STUDY ON THE HYGROTHERMAL PERFORMANCE OF HERITAGE-PROTECTED EXTERNAL MASONRY WALLS WITH INSIDE INSULATION

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SUMMARY

The efficient use of energy due to increasing energy prices and CO_2- emission excesses (climate change, etc.), but also changing comfort conditions are requiring new forward-looking concepts to minimize the energy demand of the building stock. One method to reduce the heating energy consumption of historic building stock with façades worth-preserving is the application of inside insulation systems.
This paper will present the hygrothermal performance of heritage-protected external masonry walls with typical inside insulation systems in the climate of Austria / Central Europe. The study focuses on the assessment of possible moisture accumulation inside the construction and therefore potential risks of mold growth up to freeze-thaw damage. Masonry walls with varying inside insulation wallboards (woodwool- panels or mineralwool), exposed to different climatic conditions, were designed and with the help of hygrothermal calculations analyzed and optimized. In addition to these theoretical investigations, measurements, which were conducted at a historical residental building, are discussed.

INTRODUCTION

Figure 1. Typical historic façades

The significant interaction of increasing CO_2- emissions and climate change are nowadays indeniably. Especially the building sector uses ~ 40% of the total annual energy demand and is therefore responsible for quite high pollutant emissions.
Today, in Austria, the greatest part of energy-saving potential and therefore possible reduction of greenhouse gas emissions can be found in the thermal renovation of the existing building stock, due to the fact, that strict building standards ensure, that mostly all future dwellings have to be built as low-energy houses, or even

passive houses, with very reduced energy demands. The common used method for the thermal renovation of existing walls is still the attachment of external heat insulation, which is, from the point of view of building physics, in most cases unproblematic and preferable. In most cases, this kind of rehabilitation to improve the heat protection of the envelope is implementable. On the other hand, in the majority of Austrian cities quite a large number of historic buildings, with ornamented or even listed façades exists and preserving and protecting the original substance is obligatory because of strict regulations for the monument protection. Beside that, existing buildings are often built on the road building line and sometimes an encroachment with external insulation is prohibited due to building regulations. So in that cases, inside insulation systems are mostly the only way to decrease the heating energy demands and even to improve the indoor comfort conditions of these buildings.

Inside insulation systems are influencing the hygrothermal response of existing walls in different ways. Although it is the only method to reduce the transmission heat losses, the changed temperature distribution within the wall could result in possible moisture related problems. Further it is essential to take all influencing climatic boundary conditions (e.g. driving rain, high interior moisture loads, etc.) into account and to analyze detail solutions (e.g. thermal bridges, etc.) separately.

The basic approach of this current study is to evaluate the effect of interior retrofit systems on the hygric conditions of heritage-protected masonry walls under varying exterior climate conditions.

It is important to note, that usally in Austria, according to code OENORM B8110-2, the protection against condensation is evaluated by using the dew-point- method (Glaser scheme). However this method only considers steady-state and very simplified boundary conditions and neither realistic influences like solar radiation, wetting processes due to driving rain, nor hygroscopic sorption or liquid transport are taken into account. The scope of this study is therefore to predict the long-term performance of typical austrian masonry walls under the impact of different inside insulation systems as realistic as possible by using transient hygrothermal calculations.

Additional to that, results of a field testing, which was conducted within a research project of Carinthia University of Applied Sciences and an insulation manufacturer, will be discussed in brief.

DESCRIPTION OF CASES

Internal insulation is known to be the only way to improve the thermal quality and therefore comfort conditions of exterior walls of listed building stock, but it is also assumed to be a risky method of retrofit. Hence the primary aim of this paper is to demonstrate the hygrothermal performance of typical, historic Austrian walls, built during the Gruenderzeit, provided with different interior retrofit systems, which are widely used in Austria. The common masonry type built in this period consists of clay bricks with a mean thickness of ~ 500mm and is usually covered with lime-cement stucco outside and respectively lime stucco inside. Based on this starting position within the investigations different insulation systems on the interior of the existing wall were applied, to analyze the effect of changing material combinations regarding to the whole wall performance. As shown in Table 1, in sum five different wall variants, including the “base case” were calculated. For the inside insulation mineral-bound wood-wool panels (50mm) and variants with additional mineralwool (20mm) were chosen. Especially the influence of vapor retarders was and today it still is debatable and therefore the variants combined of wood-

wool panels and mineral wool were simulated each without vapor retarder, with a conventional and with a humidity-adaptive vapor retarder to investigate their influence on the moisture situation and especially the drying potential of the chosen constructions. The constructions were calculated for the location of Vienna, the capital of Austria. Hence reduced solar radiation but also driving rain loads are important external causes, all wall assemblies were calculated with north- and with westward orientation. So in sum, 10 variants were calculated. Cases 1, 3, 5, 7 and 9 are assumed to be orientated to the North, cases 2, 4, 6, 8 and 10 to the West.

