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On-site assessment of hygrothermal performance of historic wall before and after retrofitting with insulation

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Abstract – *The impact of thermal insulation scenarios on the hygrothermal balance of traditional walls has been investigated. In three pre-World war II houses subject to a global thermal retrofit, instrumentation devices were used on-site to monitor the interior and exterior climates, and the temperature and humidity at different points inside the walls. These measurements were made before and after the retrofitting. Then a comparison was done between the hygrothermal behaviour of the old wall and the insulated wall. Based on the measures, dynamic hygrothermal simulation has been performed with a commercial tool (Wufi 2D) to anticipate the evolution of moisture inside the insulated walls over ten years. The cases analysed are a brick house retrofitted with exterior insulation and two half timbering houses retrofitted with interior insulation, i.e. cellulose wadding and moisture control barrier and wood fibre insulation board respectively.*

Keywords – *hygrothermal performance ; on-site assessment ; thermal insulation ; historic wall retrofitting*

1. INTRODUCTION

The need to save energy and master greenhouse gas emissions leads the actors of the building sector to intervene on the existing stock. This is partly reflected by the need to thermally insulate buildings. The family of “pre-world war 2” buildings represents more than 30% of the French building sector and is a real stake for energy savings and comfort improving. The retrofitting process has to take into account the heritage considerations and the different risks for the building and the occupants. In the global process of retrofitting, the presented study will focus on the walls and the humidity issue as excessive level of moisture in building leads to construction disorders [1]. The increasing number of thermal retrofits concerns buildings with common and vernacular material with sensibility to humidity. The idea of sustainable development involves guaranteeing the durability of the technical solutions applied to the walls to improve their thermal behaviour and in a larger spectrum, to decrease the energy need of the building. In [2], the main hypothesis is that instead of aiming at saving the most energy, solutions that pay regards to finding a balance between energy savings and the durability in terms of reduced moisture risk need to be put forward.

1.1 OVERVIEW OF THE HYGROTHERMAL PERFORMANCE OF INSULATED HERITAGE WALLS

Depending of the architectural particularities and the heritage conservation issues of historical buildings, the insulation process could take place from inside or from outside. The latter technique is the most efficient, when it is possible. Applying interior insulation will modify the hygrothermal

behaviour of the wall and may induce a risk on interstitial condensation, frost damage or mould growth.

In [3] the interior insulation of a historical building was instrumented for 4 years, it consists of a hydrophilic mineral wool without vapour barrier on a heritage brick wall in Prague. A lime-cement basis was applied between the insulation and the brick. The conclusion is that the system performs well and no internal condensation had occurred in the studied period. In [4] and [5], conclusions gave the benefits and disadvantages of two families of interior insulation process on historical walls after experimental analysis in laboratory and a large number of simulation with a dynamic tool. The first insulation process represents the family of vapour tight interior insulation (XPS panels or mineral wool with traditional vapour barrier) and the second one represents the capillary active insulation systems (calcium silicate boards). Results show that a vapour tight system is preferable to capillary active system from the point of view of interstitial condensation. On the other hand, the vapour tight system has a larger risk of frost damage and additionally such system would be more risky for wood beam ends, allowing an elevated moisture retention in the masonry. Concerning new insulation techniques such as vacuum insulation panels, the hygrothermal behaviour of a heritage brick wall renovated with them was investigated in [6]. The conclusions are that it provides a great thermal behaviour but there exists risks of moisture damages such as frost in the exterior part of the brick, especially in Bergen climate, and risk for wood beam ends inside the wall. Finally, an important question is raised in [7]. It is the evolution of the properties of the materials through years. In this article, it is shown that the properties of mineral wool in a building has been largely modified after 25 years of services. For instance, the degradation of the polymeric binder had caused the decrease of the hydrophobicity of the material with a greater water sorption.

