Comparing solutions for retrofitting of a listed school building with internal insulation

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ABSTRACT. Two different solutions for internal insulation applied to listed buildings are compared and evaluated. The analysis includes considerations about the air tightness, the moisture protection and the heat protection of the different systems taken into account.
In order to assess the performance of retrofitting solutions, numerical simulations have been performed; moreover capacitive sensors for temperature and relative humidity monitoring have been applied in the test rooms. A critical analysis of the simulation results is presented in the paper.
This study is performed within the European project 3ENCULT for the renovation of cultural heritages.

Keywords: Capillary activity, moisture protection, hygrothermal simulation, 3ENCULT

1 Introduction

The European project 3ENCULT (seventh framework program) aims to find proper solutions for retrofitting listed and historical buildings. In this study we present the case of a listed school which has to be renovated. The school was built in 1929/31 by the architects Bauman and Prachenzky in Hötting (Innsbruck, Austria).

For the renovation of the building, internal insulation is required, since the energetic efficiency has to be increased preserving the aesthetics of the façade.

In general, the application of insulation on the external walls represents the most important measure to reduce the energy demand of a building. For this specific case results that about 56% of the maximal achievable energy demand reduction can be obtained by applying internal insulation. A simulation performed with the software PHPP shows that the transmission heat loses through the external walls can be reduced from 66 to 14 kWh/(m^2a) applying internal insulation.

Other relevant measures, such as the use of a ventilation system with heat recovery and the renovation of the windows, lead to lower benefits (about 24% and 15% of the total achievable benefit respectively). However the application of internal insulation requires careful planning in order to avoid water condensation inside the construction and mould formation at the surface, especially at thermal bridge details.

With the aim to select an appropriate solution for the retrofitting of the whole building, two test classrooms have been refurbished and provided with two different types of internal insulation.

In the first classroom a product combining PU foam insulation and capillary-active clay (Remmers IQ Therm) has been applied. The second classroom has been provided with cellulose fibre and clay boards.

The condensation risk inside the construction and the mould formation risk have to be investigated for both systems by means of numerical simulations and measurements. The numerical simulation is profitable, since it allows easy and fast assessment and visualization of the moisture distribution inside the construction for a plurality of cases. However the numerical results are affected by uncertainties which need to be quantified: on one hand the physical model describing the hygrothermal behaviour of the construction presents approximations, on the other hand, the simulation is affected by numerical errors.

Available software for this kind of simulations are ("Delphin Software," 2011), ("WUFi Software," 2011) and COMSOL Multiphysics (Janetti, 2012).

In this study, the simulation software Delphin, based on the finite volumes method, has been employed. Since it can be assumed that for the considered cases the numerical errors are negligible, we focus here on the uncertainties concerning the physical model (material properties).

Within further development of the same project, the simulation models will be calibrated by comparing the results with measured data. With this purpose, a monitoring system for the measurement of temperature and moisture values at different position in the room and inside the construction has been installed.

2 Insulation Variants

2.1 First variant

Figure 1 shows a vertical section of the wall-ceiling junction of the two test classrooms with applied internal insulation. The first room (Figure 1, left side) presents PU-foam insulation panels employed in combination with capillary active clay. This solution bases upon the property of the clay to store moisture inside its micro-porous structure and to allow a significant liquid water transfer due to capillary forces. The pre-fabricated PU panels are perforated and the pores are filled with capillary active material, thus liquid water can be transferred through the insulation layer.

The panels are fixed to the wall by means of a fixing-clay and following covered with a layer of fine plaster.

