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Conditions for mould growth on typical interior surfaces

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Abstract

Prediction of the risk for mould growth is an important parameter for the analysis and design of the hygrothermal performance of building constructions. However, in practice the mould growth does not always follow the predicted behavior described by the mould growth models. This is often explained by uncertainty in the real conditions of exposure. In this study, laboratory experiments were designed to determine mould growth at controlled transient climate compared to growth at constant climate. The experiment included three building materials with four different surface treatments. The samples were inoculated with 8 common indoor moulds. Even after 40 weeks no growth was observed on any sample. The paper describes different hypotheses for the missing growth, and how these have been tested.

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Keywords: Constant climate; fungicides; germination of spores; mode of inoculation; mould growthtransient climate; nutrients; water damage

1. Introduction

Prediction of the service life of building constructions is of great interest to designers and building owners. Models for service life have been developed – including models for prediction of the risk for mould growth – based on excessive laboratory studies as well as on practical experience. Some of these models are formulated as mathematical models suitable for post-processing simulated conditions in building structures, while others are factorial methods. [1, 2, 3, 4]

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1.1. Testing building materials for mould growth

Testing of building materials for mould growth has been of interest for many years [1,2,5]. One of the common ways to describe the susceptibility of a substrate – e.g. building material – to mould growth is an isopleth (see Fig 1). An isopleth describes the germination time and the growth rate of specific fungi for given constant temperature and water activity conditions. Water activity is in this paper referred to as relative humidity (RH). Isopleths exist for a range of materials and material classes.

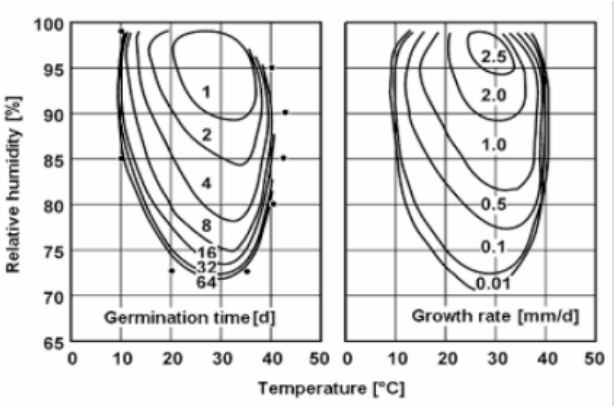


Fig. 1. Example on isopleths. Germination time (left) and growth rate (right) as a function of both temperature and relative humidity. From [1]

Most of the existing work where mould growth processes have been studied on building materials has been conducted on small specimens, and often under constant climatic conditions. Furthermore, the susceptibility to mould growth has been studied mostly on "raw" building materials such as wood, stone wool, gypsum board etc. without surface treatment. Typical materials of interest in the studies have been materials of organic origin like wood (typically pine and spruce) and building boards (e.g. gypsum board with cardboard facer, wood particle board, fiber board and plywood). The studies have focused mainly on testing mould growth at conditions for high water activity, i.e. 90% < RH < 100%, but also at lower RHs like 85% RH and even 75% RH. In some studies water was added directly on the samples, like in [6] where influence of different ways of wetting new and old gypsum board and other building materials on the growth of *Stachybotrys chartarum* was studied. A typical temperature range is 20 – 23 ºC, but some tests also exist for lower temperatures like 15ºC, 5-10ºC, and even temperatures below zero. A typical size of the small samples is around 5 x 5 cm². [6, 7, 8, 11]

A few studies have also included inorganic materials like different kinds of concrete and insulation materials [7, 9]. The role of organic matter on otherwise inorganic building materials was studied specifically in [9].

However, some experiments also exist with larger samples, which were exposed dynamic test conditions, both in respect to temperature and humidity, and even with combined materials. The variations are typically either cyclic with different lengths of periods or with natural variation of the outdoor climate [7]. An example of cyclic conditions with varying periods of both humidity and temperature is reported in [10]. Small samples of fiber board, gypsum board, spruce plywood, pine sapwood and cement screed were in this study exposed to temperature of 10ºC or 20 ºC and to relative humidity of 65% or 97% - or 90% or 100% in different cycles of 1 or 3 days.

Usually, fungal spores were inoculated on the sample surface by spraying the surface with a spore suspension. In many studies, the suspension was a mix of a number of typical indoor fungi [7, 8, 9, 10, 11]

1.2. Scope of the presented work

In order to add new knowledge to the understanding of the problem of mould growth on interior surfaces of building constructions, the study presented in this paper concentrates in proving some methodological issues: 1) Tested items were commonly used building materials in interior layers of exterior walls including final finishes such as paint or wall paper; this would be a new approach in respect to studying the sensitivity of real material combinations the way

they are used in typical buildings. 2) Samples were point-inoculated separately with pure cultures of fungal spores instead of using a spray mixture of fungal spores, enabling identification of the germination and growth of the different fungal species on the studied substrate under different conditions. 3) Testing conditions involved both constant conditions and cyclically varying humidity conditions; while testing under constant conditions would give a reference to other similar studies, the varying conditions were designed to imitate as much as possible typical conditions in those parts of dwellings, where mould growth is commonly detected. This strategy would enable a validation of the existing models for prediction of mould growth and also meets the criticism of determination of the susceptibility of building materials under constant conditions as they in real life are exposed to naturally varying conditions.

