Dr. Klaus Sedlbauer
Fraunhofer Institute for Building Physics (IBP), Holzkirchen
(Head: Prof. Karl Gertis, Ph.D.)

Unwanted Biological Growth in and around Buildings

1 Introduction

In Upper Bavaria, many of the houses have geraniums on the balcony to improve the appearance of the building. And it's not only the tourists in our region who like them. Inside the houses, too, indoor plants are a common form of decoration. But whereas the flowers on the balcony have little or no effect on the physics of the building, the "botany" in the living-room is fraught with a certain danger, if only because only a minute proportion of the water used in watering the plants actually goes to promote growth, and practically all the moisture is passed on to the surrounding air in the room.

From a building physics point of view, we might just as well water our flat in the first place. The result is not infrequently the appearance of ugly, grey patches of mould at thermal bridges, for example . This growth may look pretty when you look at it closely, but the health hazards [1] that it causes are reason enough to justify renovation on grounds of hygiene when mould appears.

By now, the conditions for the growth of the species of mould that typically occur in buildings are sufficiently well known [2] to allow us to explain the causes, using the classic example of mould in a bedroom, which we will do in Part 2 of the present publication. We will then deal with the apparently increasing problem of the growth of algae on well insulated outer facades. There are "blooms" outside as well as inside!

2 Mould in Dwellings

Mould on the inner surfaces of external parts of buildings, and at other places on and within building components, is a topic that has again been under intensive discussion recently. On one hand, this has to do with the increased awareness of dwelling hygiene and the risks to occupants' health, or rather with the anticipated requirements in this area; on the other hand, requirements on the avoidance of mould formation in the area of external components are being drawn up as part of the process of adopting European standards.

To successfully prevent the formation of mould, one must be familiar with the growth conditions for moulds. Here, moisture plays a leading role. The Fraunhofer Institute for Building Physics (IBP) has carried out exhaustive research, and has even gone so far as to develop a process [2] that allows the formation of mould to be assessed on the basis of the biological conditions for growth under unsteady boundary conditions. What emerges is a clear dependence on temperature, relative humidity, and the type of substrate (base material) for mould formation to begin, and for further growth.

Isoplethic Systems

These growth conditions are described in a so-called "isoplethic system". This consists of families of temperature and humidity-dependent curves, the so-called "isopleths", which serve to forecast the germination times of the spores, and to describe the growth of the mycelia. The lower boundary of possible mould activity is represented by the so-called "LIM" (Lowest Isopleth for Mould) curves. There are significant differences between the various species of mould, with regard to the conditions of growth. For this reason, [2] develops generally applicable isoplethic systems only for those moulds that occur in buildings and that can be detrimental to health.

Quantitative references to growth parameters of temperature and humidity of these roughly 200 species have been evaluated. To take account of the influence of the substrate – that is, the base material or any underlying impurities – on the formation of the mould, isoplethic systems are suggested for different groups of substrate, as deduced from empirical investigation. A definition of the substrate groups to which the more or less "nutritious" materials are assigned, and each of which has its own associated isoplethic systems, is given in [2], as shown in Figure 1.

