Thermal Rehabilitation of Existing Building Enclosures by Using VIP (Vacuum Insulation Panel) Sandwich and Timber Based Panels

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ABSTRACT

Today, in Austria, the major 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. In the majority of Austrian cities, quite a large number of historic buildings with ornamented or even landmarked façades exist and preservation and protection of the original substance is obligatory because of strict monument protection regulations. Beside that, existing buildings are often built along the road building line and sometimes an encroachment with external insulation is prohibited due to building regulations. So, in these 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.

This paper will present the hygrothermal performance of external masonry walls with inside insulation systems made of newly developed VIP sandwich panels and typical insulation systems consisting of woodwool panels in the climate of Austria. The study focuses on the assessment of moisture accumulation inside the construction and therefore the potential risks of mold growth up to freeze-thaw damage. Sandwich wallpanels made of a vacuum insulation core covered with woodwool boards were developed and their interaction with the hygrothermal conditions of existing brick masonry enclosures was analyzed and optimized by using hygrothermal models (heat & moisture simulations).

Additionally, a test setup with the new insulation system was installed at an existing building to evaluate the feasibility and to analyze the enclosure's performance under real conditions. First in-situ measurement results, taken at this experimental setup, will be discussed in brief.

Keywords: Energy saving potential, moisture accumulation, mold fungi growth, freeze-thaw damage

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1. INTRODUCTION

The significant interaction of increasing CO_2-emissions and climate change are nowadays undeniable. 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 major 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 because of the strict building standards which ensure, that mostly all future dwellings have to be built as low-energy houses or even passive houses with much reduced energy demands.
The commonly used method for the thermal renovation of existing walls still is the attachment of external heat insulation, which is, from the building physics point of view, 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 landmarked façades exist and preserving and protecting the original substance is obligatory because of strict regulations for monument protection. Besides that, existing buildings are often built along 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 usually 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 considers only steady-state and very simplified boundary conditions and realistic influences like solar radiation, wetting processes due to driving rain, hygroscopic sorption or liquid transport are taken into account. Therefore, the scope of this study is 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.

In addition to that, first results of an ongoing field test, which is performed by the Carinthia University of Applied Sciences together with the Knauf Insulation Technology GmbH, will be discussed in brief.

2. DESCRIPTION OF CASES

Internal insulation is known as the only way to improve the thermal quality and therefore the comfort conditions of exterior walls of landmarked 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, but also new, innovative product solutions like VIP sandwich panels. The common masonry type built in this period consists of clay bricks with an average thickness of ~500mm and is usually covered with lime-cement stucco outside and lime stucco inside respectively. 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 the whole wall performance. As shown in Table 1, a total of four different wall variants, including the “base case” were calculated.

TABLE 1: Investigated wall assemblies cases 1 to 8

<table>
<tr><th colspan="8">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></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></tr>
<tr><td colspan="8">Existing external lime-cement stucco 20mm (~0.8”)</td></tr>
<tr><td colspan="8">Clay brick masonry 500mm (~20”)</td></tr>
<tr><td colspan="2" rowspan="5">Lime stucco (existing)</td><td colspan="6">Internal lime stucco 20mm (~ 0.8”)</td></tr>
<tr><td colspan="2" rowspan="3">Mineral-bound (magnesite) wood wool panel, 50mm (~2”)</td><td colspan="2" rowspan="2">Mineral wool 20mm (~0.8”)</td><td colspan="2">Mineral-bound (magnesite) wood wool panel, 20mm (~0.8”)</td></tr>
<tr><td colspan="2">Vacuum insulation board – VIP 10mm (~0.4”)</td></tr>
<tr><td colspan="4">Mineral-bound (magnesite) wood wool panel, 50mm (~2”)</td></tr>
<tr><td colspan="6">Modified lime-cement stucco 5mm (~0.2”)</td></tr>
</table>

For the inside insulation, systems consisting of mineral-bound wood wool panels (Case 3 and 4), variants with an additional mineral wool layer (Cases 5 and 6) and newly developed VIP sandwich panels (Cases 7 and 8) were chosen. The sandwich panels are consisting of bonded wood wool boards of 20 and 50mm thickness and a vacuum board of 10mm thickness as an interlayer. This sandwich panel was developed to improve the thermal effectiveness of retrofit solutions by consistent thickness of the internal insulation system. Furthermore the applications of wood wool boards in combination with stucco on the inside of the system are providing an adequate thermal mass.

