Mould growth on building materials in laboratory and field experiments

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SUMMARY:
This paper presents the final results of a project carried out in 2005–2009 to study mould growth on eight different materials. The primary aim of the research was to expand the earlier mould growth calculation model developed for wood materials to cover also other materials. The development of the model is described in another paper for this conference titled "Classification of material sensitivity – New approach for mould growth modelling".

Mould grew at different rates on different materials and the maximum mould indices of materials varied. At the highest humidity stress mould growth was detected on each material. Wood materials were found to have the highest mould indexes. The maximum mould indexes of stone-based materials were lower than those of wood-based materials. Materials were divided into different mould growth categories on the bases of the results. Decline of mould growth was examined in both cold and dry conditions. The results indicated that frost appeared to slow mould growth on several materials while having a negligible effect on others. A dry period lowered the mould index slightly in most cases. Decline of mould growth was, however, clearly smaller with each material compared to the original decline model.

1. Introduction

Mould growth is one of the most important criteria when assessing the building-physical performance of building materials and assemblies. A mathematical model of mould growth that uses a mould index to describe the phase and intensity of mould growth has been developed earlier (Viitanen 1996). The model is intended primarily for evaluating mould growth on wood materials. A project called "Mathematical modelling of moisture behaviour and mould growth in building envelopes" was implemented in 2005–2009 to make the existing model cover also the following building materials: concrete, autoclaved aerated concrete (AAC), expanded clay aggregate (LW) concrete, edge-glued spruce board, glass wool, polyester wool, polyurethane (paper-coated and ground) and expanded polystyrene (Vinha et al.). The reference material was pine sapwood. Tests on materials and assemblies were run in laboratory and field conditions. The development of the calculation model is described in more detail in another paper written for this conference titled "Classification of material sensitivity – New approach for mould growth modelling".

2. Mould growth limit values and their definition

Mould growth was defined in this study according to an earlier developed mould index classification (Viitanen 1996). The original classification criteria were changed so as to allow applying them to the evaluation of different materials. The mould index considers both the beginning of growth (index value 1) and the degree of increase in growth (index values 2–6). Mould growth on the surfaces of materials was determined microscopically and visually. Table 1 presents the mould index classification criteria of this study.

TABLE 1. New mould index classification criteria applied in this study.

Mould index	Classification principles
0	No growth
1	Microscopically detected growth, beginning growth at places, a few hyphae
2	Microscopically detectable growth, several colonies of hyphae have formed
3	Growth perceptible to the eye, mycelium covers less than 10% of area (incipient spore production) OR microscopically detectable growth, coverage less than 50%
4	Growth perceptible to the eye, mycelium covers about 10–50% of area OR microscopically detectable growth, coverage over 50%
5	Growth detectable to the eye, strong at places or mycelium coverage over 50%
6	Very strong growth, mycelium coverage nearly 100%

3. Mould growth test arrangements

The aim of the mould growth tests was to provide a comprehensive picture of the mould susceptibility and mould growth resistance of highly different types of materials – and the interfaces between two materials within assemblies – under various conditions.

3.1 Material tests

Material tests were conducted with all test materials (pine sapwood, edge-glued spruce board, concrete, AAC, LW concrete, glass wool, polyester wool, expanded polystyrene and polyurethane) in laboratory and field conditions. The test series involved nine specimens. The reference material was pine sapwood.

3.1.1 Material tests in the laboratory

Laboratory tests on materials were conducted in the conditions presented in Table 2. Material tests were run in constant and fluctuating (4–8 week cycle) conditions. Cycling of conditions was started only after mould growth was clearly detectable on materials.

TABLE 2. Conditions in laboratory tests on materials. Cycle length in fluctuating conditions was 4–8 weeks.

Conditions Constant/cycled	Target conditions [RH %/ °C]		Actual conditions [RH %/ °C]	
	Condition 1	Condition 2	Condition 1	Condition 2
1 Constant	97/ +22		96–97/ +20 to +22	
2 4-8 week cycle	97/ +22	98/ -5	95–97/ +20 to +22	98–100/ -5
3 4-8 week cycle	97/ +22	98/ -20	96–97/ +20 to +22	98–100/ -15to -20
4 4-8 week cycle	97/ +22	50/ +22	96–97/ +20 to +22	45–50/ +20 to +22 [2)]
5 Constant	98/ +5		97–99/ +4 to +5	
6 Constant	98/-5		99–100/ -5 [1)]	
7 Constant	90/ +22		89–90 / +20 to +22	
8 Constant	90/ +5		92–95/ +4 to +5	

1) Temperature was not stable and varied a lot initially during momentary defrost cycles; humidity was remarkably high at times (condensate).2) Dry humidity was not achieved initially (failure), but dry conditions were achieved in the end.