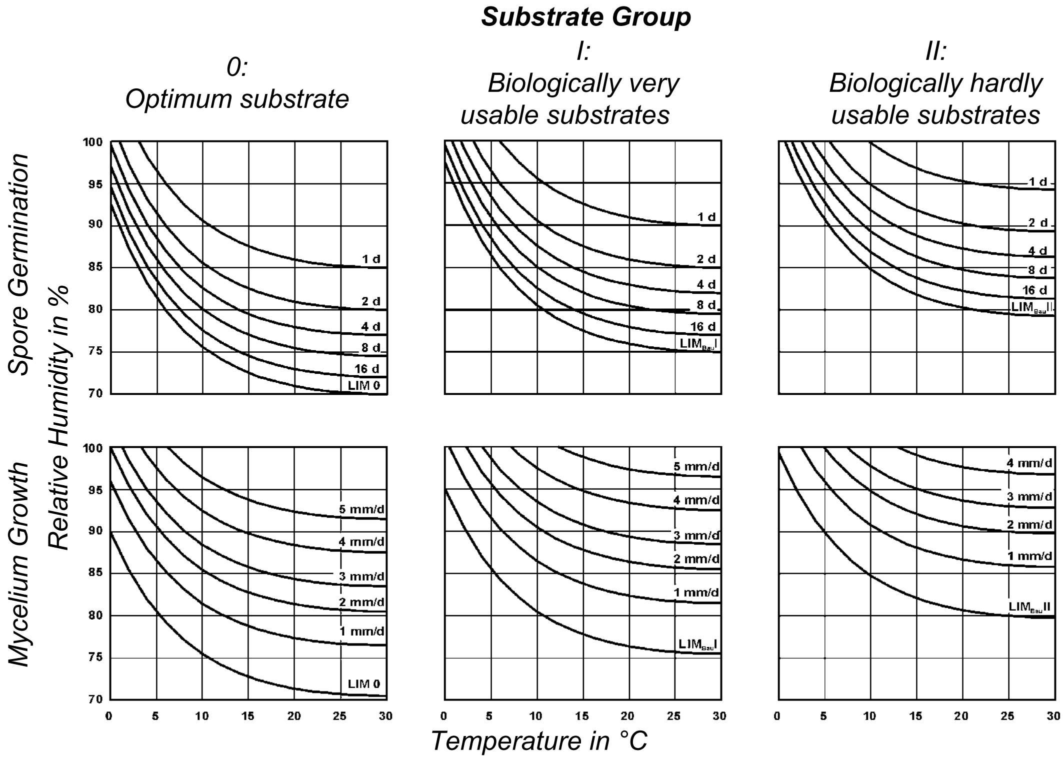


Fig. 1 Generalised isoplethic system for spore germination (top) and mycelium growth (bottom) according to [2], which applies to all moulds that occur in buildings. The diagrams shown in the figure apply to an optimum substrate (left), Substrate Group I (centre) and Substrate Group II (right). The specified curve-family parameters indicate, for the spore germination time (top), the length of time in days after which germination is complete, and for mycelium growth (bottom) the expected growth rate in mm per day.

The function of the isoplethic model is explained below, illustrated by an example.

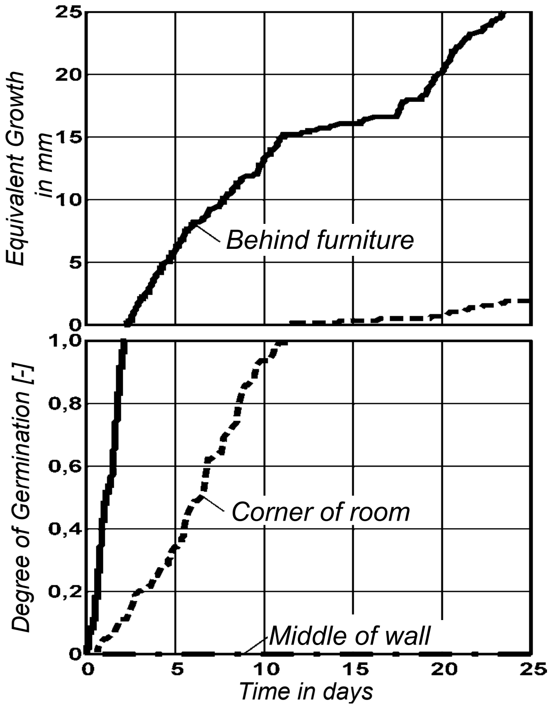
Example: Mould in the Bedroom

Problems with mould are particularly common when pieces of furniture are placed against the outer walls, or when communicating doors are left open, and the enclosed air is exchanged between the various zones of the living-unit. In these cases, mould can form in spite of the minimum insulation parameters being fulfilled. For the calculation of temperatures on the inner surfaces of outer walls behind cupboards or curtains, the future standard [3] is to contain suggestions for suitable thermal transmission resistance:

- Built-in cupboards: R_{si} = 1,0 m²K/W
- Free-standing cupboards: R_{si} = 0,5 m²K/W and
- Curtains: R_{si} = 0,25 m²K/W

These have been taken into account in the calculations below.

In order to use the isoplethic systems to make a forecast about the likelihood of mould forming, one must compare the ascertained unsteady developments of temperature and relative humidity on the surface of the part of the building with the spore germination times and growth rates in the relevant isoplethic systems, on the basis of the isoplethic model. The growth conditions, as characterised by the development of temperature and relative humidity over time, e.g. as hourly values, are entered in the isoplethic system as microclimatic framework values. That is, the individual isopleths (e.g. spore germination time of 4 days) are used to specify to what extent an hourly value that lies on this isopleth, for example, contributes to spore germination, namely 1 / (4 days x 24 hours) = 0.01. These values are added to form an accumulated specification over time, and are protracted as a time curve. If the sum value reaches 1, it can be assumed that spore germination has taken place, and that the mould is beginning to grow (Figure 2). This gives us the evaluation capability; we can specify whether or not spore germination will take place within a specified period of time.



