More Moisture Load Tolerance of Construction Assemblies Through the Application of a Smart Vapor Retarder

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ABSTRACT

Insulated lightweight building components generally need a vapor retarder at the warm side in order to avoid an excess of interstitial condensation. Depending on the climate, the retarder has to be installed at the interior or exterior, sometimes at both sides of the assembly in mixed climates. However, a retarder not only diminishes the interstitial condensation, it also reduces the drying potential of the assembly, thus increasing the risk of damage, e.g., due to moisture loads caused by imperfections in the construction. By adapting its vapor permeability according to the ambient conditions in a range between 0.7 perm and 36 perm, the smart retarder opens up its pores when good drying conditions for the assembly prevail. The principle of this retarder is explained and the effect on the moisture tolerance of building components is shown in comparison to conventional retarders by field tests of unvented cathedral ceilings in heating climates. Furthermore, its performance is also assessed by simple interstitial condensation and evaporation considerations on which many building codes are based. The results show that the smart retarder effectively reduces the moisture damage risk of building assemblies in heating climates.

INTRODUCTION

Insulated lightweight building components need a vapor retarder at the warm side in order to avoid an excess of interstitial condensation. However, a retarder not only reduces the moisture uptake of an assembly, it also diminishes the drying rate of interstitial moisture after a change of seasons. This can lead to moisture accumulation in assemblies if they cannot dry out sufficiently through the opposite side because it is vapor tight, as in unvented cathedral ceilings, for example, or because there, too, is a vapor retarder, as sometimes required in mixed climate zones. For such cases, the *ASHRAE Fundamentals* (ASHRAE 1997) recommends a special retarder called the hygrodiode, which is composed of a synthetic fabric sandwiched between strips of polyethylene film. It is rather impermeable to vapor but draws water through its fabric once condensation occurs. However, if humidity levels are high without actual condensation—this can be the case in shaded areas of the construction or if hygroscopic insulation materials such as cellulose fibres are used—the drying through the hygrodiode is severely inhibited. The solution to this problem is the smart retarder described below, which adapts its vapor permeability according to the ambient humidity conditions, thus favoring the drying process without increasing the rate of interstitial condensation.

PRINCIPLE OF THE SMART RETARDER

During the heating period, the smart retarder acts as a conventional retarder at the interior side of the assembly where humidity conditions are generally low. However, situated at the cold side, where a higher relative humidity prevails, it can become as permeable as plasterboard. Its vapor permeability measured by cup tests is plotted as a function of relative humidity in Figure 1. Below 50% relative humidity (RH), the permeability of the smart retarder (a nylon film of 50 μm thickness) is less than 1 perm. At ambient conditions above 60% RH, it becomes more and more permeable and reaches a value of 36 perm at 90% RH (determined by an inverted cup test in a climatic chamber at 80% RH). Between this value and the permeability in the dry state (< 20% RH) lies a factor of 50. The humidity-dependent variation of vapor permeability is not unusual for plastic films. The extent of this variation and the specific permeability under dry and humid conditions that correspond to theoretical requirements can be considered a novelty in building physics.

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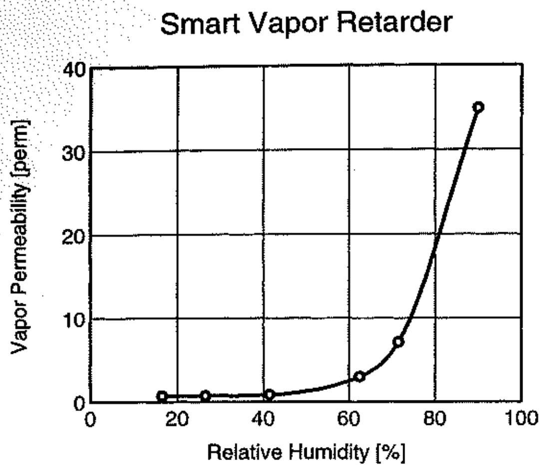

Figure 1 *Variation of the vapor permeability of the smart retarder (a nylon-based film of 50 μm thickness) with the ambient relative humidity determined by cup tests.*

The smart vapor retarder consists of a nylon-based membrane. Nylon film is used as sausage skin and for food packaging, which proves that it poses no health hazard. It is impermeable to organic compounds and gases (e.g., radon). The humidity-dependent vapor permeability is due to its capacity to absorb water, which creates its own selective pores in the material. Nylon is a rather tough plastic material with high tensile strength. Therefore, a membrane of about 50 μm has mechanical properties equivalent to a polyethylene film of 150 μm thickness.

