Influence of temperature and relative humidity on the durability of mineral wool in ETICS

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ABSTRACT

When an exterior thermal insulation composite system (ETICS) is applied to an outer wall containing build in moisture, the insulating material can be subjected to an increased moisture strain during the drying-out phase. Short-term increases in moisture levels may also arise as a result of driving rain. If high temperatures occur at the same time then they may affect the durability of the insulating material.

This paper aims to predict the moisture and temperature strains who occour in an ETICS under natural climatic conditions at three different locations in northern, middle and southern Europe using computational simulations. By comparing these results with a field test it is possible to determine the maximum hygrothermal loads which arise in the insulating material of an ETICS under European climate conditions. These maximum loads can serve as a basis to review the boundary conditions for durability tests of insulating materials in the laboratory.

KEYWORDS

Durability, ETICS, Mineral wool, pull-off strength

1. PROBLEM

To check the influence of moisture and temperature on the long-term behaviour and pull-off strength of mineral wool in Exterior Thermal Insulation Composite Systems (ETICS) the European Organisation for Technical Approvals (EOTA) proposes two different (alternative) laboratory tests. For both the mineral wool has to be exposed to a high temperature and relative humidity before the pull-off test. In the first one the material has to be exposed 7 days to climate conditions of 70 °C and 95 % relative humidity (RH) and 7 further days at 23 °C and 50 % RH (Northern Test). For the second one the mineral wool stays 5 days above hot water of 60 °C and will then be stored for 7 or 28 days in a vapour tight cup (Water Bath Test). Subject of this paper is, to determine the temperature and RH within the mineral wool layer of an ETICS under different European climatic conditions in Espoo/Finland (northern Europe), Holzkirchen/Germany (central Europe) and Lisboa/Portugal (southern Europe). Furthermore the pull-off strengths corresponding to the laboratory conditions are compared to the measured strengths of mineral wool exposed to the real climate of Holzkirchen in field tests.

2. INVESTIGATIONS

With the help of the well verified simulation tool for the transient heat and moisture transfer WUFI® [1], the hygrothermal behaviour of an ETICS based on mineral wool at the three different locations is simulated. The calculations are done for the west facing façade due to the maximum rain load at this orientation. The build up of the construction is as following: 20 mm exterior mineral render (lime cement plaster), 100 mm mineral wool, 240 mm lime silica brick and 12.5 mm gypsum board at the interior surface. The main focus is to determine the maximum moisture and temperature conditions within the insulation layer. For the exterior lime cement render a water absorption coefficient (A-value) of 1 kg/m2√h is assumed. The corresponding moisture transport coefficients are approximated according to [2]. The other material data are already included to the material database of WUFI. The basic material properties are listed in Table 1.

Construction material	Lime cement render	Lime silica brick	Mineral wool
Bulk density [kg/m3]	1900	1900	60
Heat capacity [kJ/kgK]	0,85	0,85	0,85
Heat conductivity [W/mK]	0,8	1,0	0,04
Porosity [vol. %]	24	29	95
Free saturation [vol. %]	21	25	--
Vapour diffusion resistance factor [-]	25	28	1,3
A-value[kg/m2√h]	1,0	2,7	--
Equilibrium water content at 80 % RH [vol. %]	4,5	2,5	--

Table 1: Basic hygrothermal material properties as used for the simulation

The initial moisture content in the lime silica brick amounts 10 Vol. -% (build in moisture); in the other materials an equilibrium moisture content at 80 % RH is assumed. The heat transfer coefficients are set to 17 W/m2K at the exterior, and 8 W/m2K at the interior surface. The short-wave absorption coefficient of the external plaster is 0.4. For the exterior climate hourly climate data of Holzkirchen, Espoo and Lisboa are used. The room climate varies as a sine curve between 20 °C, 40 % RH in winter and 22 °C and 60 % RH in summer. These values correspond to a normal use as dwelling house. The calculations are carried out over a time period of five years, beginning in October.