Upper part:

Equivalent mycelium growth in mm.

Lower part:

Degree of germination, i.e. proportional spore germination time. If the degree of germination is 1, it can be assumed that the spores have been able to germinate completely, and are now beginning to grow.

Fig. 2 Isoplethic model and hygrothermal calculations used to determine the germination and growth of the spores over time, following the isoplethic models for three different points (middle of wall, corner, and behind furniture).

In a case described in [4], mould was discovered behind a built-in cupboard on the north-east wall of the bedroom of a building erected in 1955. The surface and air temperatures were measured and evaluated over a longish period during a cold spell. The relative humidity measurements in the bedroom was also registered.

Figure 2 below shows the results the calculated results for spore germination on the inner surface of the wall in the middle of the wall, in the corner of the room and behind a piece of furniture against the outer wall, on the basis of these measurements. In the middle of the wall nothing happens; it is only behind the furniture that the locally prevailing conditions (lower temperature, higher humidity values) result in fast germination of the spores. In the corner of the room, spore germination is not reached for a much longer time.

By analogy, the substrate-specific iIsoplethic systems for mycelium growth can be used to predict how the moulds will spread. If, for example, an hourly value in the isoplethic system is within the range of 6 mm growth per day, this means that the mould grows 0.25 mm in an hour. Here again, a sum total value is formed, which is shown for the example of mould formation in an interior in the upper graphic (Figure 2). In the corner of the room, spore germination is achieved because of briefly prevailing, good growth conditions; there is, however, no significant mycelium growth. Behind the furniture, things are different. Here, a large area of mould is forecast, and this was observed in actual fact.

Comparison with Standards Specifications

The usual building standards include both specifications aimed at avoiding condensation and criteria for assessing microbial activity. DIN 4108 [5] and DIN EN ISO 13788 [6] mention 80 % relative humidity as the lower growth limit for mould, and DIN 68800-2 [7] gives material humidity criteria (e.g. 20 M.-%) for building products made of wood or wood materials. The value of 20 % applies to moulds that destroy wood. If you compare these two values with the critical humidity values (LIM) in [2], it can be seen in Figure 3 that the specifications in the isoplethic systems for Substrate Group II for temperatures above 20 °C agree well with the 80 % criterion for the formation of mould.

The LIM for Substrate Group I is about 4 % relative humidity lower. At lower temperatures down to 10 °C, typical of thermal bridges in older buildings, for example, the conditions in the standards are roughly equivalent to the LIM for Substrate Group I. This is only marginally lower than the situation shown in Figure 3 (80 % relative humidity at 12.6 °C) on the inner surface of an outside wall, above which formation of mould must be reckoned with according to the standard, at 20 °C and 50 % relative humidity in the room. At temperatures below 10 °C the specifications in the standard are more “rigorous”. They would even “predict” the formation of mould on outer surfaces in winter.

Figure 3 also shows the material humidity criterion of 20 M.-% mentioned in DIN 68800-2 [7], which can be expressed by means of a sorption isotherm for wood as relative humidity. By this we can see that, for moulds that destroy wood, higher relative humidity values of around 90 % are obviously necessary (Figure 3).

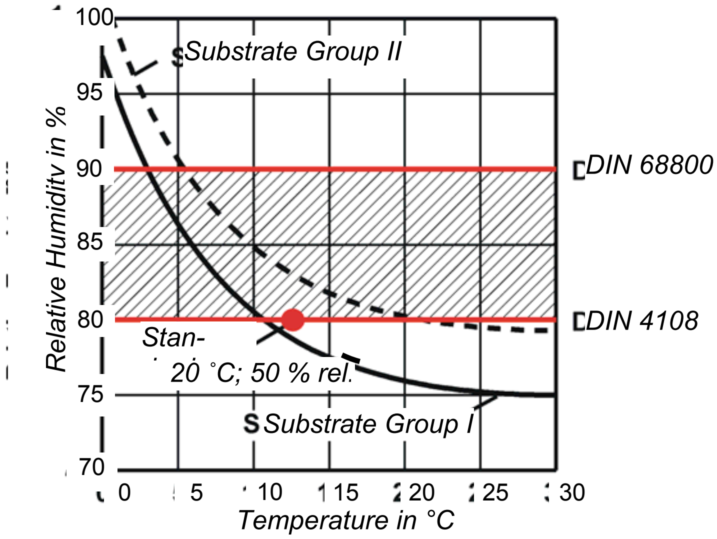


Fig. 3 Comparison of the relative humidity of 80 % mentioned in DIN 4108-2 [5] as the lower growth limit with the LIM of the isoplethic system for spore germination, assuming Substrate Group II according to [2]. The figure also shows the minimum surface temperature according to DIN 4108 at which no formation of mould should take place, taking into consideration indoor air conditions according to the standard (20 °C; 50 % relative humidity), and the material humidity criterion of 20 M.-% mentioned in DIN 68800-2 [7], which can be expressed by means of a sorption isotherm for wood (not shown) as relative humidity.

