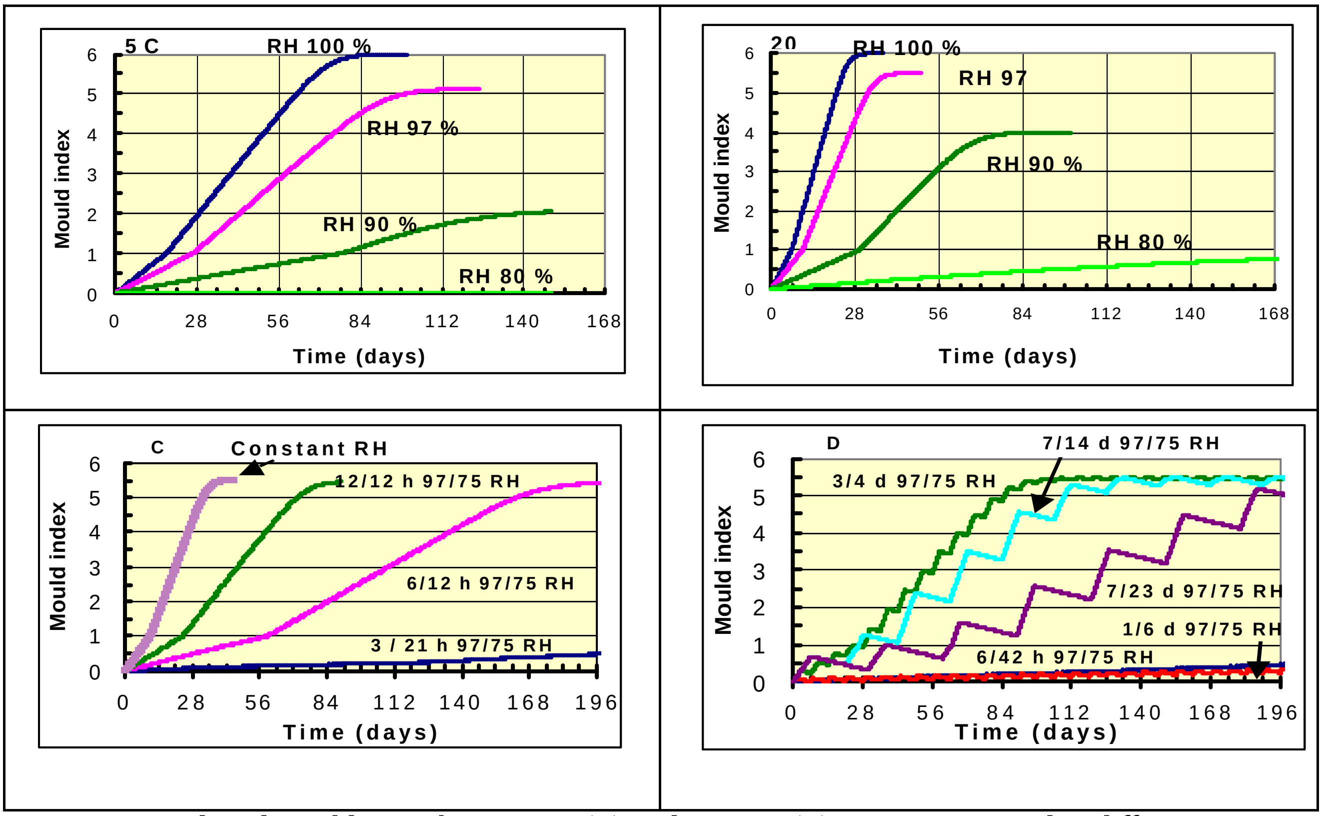

Figure 4. Predicted mould growth at +5 °C (A) and +20 °C (B) on pine sapwood in different constant humidity conditions or in varied exposures at RH 97 % and 75 % (C and D) [6, 7].

Modeling of mould growth and decay development based on humidity, temperature, exposure time and material will give new tools for the evaluation of the life time of different building materials and structure [7, 8]. Within moisture damage and ageing of buildings, the humidity, moisture content and duration of exposure is the main factor for development of organisms. In buildings, the material is most often coated, treated or painted with different products and treatments. In such cases, the surface treatment has important role for the durability and life time of substrate. Degradation of surface by micro-organisms is affected by interaction of material, surfaces and the surrounding environment and microclimate. The chemical and physical structure of the substrate as well as the surface treatments has a significant effect on the quality and service life of the treated system. E.g. several factors affect mould and decay resistance of painted wood: quality of wood material, type of the exposed structure (wall height, eaves, joint, end grains, fastenings), paint type, fungicides and their concentration in the paint, exposure conditions (type of environment, climate, humidity, temperature), exposure time, colonies of microbes and fungi.

2.3 Modelling of moisture and mould growth in different structure

Very simple method to evaluate the damage or failure risk in materials and structure is to measure and calculate the moisture or humidity level of materials for longer period [1]. Unfortunately, this method can be used only for limited targets since moisture and humidity level, as well as temperature and their duration time are changed. The minimum moisture requirement for the growth of fungi, about 20 % in wood corresponding to about 80 - 90 % RH, is often quoted in the literature. Accordingly, it is often given in building instructions as the maximum allowable moisture condition for wooden structures in order to avoid biological damages. Then the duration of the condition or the temperature has not been taken into account. According to experience, the ambient humidity in active mould damages have been above 75 - 80 % and in decay damages above 90 - 95 % at 20 ^{o}C.

