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RESEARCH ARTICLE

THE MATHEMATICAL ISOPLETH MODEL FOR FUNGI GROWTH IN BUILDING MATERIAL

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ABSTRACT

To predict the mathematical isopleths model for the growth of fungal mycelium in building material. The mould fungal growth is one of the first signs of biological growth linked to relative humidity and temperature condition in buildings materials. The numerical growth model was based on several models are found in literature. Quantification of fungal growth in the model is based on mould index used in the experiments for visual inspection. This model consists of differential equations describe the growth rate of the fungal growth index in vary fluctuating conditions including the effect of exposure time, temperature, relative humidity and dryness. Up to now the mathematical isopleth model to assess the fungal mould growth which is based on steady boundary conditions. This study presented new results for mathematical isopleth of mould growth on the surface of building materials such as wood, cement, concrete.

Key Words: Mould, building material, isopleths model and relative humidity.

1. INTRODUCTION

There are the four phases initial growth-lag, metabolic phase and log-growth phase, stationary and death phases of mould fungi[1] (Abe, 1993). For this, measurement results of fungus growth are described mathematically. At first, the influence of stationary conditions is recorded. To be able to assess transient courses of moisture content on building materials with regard to mould spore and mycelium formation, an evaluation based on the Time of Wetness[2] (Bullae, 1931). The Model of Time of Wetness is the number of hours of high relative humidity (e.g. 80 %) per day, related to 24 hours. The assumption here is that mould fungus growth takes place, although with delay for a while, if a certain limit value is exceeded, which is indicated in hours per day with a relative humidity of more than 80 % for example. The evaluation of the experiments shows that the fungal species grows only little on a building surface at a TOW of 0.5. In contrast to that, there is a strong influence at values higher than 0.5. The effect of quick changes in the relative humidity, proved that also the frequency is of nearly no influence on the fungoid growth[3] (Araujo, 2004).

1.1 A mathematical isopleth prediction of fungus mycelium Growth

Fungal mycelia do have a broad spectrum regarding the growth conditions (pH, temperature and relative humidity) than the other microbial consortia in building materials and thus they are also called primary colonizers. According to Craver and Boswall[4] (2008) prevent the microbial growth in buildings, it is therefore sufficient to concentrate upon mould fungi and to coordinate the prediction methods accordingly. At first, mould fungus species that are relevant to the model are defined in the following and divided into hazardous classes according to possible health hazards[5] (Cooke and Rayner, 1984). After having analyzed and evaluated the factors influencing the mould formation and after indication of the most important parameters, mathematical prediction model, i.e. the isopleth model (Chertov and *et al*, 2004) described in this paper[6].

1.2 Growth of fungi on building materials and their categorisation into hazardous classes

To the determination of the fungal growth conditions with respect to pH, temperature and relative humidity, those mould fungi are to be considered that occur in buildings and that represent a hazard to health or are damage relevant[7] (Hukka and Viitenen, 1999). The growth of fungi were categorise into following classes[8] (Law and *et al*., 2001):

[A] Fungus or its metabolic products are highly pathogenic.
[B] Fungus or its metabolic products may cause allergic reactions.

[C] Fungus is not dangerous to health but they may cause economic damage.

Table 1 show for these species the special data of minimum, optimum and maximum growth conditions regarding temperature, relative humidity and pH value. The values listed are sufficient to state for the 3 hazardous classes lower growth conditions for spore germination and mycelium growth. Classifying the fungi into 3 hazardous classes[1] (Abe, 1993), it is noticeable that the values of class C are only slightly different from that of class B. Therefore, it is sufficient to distinguish within the isopleth model only between the hazardous class A and a combined class B/C.

1.3 Mathematical Isopleth Model for Mould Growth

This following paragraph describes the mathematical model which is based on to predict mould mycelium formation. An isopleth system describes the spore germination times or the mycelium growth[9] (Davidson, 1998) to be expected in dependence on temperature and relative humidity. The isopleth systems that are valid for various hazardous classes and single substrate categories and with that, allow considering the influence of the substrate when predicting mould fungus formation.

1.4 Isopleth model

The isopleth systems are used for that purpose which describe the spore germination times and growth rates in dependence on temperature and relative humidity. However, complete isopleth systems are stated in literature[7, 10] (Hukka and Viitanen, 1999; Kotov and Reshetnikov, 1990) only for some fungus species. Depending on the species, these systems differ considerably from each other and are valid only for complete medium culture medium. This mathematical model cover the growth conditions of the mould fungi occurring in buildings[11] (Ito and Mizuno,2009). Only singular measurements carried out for mould fungus formation on building materials are available here as basic data as published by Edelstein (1982)[12].