1.2 OBJECTIVES

The literature review warned us on the specific risks associated with each solutions. In France but also elsewhere in Europe, solutions with hydrophilic materials are more and more promoted as systems that diminish the moisture storage in the wall structure by still allowing an inward drying. Such system are in the centre of the work presented in this article. The focus is put on three walls from three heritage buildings with projects of insulation with cellulose wadding or wood fibre insulation board. The impacts of the retrofitting scenarios on the hygrothermal balance of the traditional walls have been investigated. Measurements after and before the retrofit have been performed and completed with simulations to check the projected behaviour for ten years and compare the chosen solutions to other ones.

The building A is a brick house from the beginning of the 20th century, typical of the suburbs of Colmar region in Alsace. The retrofit consist in exterior insulation with cellulose wadding and wood fibre board for the walls, the installation of a single-flow mechanical ventilation system and the insulation of the roof. The building B is an half timbering house with a project of interior insulation with cellulose wadding and moisture control smart barrier for the walls, insulation of the roof and the

installation of a single-flow mechanical ventilation system. The building C is another half timbering house with a project of interior insulation with wood fiber board for the wall and the roof. All three houses are in Alsace, in the east of France with a continental climate.

2. METHOD

2.1 IN-SITU MEASUREMENTS

The three houses were monitored during a year before the retrofitting process and at least a year after. The local climate was assessed with a weather station (air temperature, relative humidity, wind direction and speed, rain, horizontal global solar radiation), the indoor climate in the different rooms of the houses were recorded hourly with data-loggers (air temperature and relative humidity). Finally, two walls in each houses were specifically monitored with temperatures and relative humidity probes inside the walls at three different places (four for the house A). These relative humidity measurements need special care during the installation of the sensors but it has already been successfully used in [8]. Figure 1 presents the scheme used for the house B.

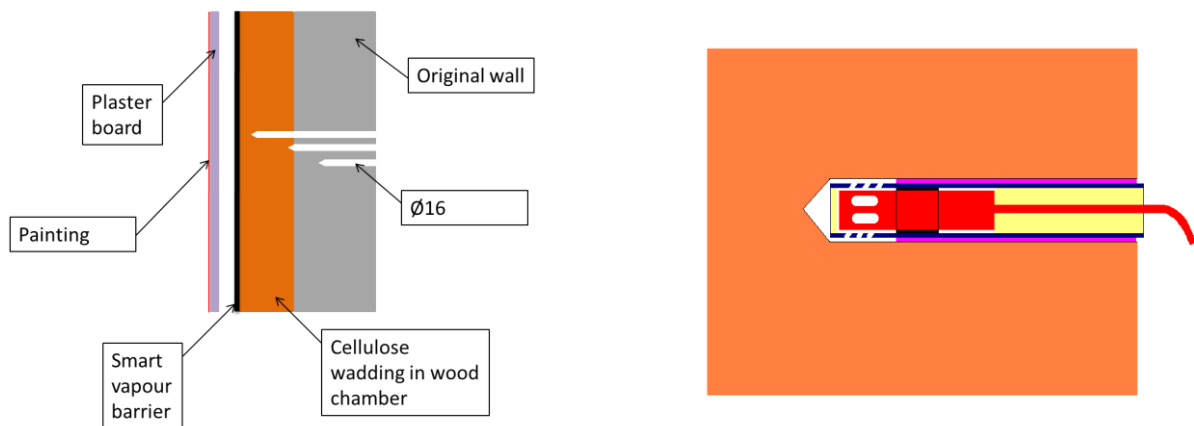


Figure 1: temperature and relative humidity sensors in the walls of the house B

To complete the set of data, thermocouples were used to assess the different surfaces temperatures. The full diagnosis of the houses before and after the retrofitting were performed, including infrared analysis, air permeability measurement and control of the ventilation system. In the 3 cases, the air permeability has been strongly improved with the retrofitting to reach the low consumption in retrofitting French label. The relative humidity measurements in the small cavity in the material are supposed to be in balance with the water content of the material around it, considering the water sorption function for the material. These materials properties have been measured in laboratory in another part of the general project (“Humibatex” from the French National Research Agency). The

figure 2 present the configuration of the monitored wall of the houses A and C, for house B it is in figure 1. The letters represent the position of temperature and relative humidity sensors.

