Comparative evaluation of the predictions of two established mould growth models

Martin Krus, Dr.-Ing. **Michael Seidler** **Klaus Sedlbauer, Prof. Dr.-Ing.**

ABSTRACT

Calculation models for the prediction of mould growth can are an essential contribution to avoid mould growth and to assess renovation measures. There are primarily two well-known and widely used models, the VTT model and biohygrothermal model. While the VTT model is an empirical model the biohygrothermal method is based on a physically founded model and considers transient ambient conditions. The result is mould growth in mm, which is, however, not intelligible to all. The Scandinavian countries in particular established a very clear six-step evaluation model, the so-called mould index. By combining the results of the biohygrothermal model and the mould index of the Viitanen model it is possible to use a primarily clear and acknowledged rating measure. A conversion function was developed allowing the transfer of the calculated growth into the mould index with very good correlation.

INTRODUCTION

Numerous damage cases in residential and non-residential buildings can be directly or indirectly attributed to the impact of moisture. Besides reducing potential damage risks the renovation of existing buildings should be aimed at improving the energetic performance. This may result in the reduction of already existing problems with moisture – e.g. mould growth caused by temperatures on the internal surfaces, which are too low – but will probably also generate new moisture problems. Therefore, mould growth, particularly on internal surfaces of external building envelope components but also in other areas on or inside building assemblies, has become an essential point of discussion in recent times. To remove or avoid mould growth causes considerable costs. Mould growth may pose a health risk for residents [Mücke W. 1999]. Any case of damage in connection with these micro-organisms arises the question anew, whether the building construction is the cause of it and thus finally the owner is responsible or whether the cause is incorrect user behaviour in the sense of insufficient ventilation. To clarify these questions measurements as well as modern hygrothermal calculation methods are

Author A is a professor in the Department of Mechanical Engineering, Accredited State University, City, State. **Author B** is a research at Commercial Company, City, State.

applied to provide information on the existing transient moisture conditions and to assess the risk of mould growth.

The biohygrothermal model described in [Sedlbauer K. 2001] is an established calculation method predicting the risk of mould growth on internal surfaces for transient boundary conditions. It is based on measured mould growth isopleths and on the calculation of the transient water content of a model spore. The result is growth in mm, which is, however, not intelligible to all. Primarily the Scandinavian countries established a six-step assessment model in the meantime, the so-called Mould Index, introduced by Viitanen and based on a description of the mould growth situation and the percentage of the envelope surface covered. Since the Mould Index is more generally understandable, the results of both models are compared and the integral growth rate form the bio-hygrothermal model is converted into the Mould Index of Viitanen.

Description of the two Models

Biohygrothermal Model WUFI®-Bio

The assessment of the risk of mould growth on building surfaces and internal building components is of special importance for building practice. Since temperature and moisture conditions are essential influencing factors of mould growth, knowledge of transient hygrothermal conditions may provide information on spore germination and mycelium growth of mould fungi. Isopleth systems describe the dependence of spore germination or mycelium growth on the surface temperature and humidity. In order to regard the influence of the substrate, that is the building materials or possible soiling, on the formation of mould, Isopleth systems for 4 categories of substrates were suggested that could be derived from experimental examinations:

Substrate category 0:	Optimal culture medium;
Substrate category I:	biodegradable building materials;
Substrate category II:	building materials containing some biodegradable compounds
Substrate category III:	non-biodegradable building materials without nutrients.

For the substrate category III no Isopleth system is given since it can be assumed that formation of mould fungi is not possible without soiling. In case of considerable soiling, substrate category I always has to be assumed (Fig. 1 left). Persistent building materials with high open porosity mostly belong to substrate category II.

In 2001 a biohygrothermal model has been developed to describe the mode of action for the fundamental means of influence on the germination of spores, i.e. the humidity available at certain temperatures in a correct way from the physical point of view. This model allows the calculation of the moisture content in a spore in dependence of transient boundary conditions, i.e. it is also possible to consider intermediate drying of the fungus spores. Fig. 1 shows a schematic diagram of the model spore which is the basis of the biohygrothermal method WUFI®-Bio.

