MOULD GROWTH PREDICTION BY COMPUTATIONAL SIMULATION ON HISTORIC BUILDINGS

M. KRUS, R. KILIAN AND K. SEDLBAUER

ABSTRACT

Historical buildings are often renovated with a high expenditure of time and money without investigating and considering the causes of the damages. In many cases historic buildings can only be maintained by changing their usage. This change of use may influence the interior climate enormously. To assess the effect on the risk of mould growth on building parts or historic monuments, a predictive model has been developed recently, describing the hygrothermal behaviour of the spore. It allows for the first time to employ the changing surface temperatures and RH for the prediction of mould growth. The calculational assessment of mould growth allows the handling of problems which until now could not be solved with simple estimations or with reasonable metrological expense. The success of refurbishment measures can thus be determined in regard to the risk of mould growth. Calculations for the Rijksmuseum Amsterdam show the possibilities of this model.

INTRODUCTION

Historic buildings and museums are the most visible and important foundation of the European cultural heritage and contribute significantly to the attractiveness and identity of Europe for its citizens and visitors. Therefore we must take care that these invaluable testimonies of our past are maintained and protected in a sustainable manner. Although huge progress has been made with air conditioning and heating technologies while saving energy for modern buildings, most of the damages to collections of works of art in historic buildings are still caused by unfavorable climate conditions. An increasing problem caused by the adaptation of traditional buildings to new uses is the proliferation of mould growth. Knowledge of how to prevent microbiological attack is already needed in the planning stage of interventions. The problem of mould growth will also gain further importance due to effects of climate change, since in various parts of Europe it will become warmer and more humid.

The application of biocides is always accompanied by risks to health and also to works of art, especially when used indoors, and moreover can prevent the formation of mould fungus only over a limited period of time. A prerequisite for preventing mould fungus without the use of biocides is the knowledge of the boundary conditions under which fungus growth takes place. In reference to the boundary conditions for the growth of fungus it turns out that the decisive parameters of influence like relative humidity [3] and temperature [10] as well as the substrate [8] have to be available over a certain period of time simultaneously in order to enable the formation of mould fungi. Therefore, the main focus of this scientific paper is the development of a planning instrument that aims at predicting the formation of mould fungus. This procedure consists of two consecutive predictive models: the Isopleth Model and the transient Biohygrothermal Model.

HEALTH AND CONSERVATION ASPECTS OF MOULD

People are exposed to mould spores in the air they breathe daily; however, sometimes moulds grow excessively in certain areas and can cause illnesses [7]. The most prevalent effect of mould on human health is caused by the allergenic impact of its spores [4]. Some moulds are more hazardous than others. Different people show a different response to mould exposure. In particular, those with allergies, existing respiratory conditions or suppressed immune systems are especially susceptible to illness. In addition, some moulds produce chemicals called mycotoxins, which can cause flu-like symptoms. It should be noted that the causes and effects of mould exposure on people are not very well understood. For this reason the exposure to an environment contaminated by mould should be restricted as far as possible by preventing conditions suitable for mould growth. Cultural heritage assets are affected by mould both in regard to aesthetic and conservation aspects.

GROWTH CONDITIONS FOR MOULD

For the construction sector, German literature often states a relative humidity of 80% at wall surfaces as the decisive criterion for mould growth, independent from temperature. Sometimes it is mentioned that many

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types of mould can also thrive at lower humidity (see for example the draft of DIN 4108-X, Mould [2]). Other growth conditions, namely a suitable nutrient substrate and a temperature within the growth range are usually taken for granted on all types of building elements.

The growth conditions for mould may be described in so-called isopleth diagrams [1]. These diagrams describe the germination times or growth rates. Below the lowest line (isopleth) every mould activity ceases. Under these unfavorable temperature and humidity conditions spore germination or growth can be ruled out. The isopleths are determined under steady state conditions, i.e. constant temperature and relative humidity. The three factors required for growth – nutrients, temperature and humidity – must exist simultaneously for a certain period of time. This is the reason why time is one of the most important influence factors. It can be assumed that germinable spores are present in most cases. This means that mould growth will occur when hygrothermal growth conditions are fulfilled.

ISOPLETH SYSTEMS

Significant differences exist among the various fungus species. Therefore, when developing common isopleth systems, all known fungi were included that can be detected inside buildings. Quantitative statements on the growth preconditions of temperature and humidity have been set up for more than 150 species that fulfill both features, as far as they are given in the literature [9]. Within the Isopleth Model the prerequisites for the growth of mould fungi of temperature and relative humidity are given at first for the optimum culture medium. These isopleth systems are based on measured biological data. The resulting lowest boundary lines of possible fungus activity are called LIM (Lowest Isopleth for Mould).

