Laboratory tests on decay of natural fibre insulation materials suggest a more differentiated evaluation and higher RH thresholds

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Abstract. To reduce CO_2 emissions and save grey energy, natural materials like wood and wooden materials are becoming more and more important. However, these products are particularly sensitive to moisture, as they can be attacked by mould or decay fungi. In contrast to mould growth, which typically is associated with visual impairment and health problems, the growth of decay fungi may result in structural defects which clearly must be excluded. Up to now it is mostly assumed that wooden materials are more sensitive to such attack than solid wood. Therefore, different wood fibre insulation materials were inoculated with decay fungi and exposed to different climates to determine the requirements for the decay process and to compare them with the requirements of decay by the same fungi of solid wood. The results prove that some natural fibre materials are equally or even more resistant to decay fungi than solid wood, while others are less. The resistant products can therefore be assessed like solid wood – for which already temperature dependent thresholds and in part also transient decay prediction models are available. Maybe even specific higher moisture levels can be acceptable. However, the results also suggest a differentiated view on natural fibre insulations, as they have a very different susceptibility to wood decay. Uniform and significantly lower limits than for solid wood are not justified.

1. Introduction

While building materials made from renewable raw materials have many advantages for reasons of sustainability and carbon footprint, and are therefore increasingly favoured, their widespread use is often hindered by uncertainty regarding moisture sensitivity and decay, which often result in not precisely known application limits.

Under European outdoor climate, the occurring combinations of relative humidity (RH) and temperature may allow for microbial growths like algae or mould over significant periods of the year. At least on materials, exposed to the outdoor climate directly on the exterior surface or behind a vented or ventilated facade or roof cover, mould growth cannot be completely excluded, it can only be limited to an uncritical level. Absolute limit values for RH, independent on the temperature, are pretty unrealistic and hardly helpful. A more accurate transient approach for such a definition of the uncritical level was presented in [1] based on the mould growth prediction models described in [2] and [3]. Also ASHRAE standard 160 does not limit the acceptable mould growth level to zero, which is rather unrealistic, but generally to a mould index (MI) value of 3 according to [3][4][5]. Especially at low temperatures and high humidity levels as well as in parts of the construction without air gaps, decay fungi can pose a higher risk than mould growth. This can be derived from the limit curves for wood rot, which are below the ones for

mould growth in the temperature range below approximately 3 °C [2][5] but also from practical experience, where obvious mould growth conditions according to the available models but no mould growth were observed [6]. In difference to mould, the growth of rot fungi often does not become visible directly and is normally only observed or detected by damages or mass loss. That means, in analogy to the mould evaluation that a starting growth of the rot fungi in the materials is accepted, while mass loss generally has to be avoided. Thus, the mass loss would be comparable to MI 3 which serves as critical limit for mould growth. According to the WTA guidelines for wooden constructions and interior insulations [8][9] it is common practice, to verify the inner part of the constructions (especially inside the airtightness layer) concerning mould growth, but not the interface between interior insulation and wall or the exterior parts of wooden constructions. The mould risk is avoided or limited to an uncritical level by a largely airtight and gap-free construction method. However, if wood or wooden materials are present at these positions, the decay risk must be analysed.

Up to now, limit values specified in standards and guidelines for such materials have been generally quite low, which considerably restricts their range of application. Manufacturers, however, claim to have good experience beyond the previously permissible areas of application. For solid wood, many investigations on durability and moisture respectively decay fungi resistance have already been performed. Also moisture and temperature dependent limit curves [9][10][11][12] as well as transient evaluation models are either already available [13][14][15] or will be available in near future [16]. Such transient models allow for a more sophisticated evaluation depending on coinciding heat and moisture conditions and their duration. For this reason, laboratory investigations were carried out on wood fibre insulation materials [13] to compare the moisture and decay fungi resistivity of wood fibre interior insulation materials to the one of solid wood at different critical temperature and humidity conditions (preliminary results after 20 weeks of incubation were published in [17]). The gained results are a first step into the direction of a more accurate transient evaluation of the hygrothermal conditions occurring in wooden and other natural fibre materials concerning infestation by wood decay fungi.

