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Adapted vapour control for durable building enclosures

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ABSTRACT

Well-insulated building envelope systems are subject to alternating vapour pressure gradients. Therefore the installation of traditional vapour barriers or retarders to avoid interstitial condensation may have undesirable side-effects. Numerous moisture damage cases can be attributed to the fact that a vapour barrier is nearly impermeable in both ways, i.e. it does not allow any dry-out either. Some wall and roof assemblies are only durable if they can dry to the interior side too. The attempt to create a perfect seal is rarely successful and should be better replaced by controlled moisture management. Therefore, the transient hygrothermal behaviour of the building enclosure is investigated and the importance of moisture leaks is discussed.

Recently, adaptable vapour retarding systems have been developed in order to assure a sufficient drying potential. Two of these retarders are presented in this paper. The humidity controlled retarder reacts to local humidity conditions by increasing its vapour permeance when drying conditions prevail. The capillary active retarder relies on capillary suction to remove moisture from the interior of the envelope. By way of several field tests their performance has been evaluated and compared to that of conventional vapour barriers. The results clearly show a faster drying of construction moisture and diminished long-term humidity within the building envelope.

The improved drying potential through the application of adaptable vapour retarders increases the durability of insulated constructions because rot, corrosion and fungal growth are less likely to occur under dry conditions. Because these retarders become more permeable in the case of condensation or high humidity their application must be restricted to buildings with normal indoor air conditions. In the case of the capillary active retarder only non hygroscopic insulation materials may be employed. Otherwise the summer condensate will be absorbed by the insulation layer before it has a chance to reach the retarder and be wicked to the other side. Despite of the limits, it is worthwhile to consider the application of the adaptable retarders in practice because the durability benefits are significant.

KEYWORDS

Vapour retarder Vapour control Drying potential Hygrothermal performance

1 INTRODUCTION

In the past questionable moisture protection paradigms like the sealing of the building enclosure against vapor diffusion processes by vapor barriers or retarders [Rose 2003] have lead to numerous damages, as unavoidable moisture uptake during and after the construction process is not taken into account in practice. Building materials that appear to be dry often contain a considerable amount of hygroscopic moisture that may migrate within the building assembly if subjected to a temperature gradient. The best workmanship cannot exclude some lateral diffusion through embedding elements, like partition walls or floors. In addition there are convective vapour entries through small defaults despite an air tightness of the building fabric that is in total satisfactory. However, real vapor barriers are tight in both directions and do not allow any drying. Even a minor accidental moisture intrusion may therefore cause considerable damage.

That is why builders should look for a better vapour control strategy which is potentially less detrimental in the case of imperfections or unfavorable construction conditions. This paper explains under what circumstances moderate vapour retarders or those with special drying characteristics represent a better solution.

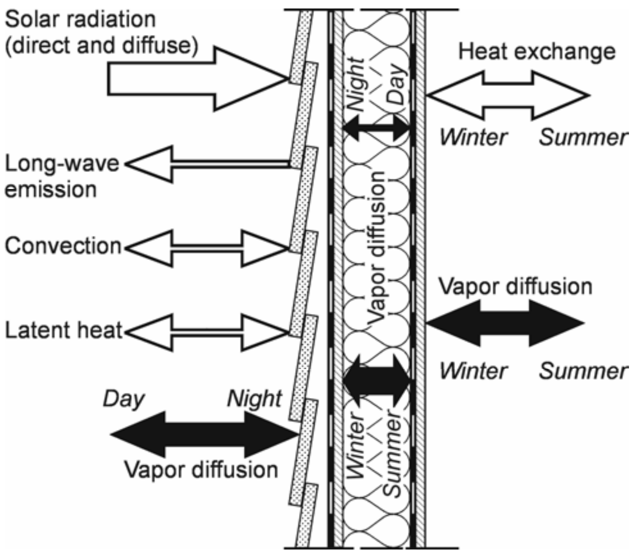

Figure 1. Schematic representation of the hygrothermal effects and their alternating diurnal or seasonal directions in a wall construction.