3. RESULTS

For validation the results are compared for the location Holzkirchen with measured data of a field test of ETICS in Holzkirchen 1998. In Figure 1 the calculated and measured combinations of temperature and relative humidity 1 cm beneath the exterior surface of the mineral wool (position of the measuring sensor) are plotted. The variation of the calculated values is larger than the measured data – probably due to only hourly steps for the calculation and approximated (not measured) liquid transport coefficients for the external render. Apart from this the correlation between calculation and measurement is satisfactory so that the calculations can be extrapolated to longer periods.

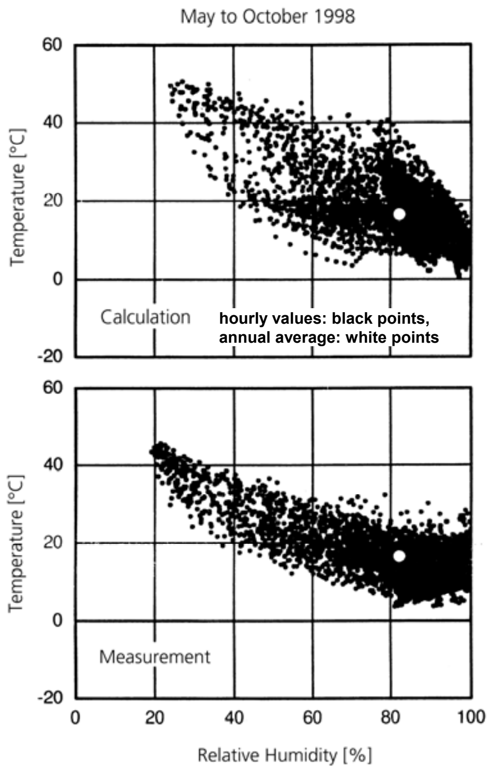

Figure 1: West facing façade at the location Holzkirchen (Germany)
Calculated (top) and measured (bottom) combinations of temperature and relative humidity in the mineral wool 1 cm beneath the exterior surface of the insulation.

Figure 2 shows the variation range and average profiles of temperature and relative humidity in the building component at the three different locations for the first and fifth year of the simulation.