The moisture performance and drying potential of the chosen retrofit systems were analyzed for the location of Vienna, the capital of Austria. Reduced solar radiation, but also driving rain loads are important external causes. Hence, all wall assemblies were calculated with north- and with westward orientation. So, in total, 8 variants were calculated. Cases 1, 3, 5 and 7 are assumed to be oriented to the North, cases 2, 4, 6 and 8 to the West.

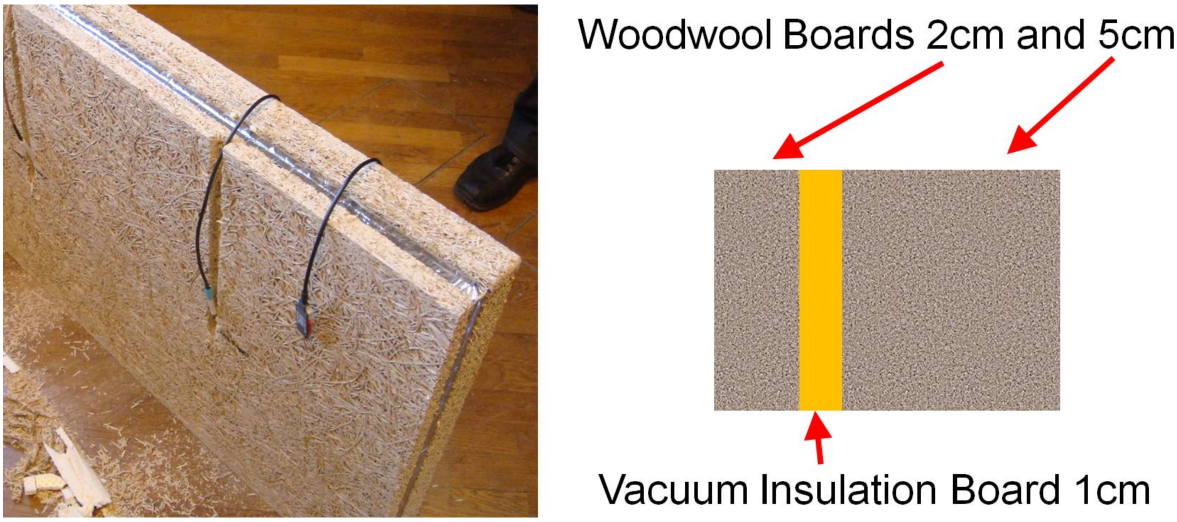

FIGURE 1: Schematic cross-section of VIP – Vacuum Insulation Sandwich Panel, drawing not to scale

It is noted, that the calculations were done only for the typical cross section of a wall and good air tightness without leakages is assumed for the interior insulation systems. Hence, convective vapor flow may lead to high condensation rates within the enclosure and consequently to 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[12]), corners (FIGURE 2), 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.

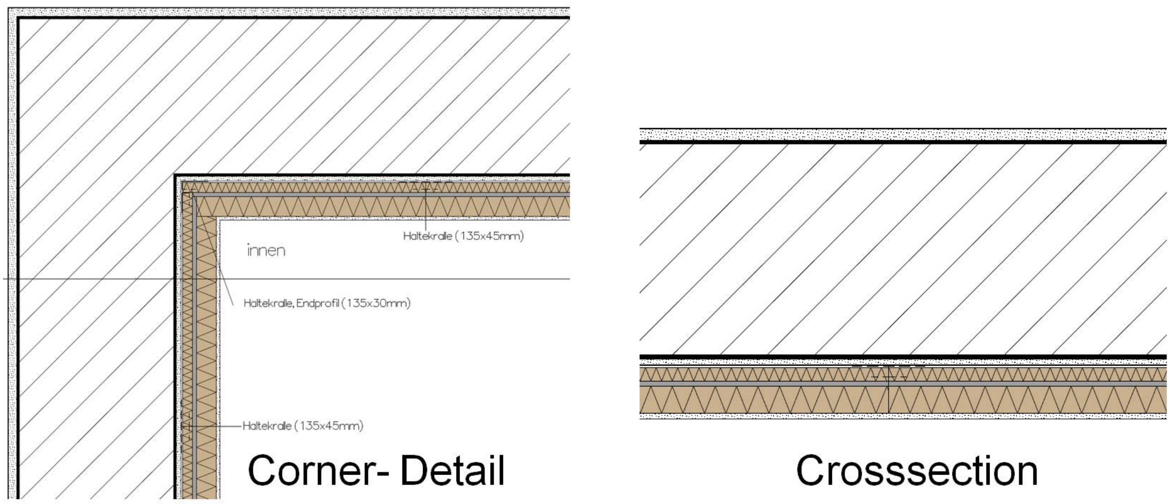

FIGURE 2: Corner connection detail and schematic cross-section of VIP – Vacuum Insulation Sandwich Panel; drawings not to scale

3. 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[7]) 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.