<table>
<tr><th colspan="10">Investigated Cases (Layers from outside to inside)</th></tr>
<tr><th>Case 1</th><th>Case 2</th><th>Case 3</th><th>Case 4</th><th>Case 5</th><th>Case 6</th><th>Case 7</th><th>Case 8</th><th>Case 9</th><th>Case 10</th></tr>
<tr><td>North</td><td>West</td><td>North</td><td>West</td><td>North</td><td>West</td><td>North</td><td>West</td><td>North</td><td>West</td></tr>
<tr><td colspan="10">Lime-Cement Stucco 20mm (existing)</td></tr>
<tr><td colspan="10">Clay Brick Masonry 500mm(existing)</td></tr>
<tr><td colspan="2" rowspan="5">Lime Stucco (existing)</td><td colspan="8">Lime Stucco 20mm (existing)</td></tr>
<tr><td colspan="2" rowspan="3">Mineral-bound (Magnesite) wood wool panel, 50mm</td><td colspan="2" rowspan="2">Mineralwool 20mm</td><td colspan="4">Mineralwool 20mm</td></tr>
<tr><td colspan="2">Vapor retarder S_d-value = 2m or 1.64 perm</td><td colspan="2">Humidity-adaptive vapor retarder</td></tr>
<tr><td colspan="6">Mineral-bound (Magnesite) wood wool panel, 50mm</td></tr>
<tr><td colspan="8">Modified Lime-Cement Stucco 5mm</td></tr>
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Table 1. Investigated wall assemblies case 1 to 10

It is noted, that the calculations were done only for the typical cross section of a wall and subjecting the interior insulation systems to good air tightness without leakages, hence convective vapor flow may lead to high condensation rates within the enclosure and consequently moisture related problems. In practice, it is recommended to perform special calculations for critical areas like thermal bridges, e.g. fixing-in timber beams (Stopp 2001), corners, embedded partion walls, etc., due to the fact, that lower temperatures in these parts of the building envelope may cause possible higher humidity levels and a accompany risk for structural damage.

DESCRIPTION OF CALCULATION

The simulations were carried out by using the software WUFI®. (Waerme und Feuchte instationaer – Transient Heat and Moisture). This software was developed at the Fraunhofer Institute for Building Physics (Kuenzel 1994) in Holzkirchen / Germany and validated using data from outdoor and laboratory tests. It allows the calculation of the transient heat and moisture transport in materials and building constructions, exposed to natural exterior and interior climate conditions.

Default Program Settings

The heat transfer coefficient at the exterior surface is variable depending on wind and temperature, at the interior 8 W/m²K. For the external stucco a short-wave (solar) radiation absorptivity of 0,4 was chosen. Long-Wave Radiation Emissivity is 0,9.

Boundary and initial conditions

For the exterior boundary conditions average hourly weather data (1976 – 2005) from Vienna / Austria were used. The calculations were performed with the same year repeated twenty times, starting on October 1st. The average temperature in Vienna is about 10.4 °C, the relative humidity about 73 %. The average amount of rain is ~ 625 mm/yr and the predominant direction of wind-driven rain is in the West.

For the indoor normal conditions were chosen. The indoor air temperature and humidity for the preliminary simulations varies as a sine curve between 20 °C / 40 % RH in the winter and 22 °C / 60 % RH in the summer.

The initial conditions for the preliminary simulations were chosen generally for all layers with 80 % RH and 20 °C. The relative high humidity level at the start was assumed to investigate the possible drying potential of the wall systems. (Karagiozis 1998)

Material properties

The material properties (Table 2) employed in these simulations were taken from the WUFI® database and respectively determined through laboratory measurements.

Material	**Bulk density [kg/m³]**	**Porosity [m³/m³]**	**Heat capacity [kJ/kgK]**	**Heat conductivity dry [W/mK]**	**Diffusion restistance factor dry μ [-]**
Lime-Cement Stucco	1900	0,24	850	0,80	19
Clay Brick Masonry	1900	0,24	850	0,60	10
Lime Stucco	1600	0,30	850	0,70	7
Mineral-bound Wood-Wool Panel	320	0,40	2000	0,09	1,9
Mineral Wool	60	0,95	850	0,04	1,3
Vapor Retarder	130	0,001	2300	2,30	2000
Humidity-adaptive Vapor Retarder	115	0,086	2500	2,40	~6900 / ~50% & ~250 / ~98%
Modified Lime-Cement Stucco	1150	0,24	850	0,33	20

Table 2. Basic material properties

SIMULATION RESULTS

The main attention within this study was focussed on the interplay between the chosen retrofit systems and the hygric behaviour of historic walls. Hence the progression of the total water content of the constructions and results concerning RH in critical parts of the envelope was

investigated, to predict their drying potential and assess the possibility of mold fungi growth. The subsequent simulations were performed for a period of 20 years. In the following graphs partially results for the whole periode and only for the 15th to the 20th year are displayed.