1.5 Isopleth systems for spore germination

If one knows about a complete isopleth system for spore germination, i.e. the spore germination times that depend on different temperatures and relative humidities[13] (Gibson *et al*.,1994), one can find out by a comparison with the transient hygrothermal conditions occurring in the building - whether there are sufficiently long growth conditions for the spores to germinate. Spore germination times are those times that are required until the development of a germ tube[8] (Law and *et al*., 2001) as the first sign of mycelium growth is visible under the microscope. So the single isolines of the isopleth system specify the times required by the spores to germinate and become visible, under corresponding stationary hygrothermal conditions[14] (Regalado and *et al* .,1996). These indications are valid for optimal culture media because complete media are used in the underlying measurements.

2 RESULTS AND DISCUSSION

To get a suitable prediction method, one has to evaluate the few measurement data available and create the isopleth systems by a process which shall be as simple as possible. To the prediction of isopleth systems for different building materials on the basis of the few data available in literature, it is assumed that the systems valid for optimal culture media do always consider the smallest humidities that are necessary to let the fungus grow, depending on the temperature[15] (Webster, 2007). Resulting from two hazardous classes, two substrate categories, and each of them for spore germination and for mycelium growth – the respective lowest isoline of which is called LIM.

2.1 Lowest Isopleth for Mould

a) Hazardous class B/C (LIM B/C): These systems refer to biological complete culture media and therefore form the lower limit of all isopleth systems as far as the growth conditions are concerned, i.e. the lowest values for relative humidity. They are the growth limit for all mould fungi occurring in buildings.

b) Hazardous class A (LIM A): Analogous to a), valid for all fungi of hazardous class A only.

c) Substrate category I (LIMMat I): Analogous to a), as for the culture medium, they do not refer to the complete medium but to materials of substrate category.

d) Substrate category I I (LIMMat I I): Analogous to c), only valid for all materials belonging to the substrate category I.

The specification of the LIM curves for the hazardous classes A and B/C is shown in Figure 29 for spore germination and in Figure 30 for mycelium growth. The temperature regarded here lies within a range from 0 °C to 30 °C only that is interesting from the view of building physics for indoor environments[16] (Swinnen and *et al*., 2004). The LIM means that on this line the spore germination time theoretically is infinitely big or the growth rate is 0 mm/d. When specifying the LIM curves, uncertainties are included in a way that microbial activity below the LIM can be excluded for all species occurring in buildings for the special hazardous classes A and B/C, particularly since the culture medium which forms the basis for the specification of the isopleths can be regarded as optimal.

To generate these envelope curves mathematically, one assumes that the LIM curve does correspond to a hyperbolic curve. This is also in accordance with the isopleths found in literature. To determine the course of the envelope curve mathematically, one uses the semi-curve of a hyperbolic cosine function, lying to the left of the bottom peak value, for a range between 0 °C and 30 °C which is interesting from the view of building physics[16] (Swinnen and *et al*., 2004), in accordance with following equation:

$$j = a \cdot \cosh(J - Jopt.) + b \quad (15)$$

With:

a, b [-] coefficients
j [-] relative humidity

J [°C] temperature

Jopt [°C] optimum temperature for fungoid growth

The course of the curve is defined by the

- fLIM (optimum temperature) = minimum relative humidity in the special temperature range

- fLIM (minimum temperature) = optimum relative humidity in the special temperature range as well as by the boundary condition

dfLIM /dJ (optimum temperature) = 0.

An isopleth system consists of the lower envelope curve (LIM), which depends on temperature and relative humidity, and a family of analogous isolines that parameterize the spore germination times, if spore germination is predicted, and the growth per time unit[17] (Trinci, 1974), if mycelium growth is described. In order to make the prediction of mould fungus formation in buildings as easy as possible[18] (Sedlbauer, 2001), it is necessary to be able to specify isopleth systems that are valid for all fungi of one hazardous class. It is the fungus *Aspergillus versicolor* for the hazardous class A and the fungi *Aspergillus amstelodami, Aspergillus candidus, Aspergillus ruber* and *Wallemia sebi* for class B/C which have fungi-specific isopleths lying close to the course of the LIM curves, within the special temperature range that is interested from the view of building physics.

