COMBINED EFFECT OF TEMPERATURE AND HUMIDITY ON THE DETORIATION PROCESS OF INSULATION MATIRIALS IN ETICS

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1. THE PROBLEM

When an exterior thermal insulation composite system (ETICS) is applied to an outer wall containing trapped moisture, then 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 strans acting on an ETICS with mineral wool insulation under natural climatic conditions and normal usage, using computational simulations. The objective of these calculations is to determine the maximum hygrothermal loads which arise in situ and their duration which can serve as the basis definition of well-founded boundary conditions for durability tests of insulating materials in the laboratory.

2. CONDUCTING THE INVESTIGATION

The following studies were carried out with the computer program WUFI which allows the calculation of the transient heat and moisture transport in building elements [1] and was developed at the Fraunhofer Institute for Building Physics in Holzkirchen. WUFI has repeatedly been validated by comparison with experimental data, including ETCICS [2],[3], [4], and is used here to simulate the hygrothermal behaviour of an ETICS comprising mineral wool and mineral rendering, installed on to lime sillica masonry with trapped moisture. The main focus the closer examination of the moisture and temperature strains on the insulation material. The following, west facing (weather side) wall assembly is used for the calculations: An ETICS, comprising 100 mm mineral wool and 20 mm mineral exterior plaster (lime cement plaster) is affixed to the outside of a 240 mm thick lime silica brick wall. The inner-facing side of the lime silica brick wall is covered with gypsum plaster. The hygrothermal material parameters required for each material are listed in Table 1. A water absorption coefficient (A-value) of 1 kg/m$^2\sqrt{h}$ is assumed for the external lime-cement plaster. The corresponding moisture transport coefficients are approximated according to [2]. The exterior plaster has an s_d-value of 0,5 m. With a thickness of 20 mm this corresponds to a vapour diffusion resistance number of 25. The heat transfer coefficient

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at the external surface is 17 W/m^2K, and 8 W/m^2K on the inside. The short-wave absorption coefficient of the external plaster is 0,4. A rainwater absorption factor of 0,7 is assumed. Hourly weather data measured in a typical year in Holzkirchen represent the climatic conditions. The room climate varies as a sinus curve between 20 °C, 35 % relative humidity in the winter and 22 °C and 65 % relative humidity in the summer. These values correspond to normal usage as a residential building. The starting point is the beginning of October with an initial moisture content of 10 vol.% in the wall, while an initial moisture content corresponding to 80 % relative humidity is assumed in the remaining building component. The hygrothermal behaviour is simulated over a period of a five years.

Table 1: List of hygrothermal material properties for the materials used

Construction material		Lime-cement plaster	Lime-sand brick	Mineral wool
Bulk density	[kg/m^3]	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	[$kg/m^2\sqrt{h}$]	1,0	2,7	--
Practical water content	[vol. %]	4,5	2,5	--

Ten different variants are investigated with WUFI based upon the standard case described above in order to examine the influence of different parameters on the hygrothermal strain on the mineral wool. An overview of these variants is provided in Table 2. In case 2, in which the inner wall surface is tiled instead of plastered, the s_d-value on the room side is set to 2,0 m taking the filling between the tiles into account [**Fehler! Textmarke nicht definiert.**]. The relative humidity and the temperature in the insulating material are observed at the two interface areas (thickness each of 2mm) to the wall (inner MW) and to the external plaster (outer MW), because the extreme values can be expected of these points, rather than in the middle of the insulation layer.