3.1 Default Program Settings

The heat transfer coefficient at the exterior surface is variable depending on wind and temperature; at the interior it is 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.

3.2 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 ten times, starting on October 1st. The average temperature in Vienna is about 10.4 °C (~50 °F), the relative humidity about 73 %. The average amount of rain is ~625 mm/yr and the predominant direction of wind-driven rain is in West. For the indoor "normal" conditions were chosen. The indoor air temperature and humidity for the preliminary simulations vary as a sine curve between 20 °C (~68 °F)/40 % RH in the winter and 22 °C (~72 °F)/60 % RH in the summer. The initial conditions for the preliminary simulations were chosen generally for all layers with 80 % RH and 20 °C (~68 °F). The relatively high humidity level at the start was assumed to investigate the possible drying potential of the wall systems. (Karagiozis[5])

3.3 Material properties

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

4. SIMULATION RESULTS

The main attention within this study was paid to the interplay between the chosen retrofit systems and the hygric behavior of historic walls. Hence, the progression of the total water content (TWC) of the constructions and results concerning RH in critical parts of the envelope were investigated, to predict their drying potential and assess the possibility of mold fungi growth. The subsequent simulations were performed for a period of 10 years. In the following graphs, partial results for the whole period and results only for the 5th to the 10th year are displayed.

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

Figure 3 shows the trend of the total water content (TWC) of all cases oriented to the North, during the calculated period of 10 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. The TWC of case 3, carried out only with wood wool panels inside, is slightly lower and ranges between ~8 kg/m² and ~10 kg/m². The lower thermal resistance of the wood wool panel provides "higher" temperature conditions and consequently lower moisture amounts within the wall. Case 5 with the chosen inside insulation system consisting of mineral-bound wood wool panels and additional mineral wool is showing a TWC gradient varying between ~9 kg/m² up to ~12 kg/m².

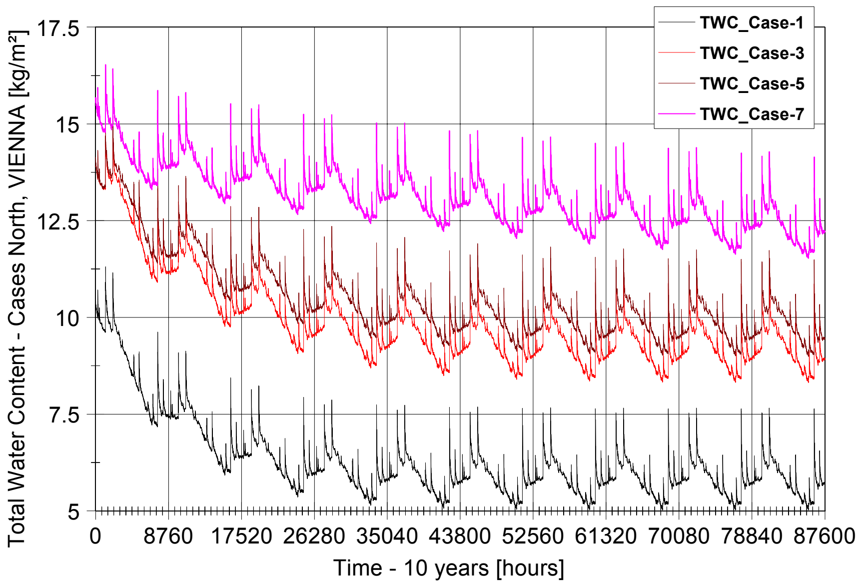

FIGURE 3: Total water content cases 1, 3, 5 and 7, Vienna North, years 1 - 10

Case 7, with the applied VIP panel, has the highest total water content of all cases. The TWC is slightly decreasing during the whole calculation period, varying between ~12 kg/m² and ~14.8 kg/m².

These first results only indicate, that all retrofit variants are providing a drying potential without rising moisture accumulation, but it is also obvious, that the application of VIP sandwich panels has a significant influence on the general hygric performance of the cross section of the wall. The use of high energy efficient VIP panels minimizes the temperature field within the wall and therefore reduces the outwards drying potential. Besides that, the VIP insulation panel with aluminum foils is acting analogical as a vapor retarder by reducing the vapor diffusion outwards during the winter, and unfortunately also reducing the solar-driven inwards drying during the warmer times of the years. (Straube[13]) 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.