2 TRANSIENT HYGROTHERMAL CONDITIONS IN THE BUILDING ENCLOSURE

The main function of the building enclosure is the protection of the indoor spaces from natural weather. Besides precipitation and wind that occur only sporadically the solar radiation and the outdoor air conditions are essential. In Figure 1 those hygrothermal parameters and their directions are represented schematically for the example of an external wall. Generally they show diurnal variations at the exterior surface and seasonal variations at the interior surface of the building enclosure. During the daytime the exterior wall surface heats up by solar radiation: this leads to an increase in temperature until there is a balance with the transfer of heat to the interior through thermal conduction and to the exterior through long-wave radiation and convection. Even before sunset when the solar radiation decreases the long-wave (infrared) emission may lead to an overcooling (cooling down below air temperature) of the exterior surface which means that condensation of the ambient humidity may occur.

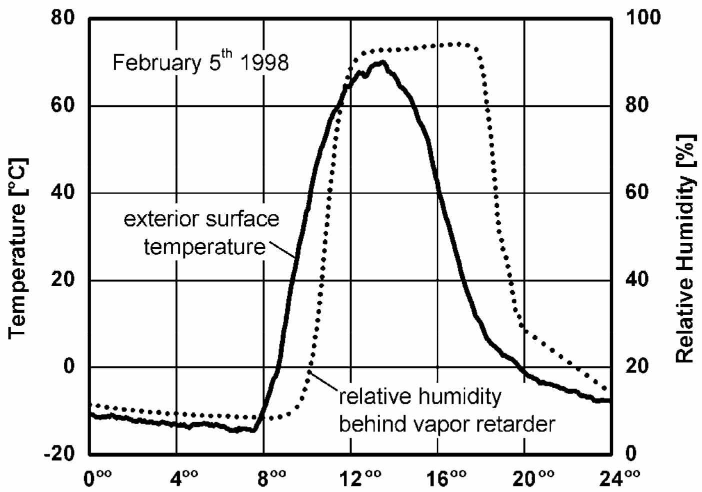

Figure 2. Diurnal evolution of surface temperature and RH between the vapor retarder and the fiber glass insulation measured at a south facing cathedral ceiling during a sunny winter period.

The processes on the exterior surface bear also consequences for the transient temperature and humidity conditions in the construction. When the exterior surface temperature rises during daytime it may cause vapor diffusion out of the exterior layers to the interior side of the wall. The extent of moisture transport to the interior side can be estimated from results in Figure 2 which were recorded in a sheet-metal cathedral ceiling (orientation: south, inclination: 50°). The measured variations of the exterior surface temperature and the relative humidity between the vapor retarder and the mineral wool insulation during a bright winter day show a very large range. Under wintery conditions the temperature of the sheet-metal covering rises from -15°C during the night to 70°C at noon. This strong increase in surface temperature drives the moisture of the wooden sheathing (bearing of the sheet-metal) to the interior side. For that reason the relative humidity between the vapor retarder and the insulation increases with a small delay from less than 10% to more than 90%. During the next night, when the exterior surface temperature falls again below the temperature of the conditioned space the direction of the vapor diffusion flow changes and the relative humidity behind the vapor retarder goes back to its initial state. These experimental results show clearly the diurnal humidity variations that may appear in the building enclosure due to vapor diffusion processes. In general the balance between nighttime and daytime diffusion fluxes results in a seasonal net flux to the exterior side in winter and to the interior side in summer.