The surfaces of material specimens were sprayed with four different mould suspensions prior to tests to ensure the presence of particles that would start growing on all materials, so that initial conditions for mould growth would be as equal as possible.

3.1.2 Field tests on materials

Field tests on materials were conducted in a shelter in a test field which provided protection from rain, snow and sunlight. Air from the outside could flow into the shelter whereby the temperature and relative humidity of the indoor air corresponded closely to those of outdoor air.

3.2 Assembly tests

Tests on wall assemblies were conducted in both laboratory and field conditions. Their aim was to examine mould growth in the interface between two joined materials within assemblies. Temperature and relative humidity of the interface were measured continuously.

3.2.1 Laboratory tests on assemblies

Laboratory tests on assemblies were conducted with the test materials so that each thermal insulation (glass wool, polyester wool, expanded polystyrene and polyurethane) formed a structural combination with the other examined materials (edge-glued spruce board, concrete, AAC and LW concrete).

Laboratory tests on assemblies were run as two separate test series consisting of three different test periods. The first series was examined in periods 1–4. The fourth cycle was the same as the first. The second test series was examined in periods 1–3. Table 3 shows the target conditions and the actual conditions measured during tests. Each test cycle lasted 4–11 months depending on the series.

TABLE 3.Target and actual conditions in laboratory tests on assemblies.

Conditions	Target conditions		Actual conditions	
	[RH %]	[^{o}C]	[RH %]	[^{o}C]
Test cycle 1	Standard 95–97	Standard +20 to +22	92–97	+20 to +25
Test cycle 2	Standard 95–100	Standard –6 to -4	88–100	-8 to -2
Test cycle 3	No target for RH	1 day cycle	45–100	-4 to -1/ +10 to +15
Test cycle 4	Standard 95–97	Standard +20 to +22	93–99	+20 to +24

3.2.2 Field tests on assemblies

In field tests, wall assemblies were studied in a test building located in a test field whose indoor air conditions could be regulated. Edge-glued spruce board or pine sapwood formed a structural combination with each thermal insulation of the examined assemblies. Temperature inside the test building was +20 ^{o}C and moisture excess compared to outdoor air was 3–7 g/m^3. Test assemblies were protected against driving rain.

4. Results of mould growth tests

4.1 Material tests

4.1.1 Laboratory tests on materials in standard conditions

Figure 1 shows the laboratory test results for all materials in standard conditions (96–97 % RH / +20 to +22 ^{o}C). "S+" means that a mould suspension was added prior to the test whereas "S-" means that a mould suspension was not added.