Figure 4 illustrates, that the relative humidity (RH) on the internal surface of case 1 (without internal insulation) varies during the period of the years 5 to 10 between ~45 % during summertime and ~60 % during wintertime. After the improvement of the thermal quality by applying a wood wool panel on the inside (case 3), 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 by 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 of the RH remaining below 70 %, so condensation but also mold growth should be avoided. Besides that, the thermal improvement with wood wool panels enhances the heat transfer value (U-value) from ~1.05 W/m²K to ~0.60 W/m²K which is a quite acceptable result for this kind of constructions.

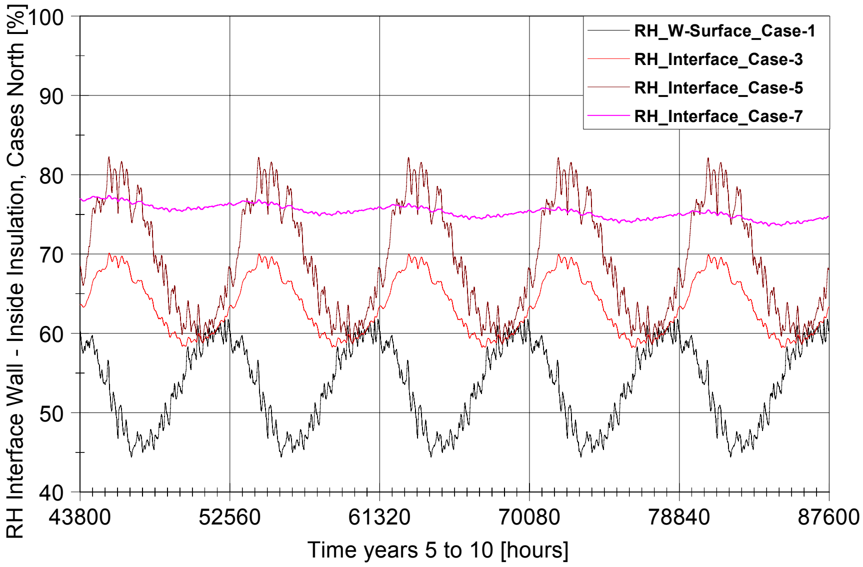

FIGURE 4: RH interface stucco-insulation, cases 1, 3, 5 and 7, Vienna North, years 5-10

In the same way, the relative humidity and temperature in the interface between old stucco and insulation were calculated for case 5, with additional mineral wool layer. It is well to see, that in this variant with a lack of vapor retarders, 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 5), the critical limit of 80 % RH regarding mold growth is exceeded and therefore a theoretical potential risk of mold growth cannot entirely be excluded. In practice, mold growth should be avoidable due to the higher PH-value of the magnesite-bound wood wool panel, as shown in research work (Juhart et. al.[4]) Summing up, it can be noticed, that the wall variant 5 is showing a very good thermal performance because the additional mineral wool insulation layer further decreases the U-factor to ~0.45 W/m².

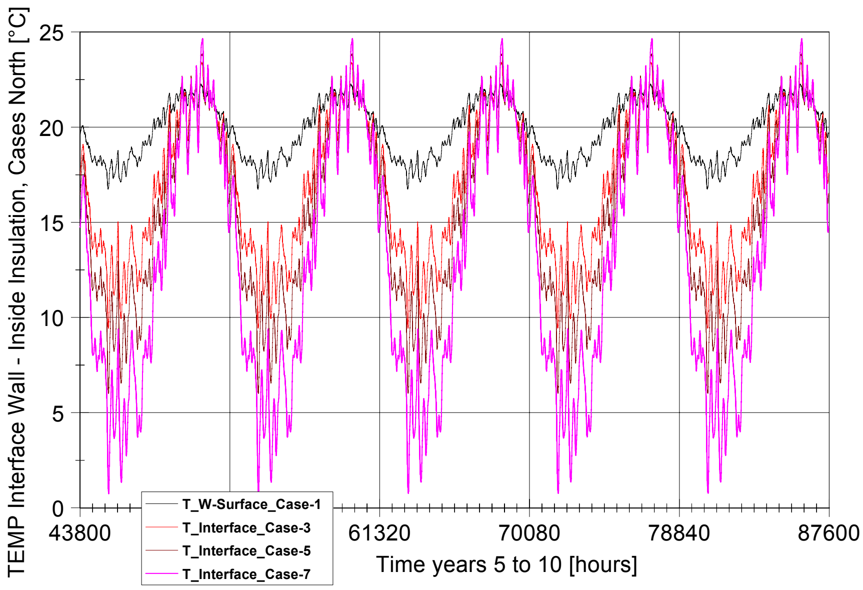

FIGURE 5: Temperatures interface stucco-insulation, cases 1, 3, 5 and 7, Vienna North, years 5 - 10

