Factors Determining Surface Moisture on External Walls

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ABSTRACT

In recent years water on external walls has become a major subject of research because it promotes soiling and microbial growth. The increase in surface moisture of façades can be largely attributed to better thermal insulation and lower thermal capacitance of external walls, leading to frequent condensation of outdoor air caused by long-wave sky radiation. In this paper, the principal moisture loads on external walls, wind-driven rain and exterior condensation, are investigated and the hygrothermal response of differently painted façades to these loads are evaluated. It turns out that the most effective driving-rain protection may show the poorest performance when exterior condensation occurs. Therefore, both characteristics have to be considered jointly. Relying on known results, the best way of dealing with both loads seems to be a moderately water-permeable surface coating.

INTRODUCTION

The hygrothermal conditions at façades of well-insulated buildings are almost independent of the indoor temperature, since the heat flow from the interior of the building is very low. Therefore, the average exterior surface temperature of modern buildings has decreased with rising energy efficiency. However, a colder façade usually results in a higher surface humidity due to lower evaporation and, possibly, exterior condensation. Soiling and microbial growth may be the consequence. To solve the problem, different measures to reduce the duration of surface moisture on stucco façades have been investigated in the past, such as infrared reflecting paints or phase change materials to enhance thermal inertia. However, none of that is commercially available yet. Therefore, this paper will explore the performance of existing coatings with respect to the most common moisture loads, rain and exterior condensation, by a combination of field and laboratory tests.

MOISTURE LOADS

The main moisture loads on façade systems are wind-driven rain and condensation of vapor from the outdoor air. Loads from the interior—due, for example, to construction moisture or a lack of air tightness—are not considered here.

Driving Rain

The driving-rain load on buildings has been studied extensively by many authors, most recently by Blocken (2004). A classification of driving-rain exposure of external walls can be found in *British Standard 8104, Assessing Exposure of Walls to Wind-Driven Rain* (BSI 1992). Whether an exposed façade is also prone to microbial growth depends on the duration as well as the intensity of the driving-rain spells and on the drying conditions between these spells. Figure 1 shows a typical microbial growth pattern on a wall caused by wind-driven rain. The vertical stripes result from run-off water carrying dirt or spores from the top of the wall, which usually sees the highest load, down to the bottom. Microbial growth caused by driving rain is a real challenge. One solution is to add biocides (chemicals that kill algae and fungi). To be effective, they have to be ingested by the living organism. This is only possible when the substance is slightly soluble, which means that the biocides will be washed out by rainwater

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Figure 1 *Growth pattern of algae on a west-facing wall caused by driving-rain exposure ("tiger pattern").*

running down the façade. Therefore, adding biocides will only temporarily solve the problem.

While a roof overhang can reduce the driving-rain load of the façade, a slight tilt of the wall may increase it. This is a rather severe problem for heritage buildings with skew envelope parts or modern architecture with deliberately inclined façades. Figure 2 illustrates the high moisture load by the intense growth of moss on EIFS samples exposed at an angle of approximately 30° against the vertical axis. While it is obvious that such a slope greatly raises the precipitation-catch ratio of the surface, in real life an increase in moisture problems can already be observed at very small inclinations. Therefore, the following tests have been carried out at the building field-test site in Holzkirchen to investigate this phenomenon.

Supplementing the continuous recording of wind-driven rain hitting the middle of a four-meter high west wall, an additional driving-rain gauge has been installed into the wall at the same height as the standard driving-rain gauge. The additional rain gauge was, however, slightly tilted (5°) with the lower end of the catch opening protruding approximately some centimeters out of the vertical plane of the façade boundary. The recorded catch ratios of both driving-rain gauges are presented for a period of two months in autumn at the bottom of Figure 3. The normal rain load (recorded with a horizontal rain gauge at the meteorological station nearby) and the average wind speed (west direction only) are indicated above. Compared to the vertical driving-rain gauge, the 5° tilt increases the catch ratio by approximately a factor of four. Even during moderate winds (5 m/s), it may almost reach the amount of normal rain. This is much more than theoretically expected (e.g., resulting from vector calculation), but it could explain the moisture problems occurring at inclined façades in practice.

There is one possible explanation for this phenomenon. The tilted driving-rain gauge collects not only the wind-driven rain hitting the façade plus a small portion of normal rain. It also collects rainwater that splashes back from the façade areas above the gauge. According to Künzel (1995), approximately 70% of the driving rain hitting the façade stays there; the rest splashes off the surface and falls to the ground. Since the horizontal component of the wind speed approaches zero close to the façade surface, it is unlikely that the splash-back water is driven back to the façade, because it will never regain the momentum of the original rain drops. Therefore, these splash-water drops will fall to the ground forming a sort of water-droplet curtain. Any protruding façade component reaching into this droplet curtain—such as the tilted driving rain gauge—will thus catch a considerable amount of splash water. If the wall area above the protruding façade component is large enough, the effective driving-rain load (including splash water) may exceed the normal rain load. For this reason, protruding or inclined façade components need a special rain protection similar to those used for roofing.

