VAPOR CONTROL IN COLD AND COSTAL CLIMATES ZONES

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ABSTRACT

The use of traditional vapor barriers or retarders to avoid interstitial condensation may have undesirable side-effects. Numerous moisture damage cases have been attributed to the fact that a vapor retarder is nearly impermeable in both directions, i.e. it does not allow any dry-out from either side. Some wall and roof assemblies are only durable if they are allowed to dry out towards the interior side as well. The current state-of-the-art experience with building enclosures exposed to transient temperature and moisture loads shows that the approach to create a durable hermetic sealing is almost impossible and should be replaced by a controlled moisture management approach. It is better to use moderate vapor retarding layers instead of vapor barriers in order to assure a sufficient drying potential. In this paper the transient temperature and moisture behavior of building enclosure assemblies is investigated for cold and northern coastal climates in the United Sates with the aid of a hygrothermal simulation model. By way of an example case, the consequences of choosing a moderate vapor retarder and a retarder that reacts to the ambient humidity are demonstrated.

INTRODUCTION

Vapor control strategies often concentrate solely on protecting the building enclosure from condensation of indoor air humidity during winter time. The simplest solution is the installation of a vapor tight layer, e.g. PE-film between the insulation and the interior finish of the structure. However, such a layer does not only protect the enclosure from the indoor air humidity, it also prevents moisture in the building assembly to dry towards the living space during warmer seasons. This may be a severe drawback when other moisture sources, such as air leakage or water penetration cannot be completely excluded. Building materials that appear to be dry often store a considerable amount of hygroscopic moisture that can migrate within the building assembly if subjected to a temperature gradient. Usually there is also some moisture contribution by lateral diffusion through embedding elements, like partition walls or floors. Even more important may be convective vapor entries through small defects despite employing an air barrier.

A solution to his dilemma would be to employ a vapor control strategy that does not totally block the important drying process and still provides sufficient protection against interstitial condensation. This can be achieved by carefully balancing the diffusion fluxes in both directions, towards the interior and exterior, with tailor made vapor retarding layers as suggested by Straube [2002]. This implies that the transient climatic loads acting on the building enclosure and their moisture contributions have to be determined in order to derive the optimum characteristics of the vapor retarding layer. Employing hygrothermal simulations is probably the most efficient way of achieving this. Therefore the practical application of such simulations for the design of a forgiving vapor control strategy for building enclosures in cold and coastal climate conditions is demonstrated in this paper by analyzing the hygrothermal loads and developing adaptable vapor control solutions.

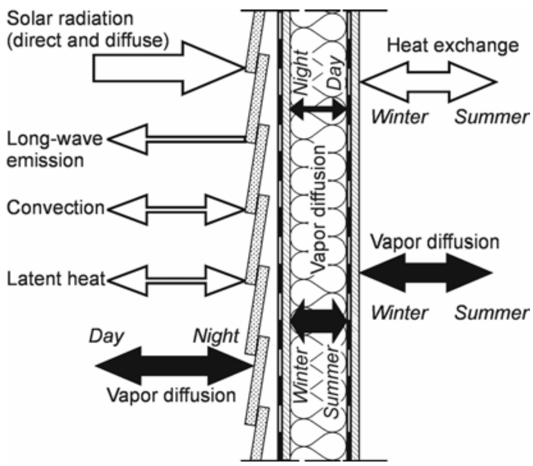

Fig. 1: Schematic representation of the hygrothermal effects and their alternating diurnal or annual directions in a wall construction.

TRANSIENT HYGROTHERMAL CONDITIONS

The main function of the building enclosure is the protection of the indoor spaces from natural weather. The building enclosure provides protection for more than precipitation and wind that occur only sporadically but solar radiation and the outdoor air conditions are also critical. In Figure 1 the hygrothermal loads, their directions and influence on the vapor diffusion process within the thermal envelope are represented schematically for a wall. Usually, the loads show mainly 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 (infra-red) 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.