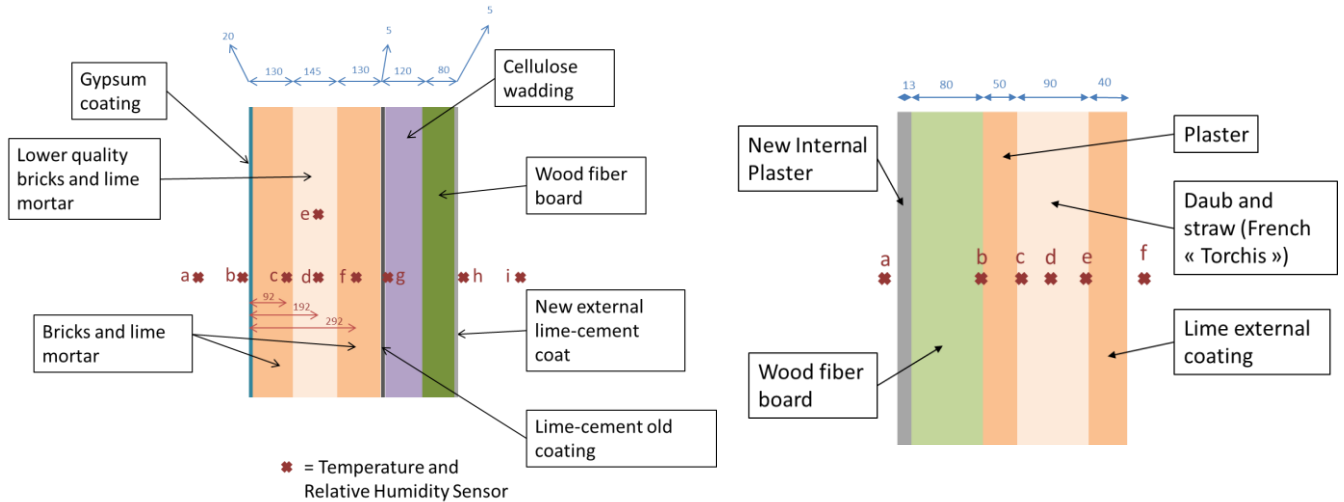


Figure 2: Monitoring and configuration of the wall east of the house A (left) and the wall south of the house C (right). (dimensions in mm)

2.2 HYGROTHERMAL DYNAMIC SIMULATION

The figure 3 illustrates the water content in the middle of the brick section of the eastern wall of the house A after the retrofitting.

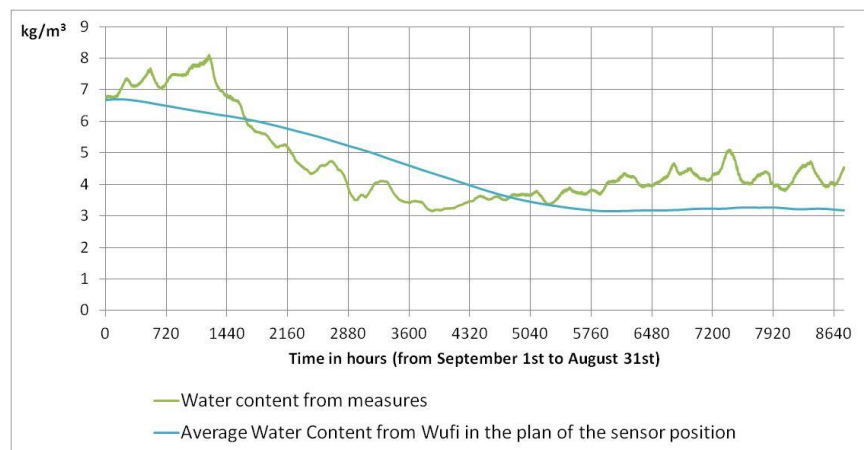


Figure 3: Water content in the middle of the brick section of the eastern wall of house A during the first year after the insulation