2. Setup of the decay investigations in the laboratory

For the lab tests, four typical wood fibre materials, which are used as interior insulation according to the specifications of the manufacturers, are compared to pine sapwood, which can be considered one of the most sensitive solid woods. The materials represent typical categories like rigid insulation boards or flexible mats, different levels of hydrophobization as well as dry and wet production process. Test specimens of 50 mm x 50 mm are used with a thickness of 40 mm for the fibre insulation and 10 mm for the solid pine sapwood samples. The products are described in **Table 1** as far as the information was made available by the manufacturers. Pictures of the specimens are provided in **Figure 1** and **Figure 2**.

Table 1: Wood fibre insulation materials for interior insulation used for the lab tests.

Material Index	Short description	Product information
A	Dry insulation board 0.5 %	dry production process, density 110 kg/m³ with hydrophobic agent: 0.5 % by mass
B	Dry insulation board 0.8 %	dry production process, density 150 kg/m³ with hydrophobic agent: 0.8 % by mass
C	Flexible fibre mat	dry production process, density 60 kg/m³ with flame retarding agent / no hydrophobic agent
D	Wet insulation board	wet production process, density 160 kg/m³ no hydrophobic agent

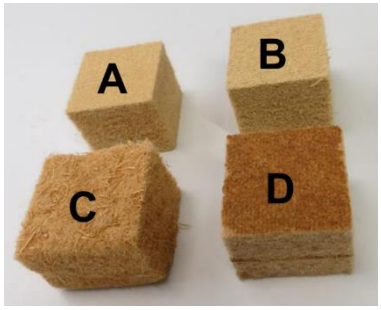

Figure 1: The four investigated wood fibre insulation materials

Figure 2: The reference material solid pine sapwood

As test fungi three different decay fungi are used, which are either commonly used for decay tests in the standards or are under suspicion to have a high affinity for wood fibre materials: *Coniophora puteana* (DSM 3085), *Trametes versicolor* (DSM 3086) and *Schizophyllum commune* (HOKI F 00315, proprietary isolate). In addition, *Serpula lacrymans* (CBS 235.33) was used in the investigations. *S. lacrymans* is responsible for many severe damages in building practice. The inoculation with the test fungi is performed by overgrown (untreated) pinewood dowels to avoid transfer of nutrients together with the mycelium (**Figure 3** and **Figure 4**).

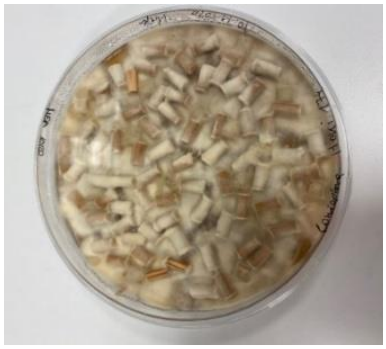

Figure 3: Overgrown wooden dowels with test fungi *Coniophora puteana*

Figure 4: Transfer of the dowels into the test specimen for inoculation

Each specimen is equipped with four dowels, each for one of the four fungi. While the growth of the different species on and around the dowels can be observed separately, the mass loss can be only measured as one single value for all species. Despite this disadvantage, an inoculation with four dowels was chosen to reduce the number of specimens to a feasible level of 180 in 6 incubation units. The inoculated test specimens (pre-conditioned to constant weight at the target climate) are placed in sterilized and airtight incubation units and exposed to constant high RH values of 95, 97 and 100 % RH at 25 °C - conditions just below respectively in a favourable range for decay fungi growth, proven in previous studies like [10]. The whole test setup for the inoculation period of about 340 days is shown in **Figure 5**.