The representative fungi which were taken as basis are *Aspergillus versicolor* for class A and *Aspergillus amstelodami* for B. The Growth can start again even after a period of unfavourable climatic conditions. In order to be able to predict the maximum growth to be expected, an isopleth system for mycelium growth has to be developed which is valid for all mould fungi. The growth velocities are stated in mm/d in dependence on temperature and relative humidity. The growth rates usually indicated in mm/d or corresponding area occupancies (e.g. 70 % of a petri dish) [19] (Schiraldi, 1995) can be used to evaluate the growth on building components only in the figurative sense in a way that the values are analyzed comparatively. To generate isopleth systems for mycelium growth that are valid for all mould fungi, measured isopleth systems of representative fungi are used again. In contrast to the spore germination, there are measured systems for several fungi existing for the mycelium growth.

Based on the special LIM, the single isolines are generated in a way that for each condition of temperature and relative humidity the highest growth rate of all fungi (as shown in Figure 2) is selected and considered. A procedure is applied here which is analogous to that for the spore germination, i.e. the LIM curve is shifted upwards, with its form remaining the same, until it crosses, coming from below, the isoline for one special growth rate[20] (Riquelme and *et ai., 1998l*) within the isopleth system measured for the representative fungus.

These values are calipered and drawn on the isothermal line at 28 °C in the isopleth system (on the bottom right of Figure 3). The assignment of the temperature-dependent growth rates at optimum relative humidity (on the top right of Figure 3) is entered on the line at optimum relative humidity (e.g. at 97 % on the bottom right of Figure 3). Connecting these 3 points of the same growth rate by means of a cosh function yields the corresponding isoline in the isopleth system for mycelium growth on the bottom right in Figure 4.

3. MODEL ASSUMPTIONS

The isopleth model can thus describe the development of the spore until the critical moisture content is reached. With the physiological activities beginning, the fungus can influence its nutrient and water balance on its own by various mechanisms. Since the present state of knowledge is not sufficient to model these procedures, the influence of the substrates shall be made possible by the following simplistic assumptions:

(i) The water absorption of the spores is calculated with the diffusion approach also after the metabolic processes have started.

(ii) The critical moisture content is determined by means of the isopleths for spore germination as follows: depending on the temperature, the lowest relative humidity at which the spore germination takes place.

3.1 Functionality of the isopleth model

To be in a position to compare the biological growth conditions with the calculated hygrothermal conditions, one has to compare, on basis of the isopleth model, the calculated transient courses of temperature and relative humidity in the building component surface with the spore germination time and mycelium growth data in the respective isopleth systems. The growth for the hazardous classes A and B/C respectively on optimal culture medium as well as for the substrate categories I and I I conditions characterized by the time courses of temperature and relative humidity, serve as input parameters. These microclimatic boundary conditions are entered into the isopleth systems as hourly values. The computer allows carrying out the evaluations on basis of the isopleth model automatically. For this, the single isopleth systems are described on basis of the equation (Cooke and Rayner, 1984)[5].

In one test series, a relative humidity of 97 % at 22 °C and 70 % and 28 °C are applied to the samples alternately for a certain daily duration. If one calculates by means of the biohygrothermal model the courses of the moisture contents in the model spore, for the case of a severe contamination with an assumed humidity period of 97 % lasting 1, 2,4 or 6 hours a day, one notices a building up of the spore moisture. Depending on how long the high humidity (97 %) lasts a day, one gets different moisture contents. When using the LIM for optimal culture medium to determine the critical moisture content, which is plausible since the “severe contamination“ is produced by an easily degradable organic substance, fungus is already formed with a humidity of 96 % lasting only 1 hour per day.