Exterior Condensation

Exterior condensation on a wall surface occurs when its surface temperature drops below the dew point of the ambient air. As already described in previous papers (Künzel and Sedlbauer 2001; Holm et al. 2004), the main reason for this temperature drop is the long-wave radiation exchange of the façade with the atmosphere, which results in a net heat flux to the sky (i.e., heat energy sink) when the sun is down or low. If the wall is a massive structure with a high thermal inertia (capacity to retard temperature changes due to a high mass), the night-time radiation sink is usually not strong enough to bring the surface temperature below the dew point for a significant period of time. However, modern exterior insulation finish systems (EIFS) don't have much thermal inertia and are subject to considerable amounts of exterior condensation (Nady et al. 1997; Künzel and Sedlbauer 2001). The photograph of a building with an EIFS in Figure 4 shows the typical spotted pattern caused by microbial growth due to exterior condensation. The bright spots indicate the position of the fasteners holding the system in place. They act as point-like thermal bridges keeping the surface temperature in a small circle above the dew point. Thus, microbial growth may help to detect all kinds of thermal bridges in wall structures.

It is no surprise that home owners and tenants living in buildings with EIFS demand a quick fix when their façades are affected by this kind of microbial growth. A new paint coat with biocides might help for a while, especially when the wind-driven rain load is low (no washing out problem). However, since environmental regulations have become more restrictive towards the use of biocides, new solutions must be found.

As demonstrated already in Künzel and Sedlbauer (2001), the application of low infrared emissivity (low-ε) coatings looks promising. Another solution could be the admixture of phase-change materials (PCM) into the lamina (EIFS surface layer composed of a reinforced stucco base coat and a finish coat) or into the external layer of the insulation slabs. The heat

Figure 2 *Moss growing on EIFS samples exposed to the main driving-rain, orientation at an angle of approximately 30° against the vertical.*

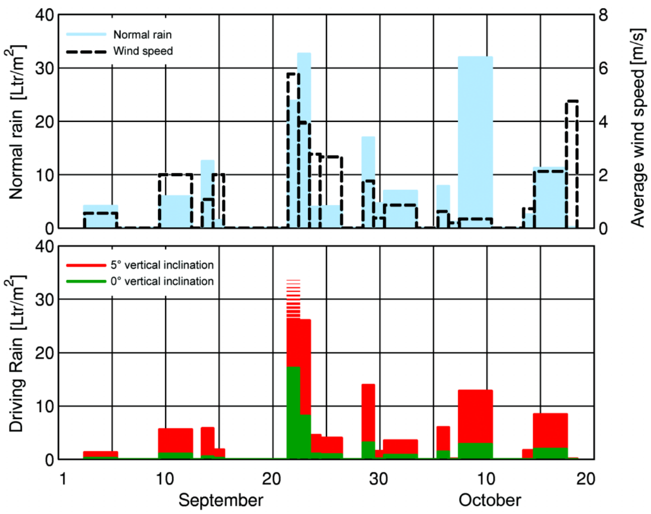

Figure 3 *Normal rain load and west wind speed recorded at a weather station nearby (top) and driving-rain load measured by driving rain gauges, with and without a 5° tilt, placed in the middle of a west-facing wall. Loads are displayed as daily res. three-day (weekend) sums.*

of fusion will slow down the cooling process, thus keeping the surface temperature above the dew point when released at the right moment. Extensive field test investigations complemented by hygrothermal simulations reported in Fitz et al. (2006) have shown that both approaches have the potential to improve the situation. However, before these scientific solutions can be turned into marketable products, there are still many problems to be solved.

One issue is the long-term performance and appearance of low-ε coatings. Another problem is the durability and workability of PCM stucco. PCM is added in the form of microencapsulated hydrocarbons. Because of their hydrophobicity, the capsules diminish the coherence of the stucco during applica-

Figure 4 *Typical pattern (in Europe often called "leopard pattern") caused by the formation of fungi or algae on EIFS as a result of exterior condensation.*

tion. An important aspect is also the temperature range where the phase change takes place. In order to be effective, the temperature range must be set just above the dew point of the ambient air. Since the outdoor-air dew point depends on the climate and the season, a lot of optimization work is required.