Cases 1, 3, 5, 7 and 9; Vienna NORTH orientation

Figure 2 shows the trend of the total water content (TWC) of all cases oriented to the North, during the calculated period of 20 years. It is well to see, that the TWC of the uninsulated existing wall varies between about 5 kg/m² in summer and about 7,5 kg/m² in winter, in the course of the years. Except of these seasonal fluctuations, the total water content shows a constant trend without upward movement. In the same way also the total water content for the rehabilitated variants was calculated. Beginning from the start, the TWC of all variants with thermal retrofitting is decreasing too and after about five years showing a constant trend in either case. Cases 5, 7 and 9 with the chosen inside insulation system consisting of mineral-bound wood-wool panels and additional mineralwool are showing a similar TWC gradients varying between ~ 9 kg/m² up to ~ 12 kg/m². Both variants with vapor retarders are showing nearly the same moisture performance and the TWC of the variant lacking a vapor retarder is only a bit higher. The TWC of case 3, carried out only with woodwool panels inside, is slightly lower and ranges between ~ 8 kg/m² and ~ 10 kg/m². The lower thermal resistance of the woodwool panel provides "higher" temperatures conditions and consequently lower moisture amounts within the wall.

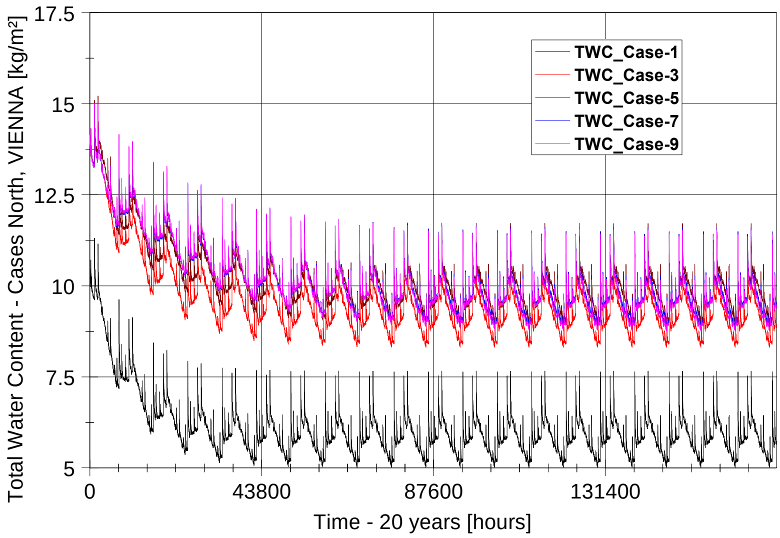

Figure 2. Total Water Content Cases 1, 3, 5, 7 and 9, Vienna North, years 1 - 20

These first results only indicate, that in all retrofit variants no rising moisture accumulation will occure, but it is also obvious, that the application of vapor retarders doesn`t improve significantly the generally hygric performance in the cross section of the wall. Vapor retarders are in fact useful to control the vapor diffusion into the wall, especially if increased thermal insulation thickness minimizes the temperature field within the wall, but it is also well known (Straube 2001) that the self-drying capacity (solar driven diffusion) due to the application of vapor retarders or – barriers might be reduced. Hence it is important to perform further investigations concerning the relative humidity and the temperatures in the interface between existing interior

stucco and the internal insulation system to analyze the risk of condensation but also mold growth and to assume, if such special retrofit systems are performable without vapor retarders.

Figure 3 illustrates, that the relative humidity (RH) on the internal surface of case 1 (without internal insulation) varies during the period years 15^{th} to 20^{th} between ~ 45 % during summertime and ~ 60 % during wintertime. After the improvement of the thermal quality by applying a woodwool panel on the inside, the relative humidity in the interface between old stucco and insulation increases and varies between ~ 58 % and approximately 70 % depending on season. The temperature in winter decreases about 5°C to a minimum of ~ 12°C. It is assumed, that from the hygrothermal point of view this retrofit method might be unproblematic, because the RH. remains under 70 %, so condensation but also mold growth should be avoided. Beside that, the thermal improvement with woodwool panels enhances the heat transfer value (U- value) from ~ 1.05 W/m²K to ~ 0.60 W/m²K which is a quite accepable result for this kind of constructions.