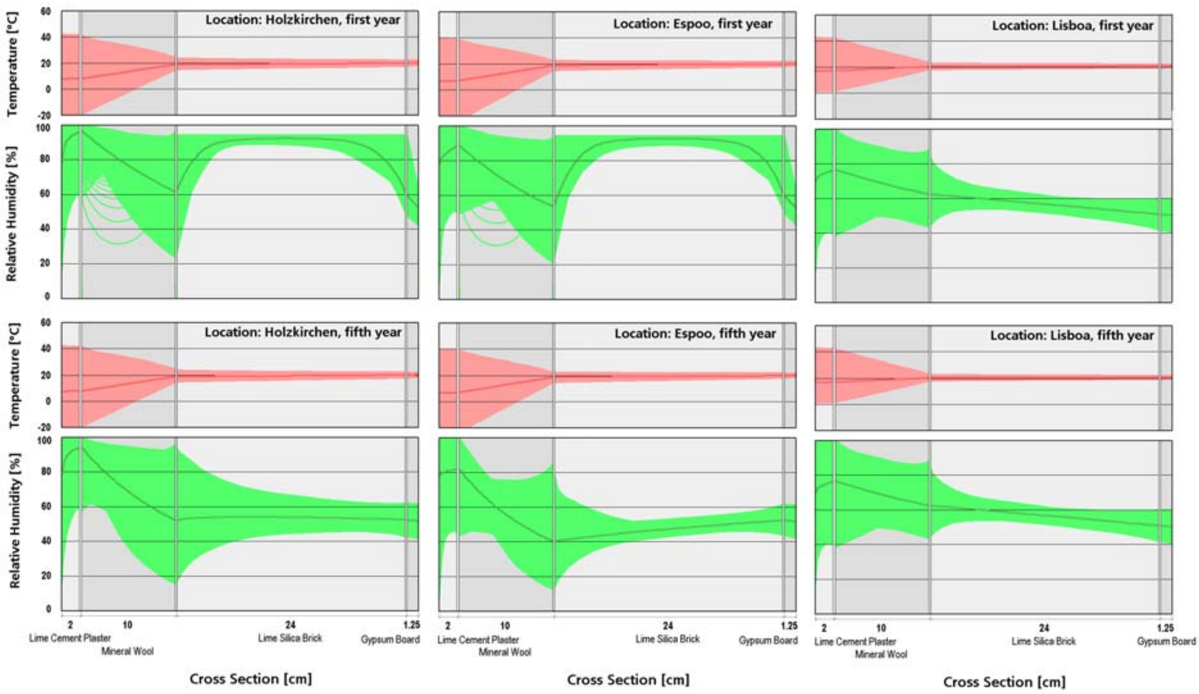

Figure 2: West facing façade at the three different locations Holzkirchen (left), Espoo (middle) and Lisboa (right). Variation range and average profile of temperature (red) and relative humidity (green) in the facade during the first (top) and the fifth (bottom) year of the simulation.

In the first year the dry out process of the lime silica brick can be seen. In the fifth year for every location the dry out is finished and the dynamic equilibrium is reached. At Holzkirchen the relative humidity within the mineral wool is in a range between 25 and 100 % RH for the first, and between 15 and 100 % in the last year. Nearly the same bandwith occurs in Espoo while the level of the relative humidity in Lisboa is higher: between 40 and 100 % RH. For all cases and all locations the highest and lowest values for relative humidity and temperature in the insulation layer arise at the interfaces between the mineral wool and the exterior render and between the mineral wool and the lime silica brick. So the combinations of relative humidity and temperature are plotted for these two positions for the first year (drying out process) and the fifth year (dynamic equilibrium) at every location.