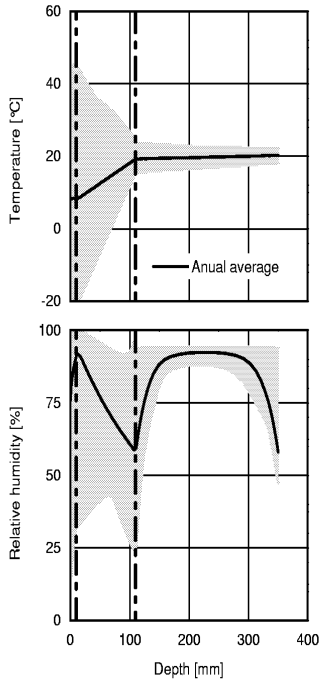

Figure 1 **Minimum, maximum and average profile of temperature (top) and relative humidity (bottom) in the facade for the standard case during the first year.**

Table 2: Conditions in the standard case (case 0) and variations in cases 1-10

Standard case (case 0)	
Construction from the inside out	Gypsum plaster 240 lime silica brick 100 mm mineral wool 20 mm external plaster with A-value = 1,0 kg/m^2√h and s_d-value = 0,5m
Boundary donditions	West façade with incident driving rain Short-wave radiation absorptivity a_s=0,4 Completion of construction work on October 1st

Case	Variations in comparison to standard case (=case 0)
1	Starting point beginning of April
2	Inside tiled
3	Short-wave radiation absorptivity a_s = 0,2
4	Short-wave radiation absorptivity a_s = 0,6
5	No driving rain
6	20 mm external plaster with s_d-value = 1,0 m
7	20 mm external plaster with s_d -value = 2,0 m
8	10 mm external plaster with s_d -value = 0,5 m
9	10 mm external plaster with s_d -value = 1,0 m
10	10 mm external plaster with s_d -value = 2,0 m

3. RESULTS

Figure 1 shows the minimum, maximum and average profiles of the temperature (top) and relative humidity (bottom) for the standard case in the whole building element for the first year after the installation. The highest and lowest values for the relative humidity and temperature arise at the interfaces between the mineral wool and the external plaster or the lime silica brick. The values within the insulating material always lie between those to the outer and inner boundaries. Table 3 shows the maximum and minimum temperatures and relative humidities for both of these locations for the entire period under calculation for 5 years following the installation, whereby the wall dried out after approximately 2 years. Annual average values for temperature and relative humidity at both insulating layer boundaries are also specified for the first year following the installation as well as once the wall has dried out.