The results concerning the retrofit method used in case 7 indicate that the relative humidity on the interface wall to the VIP panel is slightly decreasing from ~78 % RH to ~75 % RH during the course of the first 10 years without risk of mold growth or even condensation. The use of vacuum insulation boards is also optimizing the thermal effectiveness of the whole construction with a U-factor of ~ 0.22 W/m². As mentioned before, especially for the retrofit method case 7 it is very important to analyze all connection details and thermal bridging effects regarding to moisture problems separately.

4.2 Cases 2, 4, 6, and 8; 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 the west orientation in the case of Vienna, were performed. Under these circumstances the total water content of case 4 (only wood wool panel) rises during the first years, but from the 6th year on the TWC is balanced and varies between ~22 kg/m² in summer and about 27 kg/m² in winter (Figure 6). Except of these seasonal fluctuations the total water content shows a constant trend without increasing moisture accumulation.

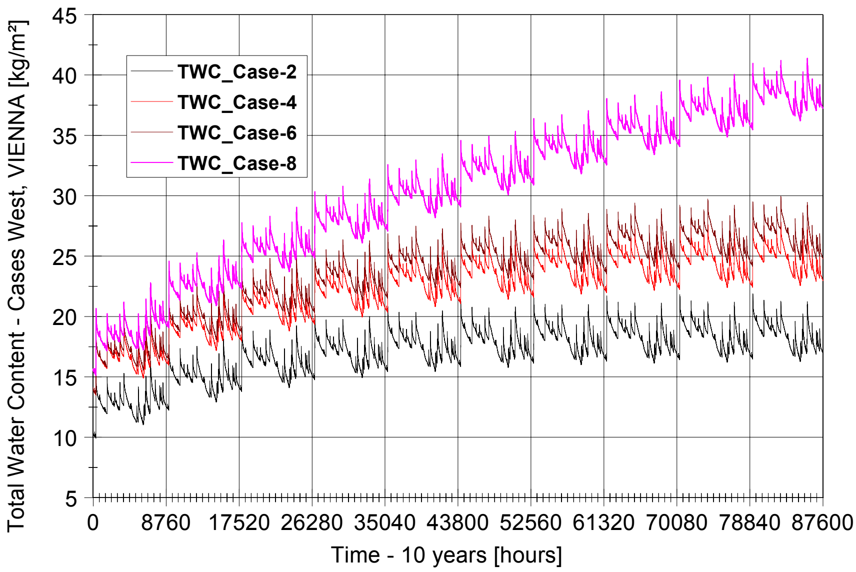

FIGURE 6: Total water content cases 2, 4, 6 and 8, Vienna West, years 5 - 10

Furthermore, the relative humidity in the interface stucco-wood wool panel is showing a steady state performance (Figure 7). 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 mineral wool layer, like in cases 6, the wall construction is also 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 ongoing moisture accumulation will not occur. Concerning the relative humidity in the interface stucco-mineral wool 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 7). 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 the more or less vapor-retardant VIP sandwich panel (case 8) is assumed to be risky because the TWC is showing a tendency to a constant uptake of moisture during the whole period of 10 years. The optimized internal VIP insulation with vapor-retardant aluminum based envelope is influencing the wall performance in different ways. The existing exterior stucco is assumed to be 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 VIP aluminum foils and the lower temperatures within the wall are also slowing down the drying to the exterior (Kuenzel[8], Kuenzel[10]). Due to these facts, the relative humidity at the interface of old wall and VIP sandwich panel is constantly increasing during the whole time of investigation. (Figure 7).

