MOULD RISK ASSESSMENT FOR THERMAL BRIDGES: WHAT IS THE IMPACT OF THE MOULD PREDICTION MODEL?

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ABSTRACT

Whereas previously the temperature ratio was commonly used as criterion to predict the mould growth risk during the design stage, nowadays other – more advanced – mould prediction models are available. These models include the main influence factors for mould growth: the surface temperature and relative humidity. Other factors, e.g. the substrate and the mould species, are only rarely included. In addition, the criterion which indicates mould risk differs for each model.

In this paper, a comparison between the different mould prediction models is made. To do so, the relative humidity and temperature courses found at the interior surface of three thermal bridges are used as an input in the mould prediction models. For some conditions it was shown that a different mould risk conclusion was drawn depending on the prediction model.

1 INTRODUCTION

To evaluate the durability of materials to mould growth and hence to minimise potential mould damage in buildings, reliable mould prediction models are necessary. While previously commonly the temperature ratio was used as criterion to predict mould growth risk during the design stage, nowadays more advanced mould prediction models are available, e.g. the VTT model [1], isopleth systems [2], the biohygrothermal model [2], etc. These models include the main influencing factors for mould growth: the surface temperature (T) and relative humidity (RH). Other factors, e.g. the substrate and the mould species, are included in only some of the existing models. In addition, most models are developed based on steady-state experiments and the criterion which indicates the mould risk differs for each model. Consequently, a different conclusion may be drawn depending on the used model.

Vereecken and Roels [3] showed widely varying results for the different mould prediction models commonly used in building simulation programs. In the latter study, however, fictitious cycles in temperature and relative humidity were analysed. The question arises if a similar discrepancy can be found for real varying climatic conditions. Thereto, in the current paper, the different mould prediction models are applied on simulated boundary conditions for three thermal bridges. The results are also compared to the conclusions obtained based on the temperature ratio. Additionally, the impact of interior insulation on the mould risk is evaluated. However, due to the lack of knowledge concerning the reliability of the current mould prediction models, the latter evaluation serves mainly as a qualitative comparison.
2 MOULD PREDICTION MODELS

In the current section, the different existing mould prediction models and mould risk criteria are briefly reiterated. A more in depth description and some remarks on the different prediction models can be found in [3].

2.1 Temperature ratio

To minimise the mould risk, IEA-Annex 14 [4] proposes a design criteria based on the temperature ratio:

$$\tau = \frac{(T_{s,\text{min}} - T_e)}{(T_i - T_e)}$$

with $T_{s,\text{min}}$ (K) the minimum indoor surface temperature and $T_i$ and $T_e$ respectively the inside and outside temperature (K). A temperature ratio of 0.7 is proposed as criterion, related to an acceptable mould risk of 5%. A lower ratio introduces an unacceptable high mould risk.

2.2 VTT model

The VTT model is an empirical mould prediction model, in which the growth development is expressed by the mould index $M$ [1]. This index ranges from 0 (no mould growth) to 6 (the mould growth covers nearly 100% of the surface) and is often used as a design criterion. A mould index equal to 1 is often defined as the maximum tolerable value, since from that moment the germination process is assumed to start. The VTT model is based on regression analysis of a set of measured data [1], based on which the influence of temperature, relative humidity, surface, exposure time and dry periods is included in the VTT model. A first VTT model was based on lab experiments on pine and spruce sapwood. The calculation procedure can be found in [1][3]. Recently, the VTT model is expanded to other materials [5].

2.3 Isopleth models

Isopleth curves separate favourable from unfavourable $T$- and RH-conditions for mould growth. A first model that uses isopleths is the ESP-r model [6][7]. In this model, the mould fungi found in buildings are subdivided in 6 categories with respect to relative humidity and temperature: Highly xerophilic, Xerophilic, Moderately xerophilic, Moderately hydrophilic, Hydrophilic and Highly hydrophilic. For each of these categories a growth limit curve defined by a third-order polynomial function is determined based on an analysis of published data. When the RH- and $T$-combination exceeds such a curve, mould growth of the matching fungi will occur. The main disadvantage of this model is that the exposure time is not taken into account. A single exceed of the isopleths is set equal to mould formation.

Sedlbauer [2] subdivided the mould species and materials found in buildings in a set of classes. For each class, he developed isopleths indicating the time till germination and the mould growth rate. The conditions below which no spore germination or growth will occur are indicated by the LIM (Lowest Isopleth for Mould)-curve. Note that the isopleths are defined based on stationary laboratory experiments. Hence, an interim drying out of the spores cannot be taken into account.

