Development of an improved model for mould growth: Laboratory and field experiments

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KEYWORDS: *mould growth, experiments, materials, laboratory test, field test*

SUMMARY:

This paper deals with the present results of some on-going mould growth experiments from a project "A Mathematical Modelling of Moisture Behaviour and Mould Growth in Building Envelopes". The work has been done in collaboration with Tampere University of Technology, Finland (TUT) and Technical Research Centre of Finland (VTT). The material experiments and experiments for exterior wall assemblies are performed both in laboratory and in field conditions. Mould growth on the surface of a material is detected using either microscope or visually with a naked eye. Determination of mould index depends on area of mould growth and type of mould growth. Experiments started in 2005 and will be going on at least until end of 2008.

The experimental results are used for further development of a present mould growth predicting model developed at VTT. The original model is based on numerous laboratory experiments on pine and spruce. The present model is improved in respect to expanded climatic conditions and for a greater variety of materials. Also the impact of naturally sedimented dirt and contact of other materials are studied.

The results until now show generally less mould growth than espected according to the original model based on pine and spruce sapwood.

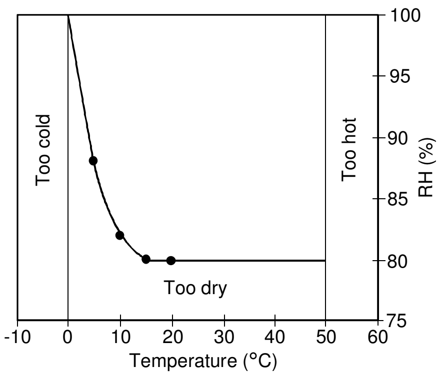
1. Introduction

Mould growth in building materials has been an important research topic at the Tampere University of Technology (TUT) and Technical Research Centre of Finland (VTT) for many years. At TUT mould growth of envelope assemblies has been analysed in several field test projects during past decade. Moreover, numerous condition analyses have been done in old buildings and, therefore, a lot of experience has been got from muold growth in practice. At VTT a mathematical model of mould growth on pine and spruce sapwood was created in 1990's by Ph.D. Hannu Viitanen (Viitanen 1996). This model includes a mathematical basic model on humidity, temperature and exposure time, and it also takes into account the delay and influence of fluctuating humidity conditions (Hukka and Viitanen 1999 and Viitanen et al. 2000).

In this new collaboration project with TUT and VTT eight other construction materials have been tested in the laboratory and field set-ups. The test materials are edge-glued spruce board, polyurethane (paper-coated and grounded), glass wool, expanded polystyrene, polyester wool, concrete, autoclaved aerated concrete and expanded light aggregate concrete. The reference material is pine sapwood. The experiments have been performed partly under constant conditions and partly also under fluctuating moisture and temperature conditions both in the laboratory and in the field. One of the objectives of this research is to extend the range and reliability of the existing mathematical model. This is achieved by extending the measurement data necessary for the model development by applying several materials and different kind of fluctuating temperature and humidity conditions. New experimental results from the mould growth on different material surfaces and in exterior wall assemblies are presented in this paper. More detailed information from existing model is presented in another paper to this conference (Viitanen et al. 2008).

2. Determination of mould growth

Mould fungus needs favourable conditions to grow. Simplified these conditions can be expressed as that the temperature has to be between 0 and 50°C and relative humidity has to be at least 80% RH (when temperature is below 20°C even more). The exposing time under fluctuated conditions and the nutrient base have also influence on mould growth (Viitanen and Bjurman 1995). In Figure 1 are shown the favourable temperature and moisture conditions for mould growth.



The mould growth on the surface of a material can be detected using microscope or visually with a naked eye. Determination of mould index depends on area of mould growth and the type of mould growth (detected under microscopy or without). In Table 1 are shown indexes for mould growth characterization. The index is based on the growth of mixed different fungus species (Viitanen and Ritschkoff 1991).