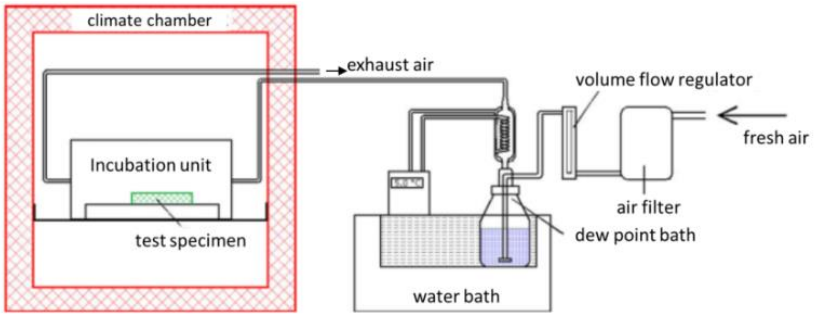

Figure 5: Test setup for the incubation period in the lab with climate chamber, incubation unit and supply of preconditioned and filtered air, first used in [18], [19].

3. Evaluation of the test results

Start and progress of the decay fungi growth was observed by different methods: visual observation by the naked eye and by the means of a stereo magnifying glass, qualitative description of the recognizable biological processes by a biological index, quantification of the mycelium cover of the surface, spread of the mycelium inside the opened specimens and determination of the mass loss of the specimens.

3.1 Visual observation

At the beginning the decay fungi mycelium was growing mainly on the dowels itself and only small differences could be observed between the different specimens: After 23 weeks (**Figure 6**) the tendency of strongest superficial growth on the pine samples was already recognizable, followed by the "wet" board D and the two "dry" boards B and A. The flexible fibre mat C shows no growth at all – also the initial mycelium growth only on the dowel had disappeared. This observation was more and more increased until the end of the investigation period after 48 weeks (**Figure 7**).

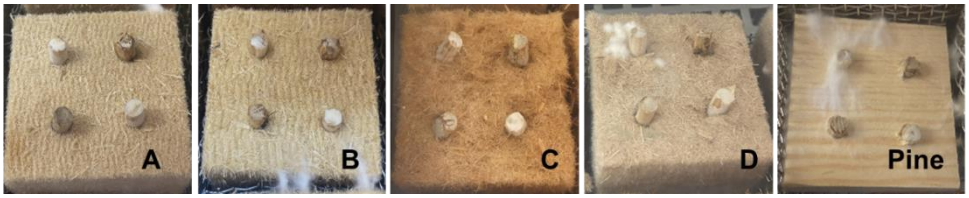

Figure 6: Visual observation after 23 weeks: Strongest decay mycelium growth on pine, followed by the "wet" board D and the "dry" boards B and A. C shows no growth at all – also the initial mycelium growth only on the dowel has disappeared.

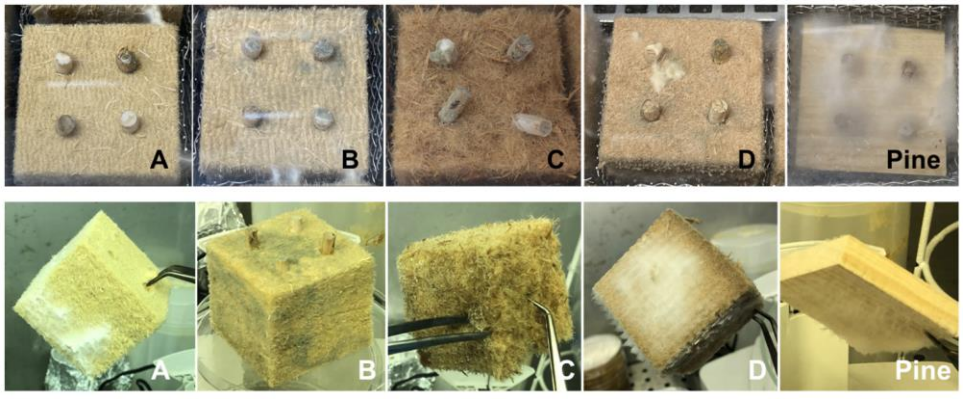

Figure 7: Visual observation after 48 weeks: View from the top (top) and from the bottom or side (bottom). Strongest growth of decay fungi mycelium on the pine specimen, but present also on all other specimens.