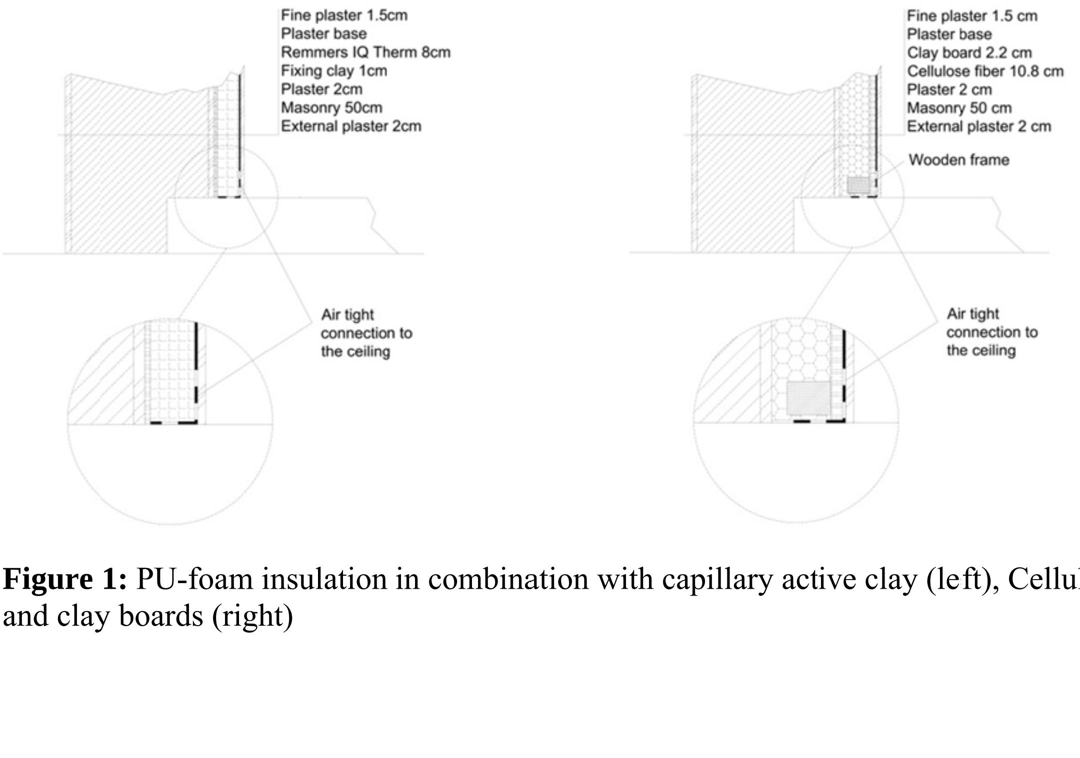

Figure 1: PU-foam insulation in combination with capillary active clay (left), Cellulose fiber and clay boards (right)

This system should allow the drying of the insulation from the internal surface. The moisture entering the construction by means of vapour diffusion (directed from warmer to colder temperature) is transported in the opposite direction through the bored panels by means of capillarity and given back to the internal air.

This system is patented and available on the market (Remmers IQ Therm), combining the advantage of the PU foam (low thermal conductivity, thus good thermal protection) with those of capillary active materials.

2.2 Second variant

The solution applied in the second room (Figure 1, right side) presents cellulose fibre combined with clay panels on the internal side. Since the thermal conductivity of the cellulose is higher compared with that of the PU-foam, the insulation layer has to be slightly thicker in order to guarantee the same total U-value of the wall (10.8 cm instead of 8 cm PU-foam). The space requirement results anyway acceptable for the considered case and does not represent a drawback for this solution.

The application procedure results easy and adequate to the use in listed buildings. A timber frame is fixed to the wall using screws and distance spacers. The frame is closed positioning clay boards on the room side (internal side) and the space between the clay boards and the wall is filled with blown in cellulose.

Difficulties arise trying to asses the condensation risk affecting this system using numerical simulation, since the material data and functions characterizing the cellulose present uncertainties.

Past studies present discordant results concerning the performance of cellulose-based systems (Pfluger, 2005) (Schafaczek, 2012). The simulation results depend strongly from the assumed capillary storage and transfer properties which in our case are not well known.

2.3 Air tightness

For both the variants presented upon, air tightness is required. The surface of the internal insulation has to be covered with a plaster base for applying the fine plaster. The latter has to be connected to the ceiling avoiding cracks. In this way, the fine plaster applied on the internal surface guarantee air tightness also at the ceiling connection. Vapour tightness is not essential, since the internal insulation can dry from the internal side by means of capillary transport.

3 Results of the numerical simulations

The external walls of the school are crossed by a ceiling with structural function. The material employed for the walls are brick and concrete, whereas the ceiling consists of a linoleum floor, a screed, reinforced concrete with hollow bricks between and a plaster layer below.

Moisture is transported by means of diffusion and convection through the hollow bricks to the wall surface.

