Investigation of the hygrical-thermal suitability of vacuum insulation boards for refurbishing of Viennese "Gründerzeit"-buildings

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1 Introduction

Vacuum insulation boards is a very interesting building material due to their high insulating efficiency attainable with small thickness. For instance the heat conductivity (0,0045W/m·K) is lowered by the good insulating efficiency of the vacuum and is approximately 10-times lower than with conventional insulating materials. Thus the thickness of the insulation board can be reduced by a factor 5 to 10. The insulation board consist of a powder core of a fine nano-structured silica acid and are coated with special high barrier foils, which can hold the necessary vacuum over decades of years. This kind of insulation is suitable for building, which should be become very well insulated and only a small thickness is available, or also for retrofitting measures, if the appearance of the building should not be changed. It offers itself for parapets, slim facade constructions, floor insulations, internal insulations, as well as for external insulations acceptable possibilities.

In the context of a project for the development of reconstruction strategies for buildings of the period of "Gründerzeit" it was tried to find out whether the vacuum insulation is suitable for an efficient energetic increasing of the insulation level of houses with facades worth to conserve and standing under monument protection. Internal and external insulations were examined. Further vacuum insulation boards were investigated embedded in render and plaster systems and situated in different element connection. To find out the thermal-hygrical behaviour of those elements and systems simulation procedures were used.

2 Climatic Conditions of the External walls

To simulate the thermal hygrical behaviour must be used realistic climatic data. Therefore a climatic data set typical for Vienna was used [Korjenic 2000]. The climatic conditions in Vienna are relatively mild. Therefore the "Holzkirchen" climate for comparative calculations was considered in order to determine, how the same construction behaves with other climatic data. The climate "Holzkirchen" is a stronger climatic load of constructions because of lower temperatures and more rain loads occur.

The computations were made by a period from 10 years. As initial condition a damage-free state with balanced moisture content according to relative air humidity of 80% was selected.

The time-dependent load quantities, which were considered, are outside temperature and relative air humidity, short-wave radiant absorption, long-wave radiant absorption and rainwater load. For the indoor climate a sinusoidal climatic state with a period duration from one year were used. The room climate varies sinusoidal between 20°C and 40% of relative humidity in the winter and 22°C and 60% of relative humidity in the summer. These values correspond to a normal use.

3 Additional thermal insulation of walls

An important retrofitting measure for buildings is the improvement of the thermal insulation of the external walls. For the investigation an external wall construction of an old building typical for the period of promoterism was selected, consisting of 2cm lime cement render outside, 50cm brickwork and 1,5cm gypsum interior plaster. The heat transfer coefficient of such an external wall can be reduced after an additional insulation with a vacuum board of 1 cm thickness from 0,9W/m²·K to 0,3W/m²·K. The behaviour of an inside and/or outside insulated wall was determined regarding to the normal state without an additional insulation. The computations were carried out by the software "WUFI - 2D" (two-dimensional simulator routine for coupled heat and moisture transfer) [Künzel 1994]. In order to verify the correctness of the results the results were checked by a computer program "COND" [Häupl 1989]. The program „COND" is based on the „Glaser" procedure and takes in consideration damp and water transfer,

The results of the calculation and simulation for three variants (initial state without additional insulation, vacuum insulation board outside and vacuum insulation inside) are represented in the following pictures. The thickness of the insulating board is 1 cm for all computed variants. The whole moisture content in an external wall in dependence of the climate respectively the time is shown in figure 1. The exterior vacuum insulation board prevents the penetration of moisture by weathering into the brickwork by its absolute water tightness. The low heat conductivity of the vacuum insulation, which keeps the construction so warm that no condensation is possible, causes a good drying effect of the wall. In this way the total water content of the wall, which results from a before existing humidity load (building humidity, old damage) possibly, can be reduced strongly.