The use of vapour barriers in building envelope systems subjected to dynamic hygrothermal loads has caused a lot of problems in the past. Many damage cases originate from the deficiency of such barriers because of inadequate workmanship or a lack of durability. Instead of improving the hermetic sealing the modern moisture protection concentrates on the moisture management of the building enclosure. That means that a limited entry of moisture is accepted when a sufficient and quick drying is assured later on. The admitted quantities of moisture and their presence in the building enclosure depend on the type of load as well as on the materials' capacity of storing moisture. In general, after a characteristic load cycle a building component is not allowed to contain more moisture than in the initial situation. For example the condensation during winter has to dry completely during summer. Infiltrating rain water must drain and dry away before the next precipitation period. Furthermore water that has been collected during a cycle must not exceed a certain limit of acceptance which depends on the moisture tolerance of the building materials in the envelope system. The evaluation of the transient temperature and moisture behavior is rather complicated and requires specific experience. In some cases computer simulations are necessary in order to assess the hygrothermal performance of a construction. Good moisture management can be recognized by its emphasis on the drying potential. The vapour control membranes described below enhance the drying capacity of a construction and may thus lead to a higher tolerance of the building envelope concerning smaller defects or property changes due to ageing.

3 HYGROTHERMAL PERFORMANCE OF THE VAPOUR CONTROL MEMBRANES

The capillary active retarder is a water permeable membrane which is composed of a synthetic fabric sandwiched between staggered strips of polyethylene film. Its brand name "Hygrodiode" is somewhat misleading because liquid water may be wicked through the fabric both ways. With a vapor diffusion resistance of 14 m equivalent air layer thickness (i.e. the vapour diffusion resistance is equal to that of a stagnant air layer which is 14 m thick) it is tighter than most kraft papers but liquid water can penetrate through capillary action via the sandwiched fabric. The membrane has a thickness of 440 µm and weighs 160 g/m². A detailed description can be found in Korsgaard & Pedersen [1992].

The humidity controlled retarder [Künzel 1996] is a nylon-based membrane (PA-film) with a thickness of 50 µm. By absorbing water vapour from the air and thereby opening the molecular pores it changes its vapor permeability with the ambient humidity conditions. Typically, its vapopur diffusion resistance lies above 4 m during the heating season and between 0.1 m and 0.4 m in summer when the assembly should dry out. This can be explained by the difference in ambient conditions at the retarder between winter and summer due to the inversion of the temperature gradient in the assembly, which results in low R.H. at the warmer side and high R.H. at the colder side.

3.1 Laboratory test (cup test)

The vapour permeabilities of the two innovative retarders and a conventional kraft paper were determined by a series of cup-tests. Because the capillary active membrane only becomes more permeable when condensation occurs, a special condensation-cup test was designed. Experimental results from a north oriented pitched roof in Central Europe [Künzel 1999] have shown that the mean roof surface temperature is about 2 K above the indoor air temperature during the summer months.

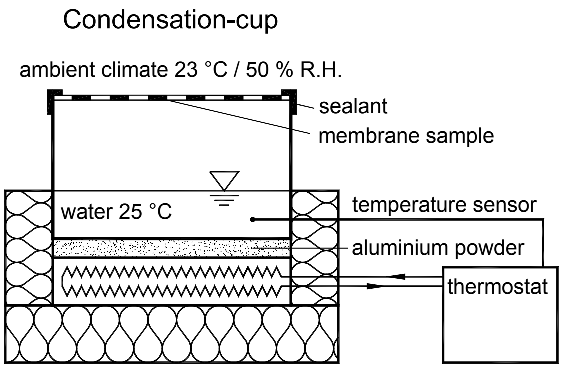

Figure 3. Test set-up for the condensation-cup measurement.

The test set-up in Figure 3 consists of a standard cup containing pure water which is kept at 25 °C by heating the bottom of the cup with a hot plate. This difference to the ambient air temperature ensures sufficient condensation on the bottom side of the tested retarder. The series started with a dry-cup test followed by a wet-cup test and the condensation-cup test. In the end another dry-cup test was carried out with the kraft paper in order to determine whether any irreversible alterations of the material could be detected (past experience has shown considerable degradation of moisturized kraft paper).