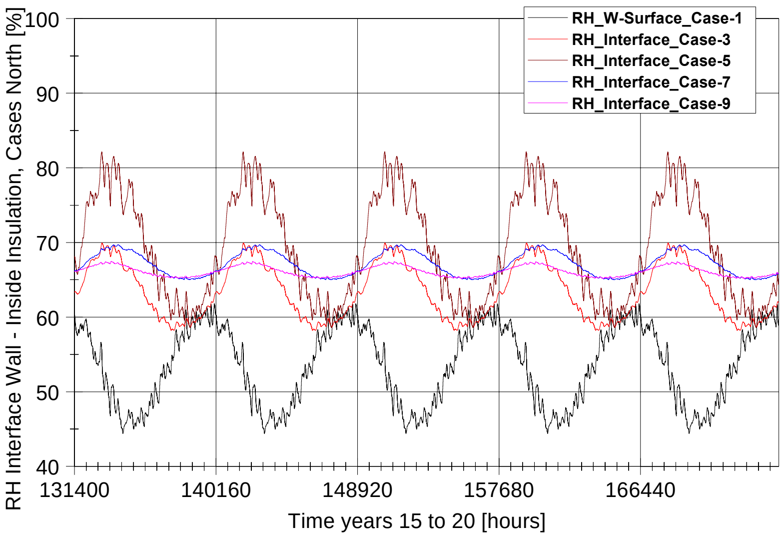

Figure 3. RH Interface Stucco – Insulation, Cases 1, 3, 5, 7 and 9, Vienna North, years 15 - 20

In the same way, the relative humidity and temperatures in the interface between old stucco and insulation were calculated for the cases with additional mineralwool combined with woodwool panels. It is well to see, that if a vapor retarder is missing, the RH. is varying between ~ 60 % up to ~ 82 % during a few weeks in winter. Hence during this time also temperatures > 5 °C are existing (Figure 4), a potential risk of mold growth cannot entirely be excluded. The application of a conventional vapor retarder is limiting the max. RH. gradient to ~ 70 %, and if a humidity-adaptive vapor retarder is used, the RH. doesn`t exceed ~ 67 % in wintertime, but it is also obvious, that the drying capacity during summertime is limited, because in cases 7 and 9, the RH. gradient won`t fall under ~ 65 %.

Summing up it can be noticed, that the wall variants 5, 7 and 9 are showing a very good thermal performance, because the additional mineralwool insulation layer further decreases the U-factor to ~ 0.45 W/m². The results concerning the relative humidity indicated, that the retrofit system should also be feasible without vapor retarders under the given boundary conditions (especially indoor humidity), because condensation in the construction should be avoided. As suggested above, there is a certain amount of risk of mold growth and especially connection details should be analyzed separately. On the other hand the drying potential to the interior without vapor retarder is higher. This aspect is quite important, because in practice it is nearly impossible to

realize a durable tightness all-over the vapor-retardant layer and cracks or perforations (e.g. connections, etc.) cannot always be avoided. Hence the drying of moisture within the enclosure (built-in moisture, or moisture due to driving rain penetration and leaky vapor barriers) to the interior will be limited.

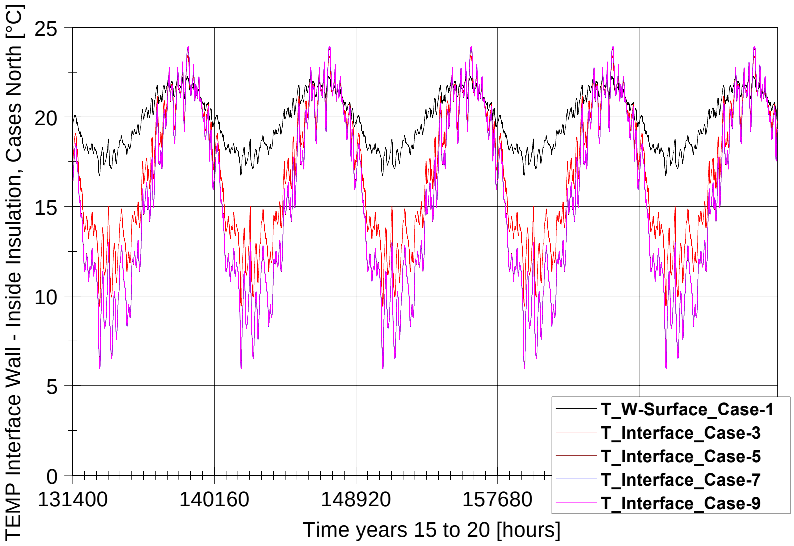

Figure 4. Temperatures Interface Stucco – Insulation, Cases 1, 3, 5, 7 and 9, Vienna North, years 15 - 20