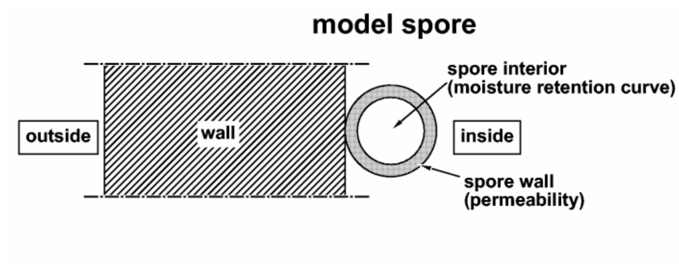

Figure 1: Schematic diagram of the Biohygrothermal Model [2]. The real relation of spore diameter and wall thickness (30 cm) amounts to approx. 1:100.000.

If the specific water content (critical water content) is achieved inside the spore, germination can be regarded as completed and mould growth will begin. This critical water content is defined by means of the isopleth systems for spore germination. Further detailed information on this model which was already successfully applied in several cases to assess mould growth is to be found in [Sedlbauer K. 2003]. Fig. 2 presents characteristic results of this program.

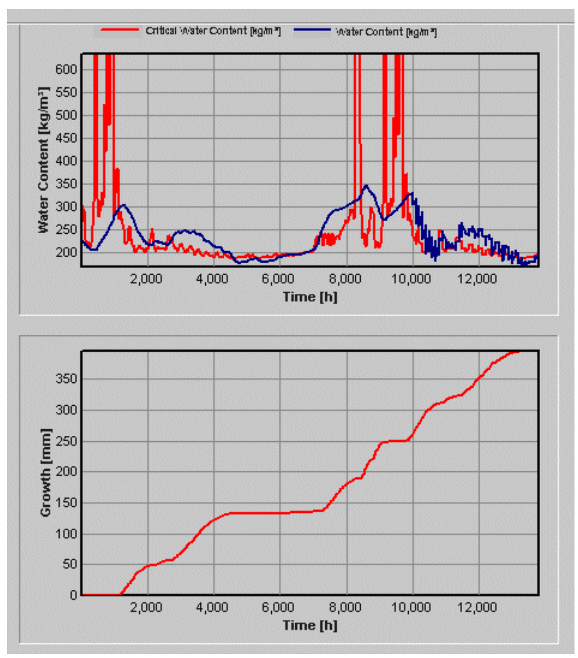

Fig. 2: Results of a calculation by means of the current Biohygrothermal model.

The Model of Viitanen (VTT-model)

The fundamentals of the mould growth model were developed by Viitanen and Ritschkoff in [Viitanen H. 1991] under laboratory conditions. The objective of this work was the determination of the times for germination and the mould growth on pine and spruce wood as well as their deterioration under defined humidities and temperatures to get the essential data for modelling. On the basis of numerous laboratory experiments with various constant temperature and humidity conditions the mathematical modelling was developed. Related studies were exclusively performed in the laboratory, since the interaction of surface humidity, material moisture content, temperature, time and microbial growth in buildings was difficult to simulate and analyze. In the model, constant and periodically changing climate conditions as well as the type of wood and the surface qualities can be selected as boundary conditions. These models have undergone continuous developments (see e.g. [Viitanen H 2007, Viitanen H. 2005-2009, Viitanen H. 2005-2009]), including the decrease of mould growth due to fluctuating moisture conditions as well as mineral materials. The results are presented in the Mould Index described in the following.

Mould Index (Wood based material)

0 = no growth
1 = some growth (microscopy)
2 = moderate growth (microscopy) coverage > 10%
3 = some visually detected growth (thin hyphae found under microscopy)
4 = visual coverage > 10% (growth found under microscopy)
5 = coverage > 50%
6 = dense coverage 100%

The results for mineral materials are presented according to [7] in the latest VTT model with a separate definition of the mould index. Thus the same mould index means a quite different growth according to the respective substrate materials.

Mould-Index (Stone-based material)

0 = no growth
1 = some growth
2 = moderate growth (coverage > 10%)
3 = coverage > 50%
4 = coverage < 100%
5 = coverage 100%

A different intensity in growth with the same mould index (according to the respective selection of the substrate) is hardly practice-oriented or clear. Therefore, the development of a transfer function is exclusively based on the mould index defined by Viitanen for wood.

Basic Differences of the two Models

The two models, the biohygrothermal model and the VTT model, are quite different. The VTT model is an empirical model exclusively based on laboratory investigations. In contrast, the transient biohygrothermal model is based on a physically founded model. The biohygrothermal model allows the selection between various substrate categories which can also be extended by specific measured material substrate categories. The Viitanen model only allows the differentiation between two different wood types or a mineral substrate.

