Influence of rain water leakage on the hygrothermal performance of exterior insulation systems

Hartwig M. Künzel, Dr.-Ing.
Department of Hygrothermics, Fraunhofer Institute for Building Physics;
hartwig.kuenzel@ibp.fraunhofer.de

Daniel Zirkelbach, Dipl.-Ing.,
Department of Hygrothermics, Fraunhofer Institute for Building Physics;
daniel.zirkelbach@ibp.fraunhofer.de

SUMMARY:
This investigation shows that ETICS on light weight structures pose no moisture problem in cold and moderate climates when the detailing of joints and openings is well done, i.e. there is no rain water leakage. This holds for all locations investigated. However, if water leakage cannot be excluded completely and therefore the North-American Standard assumptions - penetration of 1% of the driving rain load - are applied this picture changes, making the drying potential an essential feature. The normal ETICS composed of vapour retarding EPS insulation slabs cannot provide much drying towards the exterior and may therefore bear a moisture damage risk for the underlying substrate. The application of a humidity controlled vapour retarder (PA-film) instead of a conventional polyethylene film at the interior side of the building assembly enhances the overall drying potential of the construction by allowing some vapour diffusion towards the interior spaces. But only in warmer locations, like Wilmington in North Carolina or Lisbon, employing such a vapour retarder may be a compensation for small rain water leaks. The best but also most expensive solution would be to replace the expanded polystyrene (EPS) by high density mineral wool insulation slabs in the ETICS.

Alternative ways of solving the rain penetration problem are currently being developed and tested in North-America. Many systems now provide a drainage plane between the substrate and the ETICS and flashing to force the water out at the bottom of the wall. Other systems keep the face seal approach and rely on more sophisticated detailing and flashing. In both cases the long-term performance is still unknown. In order to avoid a repetition of the North-American problems with ETICS on wooden structures, it is important to communicate this issue and possible solutions to the European construction trades. Hygrothermal simulations may help to raise the awareness to the damage risks and the importance of qualified workmanship involved in the application of ETICS especially in cases of high wind driven rain loads.

1. Introduction

External Thermal Insulation Composite Systems (ETICS) also called Exterior Insulation Finish Systems (EIFS) in North America have been installed on buildings for about 50 years. Despite being exposed to higher hygrothermal loads than most façade systems, ETICS on concrete or masonry have done very well in Europe. They seem to be at least as durable as conventional façades with render or stucco [Künzel et al. 2006]. However, there is only little long-term experience concerning the application of ETICS on wood frame structures in Europe where these systems are increasingly installed to alleviate thermal bridging caused by the framework or to retrofit existing buildings. Therefore, it makes sense to analyze the situation in North America where ETICS on wooden structures have a mixed track record due to numerous failures related to elevated moisture in the construction. Since it is unlikely that the reported damage cases will remain confined to North America, this paper will investigate the hygrothermal behaviour of ETICS on wooden structures under selected climate conditions in North America and Europe.