Cases 2, 4, 6, 8 and 10; Vienna WEST orientation

The next step in this parametric study was to analyze the impact of driving rain on the moisture response of all retrofit systems. Hence further calculations with a wall exposure to the prevailing weather side, which is in case of Vienna the west orientation, were performed. Under these circumstances the total water content of case 4 (only woodwool panel) arises during the first years, but from the 10th year on the TWC is balanced and varies between ~ 22 kg/m² in summer and about 27 kg/m² in winter (Figure 5). Except of these seasonal fluctuations the total water content shows a constant trend without increasing moisture accumulation.

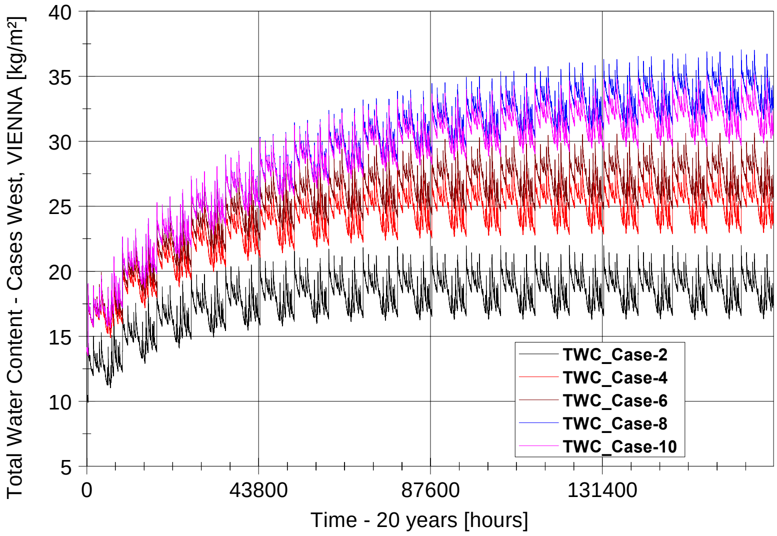

Figure 5. Total Water Content Cases 2, 4, 6, 8 and 10, Vienna West, years 1 -20

Furthermore the relative humidity in the interface stucco - woodwool panel is showing a steady state performance (Figure 6). Except of seasonal fluctuation, the gradient varies between ~ 65 and ~ 73 %. Thus condensation but also mold growth should be avoided.
The results, displayed in figure 5, further indicate, that after installing an additional mineralwool layer, like in cases 6, 8 and 10, the moisture performance and especiallte the TWC of the wall system highly depends on whether a vapor retarder is installed or not.
First of all it is important to note, that case 6 is no code-approved solution according to OENORM B8110-2, because the steady state calculation results (Figure 8) indicate, that insulation systems without vapor retarders are not applicable, due to the fact, that condensation occures. In contrast to that, the transient calculation, displayed in Figure 5, predicts, that the variant lacking a vapor retarder is only wetting up during the first years until the TWC is leveling off between ~ 25 kg/m² in summer and about 30 kg/m² in winter. Hence an increasing moisture accumulation won`t occure. Concerning the relative humidity in the interface stucco – mineralwool it is well to see, that the gradient is swinging between ~ 66 and ~ 86 %, thus an outward but especially also an inward drying is enhanced (Figure 6). Nevertheless it must also be pointed out, that certain amount of risk of mold growth is possible, because the relative humidity remains over 80 % at temperatures > 5 °C during some weeks in wintertime.
In contrast to that, the addition of vapor-retardant layers, like in cases 8 and 10, is assumed to be risky, because in both cases the TWC is showing a tendency to a constant uptake of moisture during the whole period of 20 years. The internal insulation combined with vapor retarders is influencing the wall performance in different ways. The exterior stucco is not water-repellent and therefore the enclosure is wetting up due to driving rain impact. Inward drying of this moisture is reduced due to the high diffusion resistance of the vapor retarders and the lower temperatures within the wall are also slowing down the drying to the exterior (Kuenzel 2002, Kuenzel 2004). Beside that, the relative humidity on the cold side of the mineralwool in both cases is also increasing. In case 10 (humidity-adaptive vapor retarder) the RH. varies between ~ 85 to ~ 88 %, in case 8, due to the applied tighter conventionally vapor retarder, the RH. excesses ~ 88 % almost the whole year (Figure 6).

