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A preliminary evaluation of mould prediction models based on laboratory experiments

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Abstract

This paper presents a preliminary study on the validity of the mould prediction models frequently applied in the building physics field (VTT model, Sedlbauer's isopleths, biohygrothermal model), and this based on laboratory results found in the literature. Although similar laboratory experiments serve as the input for the development of the prediction models, quite large discrepancies are observed. These findings can be used when, for instance, upgrading the current mould prediction models. Apart from a correct conversion of measurements into the mould prediction models, the collection of reliable data sets is of course of seminal importance. Therefore, additionally, some potential difficulties, challenges, etc. in experimental mould growth research will be put forward.

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Keywords: Mould risk; mould prediction models; laboratory experiments; VTT model; biohygrothermal model; isopleths

1. Introduction

Mould growth can result in a degradation of building materials [1] and can negatively influence the occupant's health [2]. To assess the mould risk on building materials, numerous mould prediction models are available. Examples of mould prediction models frequently applied in the building physics field are for instance the VTT model [3], Sedlbauer's isopleths [4] and the biohygrothermal model [4]. As shown in a prior study [5], however, each of these models struggles with several disadvantages and shortcomings. Moreover, based on the different mould prediction

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models widely varying results might be obtained. Hence, caution is required when applying those models and a blind use of them should definitely be discouraged. The question arises which model is most trustworthy. In our quest to answer this question, the current paper proposes a comparison between results obtained in laboratory experiments not used to develop the analysed models and the numerical predictions simulated based on the analysed models. The existing mould prediction models are indeed developed based on similar – mainly steady-state – laboratory experiments. Thus, ideally, especially for steady-state conditions, a good agreement would be expected. However, the discrepancy between the outcomes obtained based on an inter-comparison of the different models [5], makes us already suspect that an agreement between experimental and numerical results cannot be found for all models. To check this, in the next section of this paper a comparison between the results obtained in a laboratory experiment performed by Johansson et al. [6] and the outcome obtained with the mould prediction models frequently applied in the building physics field will be made. Johansson et al. [6] studied mould growth on wood. Though, in the current paper a statement on mould growth research on building materials in general is aimed. By using an experimental study on wood samples, however, an evaluation of the VTT model, which is originally developed for wood, is facilitated. Apart from the conversion of experimental data into prediction models, also the reliability of the input data will of course be decisive. Therefore, in the third section of the paper, a number of points of attention and challenges in the experimental mould growth research will be tackled. In this way, this paper (1) works towards a more thoughtful use of mould prediction models and (2) introduces a methodology to detect potential gaps and shortcomings to be addressed when developing novel models or when upgrading the current models.

Nomenclature

M	mould index
RH	relative humidity
SQ	surface quality
T	temperature
W	wood species

2. Preliminary evaluation of mould prediction models based on literature data

2.1. Literature data on mould growth

An overview of the experimental test conditions as imposed by Johansson et al. [6], which will be used as verification data in the current study is given in Table 1. Both steady-state and transient conditions have been studied. To analyse the mould growth, Johansson et al. [6] defined a rating scale ranging from 0 till 4. A definition of this indicator as a function of the growth extent together with the corresponding VTT mould index is shown in

Table 2. For a detailed description of the inoculation, incubation, growth assessment techniques, etc., the reader is referred to Johansson et al. [6]. The mould growth rating measured by Johansson et al. [6] together with the corresponding VTT mould index are shown in Fig. 1. As shown in these and other measurements shown in [6], fluctuations between a favourable and unfavourable relative humidity (Test B, C and E) result in less or a slower mould growth. Also the period exposed to unfavourable conditions is shown to influence the results. A longer period exposed to an unfavourable relative humidity (Test B) is shown to result in a lower mould growth rating than found for a shorter period (Test C).

Table 1. Test conditions (incubation temperature and relative humidity) exposed by Johansson et al. [6].

	Time_1	RH_1 (%)	T_1 (°C)	Time_2	RH_2 (%)	T_2 (°C)
A	Constant	90	22			
B	7 days	90	22	7 days	60	22
C	12 hours	90	22	12 hours	60	22
D	Constant	90	10			
E	7 days	90	22	7 days	90	5

Table 2. Johansson's rating scale in function of the extent of growth by a 40x magnification [6] together with the adopted corresponding VTT mould index [3].