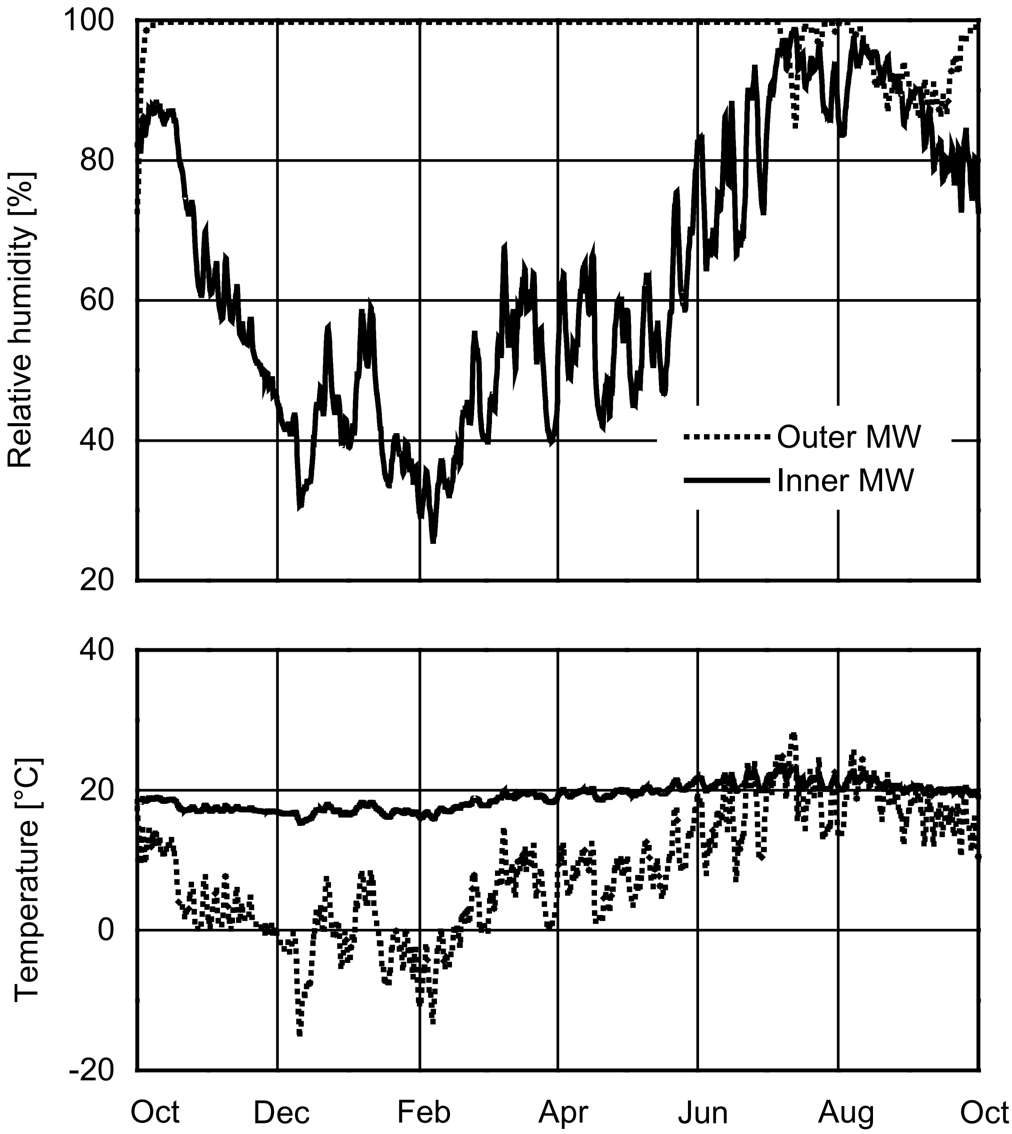

Figure 2 Course represented as 24-hour-average, of the relative humdity (top) and temperature (bottom) at both insulating layer boundaries during the first year after the installation for the standard case.
Outer MW: Boundary mineral wool / external plaster
Inner MW: Boundary mineral wool / lime-sand brick

During the first year the average temperature in the external insulating layer boundary was 8.5 °C in almost all cases. The average temperature only falls (case 3) or rises (case 4) by approximately 1 °C due to the changes in short-wave radiation absorptivity – the minimum temperature for all 11 variations is approximately 19 °C. The changes in short-wave absorptivity do however affect the maximum temperature. The maximum temperature falls from approximately 42 °C to 35 °C or rises to 51 °C. The temperature level at the boundary mineral wool/wall is, however, similar in all cases. The average temperature here is 19 °C, the minimum 15 °C and the maximum approximately 25 °C. The average relative humidity of the boundary to the external plaster exceeds 95 % in the first year after the construction. The minimum relative humidity varies between 40 and 80 % depending on the case at hand. A maximum value of 100 % occurs for all variations. At the boundary to the wall, the average relative humidity level lies at approximately 64 %. The minimum relative humidity level here is approximately 25 % and the maximum almost 100 %. As expected, once the wall has dried out the average relative humidity levels at both boundaries are lower than in the first year after the installation. However, this is still at approximately 93 % at the boundary between the mineral wool and the external plaster, and approximately 50 % at the boundary to the wall.