Growth calculated under conditions unfavourable for mould growth can be retrogressive in case of the Viitanen model in contrast to the biohygrothermal model which shows zero growth at these times. Even at temperatures below 0°C the biohygrothermal model shows a slight growth in contrast to the Viitanen model.

The most essential difference, however, is that the Viitanen model does not allow any increase of predicted mould growth beyond a limit value which is dependent on the respective climate boundary conditions, whereas the WUFI-Bio® model allows growth as long as it is possible according to boundary conditions.

TRANSFER OF CALCULATED GROWTH INTO THE MOULD INDEX

Using all the results of the laboratory investigations of Viitanen, which are the basis of all his calculations, with the biohygrothermal model are not target-oriented. For these experiments the documented boundary conditions applicable for the biohygrothermal model. Therefore the transfer is carried out on the basis of numerous calculations by means of both models. The advantage of this method is the fact that real and transient boundary conditions, which occur on the internal surfaces, may serve as a basis allowing a variety of parameter variations. Calculations are carried out by the one-dimensional hygrothermal simulation method WUFI® [8-12] which was developed by the IBP and validated in many cases to investigate coupled processes of heat and moisture transfer. The resulting surface conditions serve as input parameter for the biohygrothermal model as well as for the VTT model which was made available by Viitanen for these investigations.

Parameter Variations

Possible variations for the investigations are location (exterior climate), construction type, indoor climate and thus the moisture load. As concerns the location selection special emphasis is placed on a large scope. Besides locations with very cold winters in Northern Europe, North America and the Alps other locations with high driving rain loads on the North and Baltic Sea are selected. Locations with continental climate in Eastern Europe and moderate climate in Central Europe but also with Mediterranean climate in Italy and Spain are taken into consideration resulting in a total number of 32 different locations.

Indoor climate conditions derived from the outdoor climate according to EN 15026 or ASHRAE Standard 160 serve as a basis. Approaches with slightly or strongly increased moisture loads are selected. With regard to indoor temperatures numerous variations from 19 °C ± 3 °C to 24 °C ± 2 °C are calculated. This variety of 14 indoor climates is intended to simulate as many user habits as possible, also in the negative sense. As a matter of fact microbial growth primarily occurs due to the malpractice of users as concerns heating and ventilation or obstruction of free convection of indoor air to external wall surfaces by furniture or curtains.

Variations with a U-value from 0.3 to 1.9 W/(m²K) are used for the selected external wall assemblies. External walls with insufficient insulation find disproportionately high consideration, as they are especially susceptible to microbial growth. The extremely high U-values are intended to simulate the surface areas of thermal bridges. Monolithic constructions made of various materials as well as lightweight constructions are investigated.

Development of the Conversion Function

All in all approx. 350 calculations are carried out in this way serving as a basis to develop the conversion function. The evaluation of results is performed by comparing the respective maximum values (mould index and growth in mm) during the calculated period of 365 days. Calculations are started at the beginning and in the middle of the year. A deadline is deliberately avoided, since both methods show different intensities of mould growth under particular climate boundary conditions and at different times. Fig. 3 shows the results of this method. A regression line by means of a polynomial function is added as a red line in the diagram.

This method already presents an acceptable result. But there is obviously a large scope of variations within the range of mould index 6. Some upward deviations but almost no downward occur at a lower mould index. These deviations occur due to the specific differences of the models. Whereas the VTT model shows a maximum value (MI 6), extremely high values under favourable growth conditions can be the result as concerns the biohygrothermal model. Upward deviations at a lower mould index always occur, if mould growth is reduced during periods of unfavourable boundary conditions in the Viitanen model, whereas a reduction in growth cannot occur in case of the current biohygrothermal model.