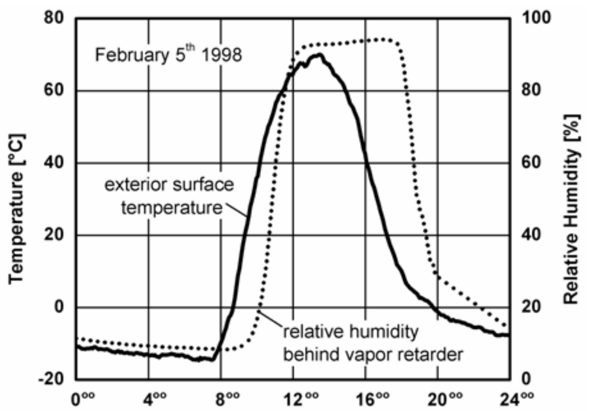

Fig. 2: Diurnal evolution of surface temperature and RH between the vapor retarder and the fiber glass insulation measured at a south facing cathedral ceiling during a sunny winter period in Germany.

The hygrothermal loads bear 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 consequences for the hygrothermal conditions in the assembly can be estimated from results in Figure 2 which were recorded in a sheet-metal cathedral ceiling (orientation: south, inclination: 50°). The fluctuations of the exterior surface temperature and the relative humidity in the mineral wool insulation next to the vapor retarder during a bright winter day can be very large. In this example, the temperature of the sheet-metal covering rises from -15°C (5°F) during the night to 70°C (158°F) at noon. This strong increase in surface temperature drives the moisture from the wooden sheathing (bearing of the sheet-metal) to the interior side. For that reason the relative humidity behind the vapor retarder rises from 10% to more than 90%, with a small delay. In the following night, the exterior surface temperature and the relative humidity behind the vapor retarder go back to their initial states. These experimental results clearly show the diurnal humidity variations that may appear in the building envelope 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.

SIMULATION TOOL TO TAILOR VAPOR CONTROL

Today, hygrothermal simulation tools are available for the practitioner to tailor the vapor control components, e.g. the vapor retarder of a building enclosure [Trechsel 2001]. For the simulations in this paper, the most widely used tool in Europe and North-America called WUFI® [Künzel 1995] will be employed. This model calculates the coupled transport of heat and moisture taking into account heat transfer by conduction, radiation and vapor flux with phase change as well as moisture transfer by vapor diffusion, surface diffusion and capillary flow. Input parameters are outdoor and indoor climate conditions on an hourly basis including temperature, humidity, radiation, precipitation and wind as well as the following material property data: thermal capacity and conductivity, humidity depending moisture retention and vapor permeability, temperature and moisture depending liquid diffusivity. Air convection is not included in the model because the real processes involving convection are rather complex. They require well defined specifications of air pressure distributions and fluctuations at different locations of the building envelope as well as exact dimensions of leakages within the building assembly. The 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 WUFI® or WUFI®-ORNL [Karagiozis et al. 2001] has also been confirmed by independent authors who compared experimental data with WUFI® predictions [e.g. Straube & Schumacher 2003, Kalamees & Vinha 2003].

Simulation tools like WUFI® are usually applied to assess the hygrothermal performance of building envelope systems and sub-systems in order to prevent moisture damage. However, they may also be used to create new and innovative envelope components or building materials by running parametric studies with virtual assemblies or material layers. One such example is the development of the smart retarder, a humidity controlled vapor retarding PA-film described in Künzel [1998]. The development of that vapor retarder would have been impossible without a hygrothermal simulation model. Therefore the development process will briefly be summarized here.

This development was inspired by moisture accumulation problems in unvented roof and wall constructions found in practice. Because most of these assemblies had rather vapor tight exterior surface layers, low-perm vapor barriers were installed to protect them from interstitial condensation. However, in the case of a minor imperfection that lead to some moisture intrusion such an assembly would fail because of the restrictive drying potential to either side. It was evident that part of the problem was the diffusion resistance of the vapor barrier. The solution to this problem was to find a vapor retarder that was tight enough to prevent excessive interstitial condensation (in the German standard on interstitial condensation the maximum amount of condensate tolerated lies between 0.5 and 1.0 kg/m² depending on the type of material in the condensation plane) while still allowing some moisture penetration to provide a sufficient drying potential for the building enclosure.

