

Condensation on façades – influence of construction type and orientation

W. Zillig, K. Lenz, Prof. Dr. K. Sedlbauer, Dr. M. Krus

Fraunhofer-Institute for Building Physics (IBP), Holzkirchen, Germany

(Director: Prof. Dr. Dr. h.c. mult Dr. E.h. mult. Karl Gertis)

ABSTRACT: Humidity is the essential condition for biological growth on façades. Beneath wetting by driving rain, condensation occurs in consequence of long wave radiation in clear nights by reaching temperatures below the dew point of the air. The importance of this wetting mechanism is obvious with regard to the occurrence of microorganisms mostly on the northern sides of buildings. In this paper results of field examinations of two construction types (ETICS and high insulating monolithic constructions) will be evaluated concerning to time periods in which the surface temperature falls below dew point temperature. In order to do a comparison between different construction types and thermal transmittances hygrothermal calculations will be done. For this, a new model which includes long wave radiation effects, is used. The influence of the thickness of the insulation (respectively thermal transmittance), and also the orientation of the construction will be shown exemplarily.

1 INTRODUCTION

In recent times more and more complaints about algal growth on façades have been made. This growth occurs mostly in the first years after completion which leads to displeasure from the building owner. Since there are different opinions about the higher sensitivity of walls with ETICS (external thermal insulation composite system) compared to monolithic walls and also the physical causes are not yet clarified for a detailed analysis different wall constructions has been erected at the test field area of the Fraunhofer Institute for Building Physics (IBP) in Holzkirchen, Germany.

2 GROWTH CONDITIONS

Algae are spread over the whole world and they are a major part of the ecosystem. They are reckoned as the biggest oxygen producer worldwide. A lot of research is done in the field of aquatic algae. But aerophytic algae have been recognised in the last years as important part in the microbiological growth on façades. Especially the occurring species that will grow on facades are not clarified yet. The current opinion is that mainly blue and green algae occur on façades. Sporadically some red or gold algae are identified. Therefore is known about the growth conditions and the biotic influences. But some common demands can be specified. For photosyn-

thesis sufficient light, water, temperature, carbon dioxide and some mineral nutrients must be present. Some algae need some trace elements (as Fe, Mn, Si, Zn, Cu, Co, Mo, B, V) for growth, which are normally available in our environment (rain, dust), so that the local micro climate is determining factor for biological growth on facades. As main climate conditions humidity and temperature must be specified.

Humidity is fundamental for algal growth as it is needed for photosynthesis. Because algae don't have any roots, the water uptake must occur directly through the cell wall by osmosis. The growth limit for green algae is at least 70 – 80 % RH (Denffer 1983) and for blue algae 100 % RH (liquid water) (Scherer 1993). Driving rain and super cooling (dew water) are the main reason for wetting of facades with liquid water. Algae can survive dry periods without any harm and can restart their growth when enough humidity is available. Therefore a drying of façades during the day is not sufficient to prevent algal growth.

Venzmer describes the optimal growth conditions on facades for green algae within a temperature range from 0°C to 40°C (Venzmer 2001). Under dry conditions algae can withstand extreme thermal conditions (heat or cold stress) much better than in humid conditions. Therefore the prediction of algal growth on facades is hard to predict. This approach describes a first attempt to solve this problem.

3 EXAMINATIONS

As mentioned above suitable temperature and humidity conditions at the outer surface of walls are necessary for biological growth. Mould fungi need a relative humidity of 80 % for a longer period of time for example (Sedlbauer 2001), whereas algae need higher humidity for their growth or even free water. Whereas an interim drying out does not harm them. Therefore the periods of surface condensation and the accumulated degree of cooling below dew point temperature are taken as criterion to classify the results.

To compare the different construction types the surface temperature und occasionally the surface humidity is measured. These data have been taken to validate the unsteady hygrothermal software WUFI (Künzel 1995). Only the modelling of the transient processes allow the presented variations of all parameter of interest. All calculations are done under consideration of long wave irradiation with climate data for Holzkirchen (calculation period 1st Jan. – 25th Sept.) in order to compare the surface temperatures with the dew point temperature of outdoor air.

The following two construction types are treated more closely. The first one is a wall made of concrete with an ETICS (20 cm concrete, heat conductivity $1,6 \text{ Wm}^{-1}\text{K}^{-1}$; 10 cm polystyrene slabs, heat conductivity $0,04 \text{ Wm}^{-1}\text{K}^{-1}$). The other wall consists of aerated concrete (thickness 24 cm, heat conductivity $0,1 \text{ Wm}^{-1}\text{K}^{-1}$). These construction types have been chosen because their thermal transmittance is comparable (wall with ETICS $U = 0,35 \text{ Wm}^{-2}\text{K}^{-1}$; aerated concrete $U = 0,38 \text{ Wm}^{-2}\text{K}^{-1}$).