For the time being, practitioners have to resort to existing solutions in order to prevent or at least retard the problem of microbial growth on EIFS façades. Without having low-ε or PCM systems at hand, the exterior condensation load on a wall cannot be altered. It is possible, however, to change the response of the exposed façade to the loads by modifying the characteristics of the surface layer. The following section deals with the feasibility of managing driving rain and exterior condensation loads through the application of different coatings painted onto the lamina of exterior insulation systems.

MOISTURE RESPONSE OF WALL SURFACE

While the time of wetness (TOW)—water droplets on the surface—due to exterior condensation may exceed the TOW caused by wind-driven rain, the driving-rain load intensity is usually much higher than the maximum amount of condensation that forms during a clear night. In order to avoid moisture problems (e.g., frost damage or reduction of insulation performance after rainwater absorption), modern façade coatings are water repellent. In Germany, the water absorption coefficient (A-value) and the vapor diffusion resistance (characterizing the drying potential) of rain-protective coatings should not exceed certain limits laid down in building standards (Künzel et al. 2004). In general, coatings based on polymeric binders have a lower A-value but a higher diffusion resistance than those with mineral binders.

Water clinging to the surface of a wall is easily available to spores of algae and fungi. While it may not be necessary to attain a surface humidity of 100% relative humidity (RH) (water droplets) in order to start microbial growth, it certainly speeds up the sporulation and growth process. Therefore, the surface wetness (amount of surface water) is a critical quantity for the probability assessment of microbial growth. Over the past ten years, several techniques have been investigated to determine the surface water content, such as infrared reflectance and electrical resistance of the surface. However, our own experience shows that the most reliable method to quantify the surface wetness is also the simplest. A blotting paper with well-defined size and properties is weighed before and after close contact with the exterior wall surface (Figure 5).

The following experiments were carried out on external wall sections (120 × 280 cm) consisting of autoclaved aerated concrete blocks with an EIFS (thermal transmittance $U = 0.3$ W/[m·K]) at the field test site in Holzkirchen (Fitz et al. 2006). The wall sections are part of an air-conditioned test hall that is exposed to the west—the orientation where the majority of the wind-driven rain comes from. Three of the wall sections had different paint coats applied to the stucco: a silicone-based coat (water absorption coefficient $A = 0.0004$ kg/[m·s]), a mineral coat with silicate dispersion ($A = 0.0008$ kg/[m·s]), and an water repellent coat, which, according to the manufacturer, develops a nanostructured self-cleaning surface layer ($A = 0.0001$ kg/[m·s]). The nanostructure is supposed to consist of tiny spikes so close to each other that a droplet of water or a piece of dirt will be prevented from reaching the surface by staying on the tips of the spikes where there is little adhesion. This principle is also called the lotus effect, because it was first discovered by investigating the leaves of lotus plants (Barthlott and Neinhuis 1997).

In order to determine the response of the exposed wall sections to the natural moisture loads, blotting-paper tests were conducted when the presence of surface water was expected (Figure 5). The first readings of surface wetness in Figure 6 were taken during the morning hours of a rainy day (light wind-driven rain). The amount of water extracted from the three coatings differs significantly. While the mineral silicate paint and the nanostructured paint stay almost dry, the surface wetness of the silicone paint is rather high in the beginning, slowly drying as the rain stops. The silicate paint, having the highest water absorption coefficient of the three coats investigated, lets some rainwater penetrate into the stucco, which could explain why there isn't much water on its surface. However, this cannot be the explanation for the lack of surface moisture on the nanostructured paint. Since it has the lowest A-value, the amount of surface water should be the highest.

For a better understanding of this phenomenon, the droplet run-off angle of the coatings had to be determined. This has been done in the laboratory with the coatings applied to a sloped plane (Figure 7). In the beginning, the run-off angle was about the same for all three paints (40°–46°). But after 24 months of exposure to natural weather, only the nanostructured paint retained its original run-off angle while the draining capacity of the other two paints deteriorated to a point where the droplets didn't even run off at the vertical position (run-off angle > 90°). This explains the performance of the

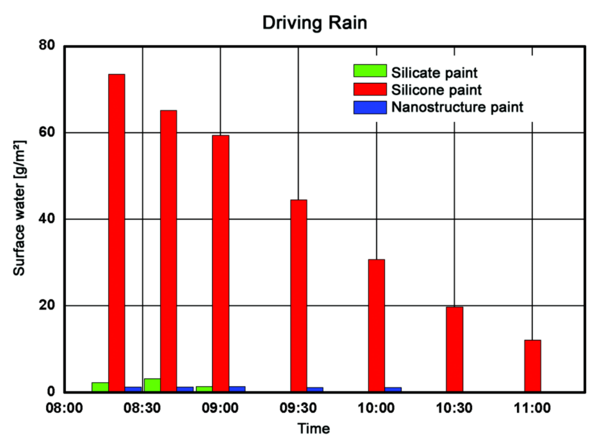

Figure 6 *Surface water extracted from a test façade with EIFS during and after a rain period in the morning hours.*