VTT mould index	Johansson's rating scale	Extent of mould growth
0	0	No mould growth
1	1	Initial growth, one or a few hyphae and no conidiophores
2 3 4	2	Sparse but clearly established growth; often conidiophores are beginning to develop
5	3	Patchy, heavy growth with many well-developed conidiophores
6	4	Heavy growth over more or less the entire surface

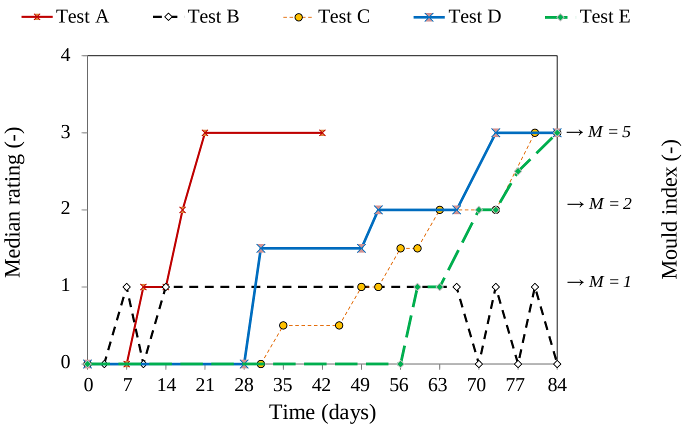

Fig. 1. Mould growth rating on a newly planed pine sapwood surface measured by Johansson et al. [6] together with the corresponding VTT mould index for the test conditions given in Table 1.

2.2. Comparison with simulated predictions

The test conditions of Table 1 have been used as an input in the original VTT model, Sedlbauer's isopleth system and the biohygrothermal model. Additionally, the mould index calculated based on the biohygrothermal model [7] is evaluated. For the VTT model, the results are calculated for W = 1 (pine sapwood) and a surface quality SQ = 0, since the measurements shown in Fig. 1 are performed on a newly planed surface. In Sedlbauer's isopleth system and in the biohygrothermal model, wood has been categorised in substrate category I. To calculate the mould growth based on Sedlbauer's isopleths, Moon's germination graph method [8] is applied. In the latter method, each isopleth curve is associated with a specific required exposure time for initiation of mould germination. For each curve, the associated accumulated exposure time can be recorded. An accumulated exposure time larger than the required exposure time results in mould germination. Similarly, the accumulated mould growth can be determined. A linear interpolation between the growth curves is applied. The results achieved with the different prediction models are shown in Fig. 2. A comparison with Fig. 1 results in the following conclusions for the test conditions analysed in this paper:

- Based on the VTT and WUFI-Bio mould indices an underestimation of the mould risk is possible; e.g. for test schemes A, C, D and E, Johansson et al. [6] measure a mould index equal to 5, while in WUFI-Bio the predicted mould indices do not exceed a value of 2. For some of these test conditions, the mould index is even lower than 1, which indicates no mould risk.

- The conclusions on the influence of the period exposed to unfavourable conditions as made by Johansson et al. [6], i.e. long periods of unfavourable conditions result in less mould growth than found for short periods of unfavourable conditions, is not observed when using the prediction models.

- The ranking of the mould growth predicted with the different models differs. For instance, whereas the VTT model and Moon’s germination graph method predict the mould risk for test scheme D and E to be (slightly) higher than for test scheme B and C, the opposite is found when calculating the WUFI-Bio mould index or when using the biohygrothermal model.

A rough overview of the main results is given in Table 3.