To take into account the temperature and relative humidity at previous time steps, Moon [8] established the mould germination graph method. In this method, each curve in the isopleth system is indicated by a certain required exposure time for initiation of mould germination. For each curve, the associated accumulated exposure time can be recorded. When the accumulated exposure time for a group is equal or larger than its required exposure time, mould growth can start. Consequently, using this method also fluctuating conditions can
be studied. However, although a delay during unfavourable conditions is included, a possible
drying out of the spores is not considered in this model.

2.4 Biohygrothermal model
To make a more reliable prediction of the mould risk possible in cases of transient
conditions, Sedlbauer extended his isopleth model with the biohygrothermal model [2]. In this
model, the moisture balance of a spore, which has a certain osmotic potential and which can
consequently absorb water from the environment dependent on the transient boundary
conditions, is calculated. This means that even an interim drying out of the fungus spores can
be considered. The spore is supposed to have germinated when a certain moisture content –
the critical moisture content – is reached. The critical moisture content can be determined
based on the moisture retention curve of the spore and the critical relative humidity found in
the germination LIM-curve.

2.5 Mould index in WUFI-Bio
Since the mould growth in millimeters as determined by the isopleth system and by the
biohygrothermal model is not a reasonable unit, Krus et al. [9] developed a conversion
function based on which the mould growth in millimeters can be transformed in the mould
index. More details can be found in [3].

2.6 General remark about the mould risk criteria
In the different models, also different definitions for the start of mould growth can be
found. For instance, in the VTT model a mould index equal to 1 is defined as the start of
germination and consequently as the value above which a mould risk exists. In the
biohygrothermal model a spore moisture content higher than the critical moisture content
indicates the start of germination. However, to evaluate the mould risk, in the latter model the
mould growth per year is used to evaluate the mould risk [10]. To do so, a ‘signal light’
defines the risk. More than 200 mm mould growth per year is indicated by a ‘red light’, which
is not acceptable. Less than 50 mm mould growth per year is indicated by a ‘green light’ and
is usually acceptable. Between those two cases an additional evaluation is necessary, which is
indicated by a ‘yellow light’.

3 APPLICATION
The analysis in the current study is performed for three thermal bridges, i.e. junctions
between an exterior and an interior wall with a different level of insulation (Figure 1a,c,e). The
indoor temperature and relative humidity is assumed to be constant and is set at
respectively 20°C and 50%. For the other boundary conditions, the material properties and the
numerical model the reader is referred to Vereecken [11]. Figure 1b,d,f shows for the different
configurations the numerically predicted temperature and relative humidity obtained in the
corner in function of the time.
4 MOULD GROWTH ASSESSMENT

The mould growth evaluation is performed based on hourly data for the predicted surface temperature and surface relative humidity in the interior corner. Figure 2 shows the critical isopleths used in the ESP-r model together with the simulated hourly T- and RH-combinations in the corner of the three configurations. For Configuration 1 and 2, the influence of wind-driven rain is visible. When interior insulation is applied at both the exterior and the interior wall (Configuration 3), no mould risk is predicted. In the latter case, wind-driven rain does not influence the results.

Figure 3 shows the simulated hourly T- and RH-combinations as obtained in the corner of the different configurations exposed to wind-driven rain together with Sedlbauer’s isopleth system for category I. For Configuration 1 and 2, the LIM-curve is exceeded. For Configuration 3, no mould risk is predicted.
Figure 2: Simulated RH-T combinations and critical ESP-r isopleths.

Figure 3: Simulated RH-T combinations and Sedlbauer’s isopleth system for substrate category I: 
  a,b) germination isopleths, c,d) growth rate isopleths.

Figure 4 shows an overview of the maximum mould intensity. As shown in Figure 4a, 
the difference between the maximum mould growth determined by Moon’s germination graph 
method (Sedlbauer’s isopleths, linear interpolation between the growth curves) and by the 
biohygrothermal model (based on the WUFI-Bio software [10] wherein the initial spore RH is 
set at 50%) is less pronounced than found in [3]. This can be attributed to the lower number of 
periods with unfavourable conditions in cases of the real varying conditions. The longer time 
span of these periods with unfavourable conditions is of minor importance. A comparison 
between the mould index determined by transforming the results of the biohygrothermal 
model (WUFI-Bio M) and the mould index obtained based on the VTT model is shown in 
Figure 4b. For the VTT model, the results obtained by both the original model and the 
updated model (sensitivity class s) are shown. The application of the original model is, 
however, theoretical since the finishing layers in this study are no wooden substrates. Where 
the VTT model implements a decline of the mould index during the periods with 
unfavourable conditions, in WUFI-Bio the mould index remains constant during these 
periods. This may result in different mould risk conclusions, as shown by a comparison 
between the WUFI-Bio mould index and the VTT mould index for class s determined for 
Configuration 2.
Figure 4: Maximum mould intensity: a) mould growth, b) mould index.