Figure 5 *Determination of the amount of surface water on a test façade with EIFS by using a special blotting paper whose mass change is being determined.*

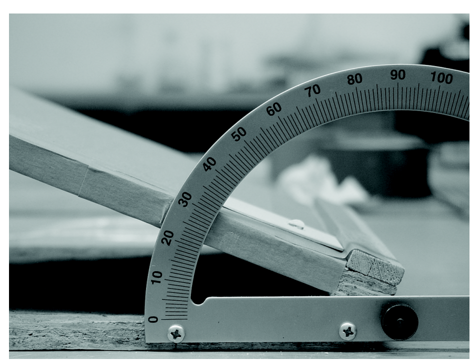

Figure 7 *Sloped plane device to determine the run-off angle of standard-size water droplets on paint.*

nanostructured paint during driving-rain events (Figure 6). The rainwater does not cling to the surface but immediately runs off to the ground.

The blotting-paper tests were repeated when exterior condensation instead of wind-driven rain was expected to be the cause of surface wetness. The readings in Figure 8 were taken during the morning hours of a day with a clear sky. The question as to why surface wetness is still increasing after sunrise will be addressed below. In comparison to the situation during a rainy day (Figure 6), there is a big difference regarding the behavior of the nanostructured paint. Instead of showing the best performance, as during the driving rain event, it now seems to show the worst, having the highest surface wetness. This is not really surprising when the respective water-absorption coefficients (*A*-values) are considered again. The coating with the smallest *A*-value, the nanostructured paint, shows the highest surface wetness because there is very little surface water penetration. Logically, the coating with the highest *A*-value—the mineral-silicate paint—retains the least amount of condensate on its surface, and the performance of the silicone based paint is somewhere n between. The load-dependent performance of the nanostructured paint must be due to the characteristics of the surface water. While the incoming rain droplets easily run off the structured surface, the water droplets forming when exterior condensation occurs seem to be different. They are either too small to be displaced by gravity or they get caught within the nanostructure somehow.

In order to explain why the surface wetness of a west-oriented façade may still increase or even start to appear after sunrise, the temporal behavior of the ambient-air humidity has to be understood. For the location of the experiments (Holzkirchen), the seasonal averages of the daily cycles of the outdoor RH and the dew-point temperature are presented in Figure 9. While the RH falls after sunrise due to the increasing outdoor air temperature, the dew-point temperature—a measure for the absolute humidity of the air—goes up. This effect has a similar magnitude in all seasons. It might be caused by dew evaporating from the ground or by fog dissolving. Since a west-oriented wall heats up very slowly in the morning, the rising dew-point temperature of the ambient air may lead to rather intense condensation on the cold façade. It is quite obvious that algae benefit from this phenomenon because there is moisture and light at the same time.

CONCLUSIONS

A prerequisite for microbial growth on external walls is surface moisture. Since the species-dependent humidity threshold and optimum conditions for the formation of algae and fungi are still a matter of research, it is difficult to predict the exposure-dependent performance of a certain wall system with respect to microbial growth. However, research indicates that a high surface humidity and the intermittent presence of liquid water tend to increase the growth probability. Therefore, comparative assessments of façade systems should be feasible.

The most important moisture loads in practice are wind-driven rain and exterior condensation. The driving-rain impact is usually independent of the composition and the thermal quality of the wall. However, if the wall has slightly inclined or protruding parts, they may experience a considerable load increase. Exterior condensation is most likely to occur on well-insulated walls when the exterior layers have a low thermal inertia. In contrast to the driving-rain load, which always existed, exterior condensation is a rather recent problem and solutions are still scarce. Moreover, a good solution to protect the façade against wind-driven rain—e.g. the nanostructured paint—may prove ineffective or even counterproductive when dealing with exterior condensation.