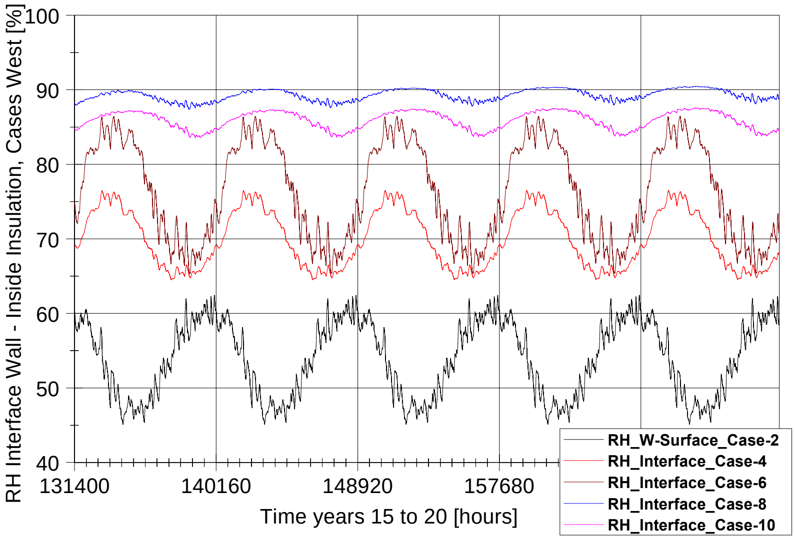

Figure 6. RH Interface Stucco – Insulation, Cases 2, 4, 6, 8 and 10, Vienna West, years 15 - 20

It is obvious, that the installed vapor retarders may increase the likelihood of damaging condensation over the course of the years and for such systems it is recommended to improve the driving rain protection (Dreyer, Korjenic 2005) to reduce the moisture accumulation within the walls. One method may be the application of hydrophobic impregnation paintings, but it is noticed, that for listed façades these coatings are often prohibited due to austrian conservation orders. Beside that, it is nowadays not really clear, how possible occuring flaws within the water repellent layer may effect the wetting process of the masonry. (Krus 2003, Kuenzel 2004)

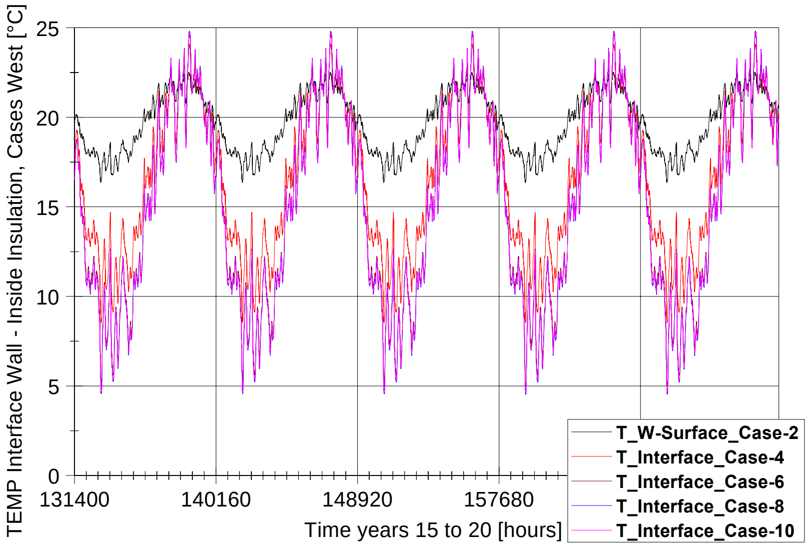

Figure 7. Temperatures Interface Stucco – Insulation, Cases 2, 4, 6, 8 and 10, Vienna West, years 15 – 20