2. Composition of External Thermal Insulation Composite Systems

ETICS in North America usually closely resemble those in Europe. The standard composition of an ETICS is shown in Fig. 1. The ETICS is usually fastened to the exterior sheathing of a wood stud wall or on a masonry wall. In most ETICS expanded Polystyrene (EPS) is used as insulation material. The use of high-density mineral fiber insulation which is also quite common in Europe is practically unknown in North America. On top of the insulation slabs a polymer modified base coat including a reinforcing glass fiber mesh are applied, followed by a finish coat. The reinforced base coat together with the finish or top coat is usually 5 to 10 mm thick.
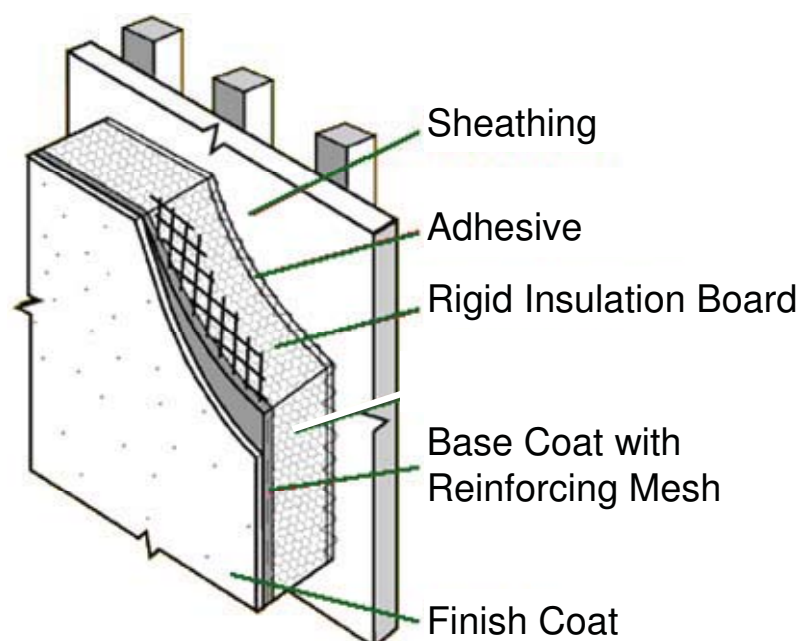
Sheathing

Adhesive

Rigid Insulation Board

Base Coat with
Reinforcing Mesh

Finish Coat

*Fig. 1: Composition of a typical **E**xternal **T**hermal **I**nsulation **C**omposite **S**ystem*

3. Track record of ETICS

In the middle of the 90s the first substantial damage cases associated with ETICS were reported from North Carolina. Similar reports from other regions with high precipitation intensities (e.g. Seattle, Vancouver) followed. The moisture problems occurred mostly at the exterior sheathing boards that served as substrate for the ETICS. Pictures of rotten OSB or disintegrated gypsum board quickly spread among the building community and forced manufactures to react [Nisson & Best 1999]. A comprehensive literature review analysing more than 10 investigations carried out on several objects each, comes to the following conclusions [Cheple & Huelman 2000]. The main reasons for moisture damage are leaks around windows and joints where rainwater penetrates beneath the insulation layer. However, problems due to air convection or diffusion of indoor air may also have caused elevated moisture in some cases. An aggravating factor is the low drying potential of the construction. Moisture can neither dry-out quickly to the exterior because of the vapour retarding foam insulation nor to the interior due to the usual presence of a polyethylene vapour barrier. The solutions proposed in [Cheple & Huelman 2000] are limited to managing rain water penetration by proper sloping and flashing of joints and wall openings and by applying drainable insulation systems. Sheathing materials that are sensitive to moisture such as untreated gypsum board are considered inappropriate as ETICS substrates. Other work has shown that enhancing the drying potential towards the interior spaces by an innovative vapour control strategy may also alleviate the problem [Karagiozis & Kumaran 1997].

The moisture problems that occurred in North American in the 90s were not limited to walls having ETICS. Buildings with normal stucco façades (render applied on building paper over OSB or plywood) were also affected [Lawton 1999]. This resulted in a new design approach that aimed at better detailing to reduce rainwater penetration and at increasing the drying potential of the whole assembly. It has been realized that it is difficult to set-up a perfect building that will never leak. Therefore the building envelope should be designed in such a way that small leaks can be handled. Consequently the ASHARE Standard 160 on criteria for moisture design [BSR/ASHRAE 2006] states that in the absence of performance proofs it should be assumed that 1% of the wind driven rain hitting the façade is deposited on the weather resistive barrier (WRB) behind the cladding. If there is

no WRB another layer should be selected where the penetrating rainwater is likely to go (e.g. sheathing beneath the ETICS in Fig. 1). The selected leakage rate in this standard is not meant to be a worst case scenario. It is not based on field test results but on hygrothermal simulations (e.g. Desjarlais et al. 2001) that showed that more than 1% of rainwater penetration may be detrimental for a large portion of existing wall structures.