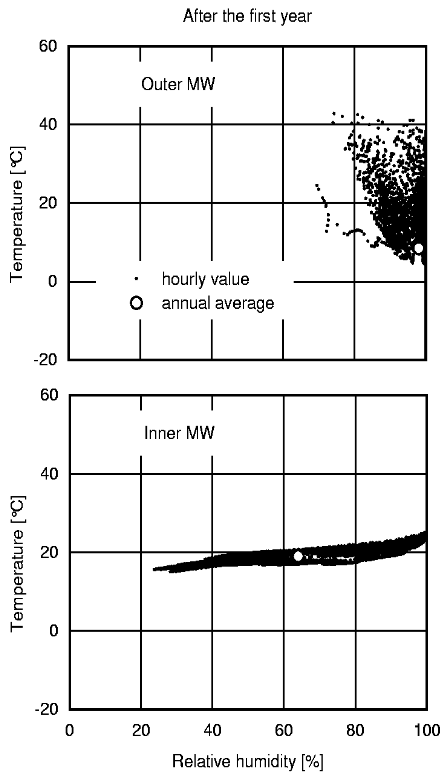

Figure 3 Correlation between temperature and relative moisture for both MW boundaries during the first year after the installation. The hollow circles represent the average values.

The following section examines the standard case (case 0) more closely. Figure 2 shows the course of the average daily values of relative humidity (top) and temperature (bottom) at both insulating layer boundaries (inner MW and outer MW) during the first year after the installation. The relative humidity at the outer boundary remains at almost 100 % until the beginning of July, then sinking slowly to under 95 %, and increasing again as autumn begins. During the first winter the relative humidity on the inner insulating layer boundary falls continually to approximately 30 %. It runs in parallel with the external surface temperature and rises to its maximum again in the summer in July. The daily average for the temperature on the inner insulation layer boundary is around 19 °C throughout the whole year.

Figure 3 and Figure 4 show the correlation between the temperatures and relative humidities, which reign on both sides of the mineral wool in the form of hourly values during the first year subsequent to the installation, and in the 5th year, i.e. in the dried-out state. The average annual values are each depicted using hollow circles.

Table 3 Minimum and maximum moisture and temperature at both insulating layer boundaries during the simulation period of 5 years as well as their annual average values during the 1st year subsequent to the installation and once the wall has dried out.

case	Insulation / External plaster								Insulation / Wall							
	Temperature				Relative Moisture				Temperature				Relative moisture			
	AV^1	AV^2	Min	Max	AV^1	AV^2	Min	Max	AV^1	AV^2	Min	Max	AV^1	AV^2	Min	Max
1	8,5	8,5	-19	43	98	93	74	100	19	19	15	25	64	53	24	100
2	8,5	8,5	-19	43	99	93	66	100	19	19	15	25	65	53	20	100
3	8,5	8,5	-19	43	99	94	80	100	19	19	15	25	65	53	24	100
4	7,5	7,6	-19	35	99	95	80	100	19	19	15	24	61	50	23	99
5	9,4	9,4	-19	51	98	92	45	100	19	19	15	26	68	57	25	100
6	8,8	8,9	-19	44	90	75	43	100	19	19	15	24	58	41	24	95
7	8,5	8,5	-19	42	99	96	80	100	19	19	15	26	65	55	24	100
8	8,5	8,5	-19	42	99	97	48	100	19	19	15	26	65	55	24	100
9	8,5	8,5	-20	45	96	89	47	100	19	19	15	24	62	51	24	99
10	8,5	8,5	-20	44	98	91	56	100	19	19	15	25	64	52	24	99
	8,5	8,5	-20	43	99	93	81	100	19	19	15	26	65	53	24	100

AV^1 Annual average value in the 1st year subsequent to the installation
AV^2 Annual average value once the wall has dried out

At the boundary between the mineral wool and the external plaster (outer MW), values are rarely recorded above 40 °C and relative humidity levels under 80 %, both in the dry state and during the drying-out phase. The temperature range is very limited at the boundary between the mineral wool and the lime-sandstone.