The results of the test series are listed in Table 1. The "Hygrodiode" has the highest diffusion resistance under dry conditions. During the normal wet-cup test with pure water some condensation occurs but apparently not enough to get a continuous water film in the fabric. During the condensation-cup test the capillary transport started within 24 hours and led to an apparent vapor diffusion resistance of 0.3 m. The PA-film already becomes very permeable under normal wet-cup conditions (a factor of 15 compared to dry-cup value). But also here the diffusion resistance is further reduced by the conditions in the condensation-cup. The kraft paper also shows a significant reduction of the diffusion resistance under humid conditions. However, the initial diffusion resistance under dry conditions is not regained during the final dry-cup test. This proves that the moisture load led to an irreversible alteration of the paper membrane. More kraft paper samples from different producers were also tested but the results cannot be reported here because the samples either decomposed or developed heavy mould growth in the wet-cup tests. The “Hygrodiode” and the PA-film showed neither alterations of their properties nor any mould growth during and after the test series.

Vapour control membrane	Vapour diffusion resistance [m]		
	dry-cup 23°C / 3% RH	wet-cup 23°C / 100% RH	condensation-cup 25°C / 100% RH
“Hygrodiode”	13.5	2.4	0.30
PA-film	3.8	0.25	0.15
Kraft paper	5.5 (1.2)	1.5	0.21

Table 1. Vapour diffusion resistance of the vapour control membranes measured by cup-tests (conditions in the cup are indicated below) in a climatic chamber at 23°C, 50% RH. The dry-cup diffusion resistance of kraft paper after the condensation-cup test is indicated in brackets.

3.2 Field Test

Laboratory tests can provide useful information about the intrinsic properties and application prospects of new building materials or compounds. To predict their behavior under practice conditions necessitates comparative field tests which should be as close to the building reality as possible. The following field test was carried out in Holzkirchen, a location 680 m above sea level close to the Bavarian Alps. Test object is a habitable roof construction whose detailed description can be found in Künzel [1999]. The considered roof component is an unvented cathedral ceiling with a pitch of 50° oriented to the North. The composition from outside to inside is as follows: Zinc covering, wooden sheathing (initial moisture ca. 40 M.-%), 180 mm mineral wool insulation between the rafters, vapor retarder (“Hygrodiode” / PA-film / PE-film), gypsum board. The moisture of the rafters and the sheathing was monitored continuously by electrical resistance sensors. The test field with the “Hygrodiode” was installed one year after the other test fields by replacing the PE-film. Therefore results from two different summers have to be compared.

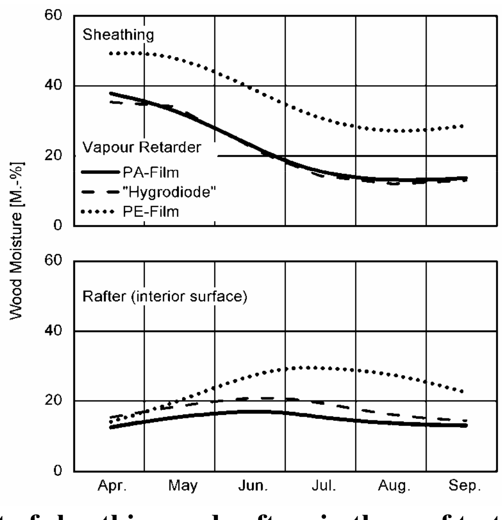

Figure 4. Moisture content of sheathing and rafters in the roof test fields with different vapor retarders during the drying period.

Figure 4 shows the measured wood moisture in the sheathing and at the interior surface of the rafters in the test fields from April to September. Starting from an elevated moisture well above the critical point of 20 M.-%, the sheathing dries under the influence of the sun and reaches uncritical conditions in late June in the test fields with the special retarders. Part of the moisture coming from the sheathing leads to a short term increase in water content at the interior surface of the rafters. But towards the end of the summer the effect of the “Hygrodiode” and the PA-film alike result in dry conditions throughout the cathedral ceiling assembly, while the situation stays critical in the test field with the PE-film. This proves that these new vapour controlling membranes have a clear advantage over the conventional polyethylene retarder in unvented roof assemblies. Similar results have also been obtained previously in the same test roof by comparing the PA-film to kraft paper [Künzel 1999].