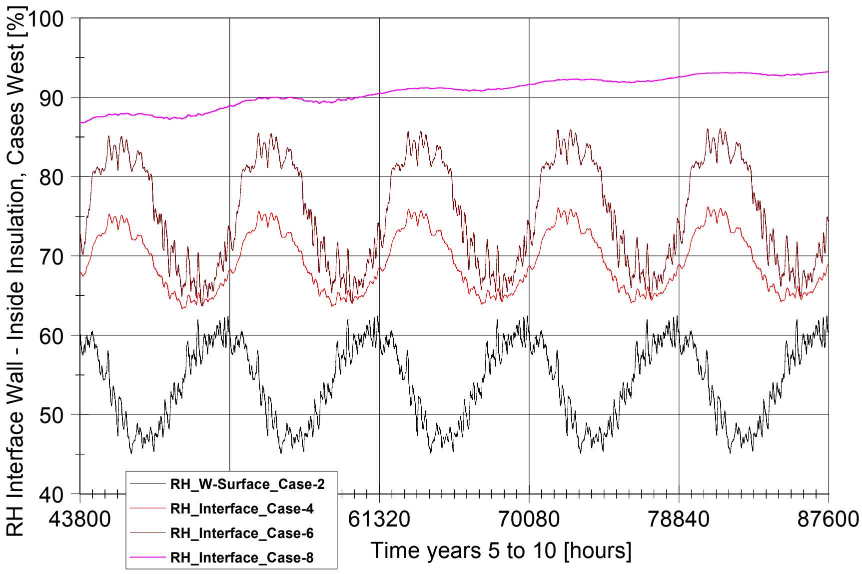

FIGURE 7: RH interface stucco-insulation, cases 2, 4, 6 and 8, Vienna West, years 5 - 10

It is obvious, that the installed VIP panel may increase the likelihood of damaging condensation over the course of the years due to its influence on the hygrothermal characteristics of the building enclosure.

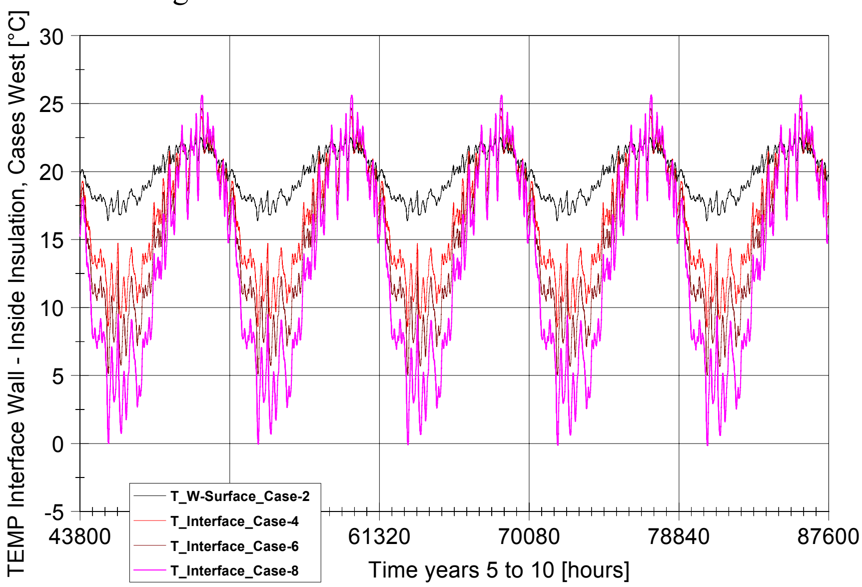

FIGURE 8: Temperatures interface stucco-insulation, cases 2, 4, 6 and 8, Vienna West, years 5 - 10

Hence, it is recommended to improve the driving rain protection (Dreyer & Korjenic[2]) to reduce the moisture accumulation within the walls, especially when VIP sandwich panels are used for retrofitting. One method may be the application of hydrophobic impregnation paintings, but it is noticed, that for landmarked façades these coatings are often prohibited due to Austrian conservation orders. Besides that, it is nowadays not really clear how possibly occurring flaws within the water repellent layer, which are unavoidable during the course of the years, may affect the wetting process of the masonry. (Krus[6], Kuenzel[9])

5. DISCUSSION RESEARCH RESULTS – FIELD TESTING

Starting in spring 2009, the Carinthia University of Applied Sciences (CUAS) is carrying out a research project regarding internal insulation systems, together with the manufacturer Knauf Insulation Technology GmbH. The scope of the research work is to investigate the influence of different internal insulation systems on the hygrothermal performance of existing building enclosures under varying weather conditions.