The first stage of the development process aimed at the optimization of the vapor permeance of the retarder by simulating the moisture behaviour of timber-framed walls and cathedral ceiling constructions exposed to Central European climate conditions. It turned out that a vapor retarding layer between 1 and 2 perm was the best compromise between the requirement to prevent excess interstitial condensation and the need to provide better drying potential of these constructions to eliminate moisture damage during the summer period. This moisture management compromise was not good enough for all considered assemblies. While the drying potential is clearly better than with the traditional poly or aluminium vapor barrier, the diffusion drying was not large enough for all types of climatic loads.

Therefore, the vapor diffusion characteristics of the optimum retarder had to be tailored in a way that enhanced the drying potential of the assembly during the summer season. This was achieved by increasing the retarder's permeance during the evaporation period (summer time) while keeping the permeance low during the condensation period (winter time). The permeance is required to be variable and this variation had to be a function of a parameter that differs distinctly between the condensation and evaporation period. As explained above, the relative humidity at both sides of an installed vapor retarder is such a parameter. A virtual material was created for the simulation that had a vapor permeance ten times higher in the summer period compared to the permeance during winter. Subsequent simulations showed that a retarder with such a vapor diffusion characteristic would provide a good solution preventing moisture problems in all the considered constructions. The only remaining item was to select a film with properties that matched the virtual retarder determined in the simulations.

Several polymeric films were tested in the laboratory and the PA-film whose vapor transport characteristics are shown in Figure 3 was chosen because its humidity depending permeance corresponds with the properties of the virtual retarder defined by the hygrothermal simulations. Experimental results [Künzel 1999] confirmed the positive results of the simulations, and this innovative material was set for a successful market introduction in Europe.

As the climate conditions in large parts of North America resemble those in Europe this variable-perm retarder would also help to solve moisture problems encountered in American and Canadian building envelope design. By way of an example case it is shown how certain types of building materials or assemblies can be transferred from one part of the world to another by applying hygrothermal simulation.

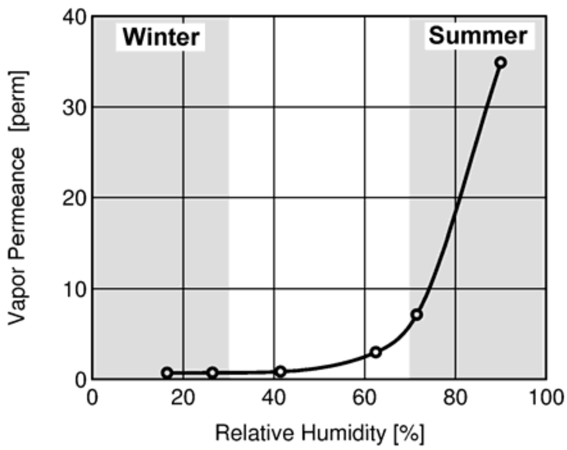

Fig. 3:Vapor permeance of a 2 mil polyamide film as a function of ambient RH

VAPOR CONTROL SIMULATIONS FOR NORTH AMERICAN CLIMATE

The building assembly considered in this paper is depicted in Figure 4. It is a 2·6 inch wood stud structure with fiber glass insulation, an exterior OSB sheathing covered by a water and vapor tight (0.1 perm) bituminous membrane (res. building paper under vinyl siding) coated with bright paint (solar absorptivity 0.4). The interior finish is provided by a gypsum board with a moderate vapor retarder. The outdoor climate chosen for the simulation was the 10% cold year for three U.S. cities from the climate data of the WUFI®-ORNL/IBP [Karagiozis et al. 2001]. The choice of the indoor climate for January is 70°F (21°C) and a relative humidity of 40% (Minneapolis) res. 50% (Boston) and 55% (Seattle). In July the indoor temperature and humidity is set for all three cities to 75°F (24°C) and 60% RH. The initial water content of the OSB is assumed to be twice the equilibrium moisture content at 80 % RH (30% by mass).