Unfortunately, and despite all precautions, mould growth could not be avoided in all cases. While it was initially feared that the mould would completely displace the rot, the results show that, even in case of mould appearance in the incubation unit, the white decay fungi mycelium was only temporarily reduced, but still present on the sides or bottom surfaces at the end of the test period.

3.2 Index evaluation

A second evaluation describes the visible biological processes in a scale, which is described in **Table 2**. The scale is clearly non-linear and more qualitative than quantitative. However, levels 0 to 2 mean either no growth or growth mainly on the dowel, but not on the specimen itself. As mainly the specimen is of interest and only small influence from the material type on the growth on the dowels is assumed, primarily levels above 2.5 or 3 are of relevance.

Table 2: Index of observed biological processes

Level	Description
0	No Growth visible
1	Little growth on the dowel
2	Strong growth on the dowel
2.5	Growth also on the material around the dowel
2.8	Growth also visible on other dowels
3	Expansion of the growth over the whole specimen
3.5	Expansion of the growth over the whole specimen, white hyphens visible also in distance from the dowels
3.6	Expansion of the growth over the whole specimen, white hyphens visible also in distance from the dowels but stronger than at 3.5
3.8	Expansion of the growth over the whole specimen, white hyphens visible also in distance from the dowels but stronger than at 3.6

The results of this second evaluation are shown in **Figure 8** for the first 133 days. As expected, with higher RH levels the microbial growth is accelerated. In the box with only 95 % RH most materials remain below 2.5 and only the dry board B just reaches 3.0. At 97 % RH, the pine wood samples show the most critical results above a level of 3 which is exceeded after 70 days. The wet board values increase slightly later and lower, the other boards do not exceed the value of 3.0. In the box with 100 % RH all materials except the flexible mat exceed 3.0 after about 40 days. Wet board and solid wood behave very similar and reach values of 3.5, the two dry boards remain slightly lower. However, due to the non-linear scale and a certain dominance of the values up to 3.0, which are of little relevance for the assessment of the fibre materials themselves, this evaluation alone does not allow a clear differentiation between some materials.