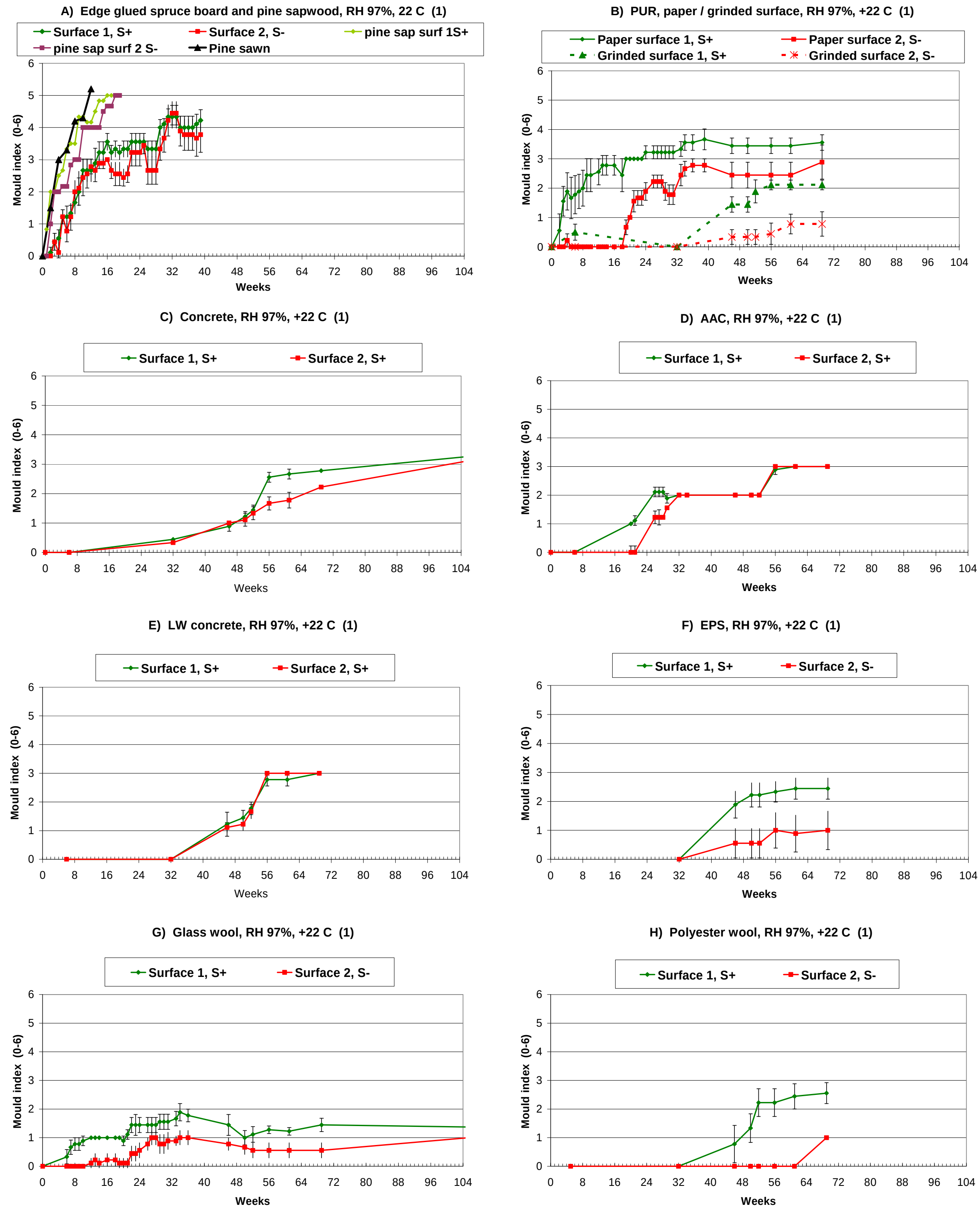

FIG 1. Mould growth development on different materials at 96–97 % RH /+20 to + 22 ^{o}C.

Total exposure time depending on material was 40–124 weeks. Figure 1 shows that mould growth was detected on all materials in the tested conditions. The mould indices of wood materials were the highest (4–5) at the end of the study. With the exception of wood materials and paper-coated polyurethane, the maximum mould index of all materials was about 3 at the end of the study.

Figure 2 presents the results at the lower moisture load (89–90 % RH / +20 °C to +22 °C) for wood materials and polyurethane.

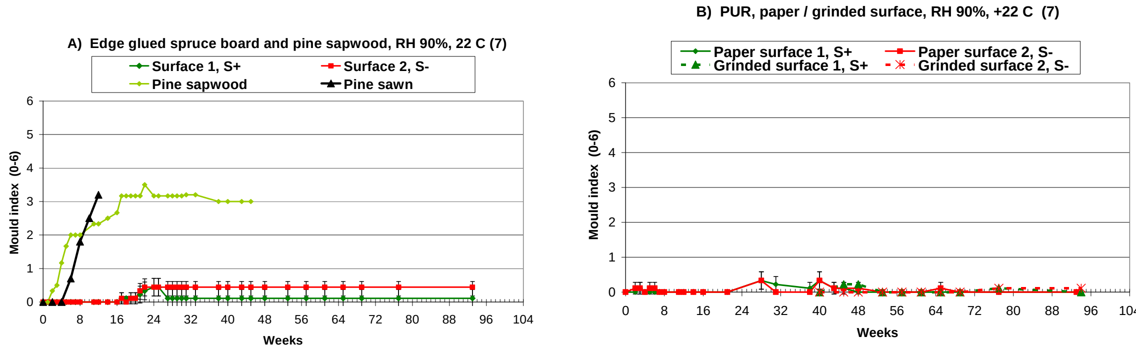

FIG 2. Mould growth development at 89–90 % RH / +20 to + 22 °C.

Figure 2 shows that at the lower moisture load (89–90 % RH) mould growth was very weak except in the case of pine sapwood for the duration of the study (exposure time 93 weeks). The mould indices of all materials in these conditions were 0–1 with the exception of wood materials.

Figure 3 shows the results for wood materials, polyurethane, concrete and LW concrete at 97–99 % RH / +4 to +5 °C.