2. Materials and methods

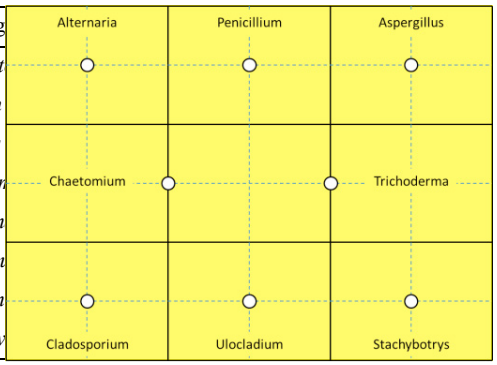
The experimental work in this study was based on a strategy where non-sterilized samples of common building materials and indoor finishes were inoculated with selected mono-cultures of indoor fungi and placed in climatic chambers with controlled – constant or cyclic – climate. Materials and finishes represented both organic and inorganic origin and different hygroscopic capacity.

2.1. Sample preparation

Test samples were prepared by giving three common building materials four different interior finishes. The final samples had a size 13.5 x 18.5 cm and the given thickness of the board. This resulted in 3 x 4 = 12 different combinations in total. Every combination had 3 replicas and 1 control sample (a total of 48 samples). Every sample was placed in a clean plastic box (22.8 x 17.8 x 4.8 cm) with an air permeable lid. Building materials were: 1) Aerated cellular concrete (H+H multi board, thickness 25 mm), 2) Gypsum board (Gyproc GN, thickness 13 mm) and 3) Oriented strand board (OSB) (Egger OSB3, thickness 15 mm). Surface finishes were chosen to represent both organic and inorganic substrates: 1) Wood chip wallpaper and paint, 2) Wallpaper with a print, 3) Paint and 4) Non-woven glass felt and paint. For inoculation of the samples, eight typical indoor fungi were chosen, which represent typical species in water damaged or damp buildings, see Table 1 [12].

Table 1. Left: Indoor fungi used for inoculation of the test samples. Origin of all fungi is water damaged or damp buildings. Right: Location of the inoculation point (open white circle) of each fungal species. Size of the test samples: 13.5 x 18.5 cm.

Indoor fung
Alternaria t
Penicillium
Aspergillus
Chaetomiun
Trichoderm
Cladosporit
Ulocladium
Stachybotry



All fungal strains were initially inoculated on petri dishes with V8 juice agar [13] to ensure purity and generate spores. The spores were harvested after 10-14 days growth. 100 µl suspension with a concentration of 2-9×10^5 spores/ml from one of the 8 fungal cultures was inoculated in each material sample as illustrated in Table 1. For control series, 100 µl of sterile water was ”inoculated” in each 8 places. Before inoculation, all material samples were pre-conditioned at 23 °C and 50% RH until moisture equilibrium (approx. 90 days).

2.2. Test conditions

The hygrothermal conditions on the interior surfaces of the building envelope are a complex function of the indoor and outdoor temperature and RH and the envelope construction itself. In addition, interior RH is a product of the moisture production and ventilation rates. The prediction of the conditions when there is a risk for mould growth on the interior material surfaces is therefore also dependent on these mechanisms. The effect of the temperature on the resulting RH on a critical material surface is illustrated in Table 2. It is given that the indoor air temperature is 20ºC. This explains why mould growth can be found in dwellings even with only moderate relative humidity of the air. The analysis in Table 2 does not concern any moisture capacity of the surface nor the construction.

Table 2. Influence of temperature on relative humidity. Indoor air temperature is 20ºC.

Indoor RH	Temperature on the interior surface	RH on the interior surface
60 %	9 ºC	100 %
60 %	13 ºC	94 %
60 %	17 ºC	72 %

On the basis of the literature study on mould susceptibility studies, and on the typical temperature and humidity conditions in dwellings [14], the following climatic conditions were selected: Constant climate: 90 % RH and 20 °C. Cyclic climate was based on a typical moisture production scheme in dwellings with peaks for cooking and showering activities as reported in [15]. It should present “the worst case”, i.e. in a cold corner or behind the furniture, where the RH is high and mould growth typically can be found. Resulting RH was defined as a series of step changes: 75% RH for 8 hours; 98% RH for 2 hours; 65% RH for 8 hours; 88% RH for 4 hours. After 41 weeks, 100 ml sterile water was added to each sample to simulate water damage. The added water was equal to 20-25 % water content (w/w). Samples were afterwards re-incubated at cyclic climate conditions.