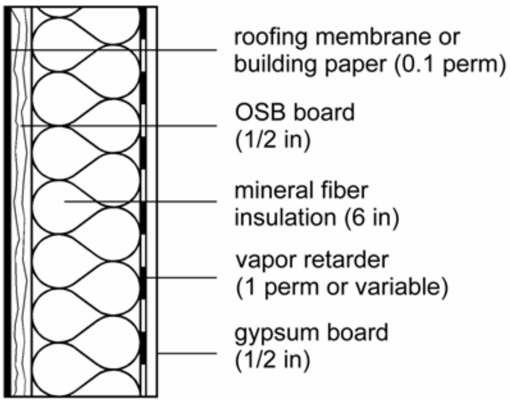

Fig. 4: Composition of the basic roof or wall assembly investigated by hygrothermal simulations

The resulting monthly averages of the vapor pressure differences between the OSB and the indoor climate is plotted in Figure 5 for a flat roof and a north facing wall. For all three locations as well as both orientations (horizontal and vertical) the vapor drive point towards the building enclosure in January and outwards of the enclosure towards the living space in July. While the vapor pressure differences in January do not vary a lot with the different locations or orientations, there is a comparatively high vapor pressure difference and hence drying potential in July between the flat roof and the indoor air. This has also been reported previously by Desjarlais and Byars [1998] who have developed a tool to assess the moisture tolerance of so-called self-drying roofs (roofs without low-perm vapor barriers). This tool helps the designer to decide what kind of vapor retarder (if any) is appropriate for his roof construction.

Compared with the drying potential of flat roofs, the drying potential of the north facing walls is much lower. For the locations considered in the paper, 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 those conditions more closely. The vapor diffusion into and out of the wall assembly (vapor diffusion balance) can be determined by hygrothermal simulations assuming the same construction details and boundary conditions as above.

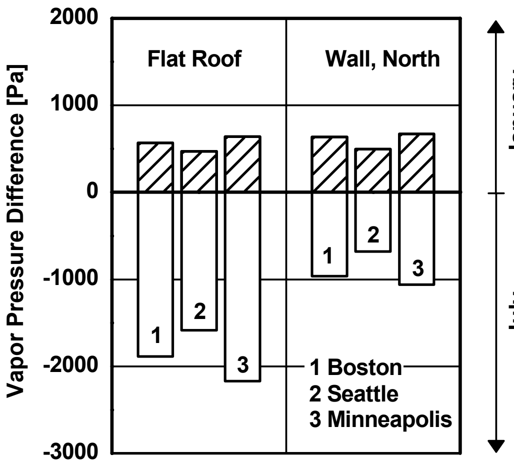

Fig. 5: Mean vapor pressure difference between the moist OSB sheathing of the building enclosure and the indoor air in January and July for 3 U.S. cities. Positive vapor pressure differences indicate condensation conditions and negative values quantify the drying potential of the building enclosure.

Figure 6 demonstrates the moisture accumulation due to condensation from November to April for Boston, Seattle and Minneapolis. The quantity of moisture drying out during the period from May to July (negative values) is also shown. In all cases, the moisture that permeates through the one-perm retarder into the wall assembly from November to April does not completely dry out until the end of July. Even though the underlying boundary conditions leading to this critical situation are rather severe, they are not unrealistic. Therefore, a one-perm vapor retarder cannot be recommended for constructions like the one considered here in climate zones comparable to the climates of Boston, Minneapolis and Seattle. The answer to this dilemma could be the installation of a low-perm retarder (permeance < 0.1 perm) using only pre-dried materials and very good workmanship. An alternative idea is to investigate new solutions. Chapter 23 of the ASHRAE Handbook of Fundamentals 2001 points out two so-called smart retarders “that allow substantial summer drying while functioning as effective vapor retarders during the heating season”. While one of these retarders, the water permeable retarder, is only suitable for roofs [Künzel & Leimer 2001], the humidity controlled PA-film developed for European climate conditions might also be appropriate here.

