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Moisture risk evaluation and determination of required measures to avoid mould damage using the Folos 2D visual mould chart

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Abstract: *There is an increased interest in and awareness of mould growth damage in buildings. Today's mould growth models are limited to only presenting the risk of mould growth. They do not take into account underlying factors and other parameters that make it possible to establish necessary measures to limit or avoid the risk of mould growth. This paper presents a chart that can be used to determine these measures, both to reduce the risk of mould growth in buildings and, at the same time, indicate the risk of mould growth. The chart can be based on all known risk models for mould growth. No new mould growth model is presented; only an illustration of how it is possible to use known models in practical moisture safety design processes. The chart can also be used to compare different structural designs, measured and calculated values, and to show how mould growth risk prediction depends on which mould model is used.*

Keywords: *Mould model, risk of mould growth*

1. Introduction

1.1 Background

Newly introduced laws and requirements, in combination with observed mould growth damage in buildings, has meant increased interest in the factors affecting mould growth in buildings [1, 2, 3]. Furthermore, recent studies also show that today's highly insulated buildings are more sensitive to mould growth damage [4]. Several models showing conditions for, and risk of, mould growth on building materials have also been developed. Most of the models are relatively similar, as shown in figure 1 [5]. However, many models are limited to only showing whether or not there is a risk of mould growth, below or above the critical lines in Figure 1, without presenting the underlying factors affecting the risk of mould growth or when the risk of mould growth would occur. The lack of knowledge about the underlying factors hides required measures to avoid mould growth and makes it difficult to compare different design solutions. Furthermore, there are different views on how the influence of duration should be regarded and how possible risk levels regarding mould growth should be dealt with [5, 6, 7, 8].

1.2 Aim

The purpose of this article is to present a chart that illustrates the underlying factors affecting the risk of mould growth in a specific location in a construction. Knowledge of these underlying factors makes it possible to evaluate the measures that can be taken to limit or avoid the risk of mould growth. Furthermore, the chart aims to make it possible to compare the conditions in different locations within a structure as well as different designs and different mould models. The risk of mould growth can be presented according to any chosen mould growth model.

1.3 Limitations

This article is limited to presenting a chart that includes the factors used to evaluate the risk of mould growth and the measures that might be required in order to avoid mould growth. No new mould growth models are presented. However, the chart has been constructed in such a way that it can be used for any mould growth model.

2. Fundamentals

2.1 Factors affecting mould growth

The risk of mould growth depends on several different factors. Besides different materials having different resistance to mould growth, there is wide agreement that the dominating factors affecting mould growth are the temperature, relative humidity (RH) and duration above critical conditions, i.e. the length of time when temperature and RH allow mould growth to occur [9, 10]. As mentioned above, the different mould growth models show similar behaviour where the influence of temperature and RH is concerned, as shown in Figure 1 [5]. Critical conditions (RH_{crit}) are defined as the conditions when mould growth is possible. RH_{crit} varies depending on temperature, as shown in Figure 1 [5, 8]. RH_{crit} occurs when the RH, at a specific temperature and time, is above the specific RH_{crit} curve for each mould growth model. RH_{crit} does not necessary lead to mould growth. Different materials have different RH_{crit} lines [9].

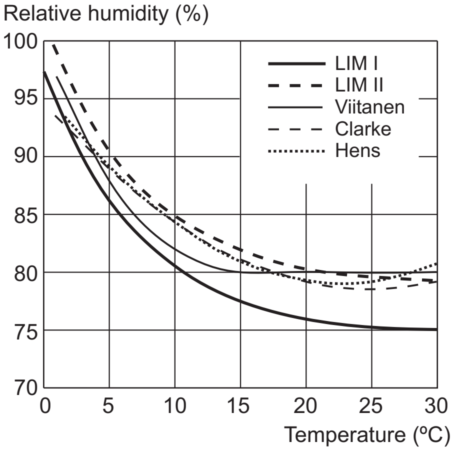

Figure 1: Different mould models show similar behaviour with respect to temperature and RH [5].

Differences between existing mould growth models mainly concern the way in which the influence of duration is treated, if at all. The influence of duration includes both the conditions above RH_{crit} and the possible decline of mould growth during non-critical conditions.

Besides each material having specific limits for RH_{crit} and the influence of the main factors temperature, RH and duration above RH_{crit}, there are other factors that affect the risk of mould growth. Examples of such factors are the amount of dirt or dust on the surface of the material, surrounding microbial conditions, shortwave radiation and moisture content in the material [9].