Considering realistic conditions in a wall or a cathedral ceiling with 20 cm mineral fiber insulation and vapor-tight exterior lining during a winter and summer period, Figure 2

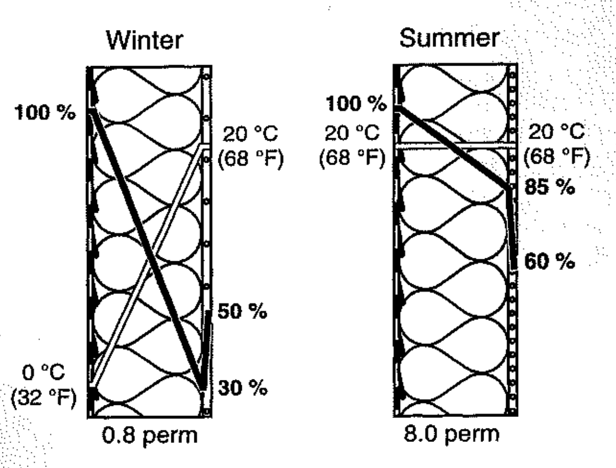

Figure 2 *Gradients of temperature (white) and relative humidity (black) in a lightweight building assembly with vapor-tight exterior lining and the smart retarder at the interior under conditions representative for central Europe. The respective permeability of the smart retarder is indicated in the text.*

shows that the relative humidity between the vapor retarder and the insulation is lower than the indoor air humidity in winter. This can be explained by the high vapor permeability of the insulation compared to the retarder, which leads to a rather uniform vapor pressure in the assembly. In the most severe case, when condensation occurs at the vapor-tight exterior lining, the vapor pressure in the assembly is equal to the saturation pressure at the exterior surface temperature (0°C [32°F] in Figure 2). At the interior surface, however, the saturation pressure is more than three times higher, leading to a relative humidity of 30% at the outward-facing side of the retarder. Thus, the mean humidity of the retarder amounts to 40% RH, resulting in a vapor permeability of 0.8 perm according to Figure 1. During a warm period where indoor and outdoor temperatures are about the same, condensate that had formed in winter can dry out to the interior as shown in Figure 2 on the right-hand side. In this case, the saturation pressure is uniform; therefore, the gradients of vapor pressure and relative humidity are parallel. Assuming an indoor humidity during summer of 60% RH leads to the humidity gradient shown in Figure 2, resulting in a mean relative humidity in the retarder of about 70% RH and a vapor permeability of 8 perm. This means that the smart retarder is at least ten times more permeable in summer than in winter, thereby favoring the dry-out of an assembly to the interior.

Its performance has been compared by calculations (Kuenzel 1995) to that of a conventional retarder with a permeability of 1.5 perm, such as kraft paper. Some kraft papers, too, show a change in permeability with increased humidity levels (Hens 1998). However, practice tests with kraft paper retarders from two German producers proved that this change in permeability can be irreversible (Kuenzel and Großkinsky 1997), i.e., the vapor diffusion resistance required to prevent condensation risks is not regained once the paper is submitted to conditions of higher humidity. Another problem is rapid mold growth on the outward-facing side of the kraft paper, which might also impair its proper function. Therefore, the comparison in Figure 3 was carried out assuming the conventional retarder had a constant permeability, as, for example, coated breather membranes.

If the exterior surface of the assembly is completely vapor tight and the indoor air is conditioned to 20°C (68°F) and 50% RH, there will be interstitial condensation below and evaporation above 9°C (49°F) at the cold side. The accumulated amount of condensate, or the maximum evaporable amount of water through the vapor retarder if the outdoor temperature is above 9°C (49°F), is plotted for a period of six weeks in Figure 3. While the amount of condensate stays well below the limit value of 0.5 kg/m^2 (according to the German Standard DIN 4108) with both retarders (the smart retarder performing somewhat better due to its lower permeability), the difference in evaporation potential once outdoor temperatures exceed the dew point is significant. The amount of condensate evaporating through the conventional retarder at 20°C (68°F) is not sufficient to totally dry out the amount formed at –20°C (–4°F),