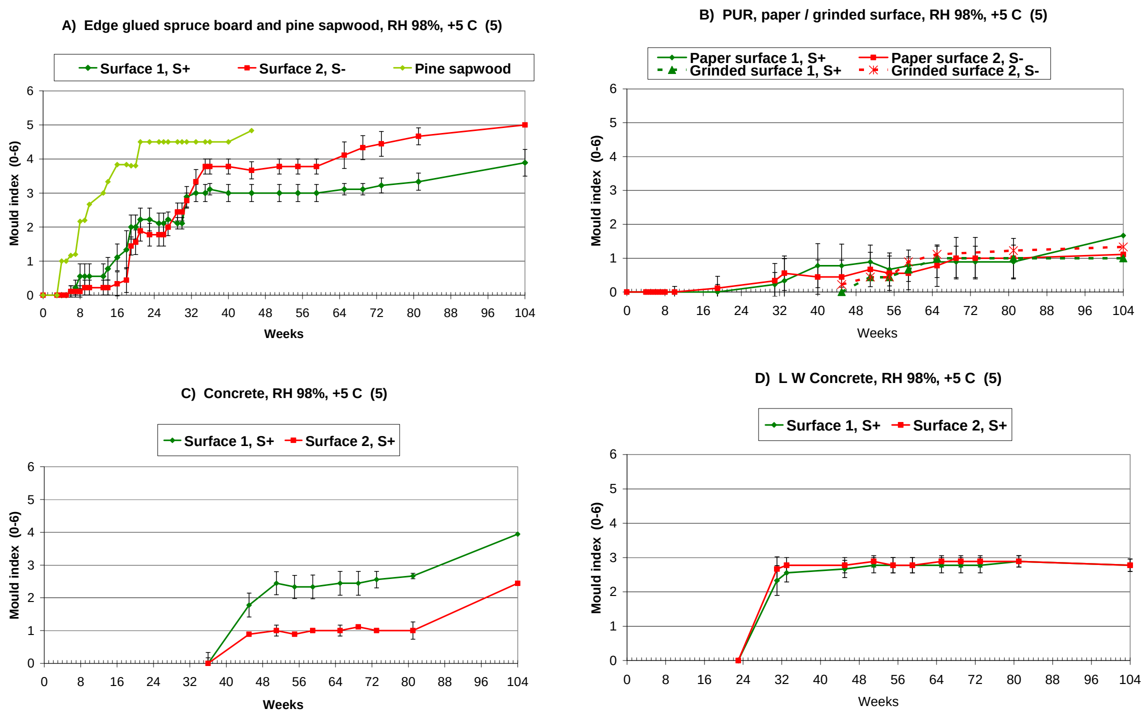

FIG 3. Mould growth development at 97–99 % RH /+4 to +5 °C.

Figure 3 shows that at higher relative humidity, temperature had no major impact on the final mould index, except in the case of the paper-coated polyurethane insulation whose mould index at + 5 °C was clearly lower from the beginning than at +22°C (total exposure time 104 weeks). The maximum mould indices of other materials were 2–3 at the end of the study.

4.1.2 Laboratory tests on materials in fluctuating conditions

Figure 4 (A and C) show the results of material tests in fluctuating conditions. The results are from a test series where the materials were exposed to warm high humidity and cycled frost conditions (-15 to -20 °C). The frost cycles are depicted in the figure by vertical bars. Figure 4 presents the results for wood materials and concrete.

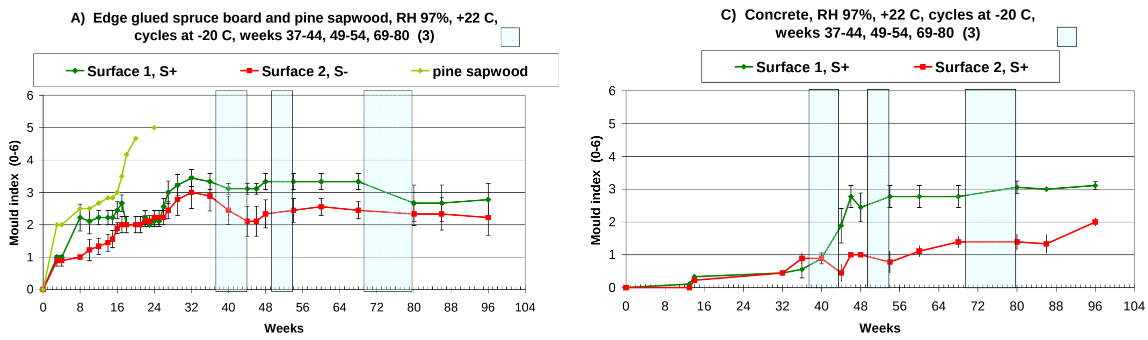

FIG 4. Mould growth development in a cycle of 96–97 % RH / +20 to +22 °C and 98–100 % RH / -15 to -20°C.