In Europe ETICS are applied for about 50 years. More than 40 million square meters of ETICS are installed on new and existing buildings every year in Germany and severe problems or damage cases have been rare [Künzel et al. 2006]. In contrast to North America where ETICS are mainly considered as a finish system, the purpose of ETICS in Europe is to provide adequate thermal performance of external walls that usually consist of masonry or cast-in-place concrete. Therefore the average insulation thickness is higher in Europe (approx. 100 mm in 2006) than in the U.S. (25- 50 mm). ETICS in Europe require a Technical Approval as a system ensuring harmonized system components and trained installers. However, it is doubtful that better quality control and workmanship alone can explain the huge difference in past performance of ETICS between Europe and North America. An important reason is probably the sensitivity of the substrate. While concrete and masonry readily absorb and redistribute small quantities of leakage water without any signs of degradation, the same amount of water may severely damage typical sheathing materials of North American stud walls such as OSB, plywood or gypsum board. Since ETICS have more recently been applied to wooden wall structures in Europe too, there may also be an increase in moisture problems as the ones described in [Schulze & Radovic 1992] and [Schumacher 2006]. Therefore it makes sense to investigate the moisture tolerance of wooden structures with ETICS for European construction types and climate conditions in order to prevent moisture-related problems.

4. Hygrothermal simulations

The transient temperature and moisture distributions in external wall assemblies with ETICS are calculated using version 4.1 of the hygrothermal simulation model WUFI[®] [Künzel 1995] which has been validated many times by comparison with experimental building envelope investigations including measurements on wall structures with ETICS (e.g. [Künzel 1998a]). In order to cover North American and European building traditions the following wall assembly has been selected.

- ETICS: 10 mm lamina (exterior rendering) on 60 mm EPS

- Sheathing: 15 mm OSB

- Cavity insulation: 160 mm glass fiber

- Vapour retarder: polyethylene film ($s_d = 20$ m) or polyamide film (0.1 m $< s_d < 5$ m)

- Interior panelling: 12 mm gypsum board (installation gap 40 mm)

The material properties are taken from the WUFI[®] database. The polyethylene (PE) film represents a standard vapour retarder with a diffusion resistance (s_d) of 20 m. The polyamide (PA) film is a humidity controlled vapour retarder whose diffusion resistance varies with ambient humidity conditions [Künzel 1998b]. It has been developed to enhance the drying potential of building assemblies [Künzel & Leimer 2001]. The colour of the exterior stucco is assumed to be bright (solar absorptivity 0.4).

4.1 Selected locations and loads

The first location considered is North Carolina where the ETICS problems started. As representative weather conditions the meteorological data for a cold year in Wilmington are selected from the WUFI[®] climate database. For Europe a sample of four locations is chosen: Hannover in the middle of Germany's Northern plain, Lisbon at the Atlantic South-West Coast of Europe, Locarno in the Southern part of the Swiss Alps and Vienna at the edge of the East-European plain. The average temperatures and humidities as well as the annual sum of wind driven rain hitting the middle of a low-rise building at the most exposed orientation are displayed for all selected locations in Table 1. While the average relative humidity does not differ much from one location to the other, the average temperature ranges from approximately 17°C to 25°C in summer and from 0°C to 10°C in winter. Hannover is the coldest place and Wilmington and Lisbon which are the warmest locations experience the highest wind driven rain loads.

The hygrothermal simulations which begin in October of the representative year are continued over a period of three years by repeatedly running through the same meteorological data-set. The initial conditions in all material layers of the building assembly are set to EMC_{80} (equilibrium moisture content at 80% RH). If rainwater penetration through imperfections cannot be ruled out, 1% of the wind-driven rain load from Table 1 is deposited on the exterior surface of the OSB sheathing [BSR/ASHRAE 2006].

Table 1: Driving rain load at the surface of the most exposed façade orientation and average hygrothermal conditions at the selected locations in North America and Europe.