3 Algae on External Walls

Recently, cases of damage through growth of algae on outside walls has been on the increase, particularly in connection with thermal-insulating compound systems (WDVS) [8, 9]. Algae are encountered significantly less frequently on monolithic walls, so one would be inclined to suspect that the temperature and humidity conditions on the outer surface of well insulated compound-system walls favour the growth of algae. The cooling down of the outer surface through radiation at night is obviously an important factor [8]. A careful analysis of the surface conditions is therefore the prerequisite for the assessment of the probability of algae and moulds developing.

To give an impression of the different surface conditions on outer walls, field investigations carried out at the IBP some years ago were re-evaluated [10] with a view to the hygrothermal conditions on the surfaces of the facades of walls of various structure, in a search for possible solutions in the area of building physics. Temperature and humidity conditions on the outer surfaces of walls that promote growth are the main prerequisite for microbiological infection of the facades. Compared with moulds, algae need even higher humidity, or even the presence of free water, for growth, although temporary drying out does not appear to harm them.

Germination and microbiological growth always take a certain length of time, and excessive moisture on facades over longer periods is very rare, so we will look at periodic wetting more closely here. For this purpose, hourly measurements of temperature and humidity are averaged over a period of at least one month, classified by time of day, so that a typical night-and-day cycle for the period emerges. This is carried out for both the environmental conditions registered at the IBP's own meteorological station and the measured facade surface temperatures.

For more than ten years, besides open-air conditions and radiation data, the surface temperatures of west-facing test surfaces, erected in the grounds of the IBP and insulated on the rear side, have been registered continuously. The temperatures are measured in the centres of a black and a white area, directly under the paint. An evaluation of the average daily cycles of the surface temperature and humidity of the white test area, with the concurrently measured open-air conditions, is shown for the different seasons over a period of three years in Figure 4.

A cooling down of the test areas at night is to be observed in all seasons. The highest long-term surface humidity coupled with moderate temperatures, however, is observable in autumn. Thus the growth conditions for algae are as a rule more favourable in autumn than in the other seasons, so further evaluation of experiments can be confined to the autumn.