In order to include the influence of the substrate, that is the building materials or possible soiling, on the formation of mould fungus, isopleth systems (Fig. 1, left side) for 4 categories of substrates are suggested that are derived from experimental examinations:

SUBSTRATE CATEGORY 0:

Optimal culture medium.

SUBSTRATE CATEGORY I:

Biologically recyclable building materials like wall paper, plaster, cardboard, building materials made of biologically degradable raw materials, material for permanent elastic joints.

SUBSTRATE CATEGORY II:

Biologically adverse recyclable building materials such as renderings, mineral building material, certain wood as well as insulation material not covered by I.

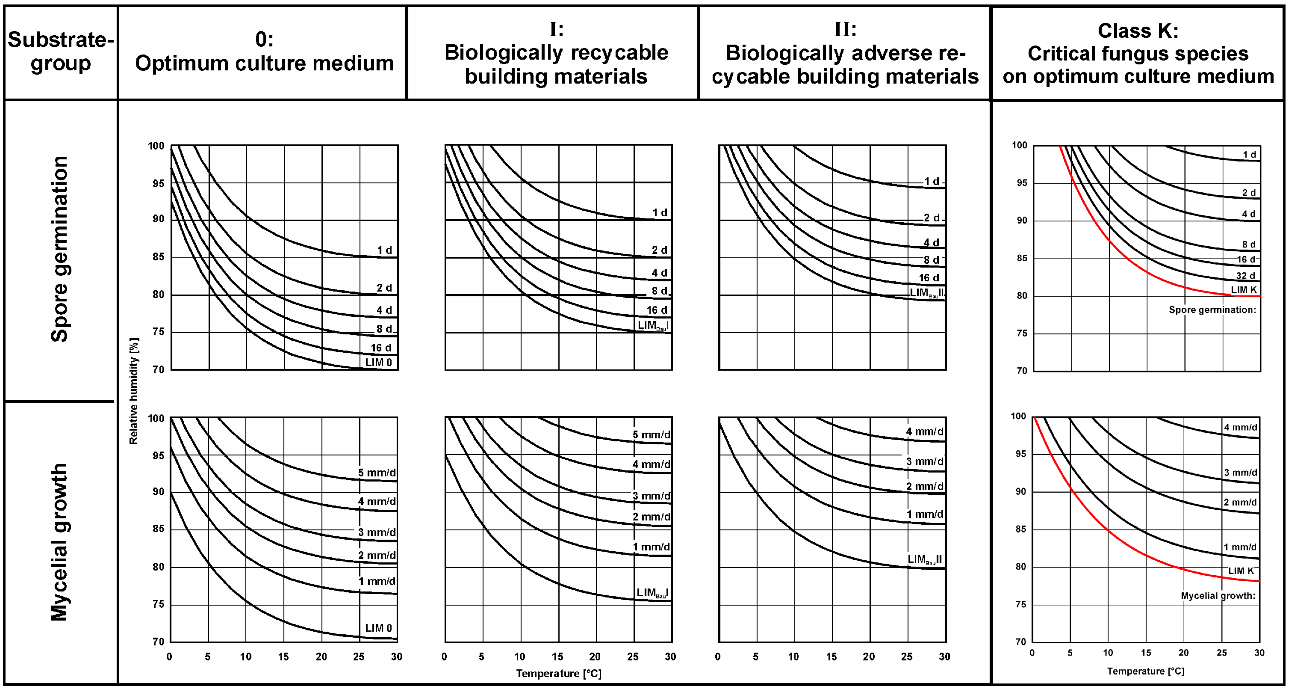

Figure 1. Isopleth systems for 3 categories of substrates, showing the influence of the substrate on the formation of mould fungus [9]. On the right, the isopleth system for the so called critical fungus species (Class K, on optimum culture medium).

SUBSTRATE CATEGORY III:

Building materials that are neither degradable nor contain 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. Persistent building materials with high open porosity mostly belong to substrate category II. The basic principle of the new method and of defining the building material categories is to assume a worst case scenario, therefore always on the safe side in preventing the formation of mould fungi. To what extent the isopleth systems can be corrected for individual building material categories towards a higher relative humidity will have to be proved by further measurements. Especially in regard to risk assessment for individual art materials with a high risk of mould growth like canvas, book, leather, etc. further research is needed and planned.