FIG. 1: Favourable temperature and relative humidity conditions for mould growth (Viitanen and Bjurman 1995).

TABLE 1: Mould growth index for the experiments and modelling.

Index	Growth rate	Description
0	No growth	Spores not activated
1	Small amounts of mould on surface (microscope)	Initial stages of growth
2	<10% coverage of mould on surface (microscope)	
3	10 – 30% coverage mould on surface (visual)	New spores produced
4	30 – 70% coverage mould on surface (visual)	Moderate growth
5	> 70% coverage mould on surface (visual)	Plenty of growth
6	Very heavy and tight growth	Coverage around 100%

3. Experimental arrangement of mould experiments

In the following, the experimental laboratory and field set-ups are described. There have been tested plain materials and the materials as a part of a thermal envelope construction.

3.1 Material experiments

Material experiments are performed for all test materials. Most of the specimens are sized 50mm x 50mm x 20mm. Test series consists of nine specimens. Each test series contain material from three different production runs. Reference material is pine sapwood. Material experiments are performed in different laboratory conditions and also in outdoor conditions in the shelter.

3.1.1 Material experiments in laboratory

Laboratory experiments for materials include seven different conditions. Most of the experiments are performed in constant conditions but some experiments are performed in fluctuating conditions in a way that two different conditions vary cyclically. In Table 2 are shown the target test conditions for material experiments in laboratory.

TABLE. 2: Target test conditions of the material experiments in laboratory.

Constant/cyclical conditions	Test condition 1	Test condition 2
Constant	97% RH / 22°C	
Cycle 4 – 8 weeks	97% RH / 22°C	97% RH / -5°C
Cycle 4 – 8 weeks	97% RH / 22°C	97% RH / -20°C
Cycle 4 – 8 weeks	97% RH / 22°C	50% RH / 22°C
Constant	97% RH / 5°C	
Constant	97% RH / -5°C	
Constant	90% RH / 22°C	
Constant	90% RH / 5°C	

One or two surfaces of the specimens were sprayed with mould suspension before the experiments started. The specimens are stored in closed plastic boxes with saturated salt solutions during the experiments to achieve the wanted humidity conditions.

3.1.2 Material experiments in field conditions

The material experiments in field conditions take place in the shelter. The wall structure of the shelter is designed so that temperature and relative humidity are same as in open-air conditions but specimens are sheltered against sun, rain and snow. Three data-loggers measure temperature and relative humidity in the shelter. This experiment is performed for all test materials. There are two different sized specimens: small specimens are approximately sized 50 mm × 50 mm × 20 mm and large specimens are approximately sized 300 mm × 300 mm × 50 mm. Some of them are seen in Figure 2. The specimens were not treated with mould suspension before the experiments started.

FIG. 2: The small specimens are placed on the steel shelves (on the left) and the piled specimens are palced on the platforms (on the right).

The small specimens are placed on the steel shelves (Figure 2). One test series consists of nine specimens. There are three extra stone based materials and wood specimens. These specimens were soaked in water for seven days before the experiments started.

The 300 mm × 300 mm × 50 mm sized specimens are piled up like in a storage. One pile consists of six specimens. There are two piles of all materials. The other pile of stone material and wood specimen were soaked in water for nine days before the experiments started. The specimens are placed on the platforms (Figure 2).

3.2 Experiments for exterior wall assemblies

The experiments for exterior wall assemblies are done both in laboratory and in field conditions. Purpose of these experiments is to study mould growth inside the assembly in the interface of two materials. Temperature and relative humidity of the interface is measured with temperature and relative humidity sensors. Experiments are done with studied materials so that each insulating material (glass wool, paper-coated polyurethane (PUR), expanded polystyrene (EPS) and polyester wool) form a structural combination with other studied materials (edge-glued spruce board, concrete, autoclaved aerated concrete and expanded clay aggregate concrete). The ground polyurethane is not tested in these wall assembly experiments.