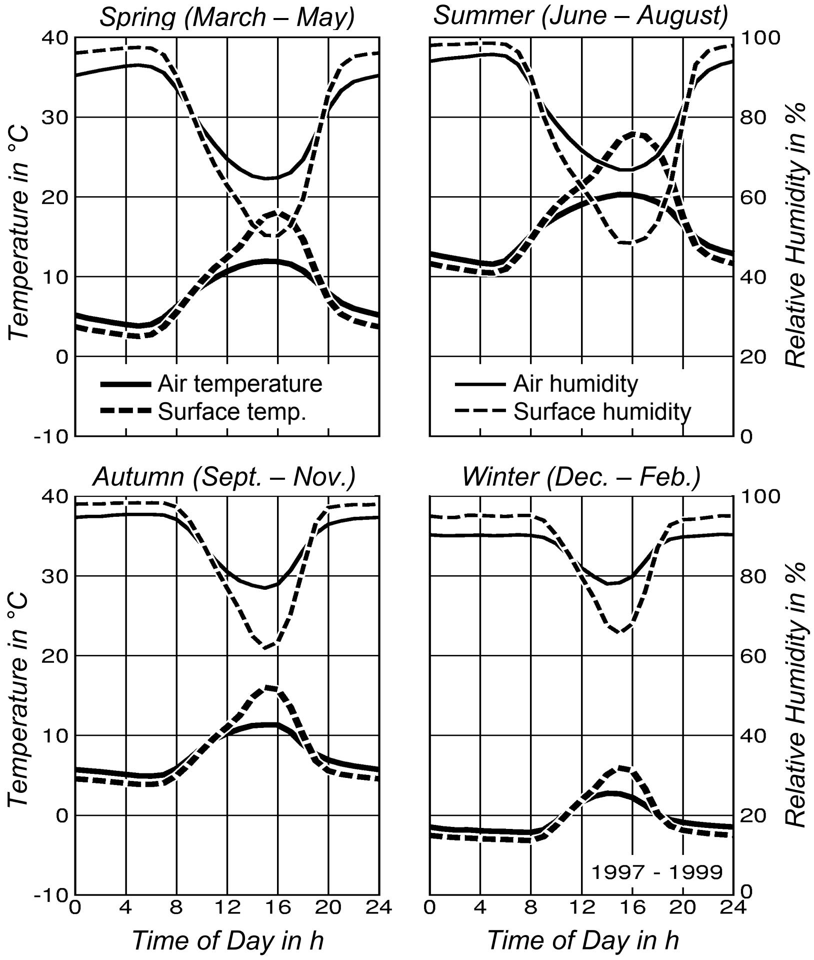


Fig. 4 Average daily cycles of the measured surface temperature and the deduced surface humidity of the white test area (dotted lines) compared with the open-air conditions according to [11]

To what extent the results from the exposed test surfaces can be quantitatively transferred to conditions in buildings can only be ascertained through parallel measurement of the objects. The object of these investigations is a heated test house in the grounds of the IBP in Holzkirchen. The containing surfaces consist of different wall constructions with similar heat transition coefficients (U coefficient). Observations are made on the west wall (U = 0.41 W/(m²K)) with 80 mm thick outer insulation (WDVS) on 240 mm sand-lime brickwork, and on the north and south facing, monolithic sections of wall (U = 0,51 W/(m²K)) made of 365 mm aerated light brick with white and red-coloured plaster.

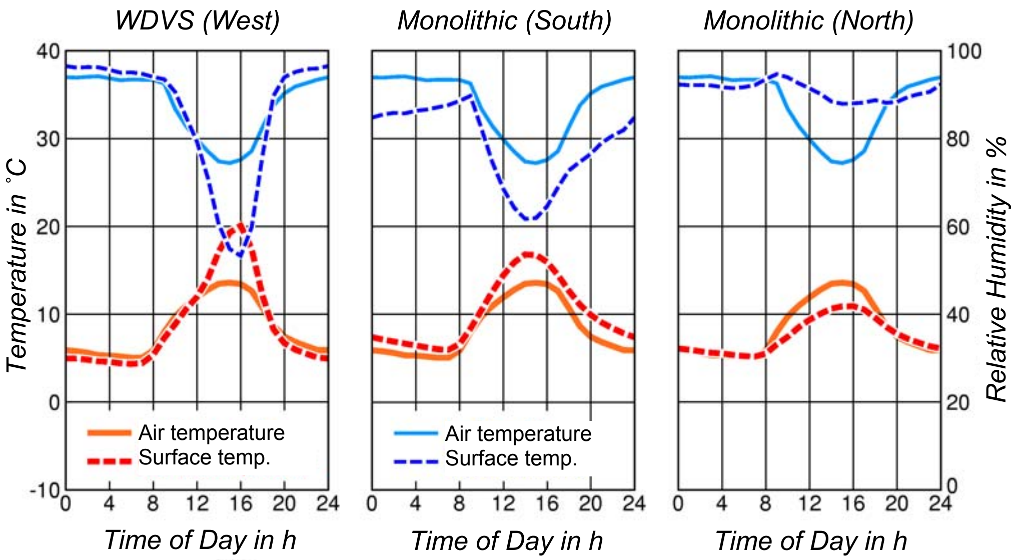


Fig. 5 Average daily cycles of the measured surface temperature and the deduced surface humidity of a west-facing WDVS facade of the test house (left figure), and of the south-facing (centre figure) and north-facing (right figure) monolithic structure compared with the open-air conditions

The average daily cycles of the outer surface temperatures, measured in the centre of the WDVS, and the deduced surface humidity values, are shown for the same time period (16th Sept. to 24th Oct.) compared with two monolithic constructions in Figure 5, which also shows the open-air conditions. Whereas measurements on the west-facing WDVS (left figure) show higher midday temperatures and therefore lower relative humidity compared with the monolithic constructions, the night temperature is somewhat below air temperature, because of the radiation and the low heat-retention capacity of the comparatively thin layer of plaster on a WDVS. The result is increased humidity on the surface.