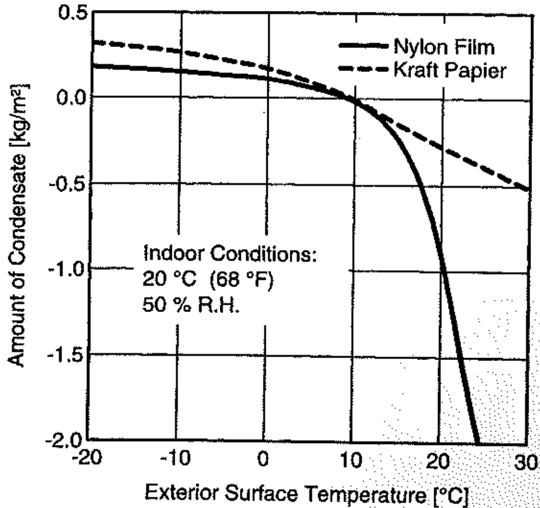

Figure 3 *Amount of condensate formed or evaporated (negative values) in an insulated (20 cm mineral fiber) building envelope with vapor-tight exterior depending on the exterior surface temperature and the retarder at the interior.*

which means moisture accumulation in the assembly cannot be excluded. With the smart retarder, the evaporable amount of water at 20°C (68°F) is more than five times greater than the amount of condensate formed at –20°C (–4°F), which makes an accumulation of moisture highly unlikely.

FIELD TEST: UNVENTED CATHEDRAL CEILING

Even if moisture problems due to vapor diffusion in unvented assemblies with a vapor-tight exterior layer can be excluded by applying the smart retarder, other sources of moisture, such as the initial moisture in rafters and joists or air infiltration through imperfections in the interior lining, might pose a risk that has to be considered. Because unvented assemblies have become for good reasons more widespread, a field test with unvented, fully insulated cathedral ceilings in a roof with a pitch of 50° was carried out at a test facility located close to the Alps between Munich and the Austrian border at 680 m above sea level. A common moisture source in this type of construction is the initial moisture in the rafters or in the wooden sheathing beneath the roof cladding exposed to rainfall during the construction period. For the roof considered here, rafters that had not been dried sufficiently were used and the sheathing was watered several hours with a hose before the metal zinc cladding, which is known to be rather vapor tight, was applied. Figure 4 shows a cross section of the assembly, indicating also the positions of the wood moisture sensors (discontinuous measurement of electric conductivity) and the partition of the cathedral ceiling in test fields with three different vapor retarders: kraft paper (ca. 1.5 perm), polyethylene film (0.07 perm), and the smart retarder (vapor permeability,

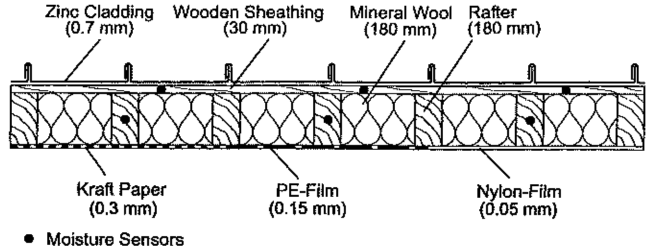

Figure 4 *Cross section of the investigated cathedral ceiling with three different retarders.*

see Figure 1). The roof surfaces, with an inclination of 50°, were oriented to the north and to the south. The roof was erected and insulated in July 1996. The recording started at the beginning of August 1996. Apart from the first autumn when the drying of the screed let to a high indoor humidity, the conditions were kept between 20°C, 40% RH, in winter and 23°C, 60% RH, in summer.

Figures 5 and 6 show the temporal development of the moisture content in the wooden sheathing and the rafters behind the three different vapor retarders. In the test fields facing south, the initial moisture of the wooden sheathing was already below the critical water content of 20 mass % at the start of the recording because the high solar radiation during the installation of the cladding dried the boards very fast. The moisture in the rafters fell within a few months below the critical value, almost irrespective of the vapor retarder applied. This is due to summer condensation caused by the unusually

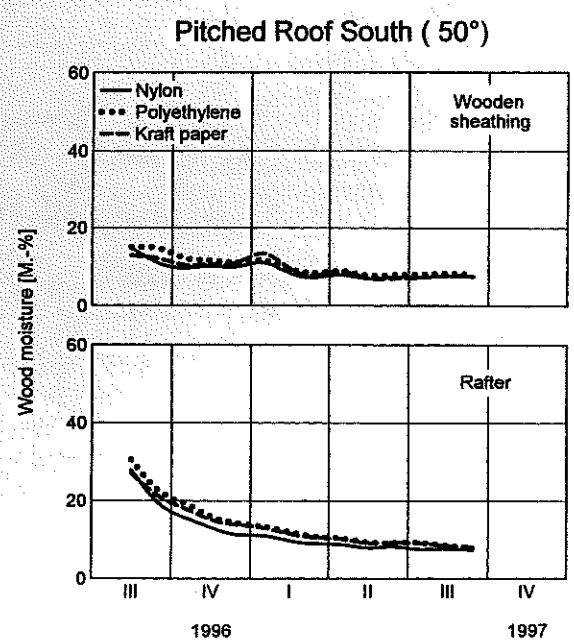

Figure 5 *Moisture in the rafters and the wooden sheathing beneath the zinc cladding over a period of one year in the test fields with the different retarders. The roman numerals indicate the quarters.*