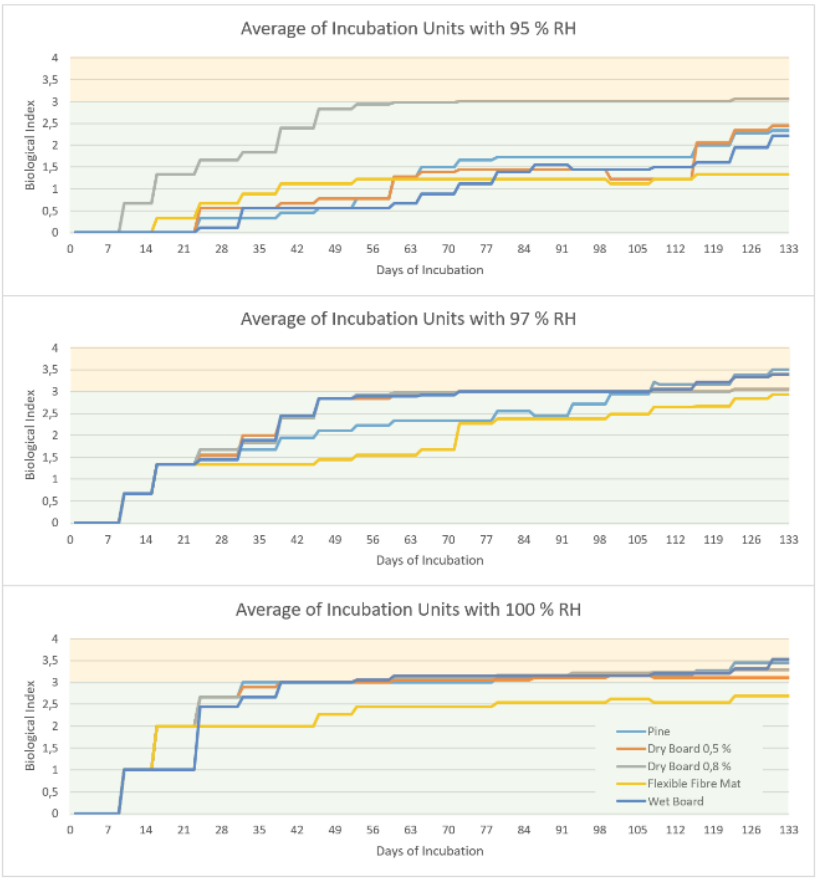

Figure 8: Index acc. to **Table 2** during the first 133 days: Different growths speed on the dowels of the test materials and the reference specimens at the three RH levels. Only pine and the wet board reach values up to 3.5 in that period.

Therefore, an additional indicator was introduced: the cover ratio of the mycelium on the visible specimen surface in percent on average of the same type of material. The estimation of the cover ratio was obtained by means of a grid which was applied schematically on the surface of the specimen. The given values are average values (n = max. 9, as the number of specimens was reduced by sampling for mass loss evaluation throughout the duration of the test). The results are presented in **Figure 9** (bottom) after 200 days of incubation in addition to the previous evaluation. The scale value difference between the solid wood and the wet fibre board is with 3.8 to 3.6 only very small. If additionally, the surface cover ratio is considered, the difference becomes much clearer with about 23 % in case of the solid pine wood to only 9 % in case of the wet fibre board. The two dry boards A and B only show a surface cover ratio below 4 % and the flexible fibre mat still no growth at all. Thus, the surface cover for the solid wood is a factor of 2.5 higher compared to the wet board, 5 times higher than dry board B and 10 times higher than dry board A.