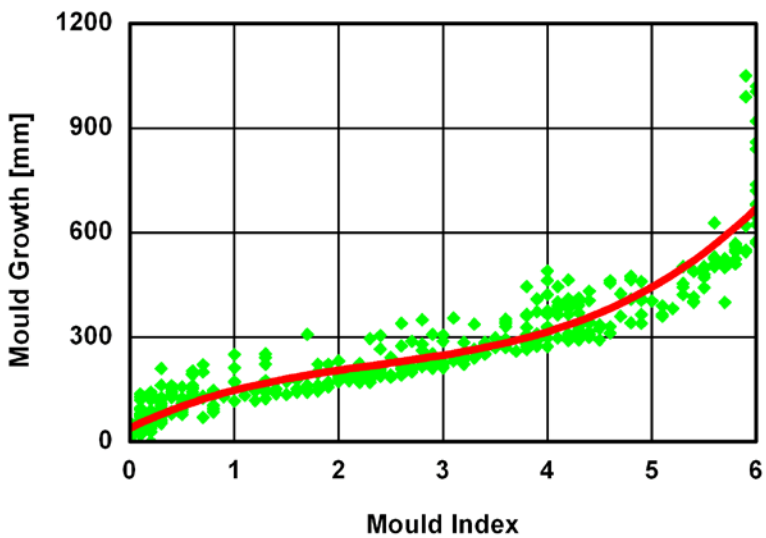

Fig. 3: Comparison of the results calculated by both models for the different variations over a period of one year. A regression line by means of a polynomial function is added as a red line in the diagram.

As a consequence two modifications are carried out. If MI 6 is reached in the Viitanen model at a certain time, calculation will only be carried out up to this point of time in the biohygrothermal model. Moreover, in all variations where reductions in growth occur according to the VTT model, the result will be corrected by the sum of reductions. If the new results of both models are listed in a diagram (Fig. 4), an even better correlation in the lower range will be the result. A BET adsorption curve serves as a regression curve in this case, since the curves are similar to a characteristic sorption curve. The function given as a red line correlates well with the results over the total range thus representing an appropriate transfer function.

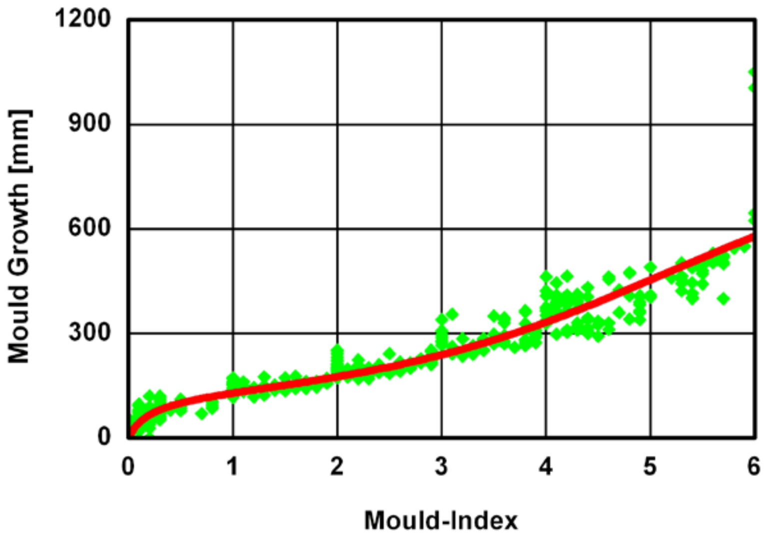

Fig.4: Comparison of the results calculated by both models for the different variations after to the modifications described. A regression line by means of a BET-function is added as a red line in the diagram

SUMMARY

Although the energetic standard of buildings was considerably improved in the last decades, there are consistent reports on building damage caused by mould growth. Microbial growth, however, may pose a health risk for residents. The application of biocides, can avoid mould growth for only a limited period of time in most cases. Therefore mould growth on the surfaces of building components should be avoided by consequent measures. In this context, a preventive strategy should be applied which prevents boundary conditions favourable for mould growth by investigating the transient hygrothermal processes in buildings.

Calculation models to predict mould growth can deliver an essential contribution to avoid mould growth and to assess renovation measures. There are primarily two models which are well-known and widely used in the meantime, the VTT model and biohygrothermal model. While the VTT model is an empirical model exclusively based on laboratory investigations, the biohygrothermal method is based on a physically founded model and considers transient ambient conditions. The result is mould growth in mm, which is, however, not intelligible to all. The Scandinavian countries in particular established a very clear six-step evaluation model in the meantime, the so-called mould index implemented in the VTT model based on coverage by percentage and completed by description.

By combining the results of the biohygrothermal model and the mould index of the Viitanen model it is possible to use a primarily clear and acknowledged rating measure. A conversion function was developed allowing the transfer of the calculated growth into the mould index with very good correlation. This conversion function as well as the respective diagram will be implemented in the calculation tool in the near future. Since both methods of prediction (VTT model and biohygrothermal model) are widely used and will continue to for some time due to their respective advantages or restrictions, it is important to allow the direct comparison of the results of both methods by the conversion function. This will promote further development of both models and encourage more wide-spread application of mould growth prediction methods in building practice.

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