Location	Driving rain load (façade orientation)	Rel. Humidity (annual mean)	Temperature (annual/monthly mean)		
			Year	January	July
Wilmington	186 l/m²a (S)	73%	16.1 °C	5.7 °C	24.9 °C
Hannover	160 l/m²a (W)	80%	8.6 °C	-0.1 °C	17.1 °C
Lisbon	193 l/m²a (W)	75%	15.6 °C	9.8 °C	20.7 °C
Locarno	133 l/m²a (E)	72%	11.5 °C	2.1 °C	22.2 °C
Vienna	112 l/m²a (W)	73%	10.4 °C	0.1 °C	20.6 °C

4.2 Simulation results

The North American damage cases have shown that the substrate layer to which the ETICS is applied, experiences the most critical moisture conditions in the assembly. Therefore the moisture content of the OSB sheathing is monitored in the present study. Fig. 2 displays the temporal variations in OSB moisture under three different scenarios. Assuming perfect workmanship (no leaks) results in permanently dry conditions (MC < 13 M-%) no matter what vapour retarder is applied to the interior side of the stud wall. If rainwater leaks are present the OSB moisture content will rise in wintertime with extended drying spells in summer. However, when there is only very little vapour diffusion towards the interior because of the rather impermeable vapour retarder (PE-film), the drying potential is limited and long-term moisture accumulation may occur (MC > 25 M-% after 3 years). By replacing the PE-film with the humidity controlled PA-film the drying potential is enhanced enough to assure long-term OSB moisture conditions below 18 M-%.
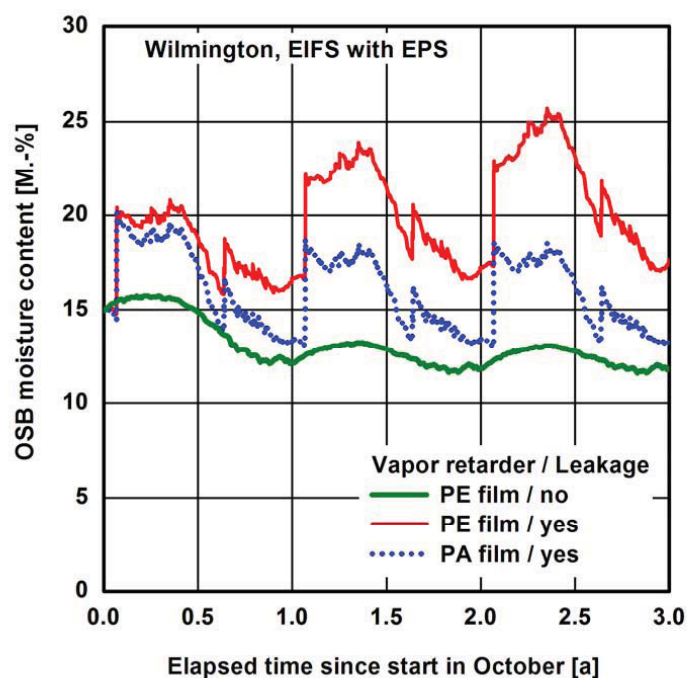

Fig. 2: Temporal variations of OSB sheathing moisture content beneath the ETICS in Wilmington for the standard case with and without rainwater leakage and with a PA-film replacing the PE-film as vapour retarder of the stud wall.

When the simulations are repeated for the coldest location considered (Hannover) there is a different picture (Fig. 3). Again, when there is no leak there is no problem. However, when there is a leak the OSB moisture content will repeatedly exceed 20 M.-% even if the dying potential to the interior is enhanced by the PA-film. An explanation for the different behaviours of the investigated building assemblies investigated under different climate conditions lies in the divergence in vapour gradients. The high summer time temperatures in Wilmington result in a considerable inward vapour drive making efficient use of the drying potential provided by the