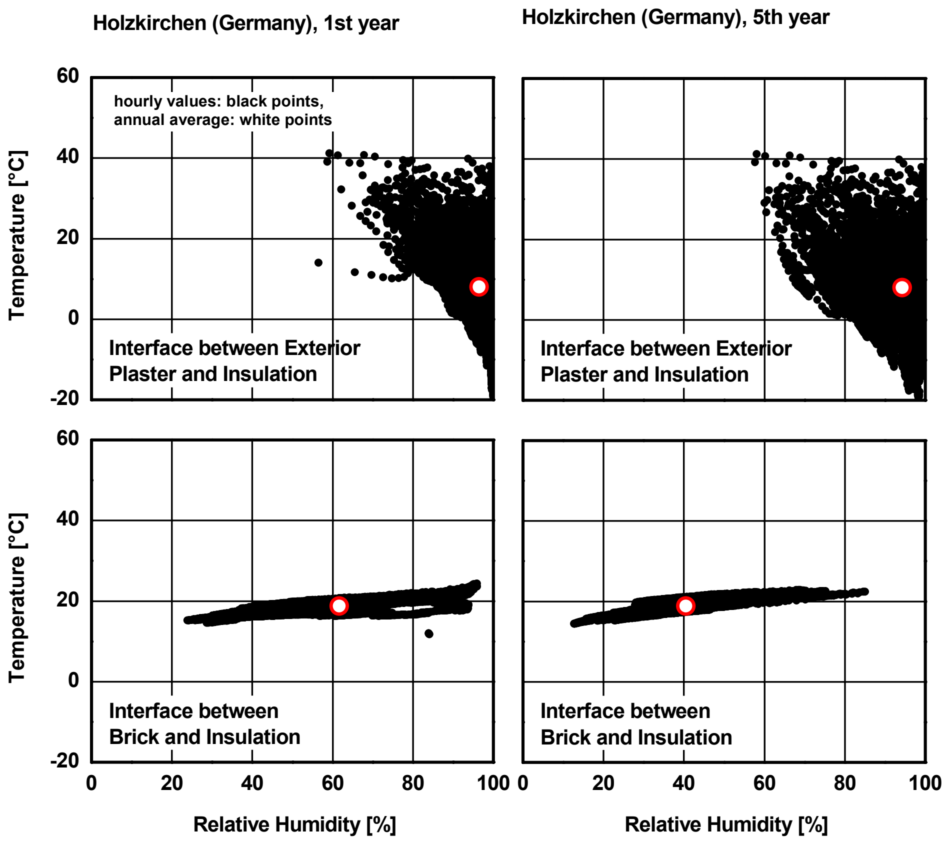

Figure 3: West facing façade at the location Holzkirchen (Germany).
Calculated combinations of temperature and relative humidity in the first (left) and fifth (right) year at two positions in the mineral wool: at the interface between exterior render and insulation (top) and at the interface between insulation and brick (bottom).

Figure 3 (left) shows these combinations for Holzkirchen. In the first year the range of the relative humidity is a little bit higher than in the fifth year while the temperature is nearly the same. The average relative humidity at the exterior of the mineral wool is in the first year at 96 % RH and in the fifth year at 94 % in both cases at a temperature of 8 °C. At the interior the temperature is about 19 °C and the relative humidity in the first year at 60 % RH and in the fifth year at about 40 %.

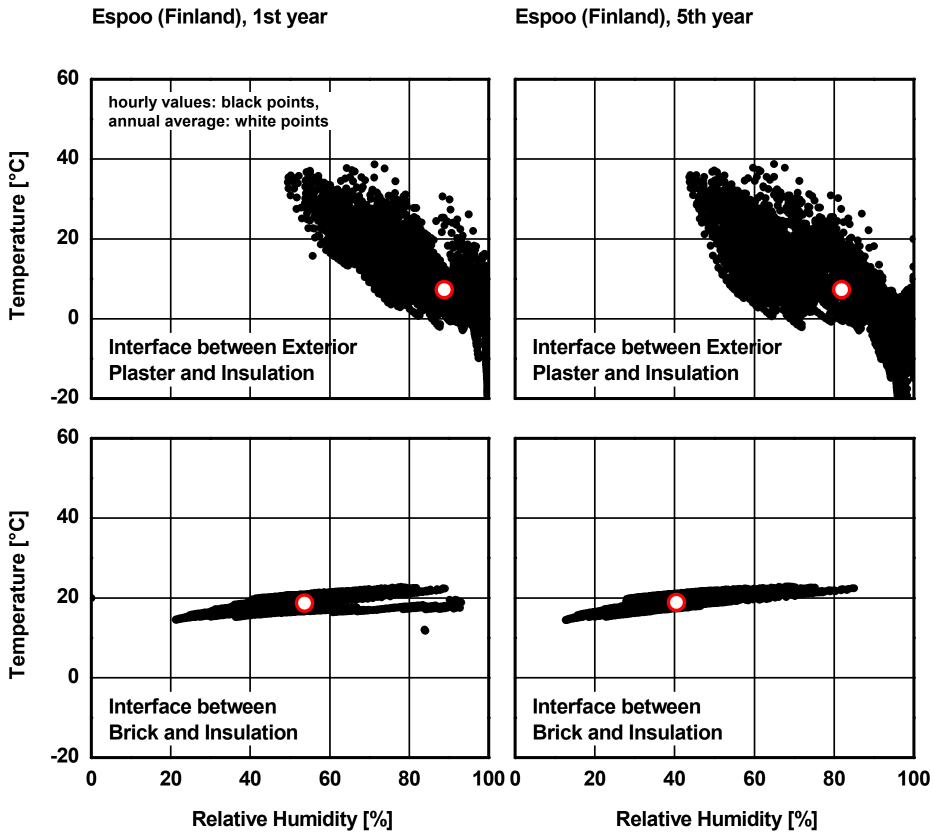

Figure 4: West facing façade at the location Espoo (Finland).
Calculated combinations of temperature and relative humidity in the first (left) and fifth (right) year at two positions in the mineral wool: at the interface between exterior render and insulation (top) and at the interface between insulation and brick (bottom).