3.2.1 Laboratory experiments for exterior wall assemblies

Laboratory experiments for assemblies are performed in two separate test series. Each series covers eight different exterior walls; thus a total of 16 different combinations are studied in the experiments. Size of one wall is 600 × 800 mm^2. The assemblies covered in the test series are listed in the Table 3. The experiments are performed in three different test phases. In the first phase, the assemblies are kept in a climate chamber under constant conditions (approx. 20 – 22°C / 95 – 97% RH). This arrangement is portrayed in Figure 3.

TABLE 3: The tested assemblies in the laboratory experiments.

First test series	Second test series
autoclaved aerated concrete + glass wool	autoclaved aerated concrete + polyurethane
autoclaved aerated concrete + polyester wool	autoclaved aerated concrete + expanded polystyrene
edge-glued spruce board + glass wool	edge-glued spruce board + polyurethane
edge-glued spruce board + polyester wool	edge-glued spruce board + expanded polystyrene
expanded clay aggregate concrete + glass wool	expanded clay aggregate concrete + polyurethane
expanded clay aggregate concrete + polyester wool	expanded clay aggregate concrete + expanded polystyrene
concrete + glass wool	concrete + polyurethane
concrete + polyester wool	concrete + expanded polystyrene

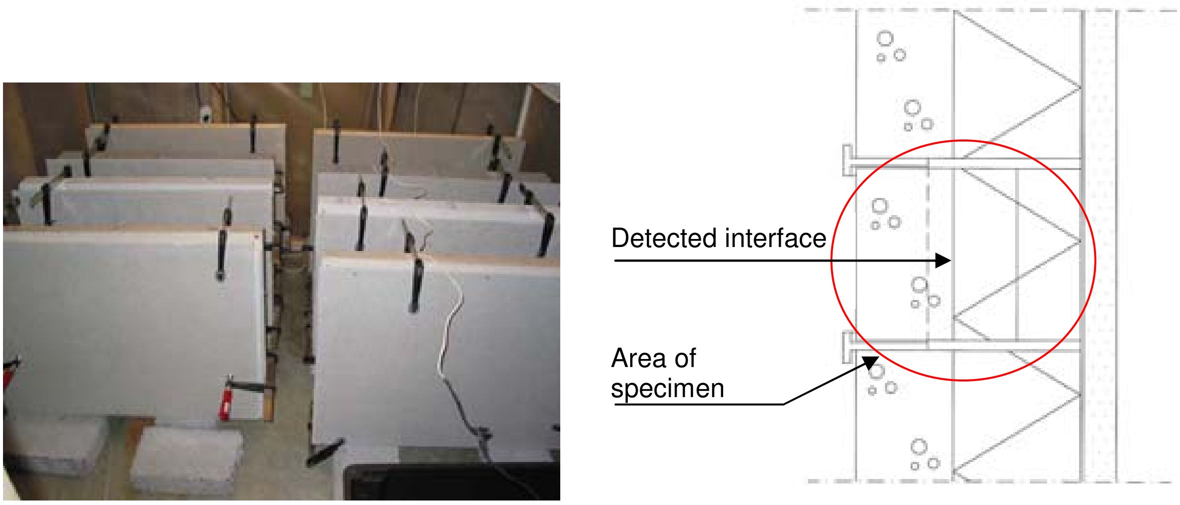


FIG. 3: The tested exterior wall assemblies in the climate chamber (on the left). The principle of the test specimen (on the right).

The second phase (winter) and the third phase (spring) of the experiments are performed in the weatherisation equipment. The tested assemblies are placed into the steel frame between the climate chambers. In the interface of façade and insulation material temperature is approximately -8 to -2^{o}C and relative humidity 95 to 100% RH during the winter phase. During the spring phase temperature in the interface is from a few degrees below zero to 10 to 15^{o}C. There is not relative humidity control in during the spring phase but a fast fluctuating temperature.

The mould growth in the interface is checked regularly. Diameter of the test specimen cylinder is approximately 70 mm. The specimen is settled into the plastic pipe so that it is easy to pull out from assembly and also diffusion is possible through the specimen. The principle of the test specimen is shown in figure 3.