In order to differentiate the mould fungi according to the health dangers they may cause, a so called hazardous class K has been defined as follows [6]: The isopleth system K applies to mould fungi, which are discussed in the literature because of their possible health effect (Fig. 1 right). For the dangerous species Aspergillus fumigatus, Apergillus flavus and Stachybotrys chartarum growth data is available from [9]. The isopleth system for the fungi estimated as critical to health is based on the available data on optimum culture medium. Precise measurements are missing to compile an adequate substrate specific isopleth for the critical fungus species.

BIOHYGROTHERMAL MODEL

For transient boundary conditions of temperature and relative humidity, either spore germination time or the rate of mycelium growth can be determined with the help of these isopleth systems. Yet the assessment of spore germination alone on the basis of the Isopleth Model has the disadvantage that an interim drying out of the fungi spores cannot be taken into account in the case of transient micro-climatic boundary conditions. Therefore in these cases, this process will predict the germination of spores more often than the Biohygrothermal Model. In order to describe the fundamental influences on the germination of spores, this new model was developed.

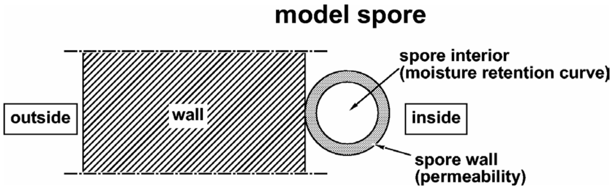

Figure 2. Schematic diagram of the Biohygrothermal Model [9].

The decisive condition for the germination of the spores is the ambient relative humidity, which determines the course of the moisture content within a spore. The objective of the so called "Biohygrothermal Model"[9] is to predict this moisture balance as it is affected by realistic, unsteady boundary conditions as they are found in buildings, in order to permit predictions of growth probabilities. Of course the moisture content of a spore is also determined by biological processes, but the current knowledge is far from sufficient to allow the realistic modeling of these. It is safe to assume that a spore begins to germinate only above a certain minimum moisture content and that no biological metabolic processes occur before this. Until the end of the germination process, the spore may be considered as an abiotic material whose properties are subject to purely physical principles (see Fig. 2). The Biohygrothermal Model describes the development of the spore only up to this point. Due to the small size of the spore, an isothermal model is sufficient, so that liquid transport processes (such as capillary suction) can be lumped together with diffusion transport. Under these assumptions only the moisture storage function of the spore and the moisture-dependent vapour diffusion resistance of the spore wall are needed as material parameters [5]. According to the assumptions noted earlier, the germination is principally affected by thermal and hygric conditions. Therefore it should be independent of the substrate. But normally the starting point of germination is defined by the first visible growth and not by the start of metabolism. The apparent start of germination depends on the quality of the substrate according to these considerations. This influence of the substrate is taken into account by using the LIMs (Fig. 1) in order to calculate the so called critical water content.

EXAMPLE "RUIKSMUSEUM AMSTERDAM"

The change of use of rooms, storeys or whole buildings will in most cases lead to a change of internal climatic conditions. This is always so if a HVAC system or additional heating is installed. Already during the planning phase of substantial refurbishment measures in the museum it could be foreseen that decisive changes of the interior climate

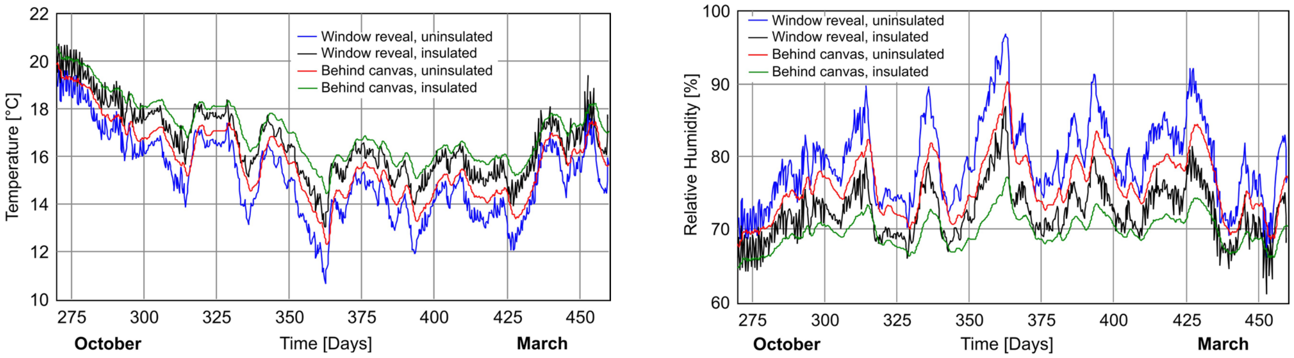

Figure 3. The course of temperature (left) and relative humidity (right) during the winter, at the reveal of a window and behind a canvas painting on the wall [11].