The time of wetness can be calculated by summing up the length of time over one year when the relative humidity RH is above 80 or 95 % at the same time when temperature is above 0 ^{o}C. The atmosphere can be characterized in relation to its fatality by calculating the time of wetness using the temperature and the relative humidity of the ambient air. The time of wetness in the building envelope parts, however, does not necessarily correspond with the time of wetness in the exterior climate. The time of wetness may be high in the building structure even in cold and dry climates if the moisture performance of the structure is poor.

After having mathematical models in mould growth or mould index, we can connect the model with building physics simulation model like TCCC2D [1, 8, 9]. In this way, we can estimate, if the conditions in different simulated structures offer a risk for mould growth. We can also simulate, if the mould risk is a significance risk and in which part of a simulated envelope structure the risk can exists. Currently, the mould growth estimation model is mainly used for comparison of different structures with different air leakages. We can ask: should we allow any mold growth at all in various parts of the building envelope or can we allow growth to occur in the exterior parts that are not directly in contact with the interior air? These are the questions that yet have to be answered. In the current situation the mold growth estimation model is mainly used for comparison purposes for which it is a powerful tool. An example of this is given in Figure 5 which shows the calculated mould index in the exterior sheathing when different cavity ventilation rates have been used in the exterior wall cavity between the siding and exterior sheathing. For this specific exterior wall case a minimum ventilation rate could be found to minimise the potential for mold growth.

Heat, air and moisture transfer simulation models can be used to predict the hygrothermal performance of building envelope components. The results from the simulations in turn can be analysed to predict failures. Various levels of accuracy can be obtained by using not only different numerical methods but also different levels of input data. Even the most sophisticated models that exist today rely vastly on the input that the users are able to insert to the programs.

In buildings, moisture transport and accumulation and interactions of different materials affect local moisture conditions and complicate the evaluation of moisture risks. The growth of fungi also changes the moisture conditions, as water is produced in the decay process and certain fungi like the dry rot fungus can efficiently transport water from a moisture source to dry structures. This will change the concept of calculations.

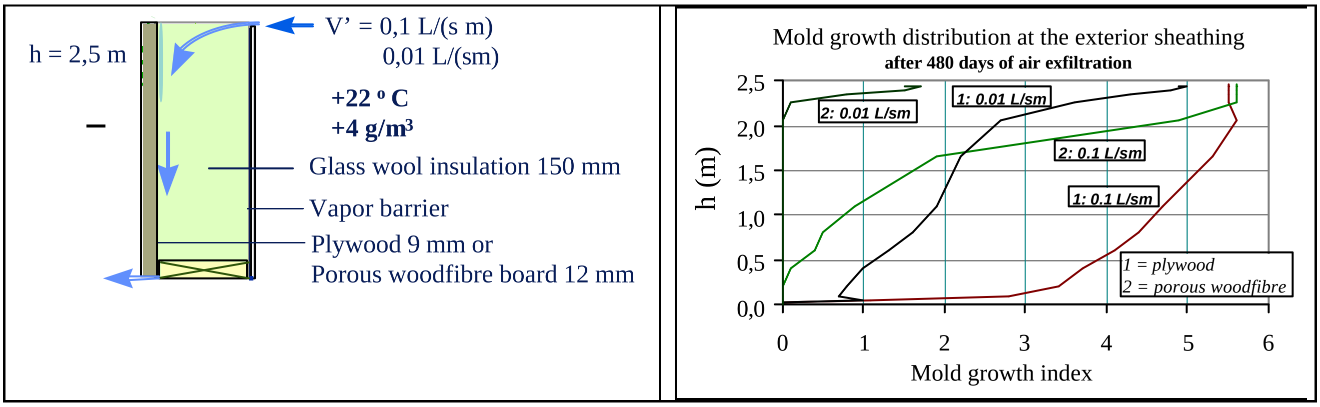

Figure 5. Mold index on the exterior surface of exterior sheathing (plywood or porous wood fiber board) at different heights of the wall as a function of different cavity ventilation rates [9].

3. Conclusions

For service life of buildings and materials, the water and temperature are often the main acting factors. Within ageing and damage of buildings, also the biological factors are involved and depended on the humidity, moisture content and duration of exposure. There is several different organisms, but using typical trace organisms invloved in damage cases we can estimate the potential risks of mould growth and decay problems. For evaluation the risk of mould growth and decay development in a building material, we need input values on material, humidity (moisture content), temperature and exposure time. Humidity or moisture content alone is not adequate. We can predict the hygrothermal performance of building envelope components with heat, air and moisture transfer simulation models. After having mathematical models in mould growth or mould index, we can connect the model with building physics simulation model like TCCC2D, when we can predict or estimate the possible mould risk in the material in the estimated structure.

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