The impact of frost on mould growth varies. With some materials growth weakens while with other its impact is negligible. All in all, fluctuating conditions were not found to have any major impact on mould growth with different materials.

Figure 5 (A and F) shows the impact of the dry period on mould growth development with wood materials and expanded polystyrene. The initial conditions were 96–97 % RH / +20 to +22 °C and the dry conditions 45–50 % RH / +20 to 22 °C.

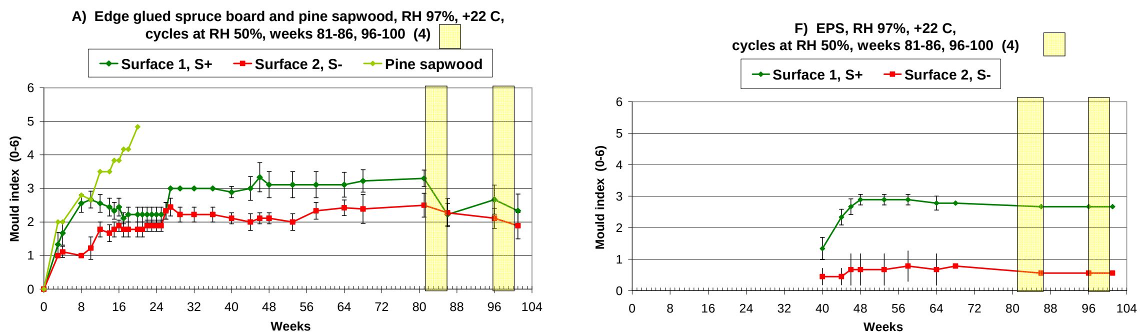

FIG 5. Impact of dryness (45–50 % RH) on mould growth development with wood materials and polystyrene. Initial conditions 96–97 % RH /+20 to 22 °C. Dry periods are indicated by vertical bars.

The dry period retarded mould growth with most materials while in some cases it had no clear impact on the mould index. The dry period was implemented only toward the end of the study.

4.1.3 Field tests on materials

Pollen and other organic dirt started to collect quickly on the top surfaces of specimens in field tests. Field tests on materials took a total of about 32 months.

The highest mould index detected at the end of tests was 5 for planed pine sapwood. The mould index of sawn pine sapwood was 4–5. The final mould index of edge-glued spruce board was 2–3. The top surfaces of polyurethane (paper-coated), glass wool and concrete as well as the undersides of polyurethane (paper-coated), expanded polystyrene and concrete had a mould index of 2–3 at the end of testing. The mould index of the top surfaces of polystyrene, LW concrete and AAC, the underside of glass wool, and both surfaces of polyester was 2 at the end of testing. The mould indices of the undersides of AAC and LW concrete were 0–1 at the end of testing.

4.2 Tests on assemblies

4.2.1 Laboratory tests on assemblies

The conditions of all assemblies (at their examined interfaces) were different due to the different building-physical properties of the materials. When reviewing the results, one should also consider that e.g. the lengths of the test cycles of different test series varied. Thus, the mould indices of assembly tests should not be compared by materials.

Figure 6 gives an example of the mould indices determined for two structural combinations (AAC–polyester wool and LW concrete–glass wool) while Figure 7 does the same for concrete–expanded polystyrene and edge-glued spruce board–polyurethane (paper-coated).