3.3 Numerical sumulations

Since the hygrothermal performance of building envelope systems depends heavily on the exterior climate it is difficult to transfer field test results to another climate zone. However, hygrothermal transport models validated by comparison with field tests in one climate zone may be employed to transfer the results to another climate. To this end, several simulation tools are available for the practitioner to assess the performance of vapour control components under any climate condition [Trechsel 2001]. The simulations in this paper are done with a tool commonly used in Europe and North-America called WUFI®. This model has been validated by a number of common exercises [Hens et al. 1996] and by well-defined benchmark cases [Künzel 1995]. The reliability of the model has also been confirmed by independent authors who compared experimental data with model predictions [e.g. Straube & Schumacher 2003, Kalamees & Vinha 2003].

Considered are building enclosure components with 16 cm of mineral fiber insulation, an exterior OSB sheathing covered by a water and vapour tight (diffusion resistance s_d = 30 m) bituminous building paper beneath vinyl siding - res. bituminous membrane when component employed as a flat roof - with a bright colour (solar absorptivity 0.4). The interior finish is gypsum board with a moderate vapour retarder (s_d = 3 m)) underneath (reference case). As locations for these building components, three cities of the northern part of the United States - Boston, Minneapolis and Seattle - are selected. The outdoor climate data (cold years) are taken from the WUFI-ORNL/IBP database [Karagiozis et al. 2001]. The choice of the indoor climate for January is 21°C and a relative humidity depending on the mean outdoor air temperature of 40% (Minneapolis) res. 50% (Boston) or 55% (Seattle). In July the indoor conditions are set to 24°C and 60% RH for all cities. The OSB is initially wet (30% by mass).

The resulting monthly averages of the vapour pressure differences between the OSB and the indoor climate is plotted in Figure 5 for a flat roof and a north facing wall. For both orientations (horizontal and vertical) the vapour drive in Boston, Minneapolis and Seattle points into the building enclosure in January and out of the enclosure into the living space in July. While the vapour pressure differences in January do not vary a lot with the different locations or orientations, there is a comparatively high vapour pressure difference and hence drying potential for the flat roof in July.

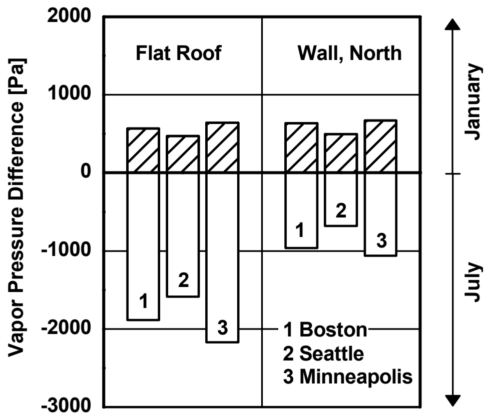

Figure 5. Mean vapor pressure difference between the moist OSB sheathing of the building enclosure and the indoor air in January and July for 3 U.S. cities. Positive vapor pressure differences indicate condensation conditions and negative values quantify the drying potential.

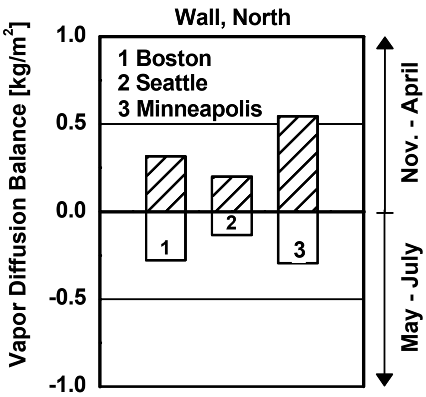

Figure 6. Calculated vapour diffusion balance of the north facing wall with a moderate retarder (s_d = 3 m) showing the maximum moisture uptake by condensation from November to April (hatched area) and the amount of moisture that dries out from May to July.