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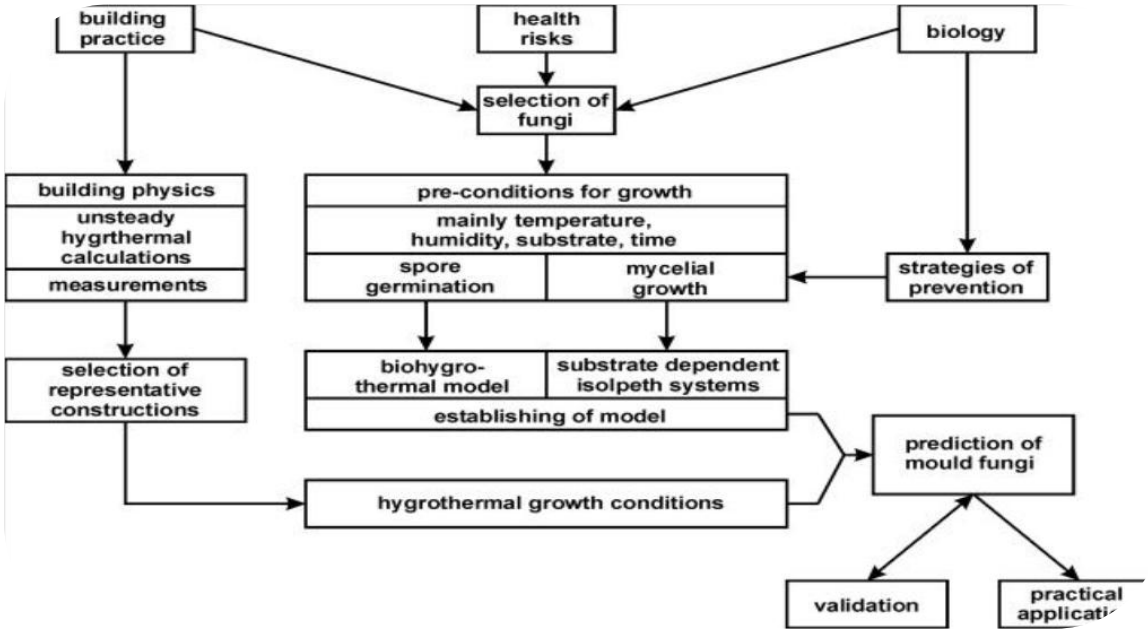


Figure 1 Schematic diagram of the methodical procedure when developing the isopleth method.

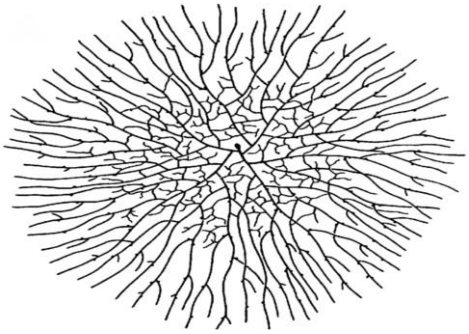
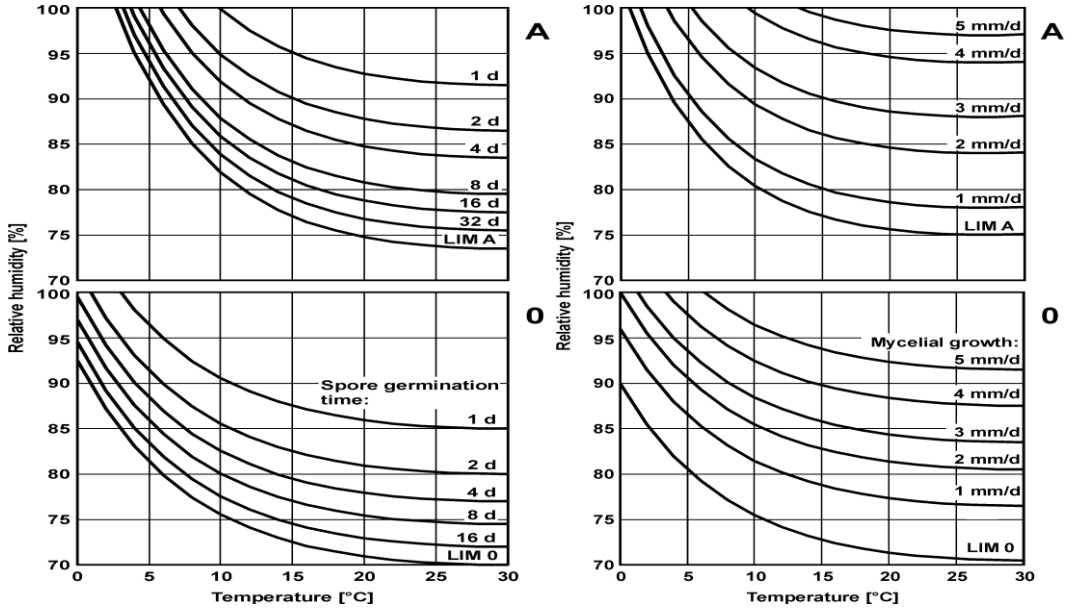


Figure 2: Representation of a fungal mycelium: Graphic reproduced from Buller (1931)[2], (Webster 2007)[15]. A hypha will generally extend apically in a straight line with small variations in orientation that are due to a shift in displacement of the Spitzenk¨orper[20] (Riquelme et al., 1998)



(A) Fungal spore germination (B) Fungal mycelium growth

Figure 3 (A) Generalized isopleth system for spore germination, valid for all fungi of hazardous class A (above) and B/C (below); (B) Generalized isopleth system for mycelium growth, valid for all fungi of hazardous class A (above) and B/C (below).