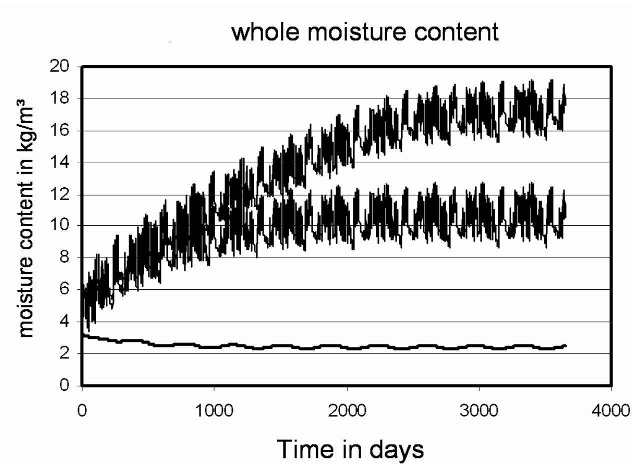


Figure 1: **Whole moisture content of an external wall. Through weathering and sorption the moisture content of a wall increases. The vacuum insulation board outside decreases and inside increases the moisture content.**

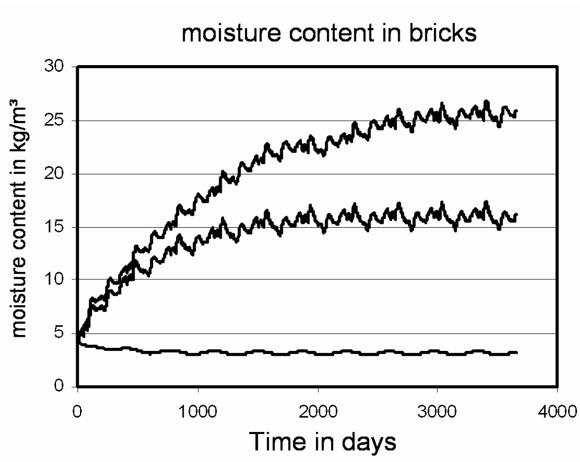


Figure 2: **Moisture content in bricks of an external wall. Trough weathering and sorption the moisture content of a wall increases. The vacuum insulation board outside decreases and a insulation board inside increases the moisture**

In the case of using a vacuum insulation as internal insulation the moisture content increases, but the total water content remains nevertheless in the tolerable range. This humidification process is to be attributed to the fact that the wall cools down strongly in the wintertime according to the great temperature gradient in the vacuum insulation board. This decreases the evaporation and more moisture from a rain load remain in the wall. In the summer time if the surface of the wall will be heated by sun radiation the temperature gradient is directed from the exterior surface into the wall, so that it is possible that existing humidity diffuses more deeply into the wall cross section. For interior insulation board a certain risk for condensation of a part of the damp flow that diffuses from the indoor to the outdoor exists. If a vacuum insulation board is used no kind of condensation could be found, because the insulation board is extremely damp tight.

In order to get an accurate knowledge over the hygrical behaviour of the construction under the influence of an internal insulation, the moisture contents for a period of 10 years was determined for building materials and construction elements. Fig. 2 shows the water content of the bricks. The humidity conditions in the external plaster are not shown, since the external plaster is exposed directly to the weather loads and thus the water content follows the loading by driving rain directly depending upon water penetration coefficient.

In the fig. 3 the conditions in the old interior plaster are represented. The old interior plaster is after a reconstruction between the vacuum insulation board on the inside and the external wall. It is visible that for an exterior insulation the hygrical conditions are completely uncritical. In case of an internal insulation after approximately three years the moisture content arises in the interior plaster and become critically. The moisture state changes into the over-hygroscopic range. The high diffusion resistance of the vacuum insulation board on the internal side of the wall prevents the evaporation of the water that is penetrated by weathering into the wall. Additionally the low wall temperatures in the wintertime and the temperature gradient into the wall have a decreasing effect to the evaporation behaviour of the wall. The drying velocity of the wall after a rain load becomes slower and the moisture balance changes to higher moisture contents. As a consequence of the increasing of the moisture content in the interior plaster the relative humidity in the pores increases too and becomes larger, so that the sorption behaviour moves into the range, in which the sorption isotherm becomes ever steeper. That means the absorption of water from the air becomes greater. Although directly condensation does not exist, in this case even more humidity will be absorbed, so that the moisture content increases after some years relatively drastically. Therefore in such cases an improvement of the driving rain protection is necessary by selection of a suitable external plaster.