3.2.2 Field experiments for exterior wall assemblies

The field experiments of wall assemblies are performed in the test building on the test field. There are installed two wall modules facing north and south. The module is divided into 4 separate exterior wall assemblies (Figure 4). The assemblies are same in both wall modules. The tested material combinations are edge-glued spruce board-glass wool, edge-glued spruce board – paper-coated polyurethane, edge-glued spruce board-expanded polystyrene and edge-glued spruce board-polyester wool. There are four specimens in every test assembly. Wood material of two specimens is edge-glued spruce board and of the other two is pine sapwood. There is also one specimen with a little piece of wood inside of it. This piece of wood is weighted regularly to determine the moisture content of wood and to check the relative humidity inside the assembly. There is also temperature and relative humidity sensors inside every assembly. The test walls are sheltered from driving rain with plywood boards.

The indoor temperature of the test house is approximately 20°C and moisture supply has been varied between 3 and 7g/m^3. Outdoor air conditions are measured by temperature and relative humidity sensors.

FIG. 4: The test building (on the left) and the wall module which is divided into four different exterior wall assemblies (on the right).

4. Results of mould experiments

4.1 Material experiments

4.1.1 Material experiments in laboratory

Growth of mould fungi was detected in all tested materials after different exposure time periods in high humidity exposure conditions (97% RH and 22°C). The mould growth on specimens has been detected with naked eye and using light microscope. In the pine sapwood, the first stage of growth (index 1) was found after one week exposure and index 3 (first visual symptoms) was detected after 4 – 8 weeks from the beginning of the test, depending on the test series (Figure 5). When the exposure progressed the highest mould index was detected in pine sapwood. The mould fungi were mostly *Penicillium*- and *Aspergillus*-types. These same mould fungi were detected also in edge-glued spruce board (Spruce Gluelam), but less and much later than in pine sapwood. Also in the paper layer of polyurethane, the mould index 1 was detected after 4 – 8 weeks, only in surfaces where spore suspension were sprayed. On the upper side of glass wool where spore suspension was sprayed, first sign of mould growth was detected after 4 – 8 weeks. On the under side, the development of mould index was significant retarded. The same type of growth response was found for other insulation material.

When the exposing time continued, mould growth was detected in all studied materials. Plenty of thin mould hyphae were detected in autoclaved aerated concrete and in expanded clay aggregate concrete. These mould fungi were detected only using microscope. It was not possible to see it with the naked eye altought there were lots of greenish pores. Most of the mould fungi were *Paecilomyces*-typed, but also *Aspergillus*-typed were common. Thin hyphae were also detected in the concrete specimens especially in "open surface pores". In concrete were also in places detected dark *Cladosporium*-mould hyphae for index 3. In light coloured materials mould hyphae could be easily found which may affect the mould index level.