humidity controlled vapour retarder. Without such a strong inverse vapour pressure gradient the drying rate towards the interior cannot compensate the rainwater leakage and damage may occur.
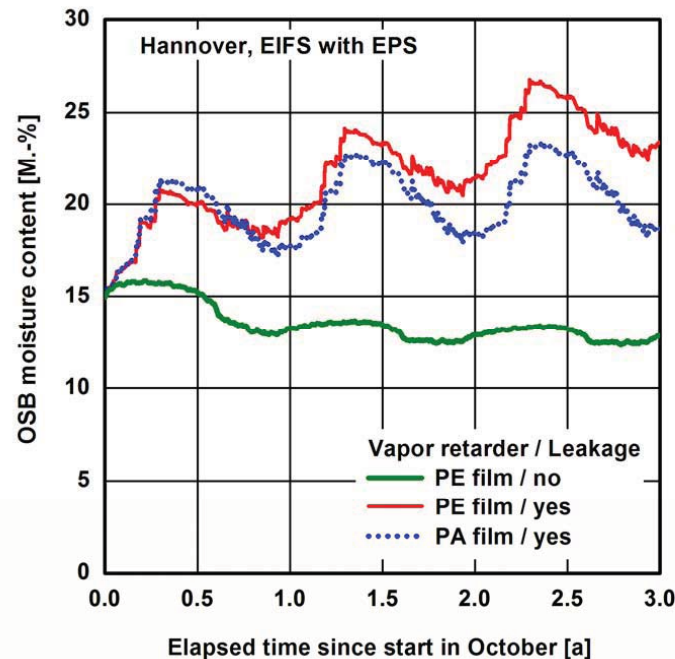

Fig. 3: Temporal variations of OSB sheathing moisture content beneath the ETICS in Hannover for the standard case with and without rainwater leakage and with a PA-film replacing the PE-film as vapour retarder of the stud wall.

A good indicator of potential problems is the maximum OSB moisture content attained during the 3rd year of the simulation period. In order to be on the safe side it should not exceed 20 M.-%. That means if rainwater penetration through imperfections is assumed, enhancing the drying potential towards the interior is no solution for Hannover. However it may help to enhance the drying potential towards the exterior by replacing the EPS insulation of the ETICS with high-density mineral wool slabs (MW). This kind of insulation material which is largely unknown in North America is widely used for ETICS in Europe. Its thermal conductivity is very similar to that of EPS but its vapour permeability is very high. When such a system is applied to a stud wall in Hannover, the OSB moisture content remains well below 20 M.-%, even if the defined rain water penetration occurs.

The simulation results of all European locations are summarized in Fig. 4 by comparing the maximum moisture content in the OSB sheathing during the third year. The best solution with the lowest OSB moisture content at all locations is the choice of mineral wool (MW) as ETICS insulation material. However, all variants seem to work in Locarno and Vienna where the annual wind driven rain load is less than 140 l/m²a. In Lisbon the situation is comparable to Wilmington, i.e. enhancing the drying potential towards the interior by employing a special vapour retarder appears to be sufficient.
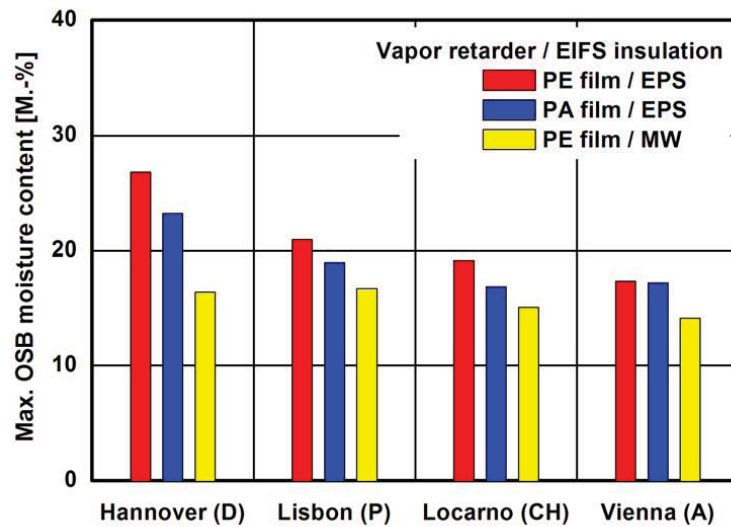
Fig. 4: Maximum moisture content of the OSB sheathing during the simulated 3-year period at different European locations depending on the vapour retarder of the stud wall and the insulation material of the ETICS.