Starting from these standard constructions a series of tests with varying parameters were performed to find out their influence on algae growth. Firstly the influence of orientation is worked out for both variants.

As a second parameter different surface properties were examined. Beneath colour (radiation coefficient) of the rendering the long wave emissivity is tested.

For ETICS the thin plaster (standard case) is compared with a thick plaster layer additionally. And at last the insulation layer thickness is varied

too. The complete list of variations is shown in table 1.

4 RESULTS

In our test site in Holzkirchen west-facing façades are affected mostly by algal discolouration. This orientation builds up the standard case in this study. Beneath this the effect of different surface properties is examined.

4.1 Validation

For a clear night the evaluation of the hygrothermal calculation software is shown in figure 1 for a west facing wall with ETICS exemplarily.

At night there is no visible difference between

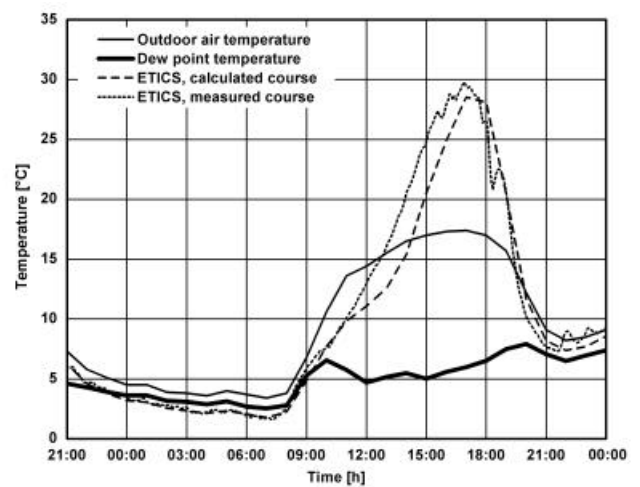


Figure 1. Comparison of measured and calculated courses of surface temperature for a west facing wall made with ETICS for a clear night and the following day in September. The courses of outside air temperature and dew point temperature are shown additionally.

measured surface and calculated temperatures. At midday the calculated course shows a delayed heating up. The reason for this behaviour is that WUFI has to calculate the west radiation from direct and diffuse solar radiation. To do this, the diffuse radiation is assumed to be isotropic. In reality there is a increase of the diffuse radiation in vicinity of the

Table 1. Variation of different surface properties used for calculation of surface temperatures.

Radiation properties		
	Radiation coefficient	IR-emissivity
Bright (standard)	0.4	0.9
Dark	0.6	0.9
Low IR-emissivity	0.4	0.6
Plaster layer thickness at ETICS		
	Dimension	
Thin (standard)	5 mm	
Thick	10 mm	
Insulation layer thickness		
	Dimension	
Thick (standard)	10 cm	
Thin	5 cm	

sun. Around noon the calculated west radiation is lower than actual measured values and therefore the calculated surface temperatures are lower as the measured values. But surface temperatures near (or lower) than dew point temperature can only be observed at night time or in the early morning hours. This justifies to calculate the surface temperatures for different variants to determine the periods of condensation and the degree of cooling below dew point temperature.

4.2 Orientation

Spring and autumn are the most critical times in year as in winter it's mostly too cold and in summer mostly too hot and dry. Figure 2 shows courses of surface temperature for wall made of aerated concrete in dependence on the orientation for a day mid September and figure 3 shows the same courses for the night time. During the day the surface tempera-

tures depends on the irradiation and therefore of the solar position. The north facing wall gets no direct radiation by the sun but only diffuse radiation. That is the reason why the north-facing wall stays below air temperature during this whole day.

The temperature on the west oriented wall never falls below dew point temperature because it gets most sun radiation in the afternoon as mentioned above. The south-facing wall reaches dew point temperature at about 3:00 in the morning. At 8:00 the surface temperature falls shortly under dew point temperature. At midnight the temperature on the east and the north oriented walls undershoot the dew point temperature. Whereas the east facing wall warms up with the first sun light at 6:00 the northern wall remains below dew point till 9:00.