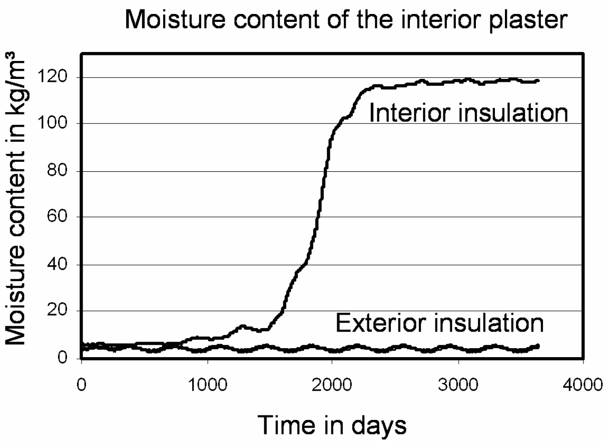


Figure 3: Moisture content of the interior plaster over the time. The exterior insulation board has no influence to the moisture content. The interior insulation system increases the moisture content.

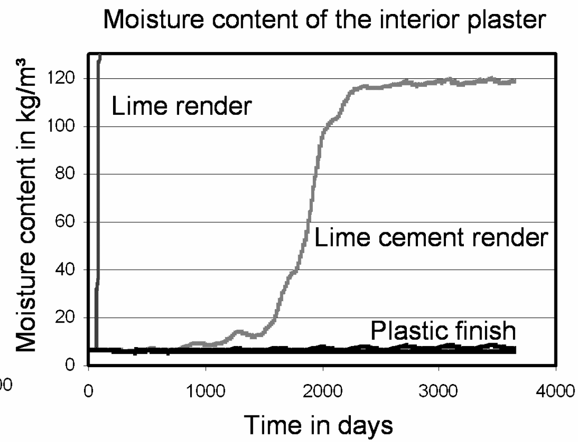


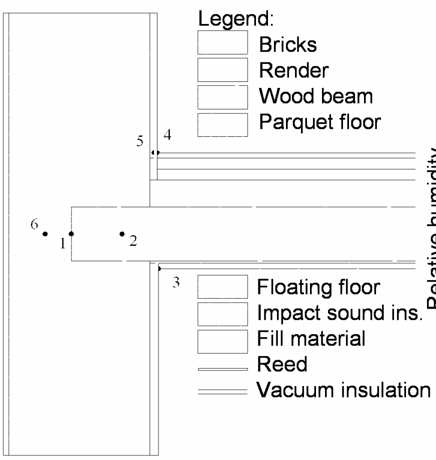
Figure 4: Moisture content of the interior plaster over the time in dependence of the kind of the exterior render system. Exterior render with a lower water penetration decreases the moisture content of the interior plaster.

The temporal development of the moisture contents in the interior plaster for different external plasters shows figure 4. The moisture contents in the wall are reduced logically, if the old external render will be replaced through a new one with smaller water penetration. Substantial result of the investigation is the description in order of quality of the effect. In case of a vacuum insulation as internal insulation the external render should be water-rejecting (water absorption coefficient $w \leq 0{,}5\ kg/m^{2} \cdot \sqrt{h}$), so that the water load by driving rain is small. The evaporation ability is given, if the thickness of the equivalent air layer is $s_d \leq 2m$. In this case the moisture load is small enough and the evaporation behaviour is high enough so that the moisture states are in an acceptable range.

4 Thermal bridge effects at a wooden beam connection

As example of thermal bridge problem the temperature field in the cross section of the joining between a wooden beam floor and an external wall with an additional insulation layer was calculated. The wooden beams, which interrupt the internal insulations, need special attention from the building design aspect. The bar heads are in a zone of the wall, which is exposed to lower temperatures than before. By the increase of the sorption humidity of the wood, condensation water formation between internal insulation and wall and by the influence of the weather inadmissibly high loads can occur.