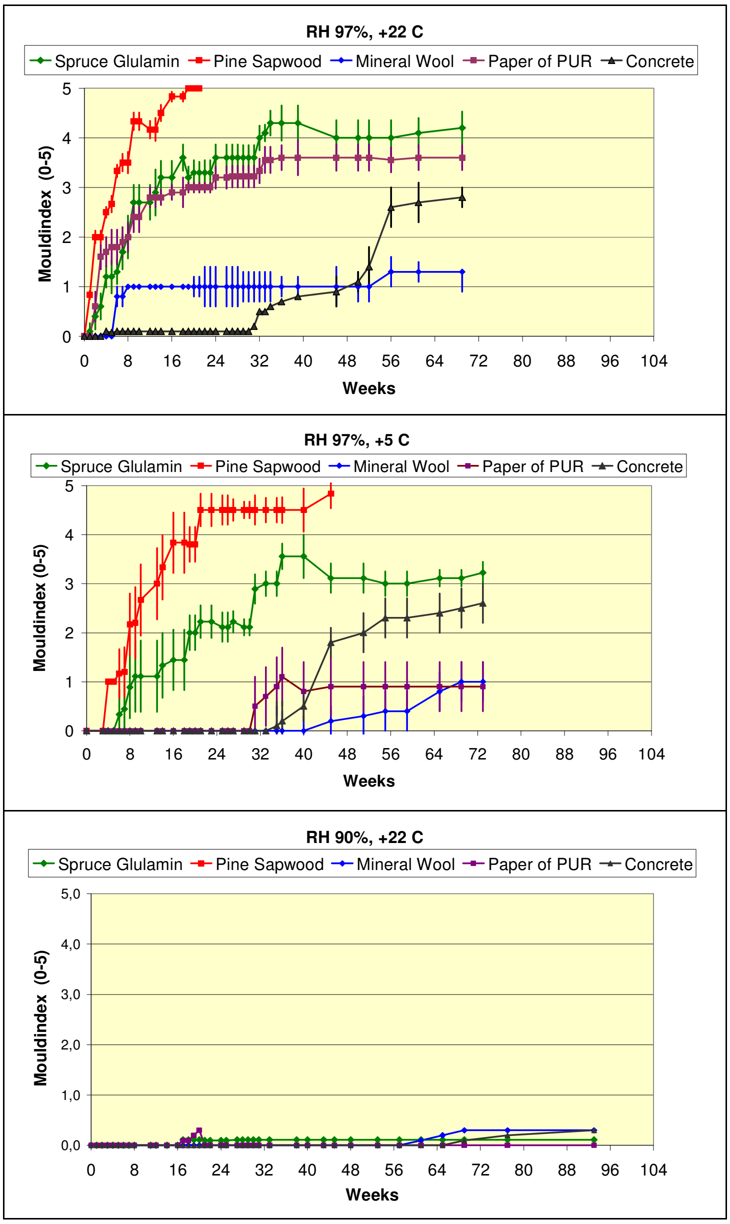


FIG. 5: Results on mould index development under constant high humidity conditions of 97% RH at 22°C and 5°C and humidity conditions of 90% RH and 22°C.

The mould growth type and intensity was different depending on the material. On paper coating of polyurethane mould fungi was also very dark and different from other moulds that were found. Only a slight growth response was found on the glass wool (like also other insulation materials). The solidity of glass wool seemed to weaken in the course of time what can affect the mould resistance. In glass wool there was mostly dark mould but also in some places light, soft mould with green spores.

Under lower humidity conditions (90% RH), no growth of mould fungi was detected in stone based materials and growth on wood-based and paper-coated products was retarded and slight. The growth at low temperatures (5°C) was also retarded.

4.1.2 Material experiments in field conditions

Mould growth in the field test materials is checked about every half a year, in spring and in autumn. The small specimens (50mm × 50mm × 20mm) are checked under microscope and the piled specimens (300 mm × 300mm × 50mm) are checked using loupe.

After five months from the beginning of the experiments the mould growth of the specimens was checked first time. On the upper surfaces of the specimens was a layer of organic dirt (for example pollen). Mould growth was detected under microscope (index 1 – 2) only on the surfaces of the small wood specimens. In the following checks mould growth was detected in the organic dirt. On the surface of the material there was more dirt if there were different open pores or microscopic holes. On the upper surfaces of the specimens is detected more mould growth than on the under side surfaces. The unexpected result is that in stone based materials there was detected more or the same degree of mould growth as in wood materials.

After 16 months from the beginning of the experiments there was mould growth on the upper surfaces of every material. The highest mould indexes were detected in paper coating of polyurethane (index 2.2) and in pine sap wood (index 2.1). The indexes are averages of nine specimens. In these materials was also visually detected mould growth (index 3). There was mould growth also on the under surfaces of edge-glued spruce board specimens which had been soaked in water. The lowest mould indexes were detected in polyester wool (mean value index 0.3) and in ground polyurethane (mean value index 0.3).