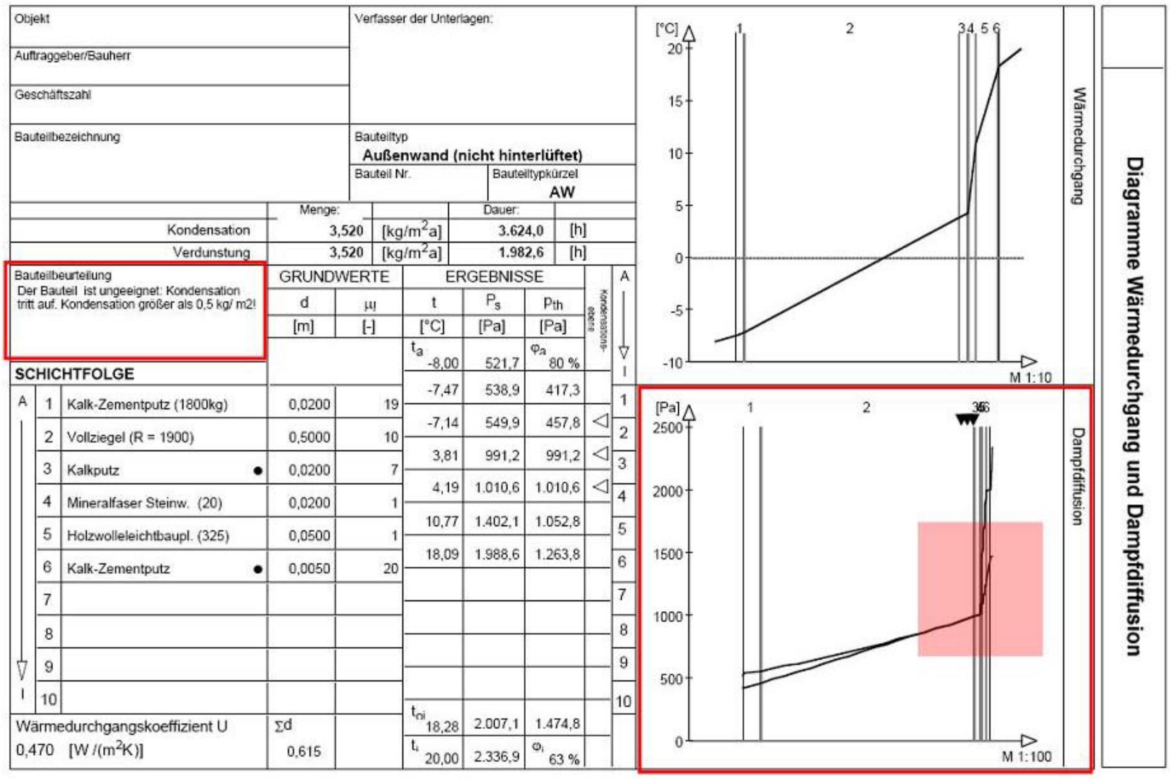

Figure 8. Steady-state calculations results regarding to code OENORM B8110-2, Cases 5 and 6

DISCUSSION RESEARCH RESULTS – FIELD TESTING

From 2004 to 2005, the Carinthia University of Applied Sciences carried out a research project in cooperation with an insulation manufacturer, to investigate the influence of internal insulation systems on the hygrothermal wall performance exposed to natural weather conditions.

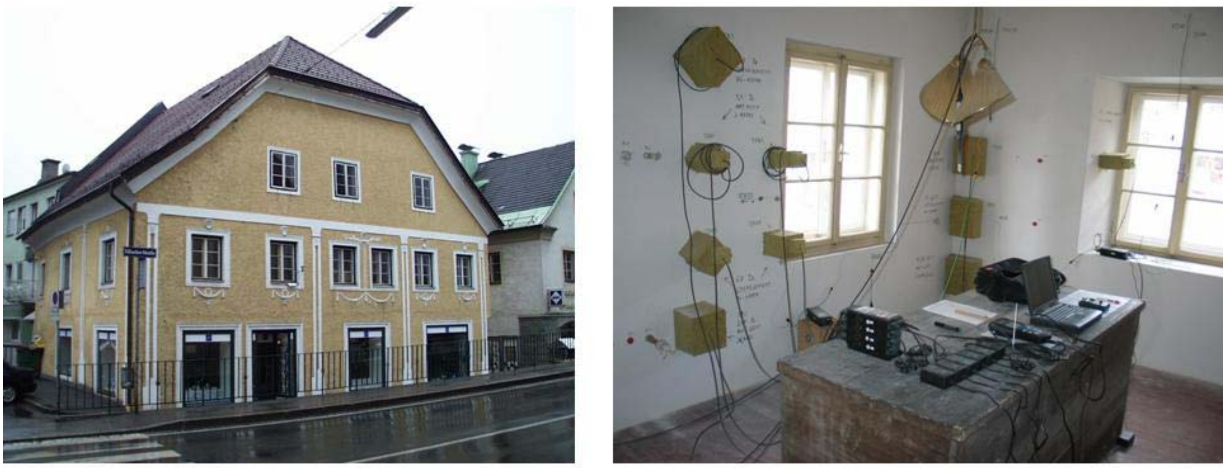

Figure 9. Exterior view of test house and test-room with measuring unit

On the north and east façade of a dwelling, built in the 17th century and situated in South Austria (Figure 9), inside insulation systems consisting of mineral-bound wood-wool panels (50mm) and variants with additional mineralwool (20mm), both without vapor retarders were installed. All wall components were equipped with special measurement equipment.