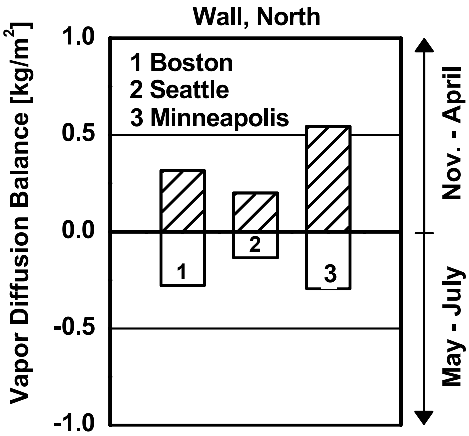

Fig. 6: Calculated vapor diffusion balance of the north facing wall with a one-perm retarder in Boston, Seattle and Minneapolis showing the maximum moisture content by condensation from November to April (hatched area) and the amount of moisture that dries out from May to July.

If the one-perm retarder in the reference case of a north facing wall is replaced by the PA-film (diffusion properties see Fig. 3) the drying potential of the assembly should be significantly increased. Figure 7 shows the results for the same situation as Figure 6 only with the variable-perm retarder. During the heating period from November to April the amount of interstitial condensation is only slightly reduced because the permeance of the PA-film under the prevailing conditions is only about 20% less than 1 perm. In all cases the accumulated condensate is well below the critical limit of 0.5 -1.0 kg/m². 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) and 4 times (Boston) higher than the amount of interstitial condensation. Because the OSB is initially rather wet (30% by mass) the amount of drying moisture can be higher than the amount of condensing vapor. 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 (hardly surprising) for the building enclosure among the location considered here.

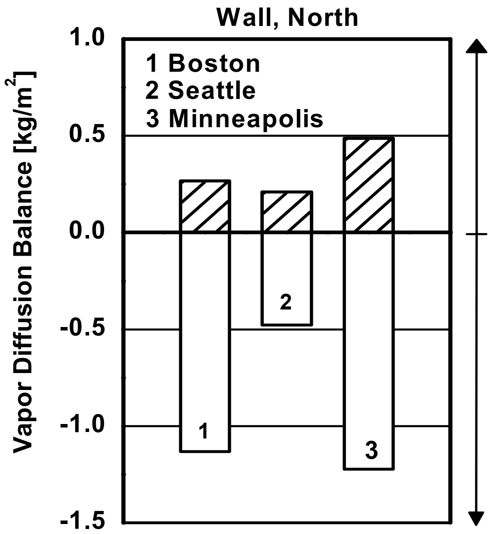

Fig. 7: Calculated vapor diffusion balance of the north facing wall with the variable-perm retarder (2 mil polyamide film) in Boston, Seattle and Minneapolis showing the maximum moisture content by condensation from November to April (hatched area) and the amount of moisture that dries out from May to July.

CONCLUSIONS

In recent years, hygrothermal simulation models have become useful tools for moisture engineering in building design. They have been successfully employed to predict the hygrothermal performance of building materials and envelope systems under different indoor and outdoor climate conditions. There are even some examples where hygrothermal simulations have resulted in the development of innovative solutions for better building enclosures. The application example presented here is of practical importance for safer moisture design of building enclosures in Europe and North America. The simulation results of the enclosures considered can be summarized as follows:

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.

An adequate drying potential towards the interior living spaces is extremely beneficial for the reduction of moisture damage risks.

The definition of an appropriate vapor retarder by hygrothermal simulations represents the best solution for a specific building assembly in a certain climate.

For cold and northern coastal climates in the U.S. as well as for similar climate zones in Europe, Canada and other parts of the world, the installation of a humidity controlled, variable-perm vapor retarder seems to be a recommendable solution for the envelope design of residential buildings.

However, even the most appropriate vapor retarder cannot compensate bad workmanship. The tolerable leakage rates for rain water penetration must not exceed the calculated summer drying rates.

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