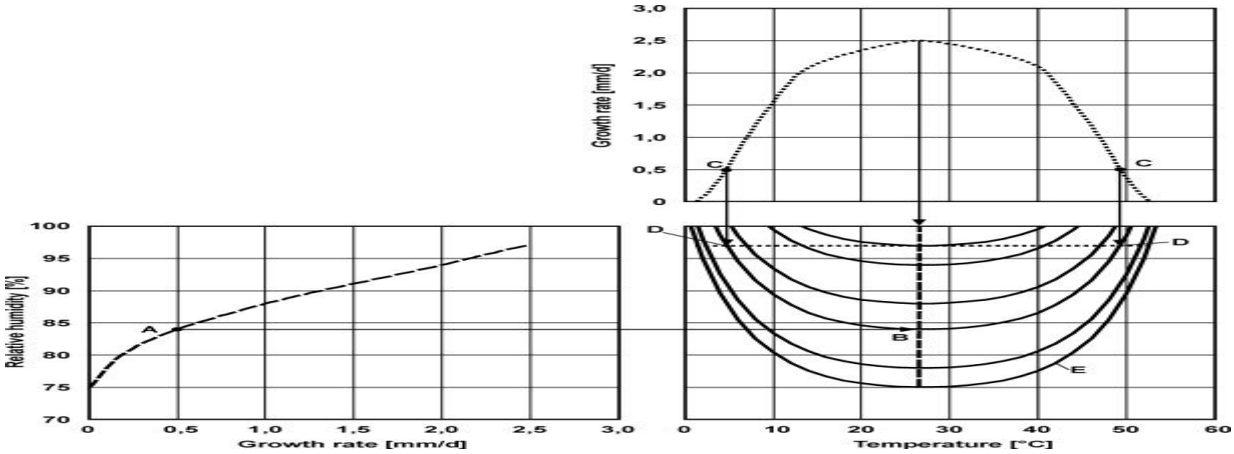


Figure 4 Schematic diagram of how to generate the isopleths by projecting them measured temperature- and humidity-dependent growth rates onto an isopleth system for mycelium growth.

Table 1 Mould Fungi Growth Index

Index Values	Growth Rate	Description
0	No growth	Spores not activated
1	Mould growth in small amount occurs on surface	Initiation phase
2	<10% Coverage of mould on surface	-
3	10-30% or <50% Coverage growth on surface	New spores produced
4	>50% Coverage of mould growth	Moderate growth
5	>70% Coverage growth on surface	Plenty growth
6	Very high and dense growth about 100% coverage surface	

In this model different mixed mould fungi are used. The mould fungi growth development is expressed by mould fungi index (M). An index value between 0-6 to be used as a design criterion that mean evaluation of mould growth on a substrate surface e.g. often M=1 expressed as the maximum tolerable value since from this point the germination process starts and the mould growth can be detected visually in between index 3-6 (Table 1).

Table2 Different sensitivity class of the substrates actinomycetes model based onVTT model[21] (Vitanen *et al.* 2011)

Sensitivity Class	Material	k_1		K_2 (max)			RH min(%)
		A<1	A>1	A	B	C	
Very sensitive	Pine sapwood	1	2	1	7	2	97
Sensitive	Wooden board, spruce	0.658	0.436	0.4	3	1.5	97
Medium resistant	Concrete, glass wool polyester	0.062	0.067	0	4	1	97
Resistant	PUR unpolished surface	0.022	0.015	0	2.5	1	97

The various building materials showed varying tolerance against mold growth under the test conditions. The results of wood substrate and other material surfaces fitted best with pine sapwood. At the 15˚C temperature, there was a lag phase for the initiation of mold growth, so this was no well fitted with this model. The second evaluation of the mold growth model with the new material sensitivity class factors was done by producing mold index levels under constant temperature and relative humidity.