The comparative courses for the wall with ETICS are shown in figure 4 respectively figure 5. The major difference to the wall made of aerated con-

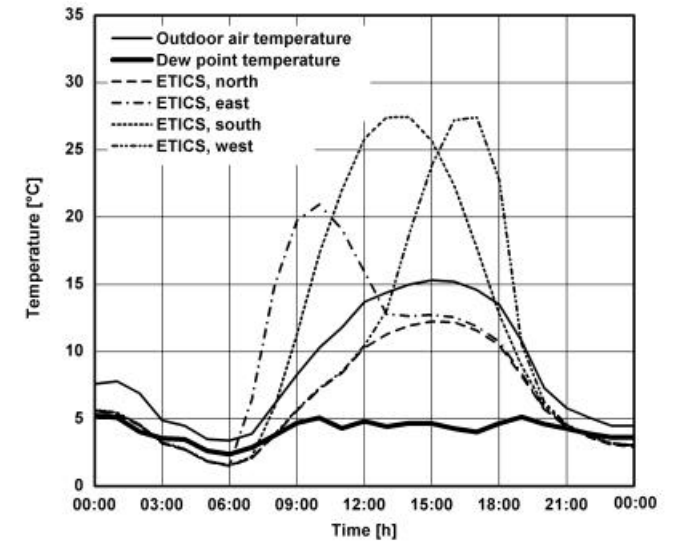
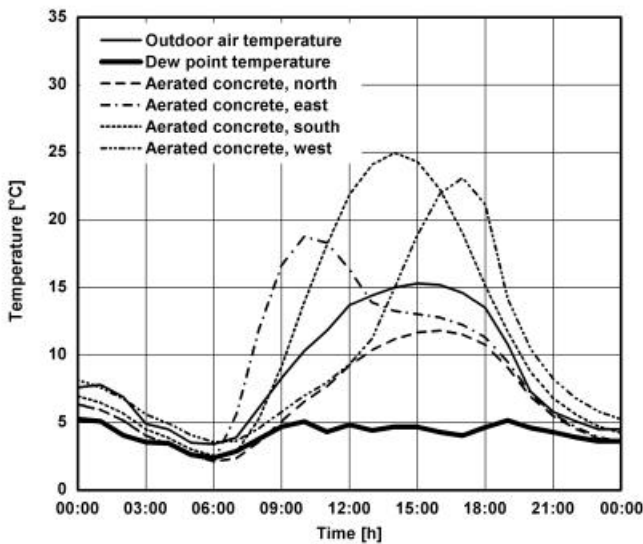


Figure 4. Courses of calculated surface temperatures in dependence on the orientation at a sunny summer day (13th Sept.) for a wall with ETICS. The courses of outside air temperature and dew point temperature are shown additionally.

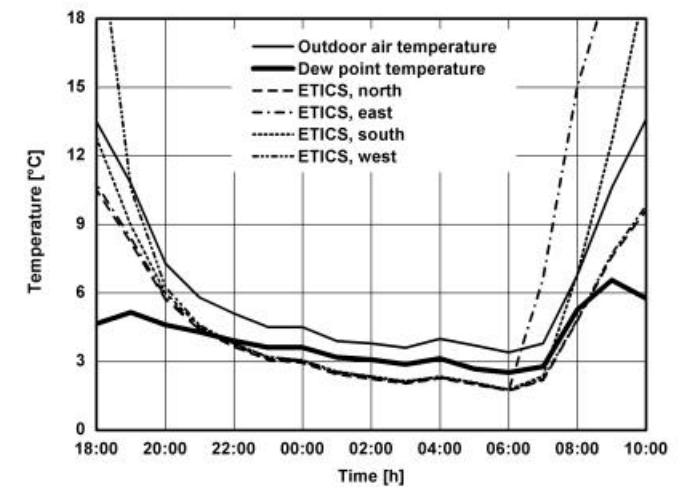
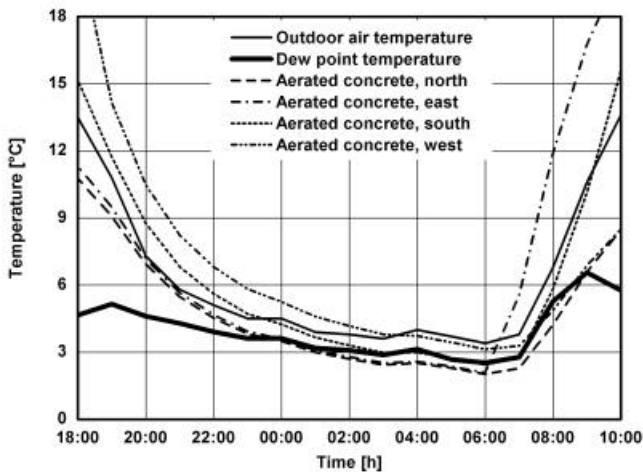


Figure 3. Courses of calculated surface temperatures in dependence on the orientation in a clear night (13th/14th Sept.) for walls made of aerated concrete. The courses of outside air temperature and dew point temperature are shown additionally.