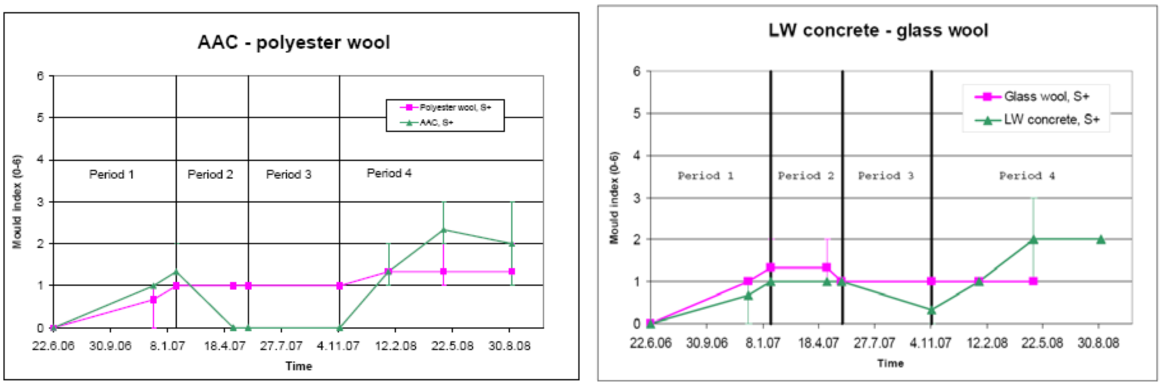

FIG 6. Mould growth index development on AAC–polyester wool and LW concrete–glass wool structural combinations.

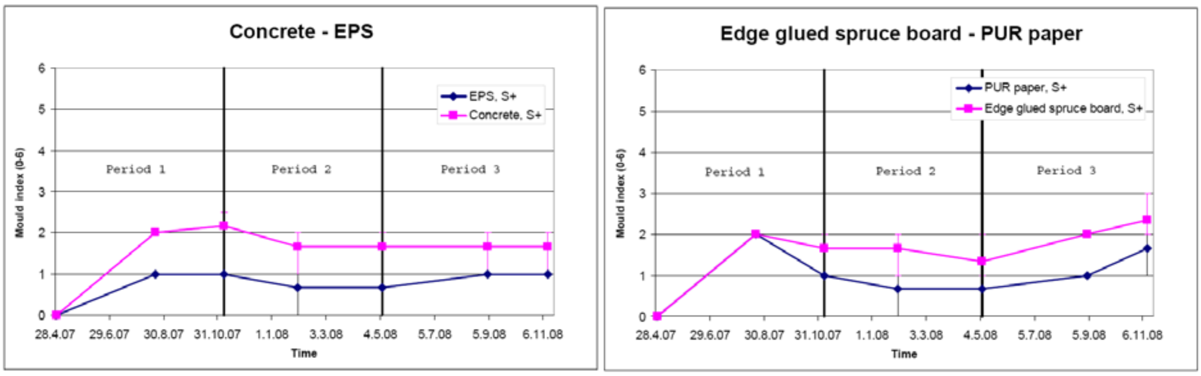

FIG 7. Mould growth development on concrete–expanded polystyrene and edge-glued spruce board–polyurethane (paper-coated) structural combinations.

The highest mould indices were detected after the fourth period with edge-glued spruce board whose indices were 3–4. The indices of AAC and concrete were 2–3 and those of other materials 1–3.

4.2.2 Field tests on assemblies

Field tests on assemblies lasted 21 months. Their mould indices varied a lot by materials. This was due the highly different conditions prevailing within assemblies. Due to the different building-physical properties of materials and the test arrangements, the relative humidities of assemblies insulated with glass wool and polyester wool (65–100 % RH) were throughout the study significantly higher than with assemblies insulated with expanded polystyrene and polyurethane (40–75 % RH). Thus, the results cannot be compared.

The highest mould indices in the field tests were found for pine sapwood (5) and edge-glued spruce board (4–5). The figures for glass wool were 3–4 and for polyester wool about 3.

5. Conclusions

This study examined mould growth on various materials and at the interfaces of two materials within assemblies by laboratory and field tests. The results were used primarily to develop an earlier mould growth calculation model as well as to divide the materials into groups based on their susceptibility to mould growth as follows: sensitive (wood-based materials), medium resistant (e.g. inorganic materials) and resistant.

In material tests at high relative humidity (97–98 % RH), mould growth was detected on all materials and sooner than in other test conditions. Growth was strongest on wood materials and paper-coated polyurethane. AAC was the stone material on which mould growth started the fastest (when mould index = 1). Yet, the final mould index of AAC was about the same as that of other stone materials, which is why it was classified as medium resistant.

At high humidity and low temperature (5 ^{o}C), mould growth was somewhat slower and more limited. However, at constant lower humidity (89–90 % RH/ +20 to 22^{o}C) mould growth was very limited (index 0–1) with the exception of pine sapwood. Decline of mould growth was examined using cold and dry conditions. The results of tests in cycled conditions varied. Frost appeared to retard growth on several materials when it lasted long. The impact of frost also depended on the material. A dry period lowered the mould index in most cases. However, the study revealed that retardation according to the original model was clearly more intense than indicated by the results of this study.

6. Acknowledgements

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