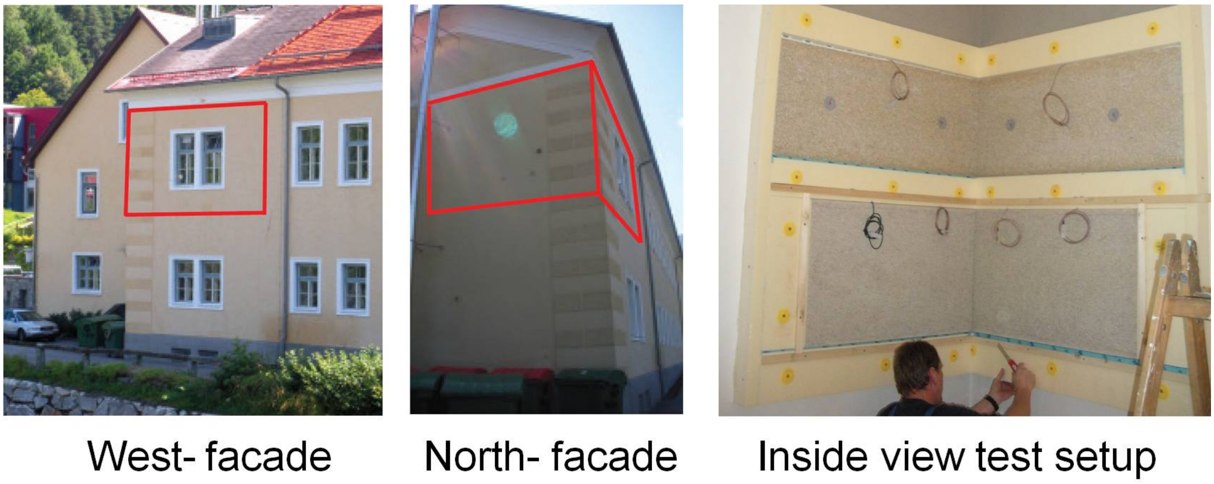

FIGURE 9: Exterior view of building and inside view of test setup

On the north and west façade of the CUAS school for architecture and civil engineering building, situated in Spittal an der Drau/South Austria (Figure 9), different inside insulation systems consisting of mineral-bound wood wool panels combined with additional mineral wool (e.g. case 5 & 6) and new VIP sandwich panels (e.g. case 7 & 8) were installed.

FIGURE 9: Mounting of internal VIP sandwich panels for in-situ measurements

The retrofit systems were mounted on a wall corner oriented to the North and the West. On the interface between existing stucco and inside insulation layers, special combined humidity and temperature sensors (Figure 10) were installed with 1.2 m distance to the corner (RH-VIP-W2, RH-BM-W, RH-VIP-N2 and RH-BN-N). In the case conducted with VIP panels, additional sensors in the wall corner (RH-VIP-W1 and RH-VIP-N1) were installed to analyze the thermal bridging effect.
The measurements started in April 2009 and are still ongoing until April 2011. Due to this reason, currently only a few measurements results are available.

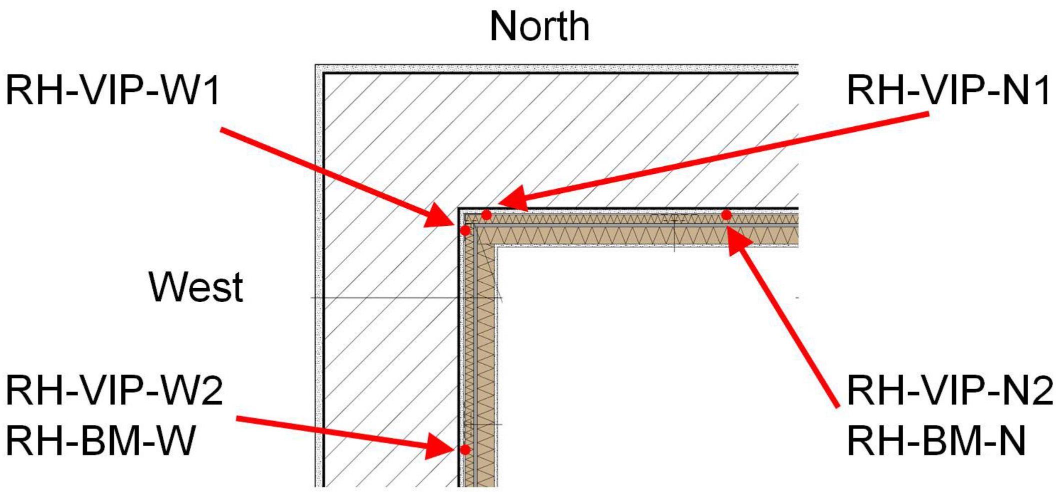

FIGURE 10: Positioning of sensors – test setup with VIP and wood wool panels

The graph in Figure 11 is presenting the first results concerning relative humidity on interface stucco to inside insulation system. It is well to see, that in the variant carried out with mineral wool and wood wool panel, the RH gradients are varying between ~38 and ~72 % RH during the first time of investigation.