Figure 5. Courses on the calculated surface temperatures in dependence of orientation in a clear night (13th/14th Sept.) for walls with ETICS. The courses of outside air temperature and dew point temperature are shown additionally.

crete is that the thin plaster layer has a much lesser heat capacity. Therefore the maximum temperatures are lying higher during the day. At night the stored heat energy is emitted fast with the result of undershooting the dew point temperature for 8 to 9 hours. At morning the heat up effects are the same as for the wall made of aerated concrete.

Figure 6 resp. 7 shows the accumulated degree of cooling below dew point, which means for each hour at which the surface temperature is below dew point temperature the difference of surface and dew point temperature is summarized. As shown in figure 6 resp. figure 7) there are obvious differences relating the course of the calculated results. For ETICS the accumulated degree of cooling below dew point temperature is about twice that of a façade with aerated concrete. Some statistics about dew point undershooting are shown in table 2. Surprisingly the

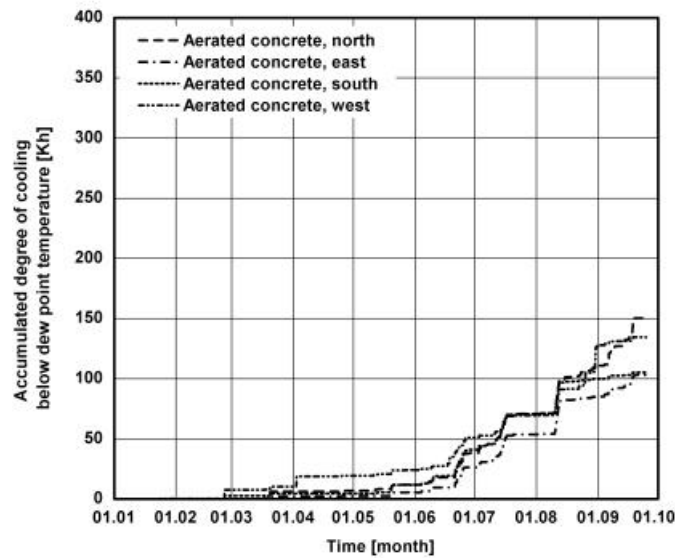


Figure 6. Accumulated degree of cooling below dew point temperature for walls made of aerated concrete in dependence on the orientation for evaluation period (1st Jan. – 25th Sept.). west-facing wall made of aerated concrete has the shortest period of condensation. Referring to the accumulated degree of cooling below dew point the western façade is only beaten by the northern one. At the wall with ETICS it looks a bit different. The west-facing wall has the longest duration of dew

Table 2. Calculated periods of surface condensation in dependence on the orientation for walls made of aerated concrete and walls with ETICS for evaluation period (1st Jan. – 25th Sept.).

Direction	NORTH	EAST	SOUTH	WEST
Aerated concrete				
Periods of condensation [h]:	369	302	298	282
Accumulated degree of cooling below dew point temperature [Kh]:	150	103	105	134
Medium daily period of condensation [h/d]:	1.5	1.1	1.1	1.1
Average degree of cooling below dew point temperature [K]:	0.4	0.3	0.4	0.5
Wall with ETICS 10 cm				
Periods of condensation [h]:	613	544	623	647
Amount of dew point undershooting [Kh]:	265	230	257	271
Daily dew point undershooting [h/d]:	2.3	2.0	2.3	2.4
Average degree of cooling below dew point temperature [K]:	0.4	0.4	0.4	0.4

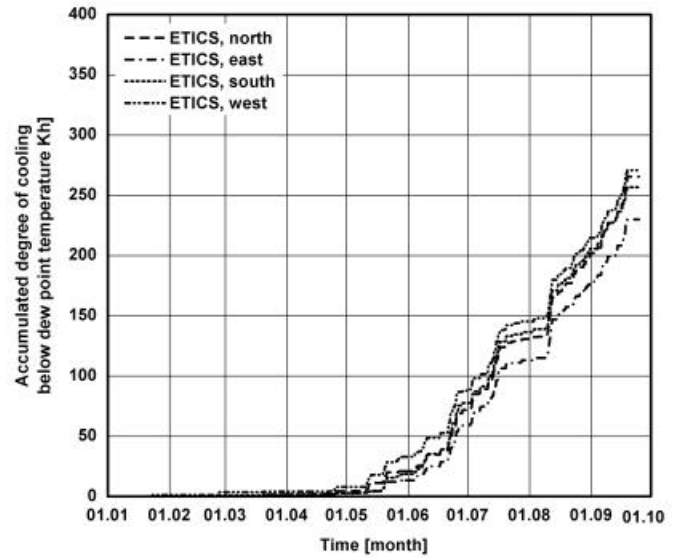


Figure 7. Accumulated degree of cooling below dew point temperature for walls with ETICS in dependence on the orientation for evaluation period (1st Jan. – 25th Sept.).

point undershooting and the highest amount of condensation. The eastern wall shows the lowest risk of algal growth.