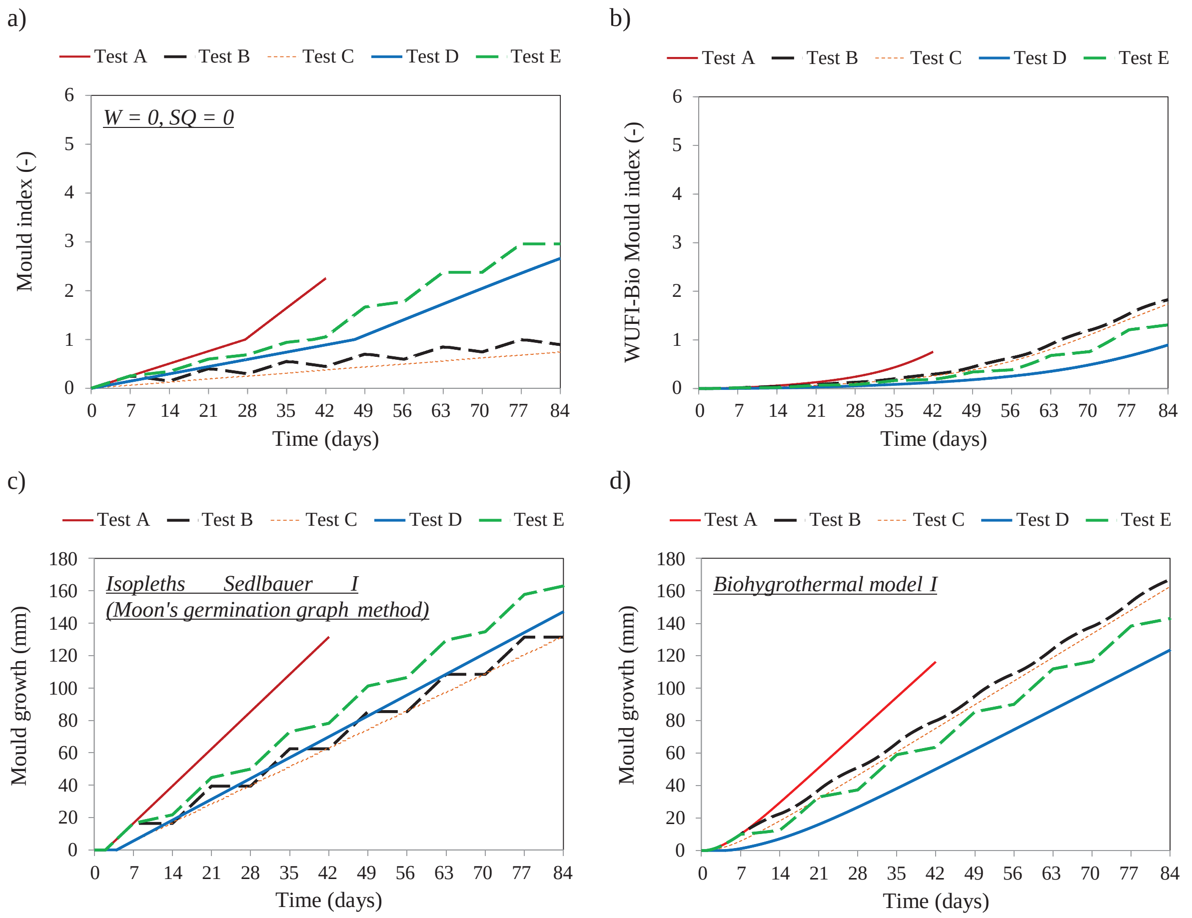

Fig. 2. Mould growth for the test conditions given in Table 1: a) original VTT model, b) mould index calculated with WUFI-Bio, c) Sedlbauer’s isopleths I, d) Biohygrothermal model.

Table 3. Rough comparison between the experimental results [6] and the numerical predictions for the test conditions shown in Table 1. A negative/positive sign indicates an underestimation/overestimation based on the mould prediction model.

Test scheme **Model**	**A**	**B**	**C**	**D**	**E**
VTT original	-	≈	- - -	-	-
Sedlbauer’s isopleths I	≈	+ + +	≈	≈	≈
Biohygrothermal model	≈	+ + +	≈	≈	≈
Mould index in WUFI-Bio	- - -	≈	-	- - -	-

3. Challenges in experimental mould growth research

The comparison made in the previous section showed some discrepancies between experimentally observed and numerically predicted results. This could be due to the difficulty of a correct implementation of the mould growth development in the models. On the other hand, the collection of reliable data to develop mould prediction models is challenging as well. In what follows, three points of attention and challenges in mould growth research and the development of mould prediction models will be discussed. A more extended discussion can be found in [9,10].

3.1. Incubation versus surface conditions

For the development of mould prediction models, test samples are exposed to a certain temperature and relative humidity. These incubation conditions are mostly wrongly used as an input in the mould prediction models; the incubation conditions are mostly assumed to be identical to the surface conditions. For steady-state experiments, this assumption will have a negligible influence. For – especially short – relative humidity fluctuations, however, an equilibrium between air and surface relative humidity will not be achieved. Fig. 3a shows this effect for a 1.25 cm thick wood sample exposed to the conditions of test scheme C (see Table 1). As shown by the VTT mould index in Fig. 3b, using the relative humidity in the air instead of at the material surface might influence the results. An accurate measurement of the surface conditions is, however, challenging. To achieve a smaller difference between surface and air relative humidity and hence to reduce the induced error, a smaller thickness of the test sample is recommended.