This means that the warmth from the interior influences the temperature, and thus the humidity, of the outer surface only to an insignificant degree. In the case of WDVS with an insulating layer of sufficient thickness, we can thus speak of thermal uncoupling of the facade from the air conditions in the interior. The conditions on the south-facing monolithic wall, shown in Figure 5, centre, show that the surface humidity always remains below that of the air. Even during the day, only comparatively low relative humidity averaging around 60 % occurs on the surface of the wall. On the north-facing wall (Figure 5, right), the surface humidity does lie below that of the air at night, too, but during the day the greater warmth retention capacity and the lack of irradiation lead to a surface temperature that is below that of the air, associated with higher relative humidity on the facade, which can also be favourable for the formation of algae.

These first results make it evident that a it is not possible to make a blanket evaluation of constructions without taking into account the exact structure and orientation. To clarify this, comprehensive empirical and mathematical investigations are at present being undertaken in the IBP.

4 Conclusion and Outlook

It is well known that the growth of mould in inhabited buildings occurs at particularly endangered places when the hygrothermal conditions are unfavourable. The main parameters are the temperature, the humidity and the substrate, all three of which must be in the favourable range for certain periods of time. For the assessment of mould formation, in dependence on unsteady boundary conditions, the isoplethic systems given in [2] determine the germination time for the spores for different groups of substrates, temperatures and relative humidities on the surface of the building parts, and give information about the possible growth of mycelia.

A realistic evaluation of the danger of mould formation, dependent on room size, production of humidity, exchange of air and type of heating or cooling, can be made with the help of a hygrothermal room model that is at present being developed and validated at the Fraunhofer Institute for Building Physics. This room model is intended to be used inn conjunction with the biohygrothermc model. It is expected to yield results that allow optimisation of various strategies against mould formation, such as correct heating and ventilation for different conditions of utilisation and climate.

The results of the experiments on the formation of algae on external facades do indicate a slight rise in the humidity of the external plaster in connection with heat-insulating compound systems, as compared with monolithic walls, but whether it is valid to deduce from this that WDVS in general is more prone to algae infection than other wall constructions must be seen in further investigations, in particular with regard to the parameters of precipitation and building moisture.

It is equally important to ascertain, and if necessary to deliberately investigate, the biological background of the growth of algae. In this context, a comprehensive joint project is at present in place at the IBP. The approaches that are being investigated include infrared-reflective coatings with varying hydrophobic characteristics for facades, and the use of heat-retaining external plasters. The colouring of the facade and the application of infrared-reflective paints are also being considered.

Bibliography

[1] Sedlbauer, K.; Gabrio, Th.:
Schimmelpilze und Beurteilungsklassen zur Gesundheitsgefährdung.
IBP-Mitteilungen 29 (2002), Nr. 401

[2] Sedlbauer, K.:
Vorhersage von Schimmelpilzbildung auf und in Bauteilen.
Dissertation, University of Stuttgart (2001)

[3] DIN 4108 – Wärmeschutz und Energie-Einsparung in Gebäuden.
Manuscript Part x: Vermeidung von Schimmelpilzen
(Draft: 1999-05)

[4] Reiß, J.; Erhorn, H.:
Beurteilung von Feuchteschäden.
IBP-Report WB 47/1997 of the Fraunhofer Institute for Building Physics, Stuttgart (1997)

[5] DIN 4108-2 : 2001-03
Heat insulation and energy saving in buildings –
Part 2: Minimum requirements on heat insulation

[6] DIN EN ISO 13788 : 2001-11
Calculation of surface temperature to avoid critical surface humidity and calculation of condensation within building parts

[7] DIN 68800 : 1996-05
Wood protection – . Part 2: Preventive building measures in building construction

[8] Blaich, J.:
Außenwände mit Wärmedämm-Verbundsystem, Algen- und Pilzbewuchs.
Deutsches Architektenblatt 31 (1999) Issue 10, Pages 1393 to 1394

[9] Klinkenberg, G. und Venzmer, H.:
Algen auf Fassaden nachträglich wärmegedämmter Plattenbauten – Schadensmaß, Ursachen und Lösungen für ein Anti-Algenkonzept.
FAS-Schriftenreihe (2000) Issue 11, Pages 29 to 40

[10] Künzel, H. M.; Sedlbauer, K.:
Algen auf Wärmedämm-Verbundsystemen.
IBP-Mitteilungen 28 (2001), No. 382.

[11] Künzel H. M.; Krus M.; Sedlbauer K.:
Algen auf Außenwänden – Bauphysik als Ursache? Bauphysik als Lösung!
Conference minutes of 3rd Dahlberg colloquium on micro-organisms and building repair, 13th to 14th Sept. 2001, Wismar, Pages 75 to 84