For all orientations the amount of condensation is obviously higher compared to the monolithic wall of aerated concrete.

4.3 Radiation

As expected for both construction types the surface temperatures are reaching the maximum temperature during the day with a dark coloured plaster as shown in figure 8 resp. 9. The two variants with a bright plaster (standard case and low IR-emissivity) both keep cooler than the dark one, but the second one is getting warmer than the standard case. Even during the day every surface has a energy loss due to long wave emission. Because of its lower emissivity the maximum surface temperature is higher compared to the standard case.

At night the thermal irradiation leads to lower temperatures of the wall with ETICS in comparison to the wall made of aerated concrete (figures 10 and 11). The surface temperatures are even sinking be-

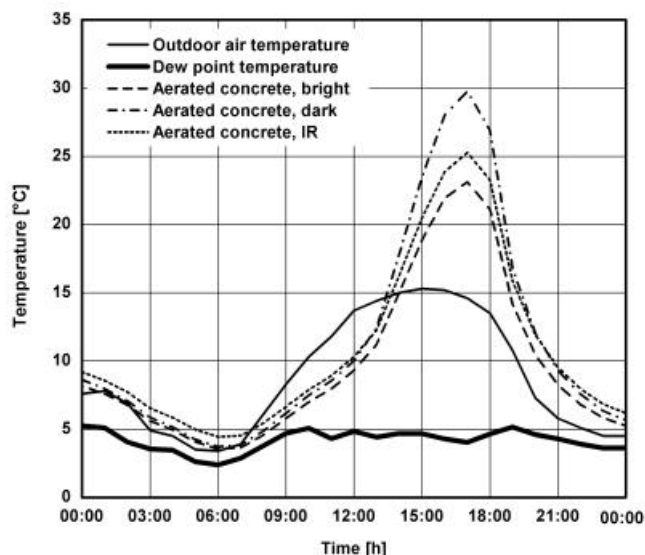


Figure 8. Courses of surface temperatures for west facing walls made of aerated concrete with different surface properties. Data for a sunny summer day (13th Sept.). The curves for outdoor air temperature and dew point temperature are shown additionally.

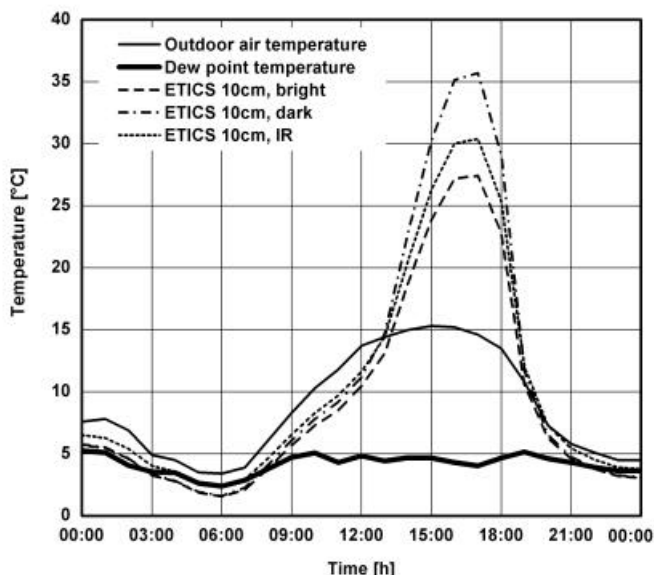


Figure 9. Courses of surface temperatures for west facing walls with ETICS and different surface properties. Data for a sunny summer day (13th Sept.). The curves for outdoor air temperature and dew point temperature are shown additionally.

low dew point temperature (ETICS with bright or dark plaster, ETICS with low IR-emissivity remains on dew point temperature) as shown in figure 11. Whereas the surface temperatures of the wall made of aerated concrete mostly remains above dew point temperature (figure 9).