The moisture distribution in the construction has been investigated using the Software Delphin ("Delphin Software," 2011). All the employed material properties are included in the Delphin database. Boundary conditions of third kind have been imposed, using constant internal values ($\theta = 20°C$, RH = 50%) and climatic data on the external surfaces (Innsbruck, METEONORM). Driving rain is not included in the simulation.

2D-simulations have been performed, considering two different vertical sections of the wall-ceiling junction: firstly, the section through the massive concrete between the ceiling bricks (Section A), secondly the section crossing the air cavity of the hollow bricks (Section B). These two cases have been investigated for both the test rooms. The convection contribution to the moisture and heat transfer through the hollow bricks is taken into account using increased diffusion coefficients for heat and mass transfer.

Figure 2 and Figure 3 report the results at the end of the simulation period (five years, winter). Notice that high moisture content is reached at the wall-insulation layer interface and in the air cavity close to the wall surface (section B). The highest RH value at the internal surface is reached at the Wall-ceiling corner. The following sub-sections focus on the investigation of the moisture risk at these three critical positions.

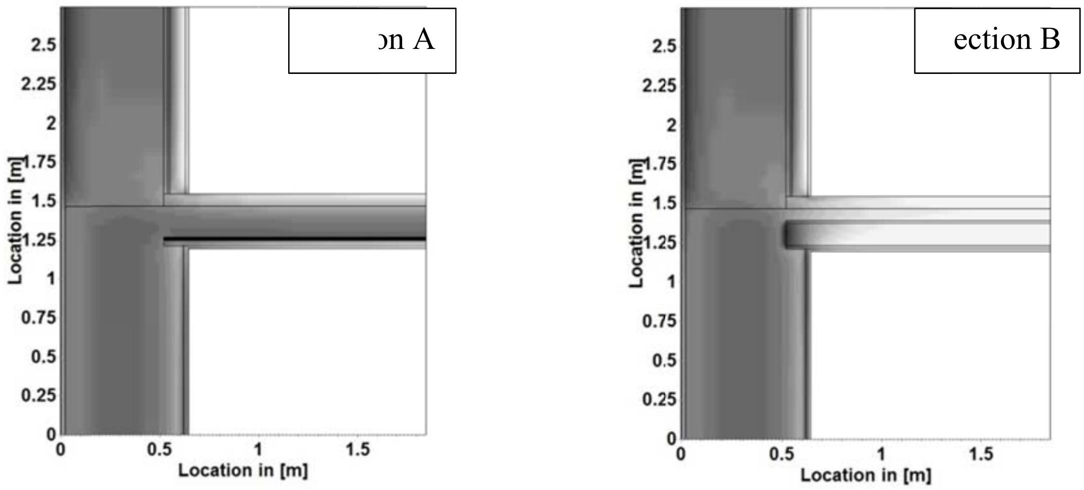

Figure 2: Moisture distribution (RH [%]) in the wall ceiling junction after five years (test room 1, Remmer system, Clay Tu2 PV 0 439 as fixing material).

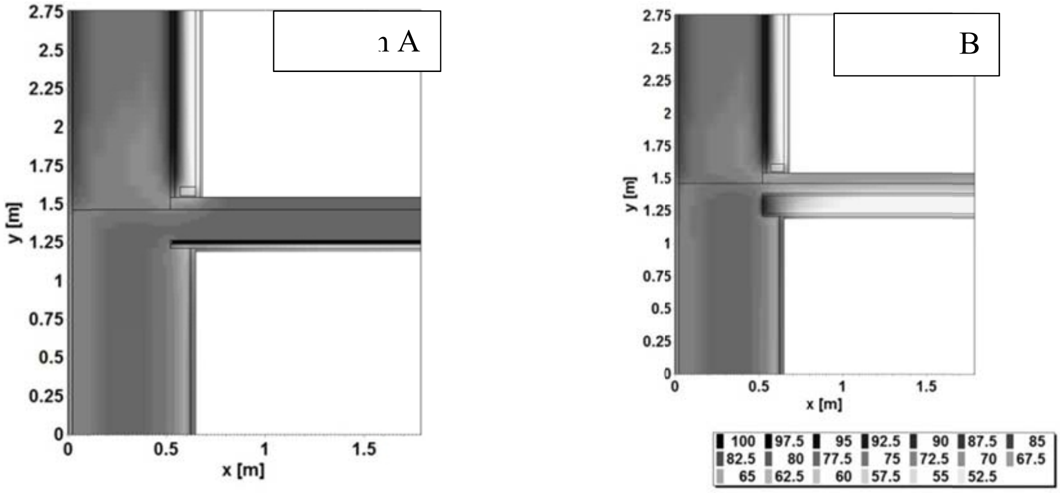

Figure 3: Moisture distribution (RH [%]) in the wall ceiling junction after five years (test room 2, cellulose type 1)