It has been already mentioned that the rainwater leakage rate of 1% of the total amount if wind-driven rain hitting the wall in the ASHRAE draft standard 160 [BSR/ASHRAE 2006] is not a worst case scenario. Therefore, the simulations are repeated for the best performing walls with mineral wool insulation, this time with higher rainwater leakage rates. Fig. 5 shows the OSB moisture content of the stud wall when 1%, 2%, 3% or 4% of the wind-driven rain load is deposited evenly over the thickness of the OSB sheathing. While the wall can still handle an increase in rain water penetration rate by the factor of 2 compared to the specifications in the ASHRAE draft standard 160, a further increase (3% or 4% of wind-driven rain load) will lead to OSB moisture content peaks in excess of 20 M.-%.
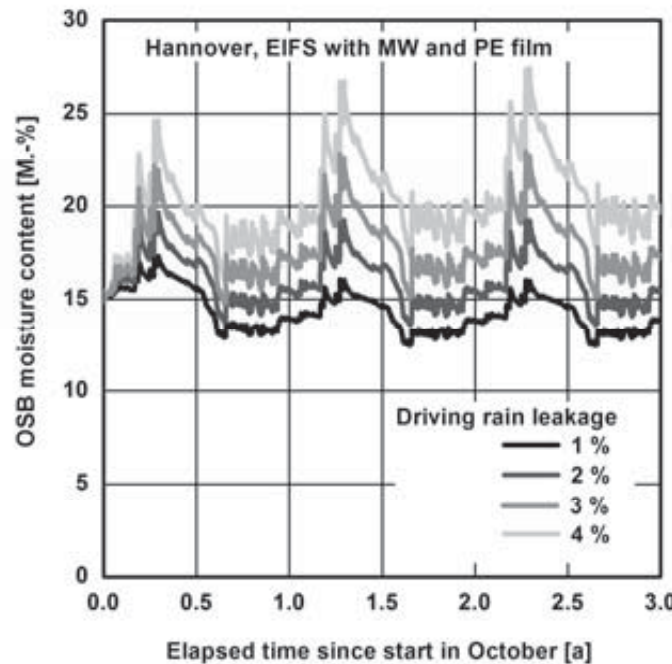

Fig.5: Temporal variations of OSB sheathing moisture content beneath the ETICS with mineral wool insulation in Hannover with different rainwater leakage rates.

5. Summary and Conclusions

This investigation shows that ETICS on lightweight structures pose no moisture problem in cold and moderate climates when the detailing of joints and openings is well done, i.e. there is no rainwater leakage. This holds for all locations investigated. However, if water leakage cannot be completely excluded and therefore the North American Standard assumptions - penetration of 1% of the driving rain load - are applied this picture changes, making the drying potential of this type of wall assemblies an essential feature. The normal ETICS composed of vapour retarding EPS insulation slabs cannot provide much drying towards the exterior and may therefore be responsible in part for increasing the risk of moisture damage for the underlying substrate. The application of a humidity controlled vapour retarder (PA-film) instead of a conventional polyethylene film at the interior side of the building assembly enhances the overall drying potential of the construction by allowing some vapour diffusion towards the interior spaces. But only in warmer locations, like Wilmington in North Carolina or Lisbon, the effect of employing such a vapour retarder is great enough to compensate for small rainwater leaks. The best but also most expensive solution to reduce the risk of moisture related problems in EITCS wall assemblies would be to replace the expanded polystyrene (EPS) by a high-density mineral wool insulation. However, even this solution will not work if the rainwater penetration exceeds the amount specified in the ASHRAE draft standard. Therefore, proper detailing and good workmanship are essential prerequisites when classical ETICS systems are installed.

Alternative ways of solving the rain penetration problem are currently being developed and tested in North America [Onysko & Thivierge 2007]. Many systems now provide a drainage plane between the substrate and the ETICS and flashing to force the water out at the bottom of the wall. Other systems keep the face seal approach and rely on more sophisticated detailing and flashing. In both cases the long-term performance is still unknown. In order to avoid a repetition of the problems with ETICS applied to wood frame structures in North America, it is important to communicate this issue and possible solutions to the European construction trades. Hygrothermal simulations may help to raise the awareness to the risks of damage and the importance of qualified stuff involved in the application of ETICS especially for locations having high wind driven rain loads.

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