As can be seen in figure 12 and 13 at both construction types the bright plaster shows the highest amount of condensation followed by the dark plaster. The wall with low IR-emissivity has the lowest amount. In case of aerated concrete the influence of colour (figure 12) is considerably bigger than for the wall with ETICS. The reason for this result is the higher heat capacity. As shown in figure 13 the comparatively good performance for ETICS with in-

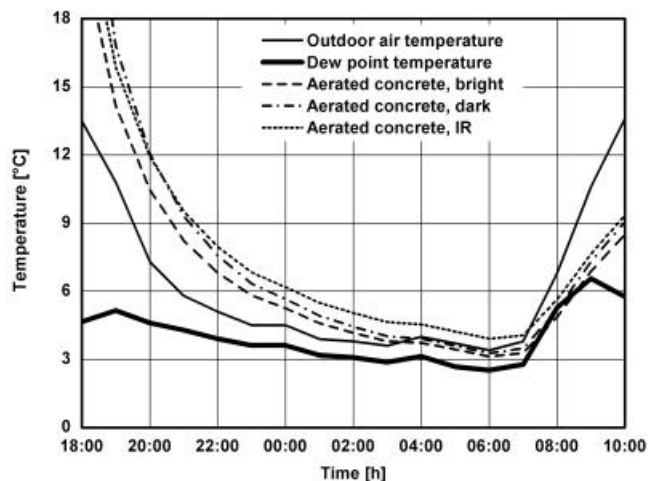


Figure 10. Courses of surface temperatures for west facing walls made of aerated concrete with different surface properties. Data for a clear night (13th/14th Sept.). The curves for outdoor air temperature and dew point temperature are shown additionally.

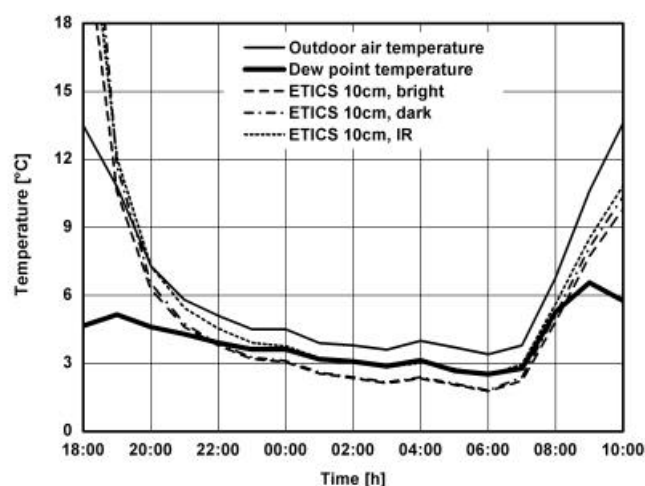


Figure 11. Courses of surface temperatures for west facing walls with ETICS and different surface properties. Data for a clear night (13th/14th Sept.). The curves for outdoor air temperature and dew point temperature are shown additionally.

frared active colour shows one possibility to reduce the risk of algal growth on ETICS.

In table 3 some statistics of the effect of the above mentioned surface properties are gathered.

4.4 Plaster thickness and insulation layer thickness of ETICS

For façades with ETICS the thickness of the outer plaster layer should have an influence on the course of surface temperature because of the correspondent heat capacity. But as it can be seen in figure 14 the difference of the standard plaster layer (5mm) and the thick plaster (10mm) is negligible. This is the same with a dark coloured surface (see table 3) Only with a low IR-emission painting greater differences can be observed; the thin plaster layer seems to be more advantageous.

As mentioned in (Bagda 2002) the risk of algal growth on façades depends on the thickness of the

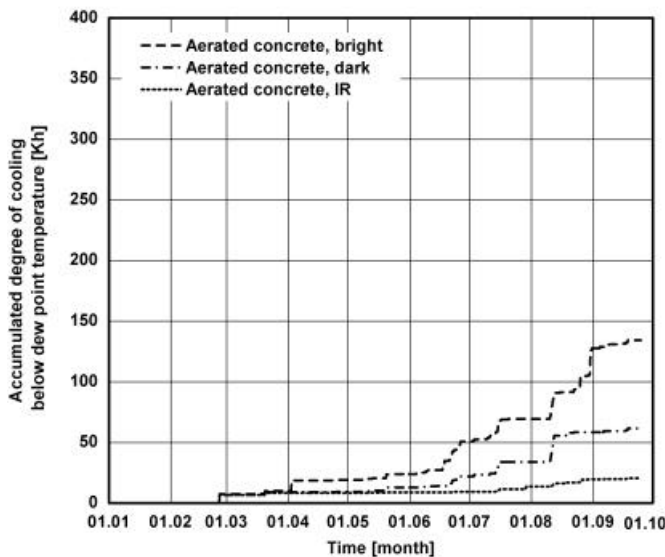


Figure 12. Accumulated degree of cooling below of dew point temperature for walls made of aerated concrete in dependence on different surface properties for evaluation period (1st Jan. – 25th Sept.).