2.2 Examples of existing mould models

Several mould models investigate the risk of mould growth using charts, as shown in Figure 1, to present their findings [5, 8]. During the evaluation of mould risk, isopleth dots, indicating an RH level and temperature at one specific time, are normally plotted on a chart similar to that in

Figure 1. Hourly based evaluation over one year will give 8760 dots. Dots above the line indicate RH_{crit} conditions and dots below indicate non-critical conditions [7, 8]. However, the point in time when critical conditions occur or the influence of duration is not shown.

Mould models including the influence of duration mainly refer to a mould index (MI) or relative dose that must not be exceeded if mould growth is to be avoided. Some models take into account the effect of duration both during RH_{crit} conditions, with regard to germinating mould growth, and during non-critical conditions with regard to the decline in mould growth, as shown in Figure 2 [5, 6]. Other models only deal with the influence of duration during RH_{crit} conditions and do not take into account any decline of mould growth [5, 7]. However, factors that affect the mould index or relative dose, such as RH or temperature or the vapour content, are not shown. There are also models that calculate the probability of mould growth in relation to duration time [12]. Some models only present a number as mould growth risk [13].

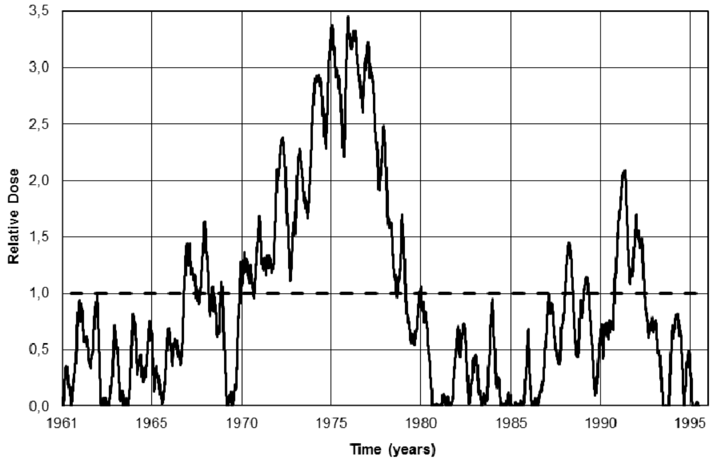

Figure 2: Mould model that takes into account the influence of duration on mould growth and decline of mould growth without showing the factors affecting the risk of mould growth [6].

3. Description of the Folos 2D visual mould chart

3.1 Parameters in the Folos 2D visual mould chart

The Folos 2D visual mould chart, shown in Figure 3, visualizes the factors temperature (yellow) on the right y-axis and RH (turquoise), RH_{crit} (red), the $RH > RH_{crit}$ difference (light brown) and MI divided by 10 (green dotted line) on the left y-axis. The time presented on the x-axis indicates the conditions at each specific time and particularly the periods when $RH > RH_{crit}$.

When a moisture risk evaluation is carried out in the design phase, temperatures and RHs are calculated. Normally, the calculated RHs for one year are shown as 8760 isopleth dots in a chart similar to that in Figure 1. The same RH isopleth dots create a line when presented over time in the Folos 2D visual mould chart. The temperature is also given for each specific point in time.

RH_{crit} conditions occur, and mould growth is possible, when the RH is above the RH_{crit} line. The RH_{crit} line is defined by the temperature that, at any specific time, exceeds the RH_{crit} limit as shown in Figure 1, i.e. the chosen RH_{crit} line from Figure 1 is converted over time by using the actual temperature at each point in time. This means that RH_{crit} conditions depend on the prevailing RH and temperature, where a high temperature gives a low RH_{crit} line and vice versa. Depending on the legislation in different countries, the RH_{crit} line could be used to define a limit [2, 14]. The RH$_{\text{crit}}$ line in Figure 3 is based on the Viitanen curve shown in Figure 1. However, it is easy to use another mould growth model by choosing another appropriate curve.