Figure 5 shows the time till mould germination occurs. The large difference between the time till germination obtained based on a mould index equal or larger than 1 (VTT original, VTT class s, WUFI-Bio M) and the criteria used in combination with the other mould prediction models ($w_{\text{spore}} \geq w_{\text{crit}}$, exceed of isopleth,...) is clearly pronounced. For Configuration 3 not exposed to wind-driven rain, also a large difference between the germination time obtained with Sedlbauer’s isopleth system and the biohygrothermal model is observed. The reason for this is the use of the LIM-curve for the determination of the critical spore moisture content.

Figure 5: Time till germination. For the ESP-r model, the results in cases of a moderately xerophilic (MX) species are shown. For Configuration 4 (not shown), no mould risk occurs.

Table 1 gives for the three configurations an overview of the obtained mould risk conclusions. For Configuration 3, nor the temperature ratio nor the mould prediction models indicate a mould risk. For Configuration 2 and 3, different conclusions are obtained. Based on the temperature ratio, the configurations are labeled as building details with an acceptable low mould risk. Due to the standardised determination procedure of the temperature ratio, the wind-driven rain has no influence on these results.
When using the VTT model, for the configurations not exposed to wind-driven rain no mould risk is found due to the decline in mould index during unfavourable conditions. When the configurations are exposed to wind-driven rain, for Configuration 2 a mould risk is predicted if the original VTT model is used.

When using Moon’s germination graph method, germination is expected to start for Configuration 2 and 3. Though, if the mould risk is evaluated based on the mould growth per year in combination with the ‘signal light’- criterion \[10\], for the configurations not exposed to wind-driven rain other conclusions are found. In the biohygrothermal model germination occurs if the spore moisture content is higher than the critical moisture content. This is the case for Configuration 2 and 3, independently of the wind-driven rain exposed to. Also here, evaluating the mould growth based on the ‘signal rule’-rule results for Configurations 2 and 3 not exposed to wind-driven rain in other conclusions than obtained when germination is used as a limit state. Based on the mould index determined in WUFI-Bio only for Configuration 2 and 3 exposed to wind-driven rain a mould risk is predicted.

Table 1. Mould risk conclusions (GERM = germination, ‘SL’ = ‘Signal light’-rule)

<table>
<thead>
<tr>
<th>Model</th>
<th>Configuration 1</th>
<th>Configuration 2</th>
<th>Configuration 3</th>
<th>Configuration 1</th>
<th>Configuration 2</th>
<th>Configuration 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without WDR</td>
<td>With WDR</td>
<td>Without WDR</td>
<td>With WDR</td>
<td>Without WDR</td>
<td>With WDR</td>
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<td>No (0.77)</td>
<td>No (0.92)</td>
<td>No (0.72)</td>
<td>No (0.77)</td>
<td>No (0.92)</td>
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<td>Yes if xerophilic</td>
<td>No</td>
<td>Yes</td>
<td>Yes if xerophilic</td>
<td>No</td>
</tr>
<tr>
<td>Moon’s germination graph method with linear interpolation (Sedlbauer I)</td>
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<td>GERM: Yes ‘SL’: Extra analysis</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Biohygrothermal model</td>
<td>&gt; (w_{\text{crit}}): Yes ‘SL’: Extra analysis required</td>
<td>&gt; (w_{\text{crit}}): Yes ‘SL’: Extra analysis required</td>
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<td>Yes</td>
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<td>No</td>
<td>Yes</td>
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</table>

5 CONCLUSIONS

A mould risk assessment was performed for three thermal bridges. Where the temperature ratio indicated the configurations as acceptable building details, some, but not all, of the mould prediction models indicated a mould risk. As also found in \[3\], the different evaluation criteria may result in different conclusions. Though, the differences between the different models are less pronounced. The number of periods with unfavourable conditions
influences the magnitude of the difference between the results obtained based on Moon’s germination graph method and the biohygrothermal model.

Additionally, the influence of interior insulation and wind-driven rain was visible. When interior insulation was applied at both the exterior and the interior wall, no mould risk was predicted by any of the models. The mould intensity and the time till germination after applying interior insulation at solely the exterior wall was lower than determined for the non-insulated thermal bridge. Wind-driven rain was found to induce an increased mould risk, while this factor is not included in the temperature ratio.

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REFERENCES