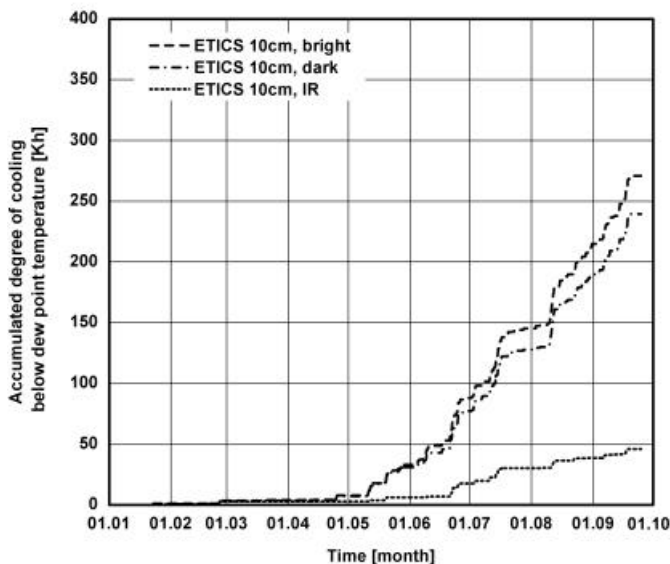


Figure 13. Accumulated degree of cooling below of dew point temperature for walls with ETICS in dependence on different surface properties for evaluation period (1st Jan. – 25th Sept.).

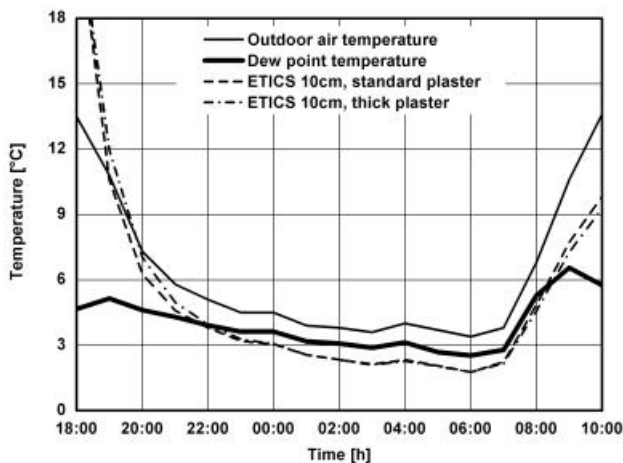


Figure 14. Courses of surface temperatures for west facing walls with ETICS and different thickness of outer plaster (standard plaster 5mm; thick plaster 10mm). Data for a clear night (13th/14th Sept.). The curves for outdoor air temperature and dew point temperature are shown additionally.

insulation slabs too. Therefore another calculation has been done to fathom this influence. The standard case, an ETICS with 10cm polystyrene slabs, is compared an ETICS with 5cm polystyrene slabs.

The higher thermal transmittance (ETICS 5cm) leads to an higher heat flow rate and therefore to higher surface temperatures in the night time of about 0.4 K. This can be seen in figure 15. But these higher surface temperatures are not sufficient to avoid surface condensation at all. As it can be seen in table 3 the “improvement” of reduced algal growth risk is not satisfying to decline these energy conservation measurements.

5 OUTLOOK/CONCLUSION

A lot of courses and data has been discussed above but no cure at all has been found. As it can be realised in real life the calculations made have shown the east and south-facing walls have the least risk of algal growth, north and west-facing walls the highest one.

In direct comparison of the wall made of aerated concrete with the wall with ETICS the advantages of monolithic walls is remarkable. Future research at the test side area in Holzkirchen will show if this behaviour is reproducible.

On the wall with ETICS the influence of plaster thickness has been examined exemplarily. The result as shown in table 3 was a bit surprising, because the “thick” plaster performed even worse than the standard case.

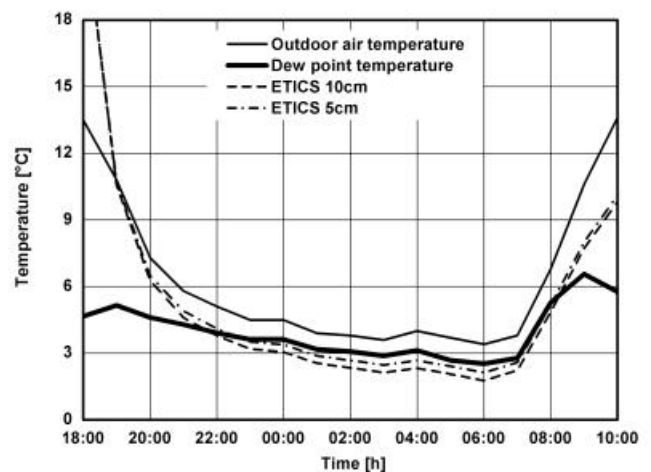


Figure 15. Courses of surface temperatures for west facing walls with ETICS and different thickness of polystyrene slabs. Data for a clear night (13th/14th Sept.). The curves for outdoor air temperature and dew point temperature are shown additionally.