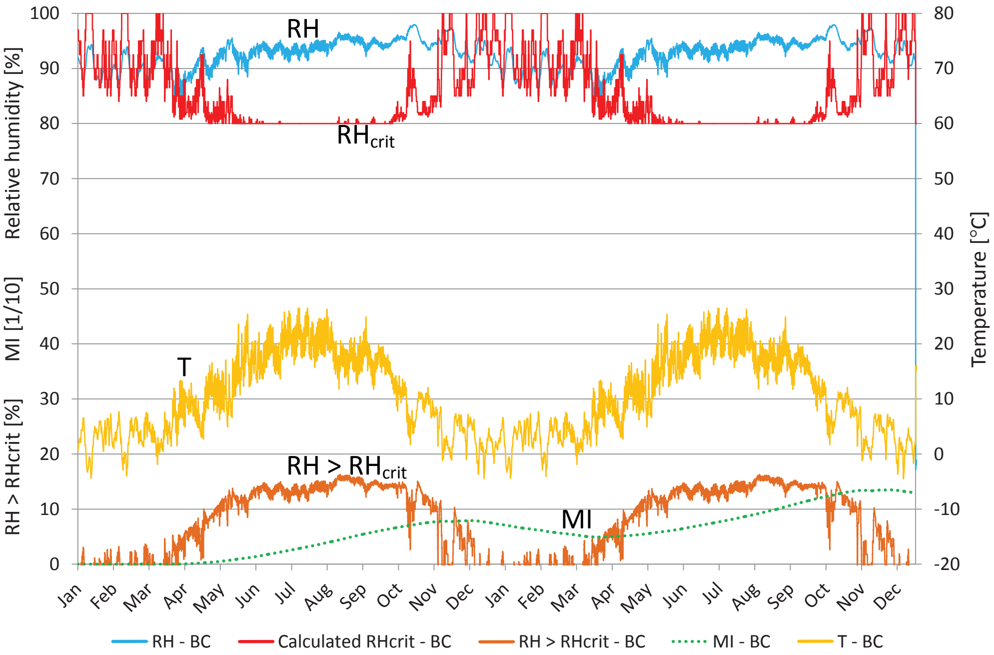

Figure 3: The Folos 2D visual mould chart with calculated values for the basic construction (BC) shown in Figure 4 including the parameters temperature (yellow), RH (turquoise), RH$_{\text{crit}}$ (red), RH > RH$_{\text{crit}}$ (brown) and MI (green dotted line).

The parameter RH > RH$_{\text{crit}}$ shows how much, when and for how long RH exceeds RH$_{\text{crit}}$.

The parameter MI shows the mould index as described in [11, 15]. In order to read the correct MI value, the scale number on the left-hand y-axis must be divided by 10, i.e. 10 = 1, 20 = 2 etc.

Furthermore, the vapour content could also be of interest. This can be easily calculated from the temperature and RH using Equation 1 and added to the chart.

$$RH = \frac{v}{v_s} \tag{1}$$

where *RH* is the relative humidity, *v* the vapour content and v_s the vapour content at saturation, depending on the temperature [16]. RH and temperature are known from the initial calculated conditions.

Other factors that affect the risk of mould growth, such as climate conditions or moisture content, could also be added to the Folos 2D visual mould chart.

3.2 Evaluating the risk of mould growth and required measures to limit the risk of damage

RH$_{\text{crit}}$ periods, when mould growth is possible, are shown as periods when RH > RH$_{\text{crit}}$ in the Folos 2D visual mould chart. The greater the RH > RH$_{\text{crit}}$ differences and the longer the periods when RH > RH$_{\text{crit}}$, the higher the risk of mould growth.

The level of RH and, furthermore, the risk of mould growth on a specific material can mainly be affected by changing the vapour content or the temperature, which affects the vapour content at saturation. A lower level of vapour content or a higher temperature gives a lower RH as shown in Equation (1) [16]. By using this relationship it is easy to define what measures are needed.

Periods with RH > RH_{crit} and high temperatures, June to September in Figure 3, have to be dealt with using measures that reduce the vapour content, such as higher rates of ventilation in the façade air gap, as shown in Figure 4.

Periods with RH > RH_{crit} and low temperatures and low vapour content, October to November in Figure 3. This period could be dealt by applying measures that result in higher temperatures, such as fitting a mould-resistant insulation board onto the outer frame, as shown in Figure 4.

Shorter periods with RH > RH_{crit}, December to March in Figure 3, would probably not need to be dealt with as the duration of RH > RH_{crit} is not long enough to create mould growth. However, in some cases, measures are required that can create both lower vapour contents and higher temperatures.

If it not is possible to create non-critical conditions, or the risk of mould growth is not predicted to be eliminated by a model that includes the influence of duration, the design might have to be changed. Materials could be replaced by materials with higher resistance to mould growth, i.e. a material that has a higher RH_{crit} limit. The design could also be changed in such a way that more or less vapour transport, dependent on the design, through different material layers is possible.