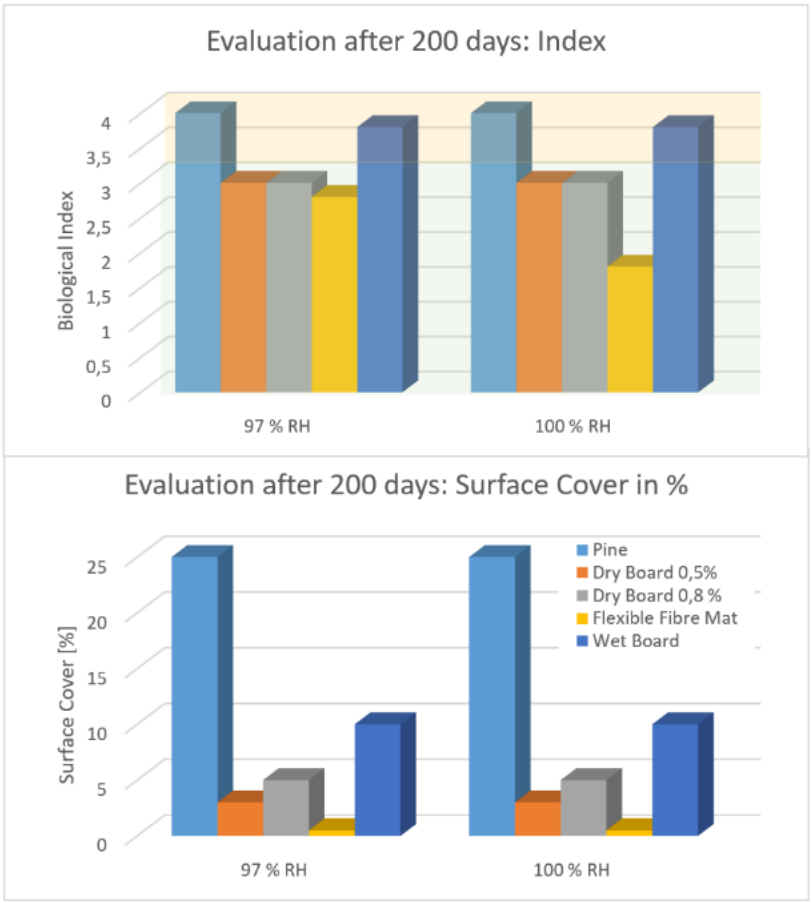

Figure 9: Index acc. to **Table 2** after 200 days (top) and coverage of the specimen surface with decay mycelium in percent (bottom) in the boxes with initially 97 % RH (left) and 100 % RH (right).

3.3 Mass loss evaluation

The third evaluation is based on the measurement of mass loss over time, which was performed after 20, 26, 35 and 48 weeks on three specimens in each case. The resulting average values are presented in **Figure 10**. For decay tests in the laboratory, normally only mass losses more than 5 % are to be regarded as unambiguous. This limit is indicated as dashed red line in the figure for orientation. In case of the flexible fibre mat, the results are not reliable due to excessive fibre loss of the specimens that became unstable with increasing humidity. As this result is in contradiction with the observations of the first two evaluations, where no microbial growth at all was observed on this material, the indicated mass loss seems not to be caused by material degradation. The results of material C are therefore greyed out.

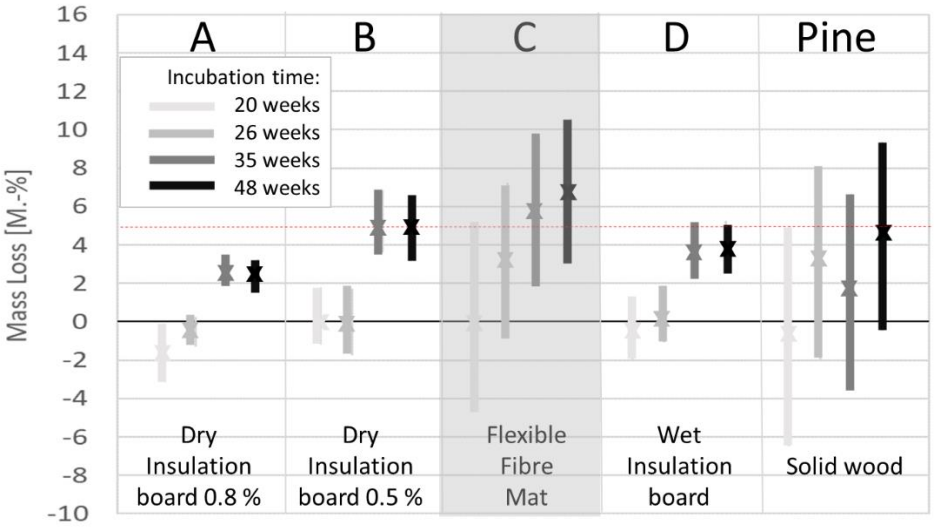

Figure 10: Evaluation of mass loss after 20, 26, 35 and 48 weeks

For the other materials, as expected, an increasing mass loss over time can be observed. Considering all four measurements the mass loss of the pine samples is higher than the mass loss of the three evaluable fibre materials A, B and D. Material B has slightly higher losses when only the third and fourth measurements are considered. However, some loss of fibers cannot be completely ruled out for the other materials either. Therefore, the ranking concerning the mass loss is as following: highest losses for the pine specimens, similar but slightly lower values for the dry board B, followed by the wet board D and lowest losses for the dry board A.