CONCLUSION

This mathematical model is neither based on linear function nor does it provide one exclusive limit state, which might apparently conflict with the ideal preconditions on an engineering approach. Biodegradation of buildings and building materials depending on the, dimension of component, type of decay, temperature and relative humidity. There are several factors involved with the microbial degradation of buildings and building materials by mould fungi and other microbial consortia. Due to this mathematical model that may help us to understand the complicated interaction of many factors. The main motive of the mould growth index model development and

application is nevertheless give a tools for better prediction and evaluation of the risk for microbial consortia growth on building material surfaces and capable to find the best solutions to ensure a safe performance for buildings and building materials.

REFERENCES

1. Abe, K. Method for Numerical Characterization of Indoor Climates by a Biosensor using a Xerophilic Fungus, Indoor Air, 1993; 3, 344-348.
2. Buller, A. H. R. Researches on Fungi, vol. 4. London: Longmans. 1931.
3. Araujo, P. and D. L. S. McElwain. A history of the study of solid tumour growth: the contribution of mathematical modelling. Bulletin of Mathematical Biology, 2004; 66, 1039–1091.
4. Carver, I. and G. P. Boswell. A lattice-free model of translocation-induced outgrowth in fungal mycelia. International Journal of Applied Mathematics, 2008; 36, 173–179.
5. Cooke, R. C.; Rayner, A. D.: Ecology of saprotrophic fungi. Kapitel 1: Heterotrophy and its consequences. Longman-Verlag, London - NewYork (1984), p. 1 - 13.
6. Chertov, O., A. Gorbushina, et al. "A model for microcolonial fungi growing on rock surfaces." Ecological Modelling, 2004; 177: 415-426.
7. Hukka, A.; Viitanen, H. A.: A mathematical model of mould growth on wooden material. Wood Science and Technology Nr. 1999; 33, p. 457 - 485.
8. Law, A. K. Y.; Chau, C. K.; Chan, G. Y. S.: Characteristics of bioaerosol profile in office buildings in Hong Kong. Building and Environment, 2001, H. 36, p. 527 - 541.
9. Davidson, F. A. "Modelling the qualitative response of fungal mycelia to heterogeneous environments." J. Theor. Biol. 1998; 195: 281-292.
10. Kotov, V. and S. V. Reshetnikov. A stochastic model for early mycelial growth. Mycological Research, 1990; 94, 577–586.
11. Ito K and Mizuno Y, Numerical Morphological Analysis of Fungal Growth based on a Reaction - Diffusion Model : Biocontrol Science, 2009; Vol.14, No.1, pp 21-30
12. Edelstein, L. The propagation of fungal colonies: A model for tissue growth. Journal of Theoretical Biology, 1982; 98, 679–701.
13. Gibson, A.M., Baranyi, J., Pitt, J.I., Eyles, M.J., Roberts, T.A. Predicting fungal growth: the effect of water activity on Aspergillus flavus and related species. Int. J. Food Microbiol. 1994; 23, 419–431.
14. Regalado, C. M., J. W. Crawford, K. Ritz, and B. D. Sleeman. The origins of spatial heterogeneity in vegetative mycelia: a reaction-diffusion model. Mycological Research, 1996; 100,1473–1480.
15. Webster, J. and R. Weber. Introduction to Fungi. New York : Cambridge University Press. 2007.
16. Swinnen, I. A. M., K. Bernaerts, et al. "Predictive modelling of the microbial lag phase: a review."Int. J. Food Microbiol. 2004; 94: 137-159.
17. Trinci, A. P. J.. A study of the kinetics of hyphal extension and branch initiation of fungal mycelia. Journal of General Microbiology, 1974; 81, 225–236.
18. Sedlbauer, K. Prediction of mould fungus formation on the surface of and inside building components, Dissertation University Stuttgart 2001.
19. Schiraldi, A. "Microbial growth and metabolism: modelling and calorimetric characterization." Pure Appl Chem, 1995; 67(11): 1873-1878.
20. Riquelme, M., C. G. R.-P. na, G. Gierz, and S. Bartnicki-Garc´ıa. What determines growth direction in fungal hyphae? Fungal Genetics and Biology, 1998; 24, 101–109.
21. Viitanen H, Toratti T, Makkonen L. Development of service life model for wooden structures. . 12th International Conference on Durability of Building Materials and Components. Conference Proceedings, 2011; Vol 1: pp 495 - 502.

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