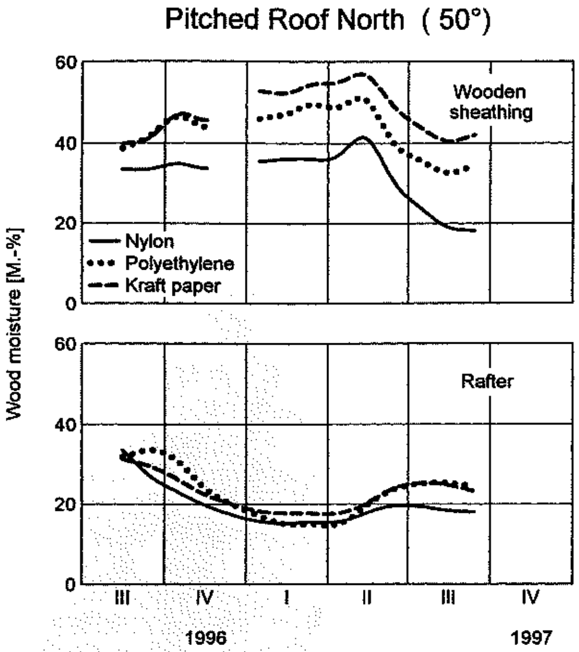

Figure 6 *Moisture in the rafters and the wooden sheathing beneath the zinc cladding over a period of one year in the test fields with the different retarders. The roman numerals indicate the quarters. The readings of the moisture in the sheathing are only shown for temperatures above 0°C because ice formation due to the high water content impairs the moisture measurements by electric resistance. This explains the missing data during wintertime in the top figure.*

high surface temperatures of the zinc cladding—uncorroded zinc has a low longwave emissivity, resulting in high surface temperatures during sunshine—up to 80°C (176°F). The condensate formed visibly on the outward-facing side of the retarder and ran off to the bottom joist due to the steep pitch of the roof. In the case of the kraft paper, condensation stains and mold growth on samples taken from the test fields were observed during this period.

In the north-oriented part of the roof, no condensation on the retarder was observed in the first summer because the zinc surface temperatures were much lower there. This explains the rather slow drying process apparent in Figure 6. The initial moisture of the rafters was about the same as in the south-oriented part, but it took more time for the moisture to reach uncritical conditions—three months in the test field with the smart retarder and four months in the other test fields. However, regarding the moisture increase of the wooden sheathing in the test fields with the polyethylene film and the kraft paper, it seems that the moisture of the rafters did not dry to the interior as much as the bottom graphs would suggest. While the moisture in the rafters beneath the smart retarder stays below 20 mass % until the end of the test period, it reaches 25 mass % in the other test fields during the next summer. This moisture increase is caused by a redistribution of the water from the wooden sheathing into the rafters, as can be detected from the curves above. Only the smart retarder allows the unvented roof to dry out sufficiently so that the rafters and the wooden sheathing are below critical conditions at the end of the test period, whereas the kraft paper and the polyethylene film trap too much water in the assembly, thus increasing the probability of moisture damage.

CONCLUSIONS

The results of the field test presented here support other experimental and calculation results documented in Kuenzel (1996), which show that the smart vapor retarder effectively reduces the moisture damage risk in the building envelope by increasing the moisture load tolerance of the assembly. This is valid for heating climates and, according to a study in Karagiozis and Kumaran (1997) about the moisture behavior of walls with EIFS (exterior insulation and finish system), also for mixed climates. In cooling climates, where a retarder at the exterior of the envelope is required, the application of the smart retarder may not be beneficial if high outdoor humidity conditions prevail, which can increase the permeability of the smart retarder to the point where it does not reduce the vapor diffusion sufficiently. The same may be true in all climates for buildings with an exceptionally high indoor humidity, such as swimming pools. Short peaks in the indoor air humidity, as in bathrooms or kitchens, do not affect the performance of the smart retarder because the interior lining acts as a humidity buffer.

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