3.1 Relative humidity evolution at the wall-insulation interface

Considering that for some employed materials there are uncertainties concerning the hygrothermal properties, more simulations have been performed using well known materials which are supposed to be similar to the employed ones. The results fluctuation gives a measure of the uncertainties affecting the prediction.

In case of the test room 1 (Remmer system) we focus on the fixing layer (about 1 cm thick) between the insulations boards and the existing wall. The employed material is special clay used for installations in listed or historical buildings. The simulation has been repeated with four different materials from the Delphin database presenting similar properties but with very different water retentions functions (see Figure 4).

The results (RH evolution at the wall-insulation interface) are compared in Figure 5, left side. The maximal value of the relative humidity presents a fluctuation of about 10%. Even if the results uncertainty is relative large, the maximal value of the relative humidity remains, also in the worst case, under 93%, excluding real risk of moisture damages at this position. Notice that in this case the material quality influences mainly the amplitude of the moisture fluctuation, whereas the mean seasonal value and the phase remain almost the same.

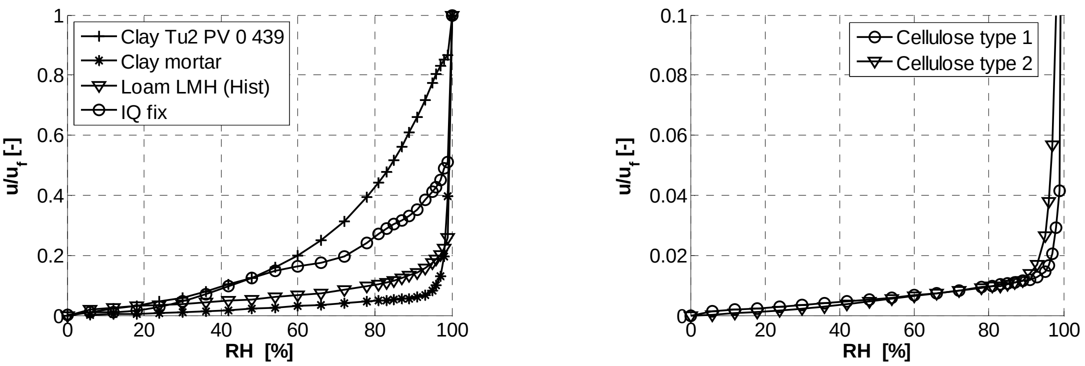

Figure 4: Normalized water retention curves for different Clays (left) and Celluloses (right)

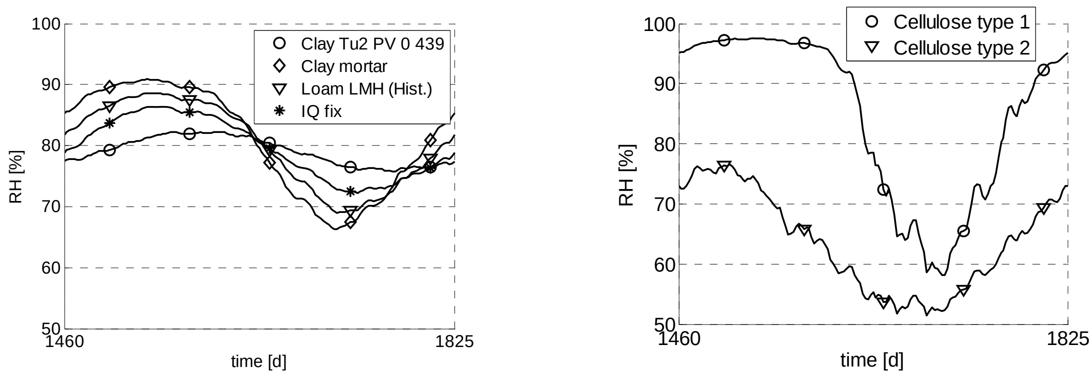

Figure 5: Relative humidity evolution at the wall-insulation interface. Left Test room 1 (Remmer system), right: test room 2 (cellulose)

In case of the test room 2 two different types of cellulose have been tested. The first type is included in the database of the Delphin version 5.6.8 (Cellulose insulation). The second one refers to the Delphin version 4.5 (“Isofloc” cellulose). These two materials present similar water retention curves (Figure 4, right) but different behaviour concerning the capillary transport.