had to be expected, also due to the change of use. Rooms which were used only sporadically or as storage rooms were now to be used for the exhibition of objects of art and as a consequence would have numerous visitors. Additionally, it was planned to fit the climate of the rooms to the requirements of the exhibited objects. This means temperatures between 19 °C and 23 °C at a relative humidity of up to 60 %. Furthermore the single glass windows were to be be replaced by modern double glazing to reduce heat losses as well as to improve security against solar irradiation and burglary. The upgraded insulation of the windows results in higher surface temperatures of the windows than of the walls. This means that now the dew point temperature is exceeded first on the walls and not on the windows as before. The probability of condensation as well as of mould growth is increased enormously. Already before the refurbishment the existing building showed moisture problems due to surface condensation. After the realisation of all measures planned, even more adverse relative humidity conditions had to be expected in the room and at the inner surfaces of the exterior walls.

The risk of condensate and mould growth was calculated for critical building details by one and two-dimensional simulations [11]. Measured data were used for the outdoor climate. To counter the predicted RH and temperatures, which are too high and too low respectively, an internal heat insulation made of diffusion-open calcium silicate was projected, because the historic façade had to remain unchanged. This kind of insulation gives higher surface temperatures, resulting in lowered RH at the wall surface. Because of its low diffusion resistance, the drying of the wall to the interior is enabled. Condensate on the wall will be spread due to the high capillarity of the insulation.

Results of the simulation for the reveal of a window and for an outside wall will be shown. The reveal of the windows is made of sandstone from inside to outside. The simulation shows that because of the high thermal conductivity of the sandstone, especially during winter time, low surface temperatures occur as well as a high relative humidity (10.8°C and 97% RH, Fig. 3). An interior insulation of 40 mm calcium silicate will improve the conditions: the temperature reaches 13.1°C at 87% RH.

It was also planned to hang canvas paintings on the thinner sections of the exterior wall of rooms which had been unused until then. If the wooden frame of a picture is fixed flat against the wall, it can be assumed that because of the feeble air exchange, the air layer behind the picture functions as an additional insulating layer, resulting in lowered wall surface temperatures. The courses of temperature and relative humidity (fig. 3, red and green colour) correspond to the inside surface of the exterior wall behind a picture. The positive influence of the interior insulating layer is obvious. During winter time the surface temperature is increased about 2°C and the RH is lowered about 10 to 15 %. Figure 4 shows the result of the mould growth prediction. Whereas with the interior insulation no mould growth is predicted, without additional insulation, increasing problems have to be expected after the planned change of use.

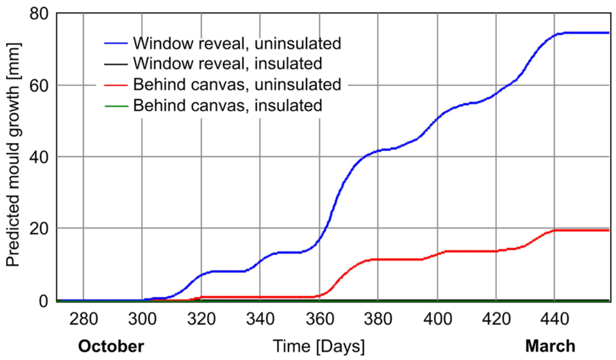

Figure 4. Predicted Mould growth behind a picture fixed on the outside wall and at the reveal of a window without insulation [11]. With insulation no mould growth occurs.

FUTURE WORK

The WUFI Bio software is freely available through the internet and is already being used as a post-processing model for various building simulation systems. The growth model is not yet validated for cultural heritage materials but further research is planned for identifying the growth conditions for micro-organisms on different historic materials used in both movable and immovable cultural heritage. A selection of the most frequently used and the most sensitive materials will be examined at Fraunhofer IBP. The results will be incorporated into the existing analysis software for modern buildings (WUFI Bio) for improved risk assessment for cultural heritage assets.

The course of the relative humidity is strongly influenced by the buffering effects of the building envelope materials and the inside furniture, as well as by the transient outdoor conditions. For the development of suitable ventilation and heating strategies these effects also have to be taken into account. Recently a whole building model for the simulation of the heat and moisture transfer effects which influence the indoor climate has been developed and validated. A combination of this model with the innovative model for the determination of the risk of mould growth makes it possible to assess different temperature and humidity regulation strategies for the preservation of indoor cultural heritage.

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