Mineral wool is subjected to the greatest strains when high temperatures and high moisture levels occur simultaneously. The corresponding extreme conditions are therefore usually adapted for laboratory resistance tests. An ETICS element in situ will encounter more extreme conditions on the external side of the insulating layer than in other areas. This becomes clear if one considers the absolute humdity which appears suitable as a measure of the hygrothermal strain because it depends on the relative humidity as well as upon the temperature. A high absolute humidity level therefore generally means a coincidence of high temperature and high relative air humidity. Figure 5 shows the frequency distribution of the absolute humidity in the first year at the insulating layer boundaries for the standard case. Values exceeding 50 g/m^3 – that corresponds approximately to the saturation moisture at 40 °C - are practically not exceeded at the external insulating layer boundary. Values never exceed the 25 g/m^3 level at the inner insulating layer boundary. Figure 6 shows the number of hours for all 11 variations, in which relative humidity between 90 and 100 % reigns at the external insulating material boundary as dependent on temperature. The shaded area shows the combined range of maximum or minimum hour frequencies occurring for all cases examined. This makes it clear that high temperatures and high humidity levels (>90 %) simultaneously only occur for very short periods.

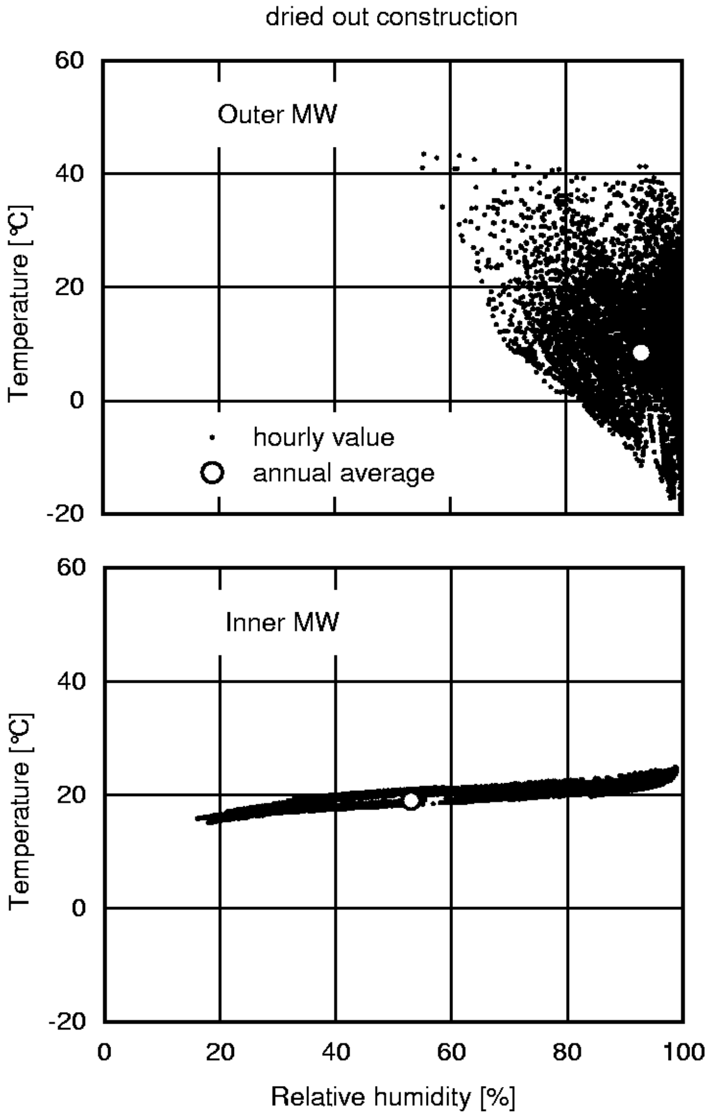

Figure 4 Correlation between temperature and relative moisture for both MW boundaries during the fifth year after the installation. The wall is already dried out. The average values are shown as hollow circles.