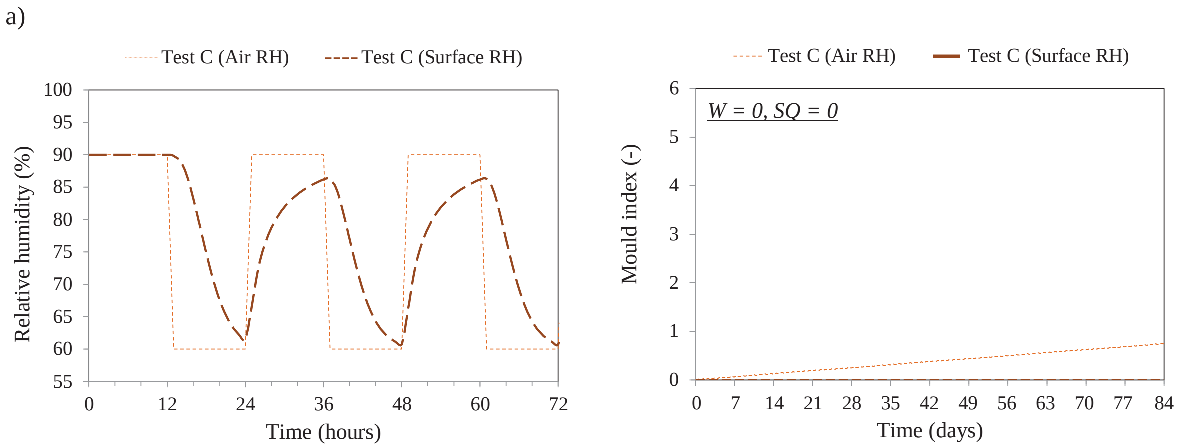

Fig. 3. a) Numerical simulated surface relative humidity on a 1.25 cm wood sample exposed to test scheme C (see Table 1), b) influence of the difference between air surface relative humidity on the predicted VTT mould index.

3.2. Definition of germination and time till germination

One of the mould risk criteria often used in mould prediction models is the start of germination. Though, an accurate assessment of the start of germination is difficult. Moreover, different definitions exist for it [11,12]. The applied definition for germination can, however, have an important influence on the germination time [11]. For the time till germination different definitions exist as well [12]. Although the applied definition can have an important influence on the outcome [12], the definition chosen in the current mould growth studies is unfortunately seldom mentioned.

3.3. Inoculation

In most laboratory studies, a spore suspension is sprayed or pipetted on the test samples. In the experiments performed by Johansson et al. [6] for instance, each of the test surfaces was inoculated with 0.4 ml of a spore suspension with a concentration of approximately 10^6 spores per ml by spraying. Such an inoculation technique differs from the real-life situation, where spores should settle on the substrate. Though, since an artificial inoculation results in a safe approach in respect to the spore availability, and hence in respect to the mould risk prediction, such an approach is preferable when developing mould prediction models. It should however be noted that the inoculation technique and the spore concentration might influence the results. For instance, the spore concentration will influence the mould coverage and hence the mould index. Though, for none of the mould prediction models frequently applied in the building physics field the inoculation technique is given.

4. Discussion and conclusion

A comparison between experimental literature data on mould growth [6] and the mould growth predicted with some mould prediction models frequently applied in the building physics field showed significant discrepancies. These discrepancies can serve as an indicator of the gaps in the current mould prediction models. In this way, the experimental data set used in the current study suggests that mainly the influence of the duration of unfavourable conditions and – especially – its implementation in the mould prediction models demands a further research. A more extended data set of experimental results is however preferred to achieve a better view on the validity of the current mould prediction models and to define potential gaps in those models. Furthermore, some challenges in experimental mould growth research were tackled, showing that the collection of reliable data to develop the mould prediction models is challenging as well.

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References

[1] Sterflinger K. Fungi: Their role in deterioration of culture heritage. Fungal Biol Rev 2010;24:47-55.
[2] Platt SD, Martin CJ, Hunt SM, Lewis CW. Damp housing, mould growth, and symptomatic health state. Brit Med J 1989;298:1673-78.
[3] Hukka A, Viitanen HA. A mathematical model for mould growth on wooden material. Wood Sci Technol 1999;33:475-85.
[4] Sedlbauer K. Beurteilung von Schimmelpilzbildung auf und in Bauteilen. 2001. Dissertation Universität Stuttgart.
[5] Vereecken E, Roels S. Review of mould prediction models and their influence on mould risk evaluation. Build Environ 2012;51:296-310.
[6] Johansson P, Bok G, Ekstrand-Tobin A. The effect of cyclic moisture and temperature on mould growth on wood compared to steady state conditions. Build Environ 2013;65:178-184.
[7] WUFI-Bio 3.0. Rel.3.0.085. Sedlbauer, Krus, Willig. Fraunhofer Institute for Building Physics. http://www.hoki.ibp.fhg.de/wufi/downloads [07/08/2013].
[8] Moon HJ. Assessing mold risk in buildings uncertainty. 2005. PhD Thesis, Georgia Institute of Technology.
[9] Vereecken E, Vanoirbeek K, Roels S. Towards a more thoughtful use of mould prediction models - A critical view on experimental mould growth research. Submitted to J Build Phys.
[10] Vereecken E. Hygrothermal analysis of interior insulation for renovation projects. 2013. PhD Thesis, KU Leuven, Belgium.
[11] Luz C, Fargues J. Temperature and moisture requirements for conidial germination of an isolate of Beaveria, pathogenic to Rhodnius prolixus. Mycopathologia 1997;138:117-125.
[12] Dantigny P, Bensoussan M, Vasseur V, Lebrihi A, Buchet C, Ismaili-Aloui M, Devlieghere F, Roussos S. Standardisation of methods for assessing mould germination: A workshop report. 2006. Int J Food Microbiol 2006;108:286-291.