Compared to the flat roofs the drying potential of the north facing walls is much lower. For the locations considered here, the north facing wall receives less solar radiation than any other orientation which means it also has the lowest drying potential. Therefore it is necessary to examine the hygrothermal conditions more closely. For Boston, Seattle and Minneapolis the moisture accumulation by condensation from November to April (positive values) and the amount of moisture drying out during the period from May to July (negative values) are shown in Figure 6. In all cases, the moisture that permeates through the moderate retarder (s_d = 3 m) into the wall assembly from November to April does not dry out completely until the end of July. Even though the underlying boundary conditions leading to this unfavourable situation are rather severe, they are not unrealistic. Therefore, installing a moderate retarder in this wall assembly cannot be recommended for climate zones comparable to the ones investigated here.

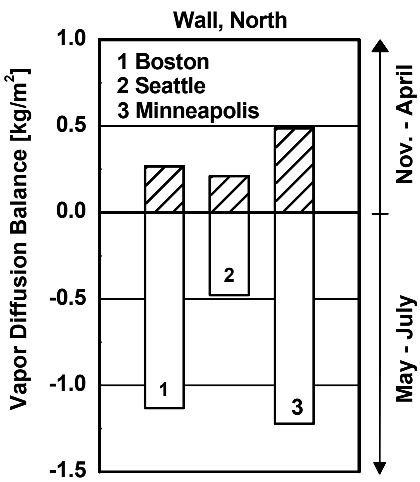

Figure 7. Vapour diffusion balance of the north facing wall with PA-film showing the max. condensation (hatched area) and the amount of moisture, drying out from May to July.

If the moderate retarder (s_d = 3 m) in the reference case of a north facing wall is replaced by the 50 µm thick PA-film the drying potential of the assembly should be significantly increased. Figure 7 shows the results for the same situation as in Fig. 6 only with a different retarder. During the heating period from November to April the amount of interstitial condensation is only slightly reduced by the PA-film because its diffusion resistance under winter conditions is not much higher than 3 m. In all cases the amount of condensate stays below the safety limit of 0.5 kg/m² for interstitial condensation formulated in the German standard on moisture protection (DIN 4108-3) in order to prevent durability problems.

In spring and early summer (May till July) the amount of moisture drying out through the polyamide film into the living space is 2.5 times (Seattle, Minneapolis) res. 4 times (Boston) higher than the amount of interstitial condensation. Because the OSB is initially rather wet (30% by mass) the amount of moisture drying out can be higher than the amount of condensing vapour. That means if the only moisture present in the building assembly results from interstitial condensation the required time for the drying process is shorter. In Boston the dry state will be reached in the middle of June, in Minneapolis end of June and in Seattle in the middle of July. This shows that the climate of Seattle is the least favorable for the building enclosure among the location examined here.

4 CONCLUSIONS

There are a number of ways moisture can enter the building enclosure and interstitial condensation due to vapor diffusion is hardly the most important one. Therefore an adequate drying potential also to the interior is the best way to prevent moisture damage or durability problems. In many cases the use of vapour retarders with a moderate diffusion resistance (sd = 3 m) offers sufficient control of interstitial condensation during the heating period without completely blocking the way out for any unintended moisture in the construction. The laboratory and field tests as well as the numerical simulations have shown that vapour controlling membranes that enhance the drying potential of the building envelope towards the interior are superior to conventional vapor retarders for the durability of insulated structures under Central European and Northern U.S. climate conditions. If the drying potential of a moderate retarder is too small for the design case or additional safety against moisture problems is desired, the installation of special vapour control membranes like the PA-film or the "Hygrodiode" should be considered.

In cases with an extremely high interior moisture load, for example in swimming halls, impermeable vapour barriers should be installed. A polyethylene film (sd ~ 30 m) is hardly ever appropriate because it is not tight enough for an extreme interior moisture load and too tight for most dynamic load conditions (very low drying potential when vapour pressure gradient inverses in summer).

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