3. Results

Fig. 2. Left: Sample with aerated cellular concrete and wallpaper. No growth is seen even after 41 weeks at 20 °C and 90 % RH. Right: Sample with gypsum board and wallpaper 4 weeks after adding 100 ml sterile water (rotated left 90°). The black growth is *Chaetomium*.

The samples were monitored on a daily basis during the first week, and afterwards on a weekly basis. The samples, which were under constant conditions of exposure, were followed for 41 weeks and the growth was assessed visually and photographed (see Fig 2, left). The samples in cyclic conditions were assessed with a stereo microscope. “Growth” was defined if air mycelium was visible at the inoculation location.

No growth was observed during the 41 weeks the experiment the experiment was running, neither with constant nor cyclic conditions. However, weak growth was observed during the first week within the droplet of the suspension, but it all dried out. After adding water, significant "foreign" growth was observed on the edge of OSB board already 2 weeks after this simulation of water damage. After 2 weeks, inoculated *Aspergillus, Penicillium* and *Ulocladium* were growing, but only on aerated cellular concrete and gypsum board with wall paper. *Chaetomium* was growing on gypsum board and OSB with non-woven glass felt. Observations on all sample variations are summarized in Table 3

Table 3. Mould growth – both inoculated and foreign – on the different samples 2 weeks after simulation of water damage and incubation at cyclic climate conditions

Finish/ Building material	**Paint**	**Non-woven glass felt and paint**	**Wood chip wallpaper and paint**	**Wallpaper with a print**
Aerated cellular concrete	No inoculated growth 1 % foreign growth	No inoculated growth 2 % foreign growth	No inoculated growth 5 % foreign growth	*Penicillium, Aspergillus, Ulocladium* 10 % foreign growth
Gypsum board	*Chaetomium* 15 % foreign growth	*Chaetomium* 20 % foreign growth	*Chaetomium* 25 % foreign growth	*Chaetomium, Penicillium, Aspergillus, Ulocladium* 50 % foreign growth
OSB	No inoculated growth 10 % foreign growth	*Chaetomium* 45 % foreign growth	No inoculated growth 40 % foreign growth	No inoculated growth 75 % foreign growth

4. Discussion

The rather unexpected experimental result of no mould growth under the studied conditions that according to the literature should initiate a certain growth resulted in several hypotheses, which are shortly introduced and discussed here:

The fungal germ tubes and the starting mycelium dried out short after the inoculation. The incubation took place in high humidity (RH=90%) but the samples were too dry by the time of inoculation as they had been incubated at RH=50%. Pre-conditioning under more humid conditions, e.g. at RH=90%, was not chosen because of the risk of initiation of germination and growth of the any present spores in the materials. This "foreign" growth would have disturbed the study whose scope was to establish more knowledge on conditions for growth of different indoor fungi on different interior surface materials. It is shown that materials like the cardboard of the gypsum board usually contain mould fungi spores that will result in growth when exposed to humid conditions, without any further contamination [16].

The inoculation method itself gave fungi non-optimal germination and growth conditions. When spores are added in a suspension, many species germinate already within 4-12 hours and are very sensible to drying thereafter. In the presented work a single droplet of spore suspension was added in test samples while the common method of inoculation according to literature is spraying spore suspension on the entire sample surface. Accordingly, in the present study there was a much smaller water reservoir for germination and growth of the fungi, and this could explain the missing germination and growth. In addition, also isopleths support this: There is need for more water for germination than for continuation of the growth, see Fig 1.

One of the hypotheses for missing growth was that the materials and finishing materials had fungicides. This was falsified as growth was observed on all samples after adding (enough) water.

Also, there was no lack of nutrients for fungal growth as most of the samples had enough and suitable small carbohydrates to support the growth. The least growth was seen on the inorganic materials with inorganic surface treatment.

Yet another explanation for the missing growth for the case with cyclic conditions was that the resulting RH in the sample boxes was not dynamic at all: Empty boxes had been monitored, and the humidity in those boxes varied as it was planned to according to the test conditions described in Section 2.2. However, when the boxes contained material samples, the moisture capacity of the samples was enough to keep the RH in every box around 75 – 80% RH. In contrary, the fluctuations for the case with constant RH = 90% cannot explain the missing growth, as the RH was rather higher than 90% than lower.