In Figure 4 the combinations of RH and temperature are plotted for Espoo. Also here the relative humidity is higher in the first than in the fifth year but on a lower level. At the exterior of the insulation the average value falls from 89 to 82 % RH at about 7 °C, at the interior from 54 to 40 % RH at a temperature of 19 °C like in Holzkirchen. In Lisboa (Figure 5) the average relative humidity at the exterior of the insulation in the first year is even lower at 82 % and at 76 % in the last year. The temperature is at about 17 °C. At the interior the average temperature is at about 20 °C and the average relative humidity falls from 75 to 62 %, this is about 20 % higher than in Holzkirchen and Espoo. Dependent on the room climate conditions the temperature at the interior of the insulation layer at all locations is always in a range of 17 to 23 °C. Relative humidities over 90 % hardly occur. At the exterior interface higher temperatures as well as higher relative humidities are possible but at higher temperatures the relative humidity becomes tendentious lower. So combinations of RH higher than 90 % and temperature higher than 30 °C occur very rarely, temperatures over 40 °C at the same range of relative humidity (between 90 and 100 %) cannot be observed at no location neither in the dynamic equilibrium nor in the drying out phase. Comparing the three different locations the most critical conditions with the highest relative humidity can be observed at Holzkirchen while the drying out phase of the lime silica brick in the first year. So also the field test results for the progression of the pull-off strenght of mineral wool in Holzkirchen can be deemed to be representative for Europe.