The results calculated with the two variants present significant differences in the oscillation amplitude as well as in the mean values (Figure 5, right side). In particular, the variant including the first cellulose type reaches in the winter values of relative humidity up to 97%, which can be critical for mould formation and degrading of the material. The second variant, on the contrary, shows non critical values during the whole year period (max. 75% RH). In case of the cellulose-based system, the simulation does not give sufficient information on the construction performance, thus measured data are required for an adequate evaluation.

3.2 Moisture risk at the wall surface bordering the air cavity

In Figure 6 the relative humidity evolution at the wall surface bordering the air cavity of the hollow bricks is reported for the test room 2 (cellulose) before and after the retrofitting. The results concerning the test room 1 are similar and are not reported here. Notice that the insulation leads to a slight temperature decreasing and a relative humidity increasing at this position.

The internal relative humidity influences strongly the moisture evolution in the air cavity. The graphic shows that with 30% internal relative humidity, a maximal value of about 75% is reached at the surface inside the air cavity whereas 50% internal relative humidity leads to values higher than 90% at this position.

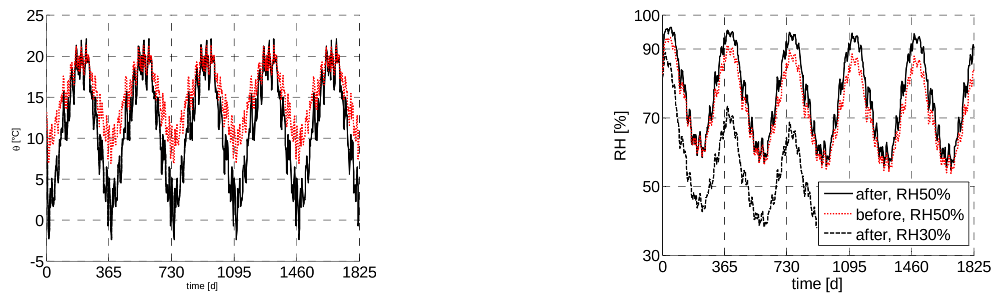

Figure 6: Temperature (left) and relative humidity (right) evolutions before and after the insulation application with 50% and 30% internal RH. Section B, room 2

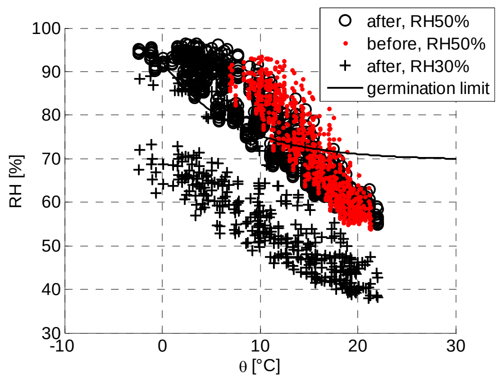

Figure 7: Mould germination, results before and after the insulation application with 50% and 30% internal RH. Section B, room 2

The temperature and moisture conditions reached in case of 50% internal relative humidity can lead to mould growth, as shown in figure Figure 7. Here the mould germination limit is reported according to the isopleths model (Sedlbauer, 2001). On the countrary, internal relative humidity of 30% leads to uncritical conditions. Thus, the internal moisture has to be controlled and the installation of a ventilation system is necessary for the moisture protection.

3.3 Relative humidity evolution at the wall-ceiling corner

The highest RH value at the internal surface is reached at the wall-ceiling corner. No significant difference can be observed between the two insulation variants, thus we report here only the results concerning the second one (cellulose).