4.2 Experiments for exterior wall assemblies

4.2.1 Laboratory experiments for exterior wall assemblies

The exterior wall assemblies of the first series were approximately 7 months in the conditions of the first phase (autumn), approximately 4 months in the conditions of the second phase (winter) and approximately 6 months in the conditions of the third phase (spring). After the third phase the exterior wall assemblies are in the autumn phase again. The tested structures were treated with mould suspension before the experiments started.

After about three months from the beginning of the experiments mould growth was detected on the surfaces of edge-glued spruce board. In edge-glued spruce board – glass wool –combination was detected index 1 and in edge-glued spruce board – polyester wool –combination index 3. Mould growth was not detected on the surfaces of glass wool and polyester wool. After six months from the beginning of the test the mould indexes on the surfaces of the edge-glued spruce board specimens varied between 1 and 3. The mould indexes in the other materials varied between 0 and 1.

In the end of the first phase there were still highest mould index values on the surfaces of edge-glued spruce board. In edge-glued spruce board – glass wool –combination the indexes varied between 2 and 3 and in edge-glued spruce board – polyester wool –combination between 1 and 3. The mould indexes on the surfaces of the glass wool specimen were between 1 and 2 depended on the assembly. On the surfaces on polyester wool the index was 1, on the surfaces of autoclaved aerated concrete indexes were between 0 and 1 and on the surfaces on concrete the index was 1.

After three months from the beginning of the second phase there was not increase in mould growth in any material. On the surfaces of some materials like autoclaved aerated concrete the mould indexes were decreased one figure. The mould indexes on the surfaces on the wood specimen were same as in the end of the first phase.

After third phase the mould indexes were at same level as in the end of the second phase. Another autumn phase is still going on.

The exterior wall assemblies of the second series were in the conditions of the first phase about 7 months. The highest mould indexes were detected on the surfaces of concrete with both insulation materials. The indexes varied between 2 and 3. The mould index on the paper surfaces of polyurethane was 2 in autoclaved aerated concrete – polyurethane, concrete – polyurethane and wood – polyurethane combinations. The mould index on the paper surface of polyurethane was between 1 and 2 in expanded clay aggregate concrete – polyurethane combination. The mould index of expanded polystyrene was 2 with expanded clay aggregate concrete and autoclaved aerated concrete and the mould index of expanded polystyrene was 1 in another combinations. On the surfaces of the edge-glued spruce board specimens the mould indexes were 2. The exterior wall assemblies of the second series are in second phase at the moment.

4.2.2 Field experiments for exterior wall assemblies

The field experiments for exterior wall assemblies started approximately 13 months ago. The mould growth was checked after 5 and 11 months from the beginning of the experiment. The mould growth was not detected in any material. The temperature inside the tested assemblies was between -10 and 20°C. The relative humidity of the interfaces of expanded polystyrene and also of edge-glued spruce board and paper-coated polyurethane and edge-glued spruce board was between 50 and 70% RH. Inside the glass wool and polyester wool assemblies the relative humidity was between 70 and 90% RH.

5. Conclusion

Laboratory and field tests have been performed on eight different building materials and wall assemblies as combinations of these. The aim was to provocate mould growth and to follow the development of it. The motivation is to gain knowledge and experimental data for further mould modelling development work. The results will give valuable information on mould growth on some very different but common building materials and also whether a condition is critical or not.

There was detected mould growth in every material for the conditions where the target relative humidity was 97% RH. The highest mould indexes were found on pine wood, spruce (glue board) and papercoating of polyurethane. The present results of the experiments in the cyclical conditions are variable. It is possible that temperature -20°C has less influence on mould growth than temperature -5°C. In the conditions where target relative humidity is 90% RH, the detected mould indexes were very small, even for 22°C. It is important to notify that the detected mould growth has been insignificant (mould index ≤ 3) until now. In common usage of the tested construction materials, there may be a dirt layer on the surface that can cause some mould growth (index 1 – 2). However, the mould index will not likely increase further, if the dirt layer is the only reason for mould growth.

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