5. Conclusion

The experimental study reported in this paper indicates that dry (50 % RH) building materials can be very resistant to mould growth if they are exposed to high relative humidity (90 % RH) only for a limited period, while organic building materials are very vulnerable when exposed to water. These conclusions support well the existing guidelines about avoiding high moisture or any water damage during the construction period as well as that buildings should be designed such that RH on interior surfaces never exceeds 75% RH.

For future studies, the authors would recommend studies addressing the necessity of presence of liquid water for the germination: How high RH is needed for the germination and how long time it must be sustained at such a level? Is free water needed? How does the inoculation method influence the growth?

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References

[1] Sedlbauer K. (2001). Prediction of mould fungus formation on the surface of/and inside building components. University of Stuttgart, Fraunhofer Institute for building Physics, Doctoral thesis. Stuttgart. Germany

[2] Ojanen, T.; Viitanen, H.; Peuhkuri, R.; Lähdesmäki, K. Vinha, J.; Salminen, K. (2010) Mould growth modeling of building structures using sensitivity classes of materials. Proceedings to Performance of Exterior Envelopes of Whole Buildings XI, Clearwater, Dec 2010. Florida.

[3] Viitanen, H; Toratti, T; Makkonen, L; Peuhkuri, R; Ojanen, T.; Ruokolainen, L.; Räisänen, J. (2010) Towards modelling of decay risk of wooden materials. European Journal of Wood and Wood Products. Vol. 68 (2010) No: 3, pp. 303 – 313

[4] A. Silva et al. (2016), Methodologies for Service Life Prediction of Buildings, Springer International Publishing Switzerland, DOI 10.1007/978-3-319-33290-1_6

[5] Viitanen H. (1996). Factors affecting the development of mould and brown rot decay in wooden material and wooden structures. Effect of humidity, temperature and exposure time. Doctoral thesis. Uppsala. The Swedish University of Agricultural Sciences, Department of Forest Products. 58 p.

[6] M.Y. Menetreza K.K. Foardeb T.D. Webberb D. Betancourta T. Deana (2004) Growth Response of Stachybotrys chartarum to Moisture Variation on Common Building Materials Indoor and Built Environment

[7] Lähdesmäki K., Salminen K., Viitanen H., Vinha J., Ojanen T., Peuhkuri R. (2011). Mould growth on building materials in laboratory and field experiments. Proceedings of 9th Nordic Symposium on Building Physics, Tampere.

[8] Ritschkoff A.-C., Viitanen, H. and Koskela, K. (2000). The Response of Building Materials to the Mould Exposure at Different Humidity and Temperature Conditions, In: Seppänen, O. and Säteri, J. (ed.), Healthy Buildings 2000, Vol. 1, 6–10 August, Finnish Society of Indoor Air Quality and Climate (FiSIAQ), Espoo, FI, pp. 317–322.

[9] Viitanen, H. (2004). Betonin ja siihen liittyvien materiaalien homehtumisen kriittiset olosuhteet– betonin homeenesto [Critical Conditions for Mould Growth in Concrete and Other Materials], VTT Working Papers: 6 (in Finnish, English Abstract).

[10] Viitanen, H. and Ojanen, T. (2007). Improved Model to Predict Mould Growth in Building Materials, In: Thermal Performance of the Exterior Envelopes of Whole Buildings X – Proceedings CD, 2–7 December, Clearwater Beach, USA, ASHRAE, DOE, ORNL

[11] Holme, J. (2009) Mould growth on board-based wind-barrier products Energy Efficiency and New Approaches – Proceedings of the Fourth International Building Physics Conference (Bayazit N.T. et al. eds), Beysan Matbaacilik ve Reklamcilik, Istanbul, 75-82.

[12] Andersen, B., Frisvad, J.C., Søndergaard, I., Rasmussen, I.S. and Larsen, L.S. (2011). Associations between fungal species and water damaged building materials. Applied and Environmental Microbiology. 77: 4180-4188.

[13] Samson, R.A., Houbraken, J., Thrane, U., Frisvad, J.C. & Andersen, B. (2010). Food and Indoor Fungi. First Edition. Centraalbureau voor Schimmelcultures, CBS−KNAW. Utrecht, The Netherlands.

[14] Targo Kalamees, Minna Korpi, Juha Vinha, Jarek Kurnitski (2009): The effects of ventilation systems and building fabric on the stability of indoor temperature and humidity in Finnish detached houses. Building and Environment 44 pp. 1643–1650

[15] Künzel, H.M.; Holm, A.; Sedlbauer, K.; Antretter, F.; Ellinger, M.(2004) Moisture buffering effects of interior linings made from wood or wood based products. IBP Report HTB-04/2004/e

[16] Andersen, B., Dosen, I., Lewinska, A. M., & Nielsen, K. F. (2017). Pre-contamination of new gypsum wallboard with potentially harmful fungal species. Indoor Air, 27(1), 6-12. DOI: 10.1111/ina.12298