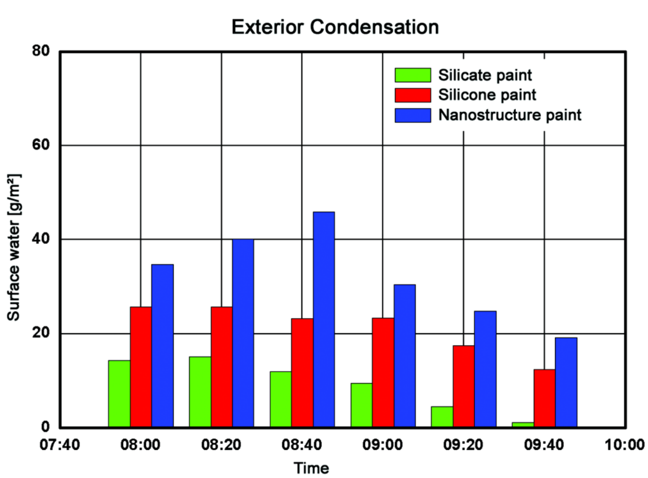

Figure 8 *Surface water extracted from a test façade with EIFS in the morning of a clear day.*

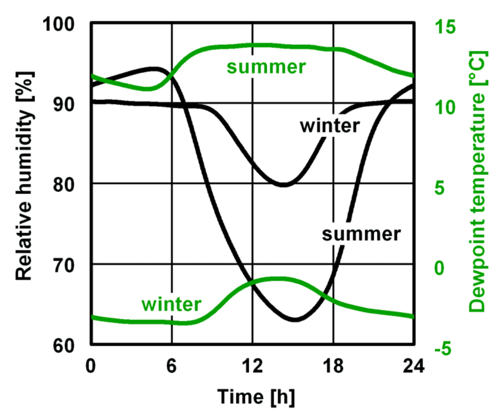

Figure 9 *Average daily cycles of RH and dew-point temperature at Holzkirchenin in the summer and winter months.*

However, the moisture load is only part of the problem. The drying potential or the removal of surface moisture is equally important. Exposure to high winds or the sun combined with dark color is beneficial, but the removal of surface moisture by temporary storage within the wall assembly may also be a way of reducing surface wetness. The performance of the mineral paint with silicate dispersion is due to this effect, with the stucco acting as moisture buffer. While the combination of a large internal buffer and a high water permeability of the surface coating may reduce exterior condensation, it can be problematic when driving rain occurs. The high intensity of wind-driven rain may result in a buffer overflow and impair the performance of the whole system. Therefore, the water permeability of the paint coat (usually characterized by its water-absorption coefficient on stucco) has to be limited. The upper and lower limits may depend on the different loads at the building site.

Since the façade coatings investigated in this paper do not represent very effective measures for reducing surface moisture under all load conditions, alternative solutions should be developed. Currently, there are several innovations in the pipeline. Low-emissivity coatings and stucco with PCM have already been examined in the investigation of Fitz et al. (2006). The potential of both options to solve the exterior condensation problem looks promising. Another possibility may be the application of photocatalytic compounds on the façade surface. Under their influence, dirt and organic matter are supposed to be decomposed by photocatalytic reactions in the presents of ultra-violet light. However, this approach was not part of the investigation mentioned earlier, and practical information is still scarce. The future will show which innovation really works in practice and, more importantly, whether it is durable and affordable.

REFERENCES

Barthlott, W., and C. Neinhuis. 1997. The purity of sacred lotus or escape from contamination in biological surfaces. *Planta* 202:1–8.

Blocken, B. 2004. Wind-driven rain on buildings. PhD thesis, Catholic University of Leuven, Belgium.

BSI. 1992. *British Standard 8104, Assessing exposure of walls to wind-driven rain*. London: British Standards Institute.

Fitz, C., W. Hofbauer, K. Sedlbauer, M. Krus, and K. Breuer. 2006. Prognoseverfahren zum biologischen befall durch algen pilze und flechten an bauteiloberflächen auf basis bauphysikalischer und mikrobieller untersuchungen. Bauforschung für die Praxis Band 77, Fraunhofer IRB Verlag, 304 Seiten.

Holm, A., W. Zillig, and H.M. Künzel. 2004. Exterior surface temperature and humidity of walls—comparison of experiment and numerical simulation. *Proceedings of Buildings IX Conference, Clearwater Beach, FL.*

Künzel, H.M. 1995. Simultaneous heat and moisture transport in building components: One- and two-dimensional calculation using simple parameters. Fraunhofer IRB Verlag.

Künzel, H.M., and K. Sedlbauer. 2001. Biological growth on stucco. *Proceedings of Buildings VIII Conference*, *Clearwater Beach, FL*.

Künzel, H.M., H. Künzel, and H. Holm. 2004. Rain protection of stucco façades. *Proceedings of Buildings IX, Clearwater Beach, FL*.

Nady, M., A. Said, W.C. Brown, and I.S. Walker. 1997. Long-term field monitoring of an EIFS clad wall. *Journal of Thermal Insulation and Building Envelopes* 20: 320–38.