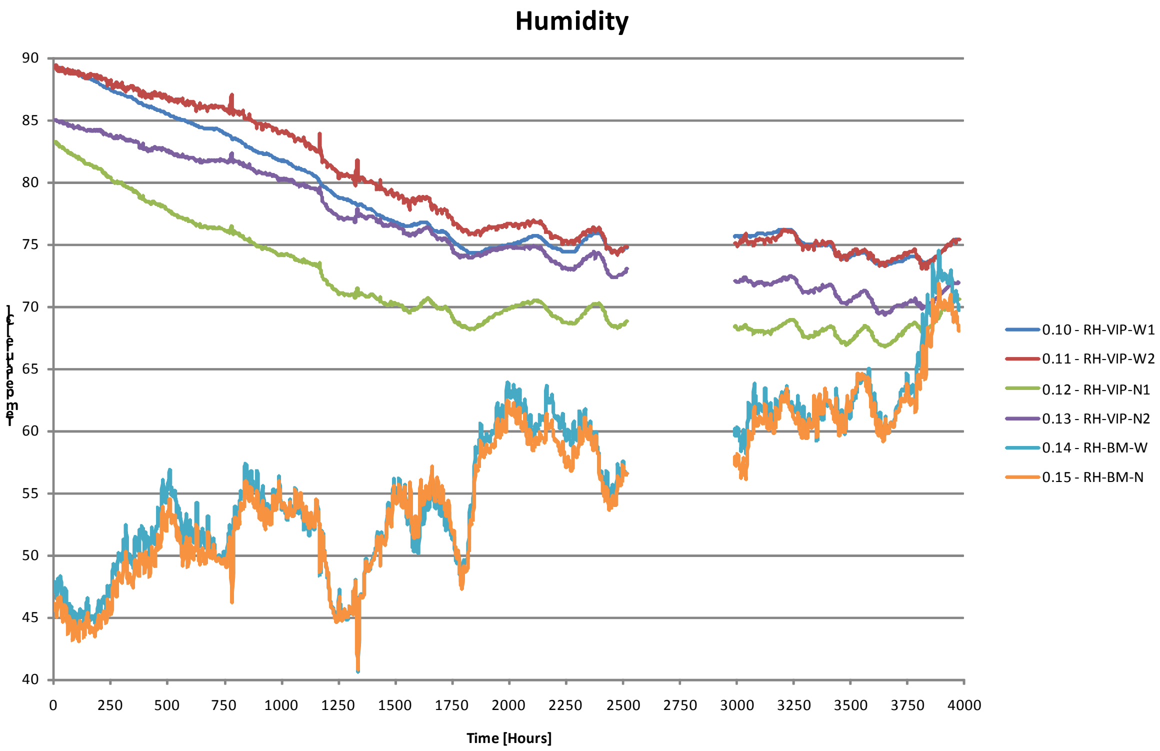

FIGURE 11: Positioning of sensors – test setup with VIP and wood wool panels

In the cases of inside VIP panels, the RH gradients are decreasing during the first month from ~82 and ~88 % RH. to ~68 and ~72 % RH until now. The relative high humidity level at the beginning is a result of the higher initial moisture of the adhesive, which was used to bond the VIP panels onto the old stucco. The present measurement results lead one to assume, that no moisture build-up is observable, but it is mentioned, that the next month during wintertime 2009/10 should be waited for.

6. 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 successfully 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, 0.45 or even ~0.22 W/m²K in cases with applied VIP sandwich panels as inside insulation. 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. In cases without additional wetting processes, e.g. when the walls are oriented to the North, all retrofit systems are providing a good drying ability of the existing enclosure without condensation risks. 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-retardant VIP panel is applied inside. So, in those cases it is recommended to reduce the water uptake of the façade by using special impregnations and to apply capillary brakes (horizontal waterproofing, chemical grouting, etc.) in the foundation area. The results further indicated, that an analysis regarding the moisture performance with steady-state calculation methods, as recommended in OENORM B8110-2, will never be accurate enough to predict the real wall performance under realistic climatic conditions (Borsch-Laaks[1], Haeupl[3]). So, summing up, one can observe, that redevelopment variants, especially with inside insulation, should always be designed with the help of hygrothermal models during the design process in order to predict an enclosure behavior as realistic as possible.

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