Table 3. Periods of surface condensation of a west-facing wall in dependence on the construction parameters and different surface properties for evaluation period (1st Jan. – 25th Sept).

Surface property	standard	dark plaster	with IR
Aerated concrete			
Periods of condensation [h]:	282	176	84
Accumulated degree of cooling below dew point temperature [Kh]:	134	62	21
Medium daily period of condensation [h/d]:	1.1	0.7	0.3
Average degree of cooling below dew point temperature [K]:	0.5	0.4	0.3
Wall with ETICS 10 cm, standard plaster			
Periods of condensation [h]:	647	579	253
Accumulated degree of cooling below dew point temperature [Kh]:	271	239	46
Medium daily period of condensation [h/d]:	2.4	2.2	1.0
Average degree of cooling below dew point temperature [K]:	0.4	0.4	0.2
Wall with ETICS 5 cm, standard plaster			
Periods of condensation [h]:	519	468	124
Accumulated degree of cooling below dew point temperature [Kh]:	180	151	18
Medium daily period of condensation [h/d]:	1.9	1.8	0.5
Average degree of cooling below dew point temperature [K]:	0.3	0.3	0.1
Wall with ETICS 10 cm, thick plaster			
Periods of condensation [h]:	661	585	279
Accumulated degree of cooling below dew point temperature [Kh]:	283	239	56
Medium daily period of condensation [h/d]:	2.5	2.2	1.0
Average degree of cooling below dew point temperature [K]:	0.4	0.4	0.2
Wall with ETICS 5 cm, thick plaster			
Periods of condensation [h]:	518	466	155
Accumulated degree of cooling below dew point temperature [Kh]:	181	153	20
Medium daily period of condensation [h/d]:	1.9	1.8	0.6
Average degree of cooling below dew point temperature [K]:	0.3	0.3	0.1

As surface temperatures are coupled with thermal transmittance of the construction the thickness of the insulation slabs has been varied. But the results show that even with 5cm polystyrene slabs surface condensation occurs. The risk of algal growth is reduced but at expense on higher energy loss.

Only surface condensation has been investigated above but the influence of driving rain as humidity source has to be considered too. Condensation occurs mainly in clear nights when irradiation has its maximum. And in these cloudless nights rain is implausible. Especially in area of Holzkirchen, west facing walls are getting additional humidity by driving rain. But the main direction of driving rain is regionally different and this effect has to be considered therefore.

To asses the influence of driving rain on the risk of algal growth the effects of hydrophilic or hydrophobic surfaces has to be analysed. Until now the performance of highly hydrophobic surfaces which lead to droplets on the surface can not be calculated correct in respect to water supply for algal growth and therefore this effect has to be examined in field test.

But there are more unsolved questions about required environmental conditions needed for algal growth. Beneath the dependence on chemical composition of outer plaster or painting the humidity and thermal conditions which support algal growth are

not been examined yet. Further research is still needed to get more information about the algal life on façades.

REFERENCES

- Bagda, E. 2002. *Algen und Pilze (Algae and Fungi)*. Ausbau und Fassade, 4/2002: 42-43.
- Denffer v., D., et al. 1983. *Lehrbuch der Botanik für Hochschulen*. Begründet von E. Strasburger, F. Noll, H. Schenk, A.F.W. Schimper. 32. Auflage / neubearbeitet von Dietrich von Denffer, Hubert Ziegler, Friedrich Ehrendorfer, Andreas Bresinsky. Fischer. Stuttgart; New York.
- Künzel, H. M. 1995. *Simultaneous Heat and Moisture Transport in Building Components. – One- and two-dimensional calculation using simple parameters*. IRB Verlag: 1-154, ISBN 3-8167-4103-7.
- Scherer, S. 1993. *Anpassungen von Cyanobakterien in Wüsten*. In: Hausmann, K. & Kremer, B. P.: *Extremophile: Mikroorganismen in ausgefallenen Lebensräumen*. VCH. Weinheim; New York; Basel; Cambridge; Tokyo, S. 179-193.
- Sedlbauer, K. 2001. *Vorhersage von Schimmelpilzbildung auf und in Bauteilen (Prediction of Mould Growth on Top of and Inside Building Parts)*. Thesis, University of Stuttgart.
- Venzmer, H. 2001. *Grüne Fassaden nach der Instandsetzung durch WDVS? Nicht bestellt und dennoch frei Haus*. 3. Dahlberg-Kolloquium