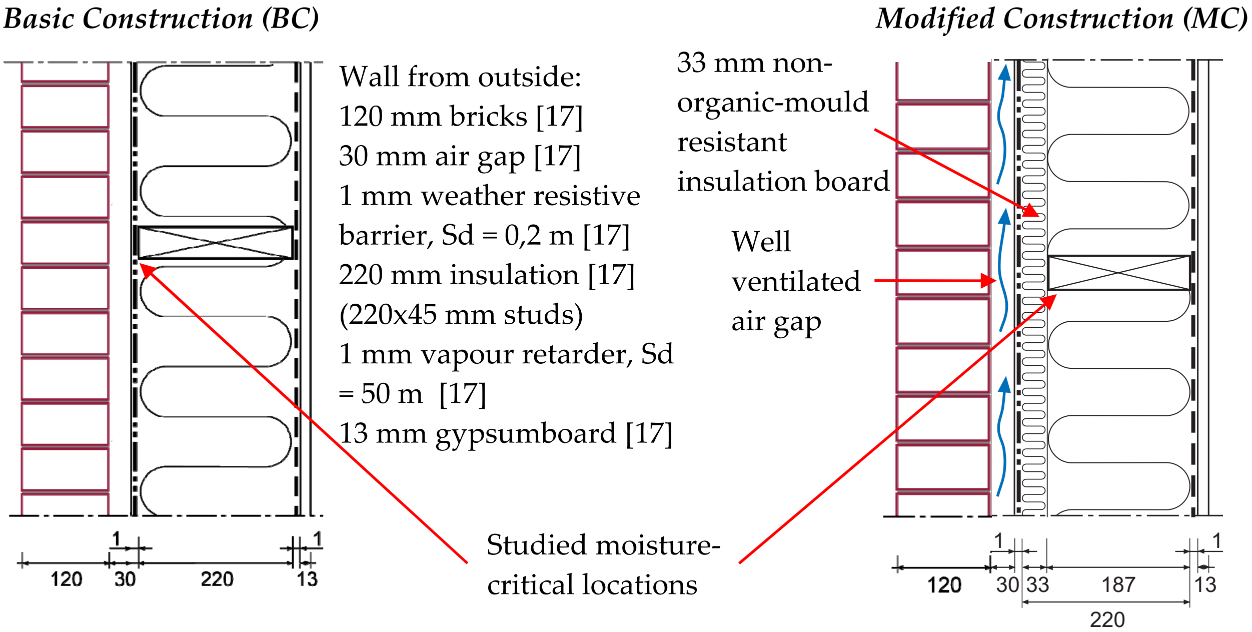

Figure 4: Example of possible measures that could be used in Swedish climate conditions to eliminate or reduce the risk of mould growth [4]. Calculations made using WUFI 5.0 [17].

4. Other possible comparisons using the Folos 2D visual mould chart

The Folos 2D visual mould chart could also be used to compare different locations within structures or different structural designs, different mould models with different risk levels of mould growth, and differences between measured and calculated temperature and RH in actual structures. Figure 5 shows a comparison carried out using WUFI 5.0 calculations for the Basic Construction (BC) and the Modified Construction (MC) shown in Figure 4. Figure 6 shows an example of how the Folos 2D visual mould chart could be used to compare measured and blind calculated values.