In figure 5 the examined beam head zone in the external wall with an internal insulation layer made from vacuum insulation board is represented. The numbers in the figure 5 show the monitor positions, which were examined more exactly. For the evaluation of the thermal hygrical conditions were used research results from Viitanen [Viitanen 1996], which describes the danger of the formation of wood-damaging processes. If the relative air humidity and the temperature [Viitanen 1996] are higher than certain levels, than it will be possible that destruction and decay of wood occur. In the figure 6 the critical hygrical conditions are represented according to Viitanen for an time period of 4, 8, 12 or 24 weeks. Further in the figure 6 the yearly variations of the temperature and relative air humidity at two positions in the beam head compared with the critical states according to Viitanen are indicated. The calculation was done without the influence of driving rain. On the assumption of the Viennese climate the relative humidity's are 60% approximately, i.e. that the danger of destruction and decay is not given at the wooden beam ends. For a climate like in Holzkirchen (town in Bavarian), which is stricter than in Vienna, harmful states can happen.



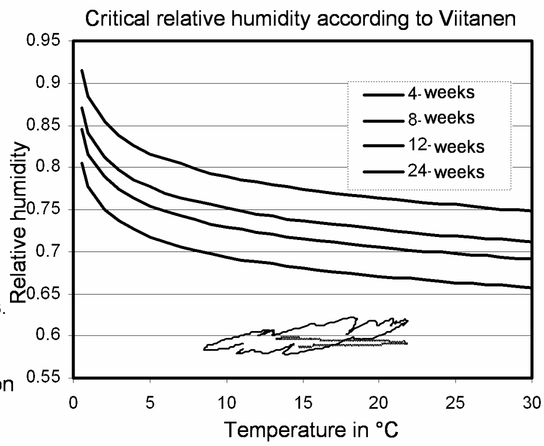


Figure 5: Cross section of the beam end. At the numbered location were investigated the thermal hygrical states relating to condensation and grow of mould.

Figure 6: Critical relative humidity's of wood according to Viitanen [Viitanen 1996] and relative humidity's in the cross section in the time period of one year by Viennese climatic conditions.

5 Evaluation of a window element

Very often the windows in old buildings are small. An additional thermal insulation particularly at the reveal can make worse the daylight situation in the rooms. With the use of a thin vacuum insulation in the reveal, fall and parapet it is possible to decrease the daylight situation only insignificantly.

A window joining with the wall in the case of an internal vacuum insulation board was examined. By a vacuum thermal insulation on the inside wall parts cool down more strongly, so that wooden construction components could be possibly endangered. Figure 7 shows the investigated wooden window, built into a brick wall with lime cement render outside and vacuum insulation inside. In the variant (A) only the interior surface of the wall was insulated and in the variant (B) is fixed an additional insulation at the reveal. For several monitor positions at and in the wood the risk of the rottenness was determined.

Fig. 8 shows the relative humidity in the represented monitor positions. The relative air humidity's exceed only initially critical humidity levels. In the time period of ten years the relative humidity drops slowly and adjusts themselves to equilibrium between 55% and 75% of relative air humidity. Therefore a direct danger of the wood rotting does not exist for the wooden window. However this computation without consideration of a rain load was accomplished. Humidity increases by rains are to be minimized if necessary by suitable external plasters.

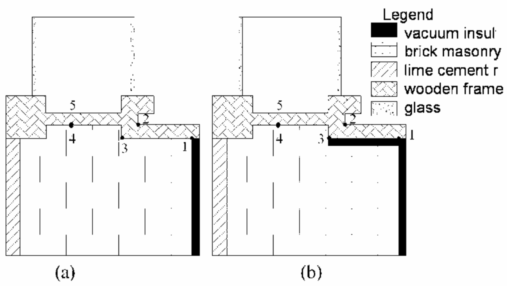


Figure 7: Cross section of the window wall joining. Variant (a) interior insulation of the wall, variant (b) Interior insulation of wall and reveal. At the numbered location were investigated the thermal hygrical states relating to condensation and grow of mould.