In Figure 8 and Figure 9 the evolutions of temperature and relative humidity before and after the renovation are compared (50% internal RH). Notice that for the section A (Figure 3 left side) the application of internal insulation lead to higher temperature and lower relative humidity (Figure 8), whereas for the section B no significant difference can be observed (Figure 9 and Figure 10)

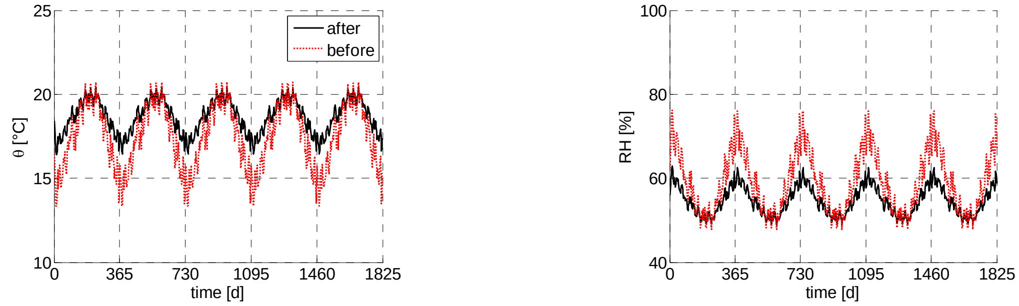

Figure 8: Temperature (left) and relative humidity (right) evolutions, section A, room 2

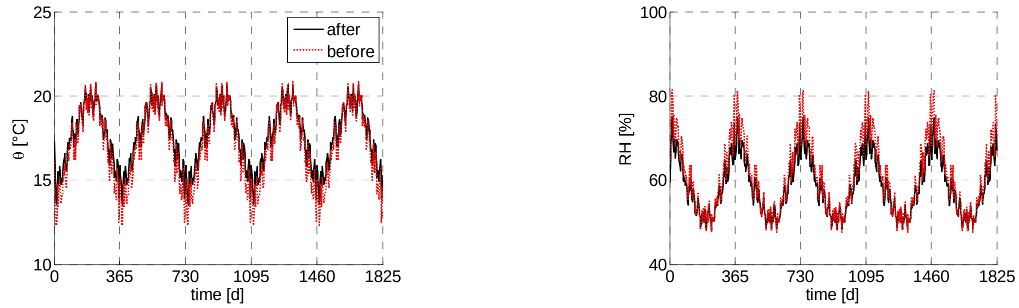

Figure 9: Temperature (left) and relative humidity (right) evolutions, section B, room 2

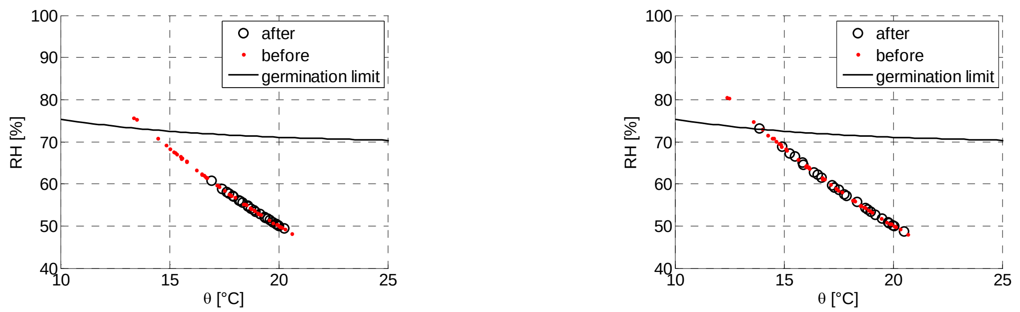

Figure 10: Mould germination limit section A (left) and section B (right), room 2

5 Conclusions

Numerical simulations for the evaluations of moisture damages concerning two different internal insulation variants have been performed.

The prediction of the moisture evolution at the insulation-wall interface presents uncertainties since some material properties are not available. In particular for the cellulose-based system, further experimental work should be done for allowing a realistic prediction.

Within further developments of the same project, results of the installed monitoring system will be evaluated and compared with the simulation results.

The internal relative humidity should be limited in order to exclude mould growth conditions inside the cavity, thus the installation of a ventilation system is recommended.

At the internal surface (wall-ceiling corner) no critical conditions for mould growth have been identified.

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