4. Discussion of the lab test results

The measured mass loss was smaller than expected, especially when compared to former investigations like [13] or [15], which showed under similar favorable conditions (temperature > 20 °C and high humidity near 100 % RH) sometimes more than 20 % mass loss after only 4 months. In the first weeks of the test period, presumably slightly lower humidity conditions than planned prevailed in the incubation units. This may have slowed down and delayed the decay process to a certain extent. Certainly, the occurring mold growth may have had a retarding effect on the wood rot processes. To check whether the rot fungi have been affected by drought or mold, the vitality of the fungi on the dowels (taken from the specimens after 48 weeks). was verified by growing them again on nutrient medium in petri dishes at the end of the test procedure in the lab. After only four days the mycelium of the decay fungi became visible again in all four petri dishes, although cross contaminations cannot entirely be excluded. However, this confirms that the decay fungi were still alive and active, even if no strong degradation could be observed. In addition, current results from another ongoing research project [20] with the same incubation method also show similar low mass loss values.

Additionally, other effects can influence the mass loss level. One point is the relation between fungi mycelium and specimen size, which may play an important role: the more fungi mass is added, the higher will be the initial mass loss of the specimen. In the mentioned previous investigations [5][15], the transferred mycelium was clearly bigger in relation to the specimen compared to the current investigation and presumably also included parts of the nutrient from the petri dishes, while now hardly any nutrients were transferred as only infested dowels were used. Therefore, the applied test method has the advantage that likely more realistic start conditions for the infestation are used.

It must therefore be assumed that every different test setup may also lead to different mass losses. The hygrothermal conditions without any mass loss (safe area) as well as the initiation period should not, in contrast, be affected by the test method. As in normal constructions in practice only spores but no

mycelia are present, all lab tests can be assumed to be on the safe side concerning the duration until the start of material degradation. However, after the start, the degradation could also proceed faster in practice, as far as the decay fungi can spread over a wider area of the material's surface, while in the lab no additional spores are available and the starting point is limited to the dowel.

In summary it can be stated that the results of the performed investigations showed significant growth of decay fungi mycelium and mass loss of the specimens. All fungi were still alive at the end of the tests and the question, whether the examined wood fibre materials or the solid wood specimens are more resistant against decay fungi could be clearly answered - even if quantitative statements are only possible to a limited extent due to the partly unclear boundary conditions.

5. Conclusions and outlook

The four involved wood fibre materials show a rather good decay resistivity at high moisture levels and have proven to be more resistant against decay fungi than solid pine sapwood. Therefore, the same or even higher limit values or limit curves can be used for the evaluation of these materials like for solid wood. Such limits are currently available as limit curve depending on RH and temperature in WTA guideline 6-8 [9] but also as transient decay prediction model according to [10] and they are topic of current research in ongoing projects [16].

However, the presented proceeding is only valid for particularly moisture resistant wooden or natural fibre materials. In a follow-up project [20] currently further natural fibre materials are investigated, and preliminary results show that other wood fiber materials can also be clearly less resistant than solid wood. That means that the resistivity needs to be verified individually for every product. For this purpose, a preferably simple and quick laboratory test will be beneficial.

For the tests performed here, still four decay fungi were used. But the results here seem to indicate, that at least *Serpula lacrymans* and probably also *Trametes versicolor* are only of little relevance in the performed test and for the investigated materials, while *Coniophora puteana* and *Schizophyllum commune* seem to be the more critical fungi for that purpose. The results seem to proof that the materials show an analogous sensitivity at different temperatures and humidities. That would suggest that a single test under rather extreme boundaries, like the one, proposed in EN 113[21], could be sufficient for the classification "equal or more resistant than solid wood". However, this assumption needs to be verified using a much broader data base than the one available from this project. Furthermore, separate classes for different sensitivities will be required, adequately representing both lower and obviously higher resistance of different wood and natural fibre materials by individual limit value curves. Such classifications could simplify and improve the evaluation of the decay risk of constructions with materials made of natural fibre materials. On this basis, it can then also be better examined whether mould or decay is the relevant damage mechanism in each case.

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