Figure 10. Demounting of internal insulation system

The measurements were performed during the period March 12th 2004 until March 12th 2005. The in-situ measurements verified, that no condensate occurred in the interface between old stucco and insulation and after demounting the insulation systems at the end of the project period also no mold build-up was observable, although during wintertime the relative humidity rose up to ~ 85 % during a few weeks (Figure 11). Comparing simulations additionally indicated, that both insulation systems are applicable without vapor retarders under the given boundary climates (Juhart, Seiler 2005).

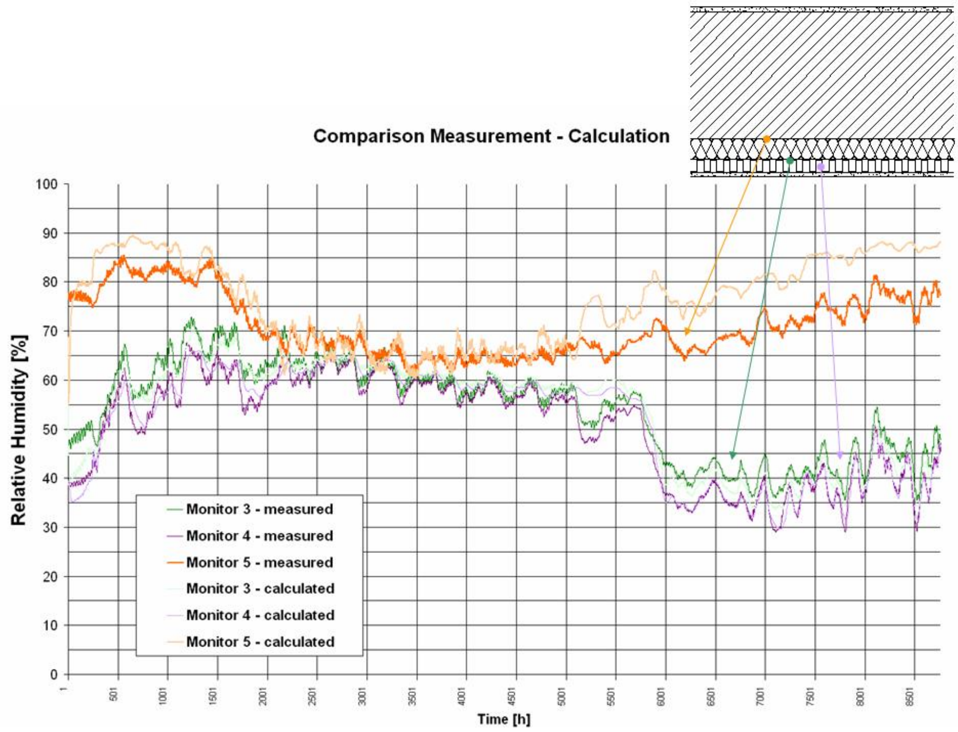

Figure 11. Comparison Calculation – Measurement,
Relative Humidity on interfaces of inside insulation

It is noted, that due to the north- and eastward orientation of the test-walls the influence of driving rain penetration was not observed.

DISCUSSION AND CONCLUSIONS

This paper presents results concerning the hygrothermal behavior of heritage-protected masonry walls carried out with different internal insulation systems, exposed to varying exterior climatic impacts. The investigations have shown, that internal insulation systems can sucessfully improve the thermal quality of the building enclosure by reducing the heat transfer value (U- value) from ~ 1.0 W/m²K to quite acceptable ~ 0.60 or even ~ 0.45 W/m²K in cases with applied inside insulations. Hence it is possible to reduce the heating energy demand and to enhance the living comfort of the listed building stock.

Further detailed analysis has shown, that the hygric performance of redeveloped masonry walls highly depends on the available drying potential. The use of vapor retarders sucessfully reduces the vapor diffusion and therefore amount of condensation. On the other hand, if a relatively high level of humidity, e.g. due to driving rain penetration or even rising humidity because of a lacking moisture proofing, within the construction is existing, inward drying may be reduced, if a vapor retarder inside is applied. The results indicated, that a proof regarding to water-vapor diffusion with steady-state calculations methods, as recommended in OENORM B8110-2, are not accurate enough to predict the real wall performance under realistic climatic conditions (Borsch-

Laaks 2005, Haeupl 2004) and sometimes maybe dangerous, because even code-approved solutions, like in case 8, could lead to unacceptable increasing moisture amounts.
So summing up one can observe, that redevelopment variants, especially with inside insulation, should always be designed with the help of hygrothermal models while the design process to predict a realistic as possible enclosure behavior.

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