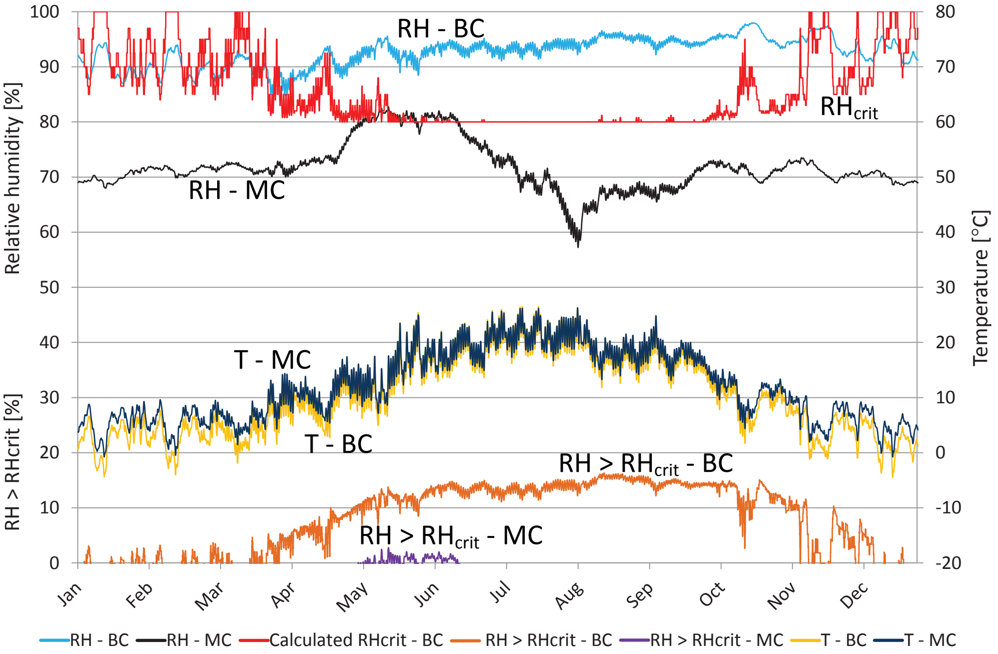

Figure 5: Folos 2D visual mould chart with comparison of critical location in the basic (BC) and modified (MC) structure. BC temperature (yellow), MC temperature (dark blue), BC RH (turquoise), MC RH (black), RH_{crit} depending on BC temperature (red), MC RH > RH_{crit} (brown), MC RH > RH_{crit} (purple).

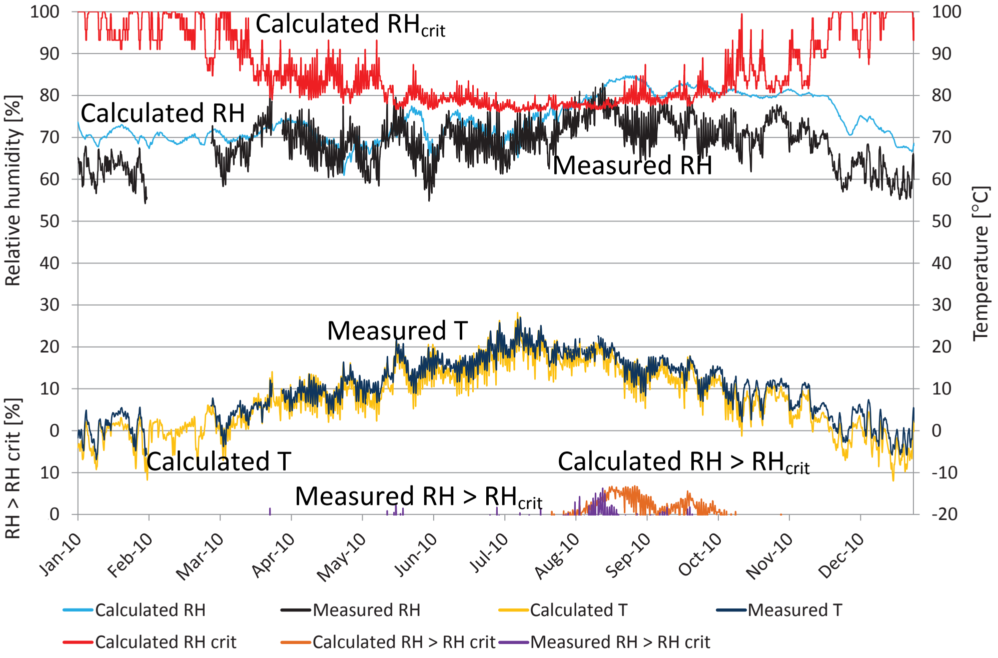

Figure 6: Folos 2D visual mould chart with comparisons of measured and calculated temperatures and RH in a construction [18]. Levels of RH_{crit} from LIM I in Figure 1 [8]. Measured temperature (dark blue), calculated temperature (yellow), measured RH (black), calculated RH (turquoise), RH_{crit} depending on calculated temperature (red), measured RH > measured RH_{crit} (purple), calculated RH > RH_{crit} (brown).

In order to limit the number of plots, there is only one RH_{crit} plot and no mould index (MI) in Figures 5 and 6. Gaps in the comparison between measured and calculated values indicate a lack of measured values.

In the comparisons between measured and calculated values, differences can be seen in the Folos 2D visual mould chart, as shown in Figure 6. By using the relationship in Equation 1, it is easy to determine whether the differences between the measured and calculated RH depend on the differences between measured and calculated temperature, or vapour content, or both. A separate plot for calculated vapour content might need to be added to the chart.

5. Discussion

The article demonstrates how the Folos 2D visual mould chart might be used to evaluate the risk of mould growth and, at the same time, establish what measures need to be taken to limit or avoid the risk of mould growth. This is done by investigating the underlying factors, such as temperature and RH. The Folos 2D visual mould chart could also be used to compare different structural designs, measurements and calculations, and different mould models. To encourage the use of the Folos 2D visual mould chart it could be introduced as a tool when implementing the ByggaF moisture safety design recommendations during the design phase [19].

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