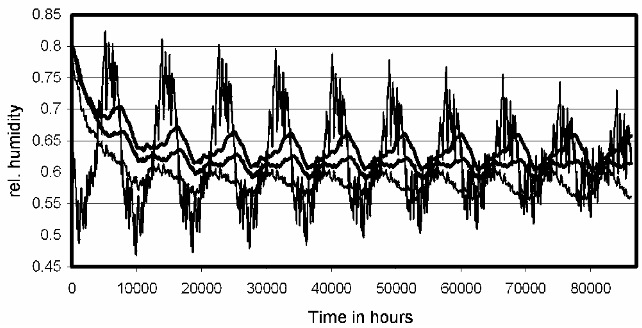


Figure 8: Humidity at several positions in the wood frame versus time. The plotting shows a drying behaviour at all positions.

If one determines the moisture contents with consideration of reveal insulation on the inside, then the air humidity's change only insignificantly. An essential thermal bridge effect in the frame area does not exist for a walls and wooden windows typical for the period of promoterism.

6 Investigation of the installation situation

With the installation of boards it is usually that at the ends joints exist and the boards fit more or less well together. In the fig. 9 possible arrangements are represented with and without a joint. In the figure 10 typical states of the moisture content of the mortar behind the vacuum insulation board are shown. In the joint of 1 cm width the moisture penetrates and the temperature field is changed by the influence of the thermal bridge effect. In normal cases the effects are small. The humidity increases only some per cent. The influence on the total water content of the construction is negligible.

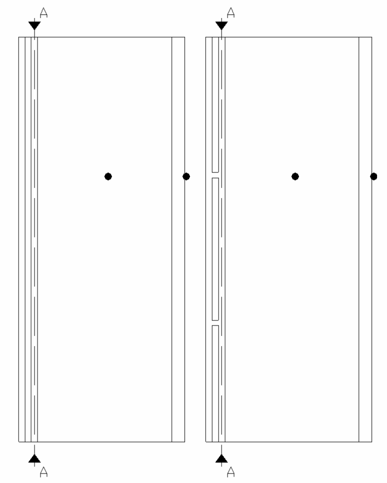


Figure 9: Cross section of the external wall with and without a joint between the insulation boards. The width of the joint is 1 cm.

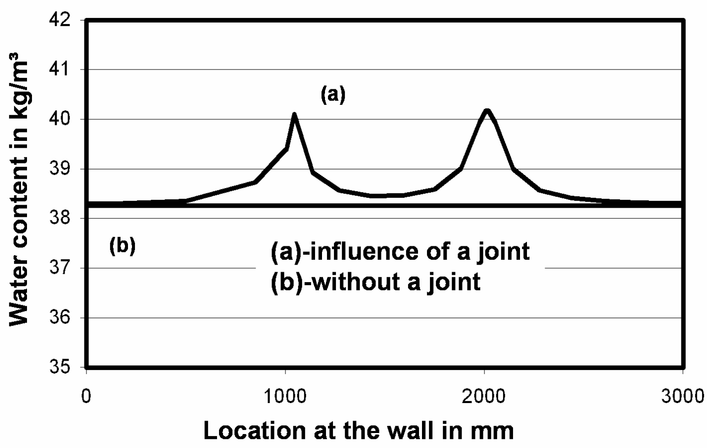


Figure 10: Water content of the mortar between the vacuum insulation boards and the brick wall.

7 Summary

The aim of this investigation was to analyze the thermal hygrical behaviour of selected constructions. Investigation shows, that vacuum isolation can be used successfully for interior and exterior insulation.

For interior insulation systems exist in the case of a driving rain load a certain danger for increasing of the moisture content. This load can be decreased by an appropriate selection of the external plaster clearly.

The evaluation of different thermal bridges like wooden beam wall connection, window connection and joint problem between two boards show that the thermal bridge effect is not essential. The examined construction components show uncritical hygrical conditions without substantial driving rain effect, i.e. a water tight envelope is necessary. Also in the joints of small width with a low damp and water permeability no harmful states arise. The influence of the external climate is to be considered. The comparison of the hygrical behaviour of different locations shows substantial deviations.

8 Reference

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