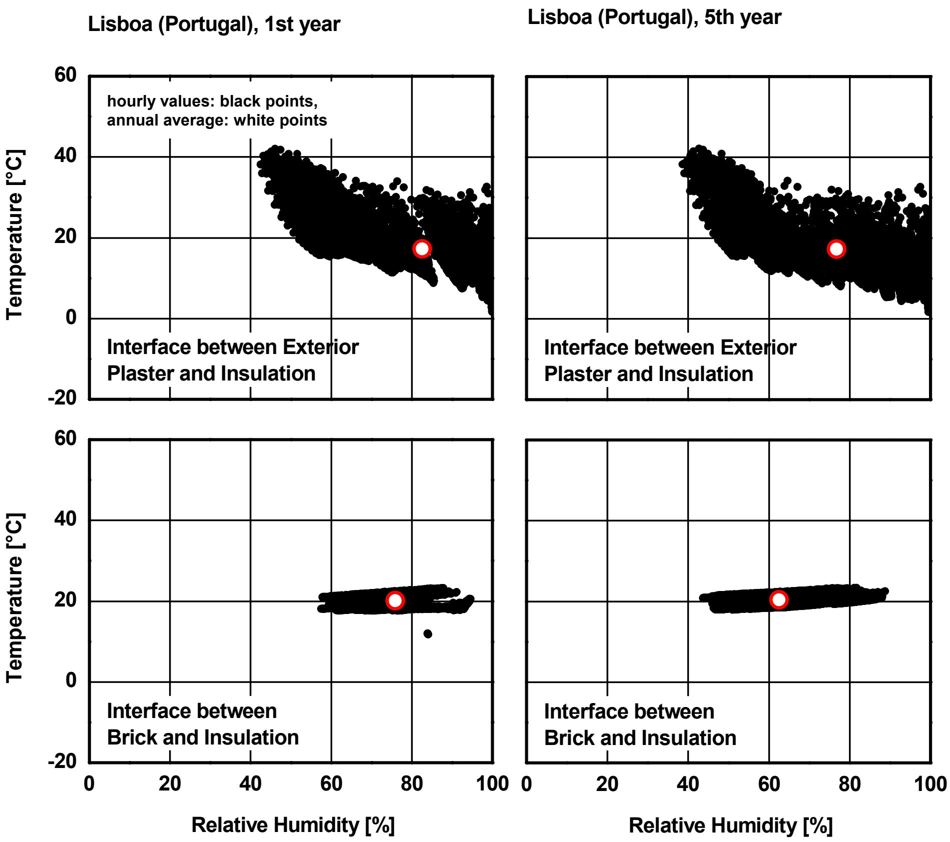

Figure 5: West facing façade at the location Lisboa (Portugal).
Calculated combinations of temperature and relative humidity in the first (left) and fifth (right) year at two positions in the mineral wool: at the interface between exterior render and insulation (top) and at the interface between insulation and brick (bottom).

Table 2 shows the pull-off strength of mineral wool after the two EOTA laboratory tests and after 1, 4, 11, 18 and 30 months of natural weathering in a field test at Holzkirchen compared with the properties of the new material. The results are very different for mineral wool standard boards and lamella boards. The standard boards have a fibre direction parallel to the wall surface while the lamella board fibres are perpendicualar to the surface. So the pull-off strength of the standard baord is more influenced by the properites of the binder and the strength of the lamella by the strenght of the fibres itself. Due to this the strength of the lamella board is with a mean value of 89 kN/m² for the new material much higher than the strength of the standard board with only 12.7 kN/m².

At the standard board the pull-off strength is reduced to 37 % after the Northern Test and 44 % after the Water Bath Test. Compared to this the strength after the field test stays clearly higher with a range of 51 % and 79 % of the initial strength. The lowest values occur after 4 months with 51 %, afterwards the strenghts is rising again up to 79 % after 30 months. The strength of the lamella board falls after the laboratory tests similar to the standard board to 35 % (northern test) and 43 % (wather bath test). In the field test the strength seems to be only little reduced with values between 80 % after 4 months and 97 % or 100 % in the further measurements. So the reduction seems to occur due to the strains during the construction process and the drying out phase when a certain level of relative humidity and temperature can be exceeded. With the gradually drying out of the construction the strength seems to increase again. At least for both boards after four months no further reduction of the pull-off strength can be observed.

Mineral wool type	new material	Northern Test	Water Bath Test	after field test [months]				
				1	4	11	18	30
board	100 %	37 %	44 %	67 %	51 %	69 %	61 %	79 %
lamella	100 %	35 %	43 %	-	80 %	100 %	97 %	100 %

Table 2: Pull-off strength of mineral wool after two different EOTA laboratory tests and 1, 4, 11, 18 and 30 months of field test at Holzkirchen (west facing façade, starting in April 1998) compared to the strength of the new material (100 %).

4. DISCUSSION OF THE RESULTS AND CONCLUSION

The results of these investigations show that strongly varying moisture strains can occur in the mineral wool insulating layer of an ETICS. The highest values of relative humidity and temperature can be observed at the interface between the mineral wool and the exterior render – independent on the three examined climate locations. The most critical conditions occur in Holzkirchen. But even here high temperatures (> 30 °C) and high moisture levels (> 95 % RH) at the same time only occur for very short periods, as a high absolute humidity immediately causes a strong diffusion transport into areas with lower absolute humidity. So critical hygrothermal strains in the mineral wool are rapidly diminished due to its high permeability to water vapour.

Stability tests conducted under extreme moisture conditions and temperatures of over 50 °C are not representative for the conditions which can occur in the insulation layer of an ETICS under European climate conditions and lead to significant lower pull-off strengths than under real conditions. The field test results show that the reduction of the pull-off strength occurs in the first month after construction, in the further month no more decrease can be observed. That means that the argument that the laboratory tests represent accelerated weathering needs more profound analysis and the unrealistic high temperature and relative humidity of the tests should probably be replaced by conditions which are more conform to practice. In future the application of hygrothermal simulations could help to specifiy the conditions of accelerated weathering tests in the laboratory.

5. REFERENCES

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