4. DISCUSSION OF THE RESULTS AND CONCLUSION

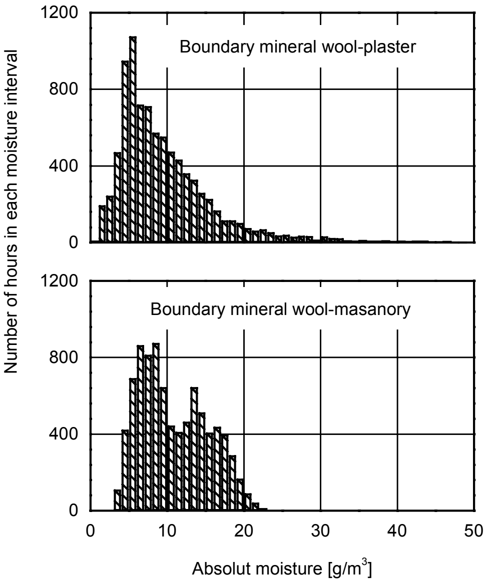

Figure 5 Frequency distribution for the absolute moisture in specific intervals during the first year after the installation on both MW boundaries. Interval width: 1 g/m^3

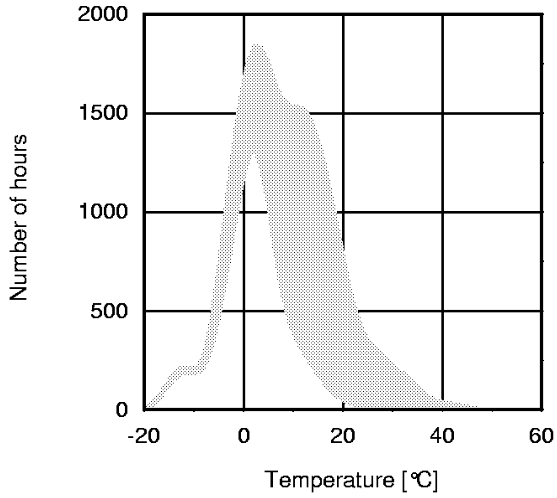

Figure 6 Number of hours, in which a relative moisture between 90 and 100 % reigns at the outer insulation material boundary, dependent on the temperature at this point. The shaded area represents the maximum and minimum hour frequencies occurring among all 11 observed cases

The results of the one-dimensional moisture simulation show that strongly varying moisture strains can occur in the mineral wool insulating layer of an ETICS. Inside the actual mineral wool itself the outside-facing side is, on average, damper than other areas. While the average relative humidity on the side facing the external plaster lies at over 95 %, the level near the lime silica brick wall during the drying out phase is between 60 and 70 %. Seasonal as well as daily fluctuations occur on both sides, with the seasonal fluctuations being more pronounced. In contrast to the temperature the changes in humditiy are greater further inside the mineral wool. The average humdity levels here are between 20 and 40% in the winter, while a level of almost 100 % is reached in the summer. But the temperature only varies between approximately 15 °C and 25 °C. The relative humidity levels vary between 70 and 100 % on the side facing the external plaster. The temperatures here can lie between approximately – 20 °C and 45 °C. On average, the relative humidity is about 95 % at this boundary, and the temperature 8,5 °C. At the boundary to the wall the average levels are approximately 50 % relative humidity and 20 °C.

The evaluation of the calculated results shows that high temperatures (>30 °C) and high moisture levels (>95 % rel. humidity) only occur at the same time for very short periods. This is understandable since the associated high absolute humidity immediately causes a strong diffusion transport into areas with lower absolute humidity. This process means that critical hygrothermal strains in the mineral wool are rapidly diminished due to its high permeability to water vapor. Stability tests conducted under extreme moisture conditions and temperatures of over 50 °C therefore only seem to provide data of limited usefulness on the behaviour of insulating boards in situ because these conditions do not occur in practice. The unrealistic conditions for the stability tests should be replaced by conditions which conform to practice.

5. LITERATURE

[1] Künzel, H.M.: Verfahren zur ein- und zweidimensionalen Berechnung des gekoppelten Wärme- und Feuchtetransports in Bauteilen mit einfachen Kennwerten. Dissertation Universität Stuttgart 1994.

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