The measurement campaign only allows to draw conclusions on one year whereas the risks involving humidity could be on the long terms. The simulation tool Wufi from the Fraunhofer Institute, based on the work of Künzeli [9] was used to simulate ten years. A comparisons between the simulation and the year of experimental data was performed for all buildings. It shows a satisfying

convergence on the northern and eastern walls. On the western or southern walls, the rain and the solar radiation add complexity to the confrontation and the comparison is more difficult. The initial data needed for the simulation have been set up with the measurements. The simulations and the measures do not perfectly fit but it was considered enough given the objectives of the study. Explanations for the differences could be mostly differences between the properties of the materials in the model and the real ones. The boundary conditions of the 2D models are the measured climates for the exterior and the interior. The other boundaries have been considered adiabatic.

3. RESULTS AND DISCUSSIONS

3.1 EXTERIOR THERMAL INSULATION

3.1.1 Durability of the solutions

The simulation results presented on figure 4 illustrate the comparison between the hydrophilic, capillarity active and vapour open solution chosen in the house A and a solution with expanded polystyrene for the same thermal resistance. The average water content in the old masonry is in both cases far lower after the exterior insulation and is lower with the chosen solution than the EPS in winter and spring.

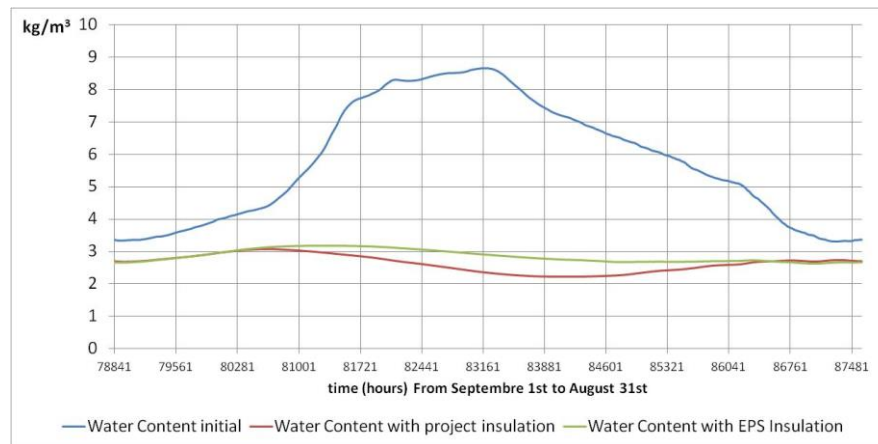


Figure 4: Comparison of the average water content in the brick of the house A on last year of simulation b -

The maximum water content ratio in the cellulose wadding is 4.8% in mass of water by dry mass. The notice criteria for this material to avoid moisture risk is 15%. The interface between the insulation material and the old masonry wall have been checked and the water content there is higher with the cellulose wadding than with the EPS solution but in both cases, no interstitial condensation have been noticed. The level of moisture in all material is steady over the simulations years.

3.2 INTERIOR THERMAL INSULATION

3.2.1 Ventilation consideration

The air change rate inside the building is strongly affected by the low air permeability of the building envelope after the retrofitting process. The installation of a ventilation system is strongly recommended to keep a reasonable level of air change rate. In the example of the house A, the indoor relative humidity was at an average of 69 % before the retrofit and at an average of 59 % after it with the services of a mechanical ventilation system (single flow).

3.2.2 Durability of the solutions

The measurements during a year before and after the insulation of the walls for the house C show that the water contents inside the original parts of the walls are higher after the retrofitting project but this higher level is still largely acceptable for such construction materials. No interstitial condensation was noticed. No risk with the wood fibre board in the “dry rooms” but in the “services room” with a higher humidity rate, a smart vapour barrier is needed to avoid interstitial condensation. The figure 5 present a confrontation between measurements and simulation results. The differences could be explained by materials properties as “daub and straw” is difficult to characterise and by the southern wall boundary condition which is affected by direct radiations and rain.

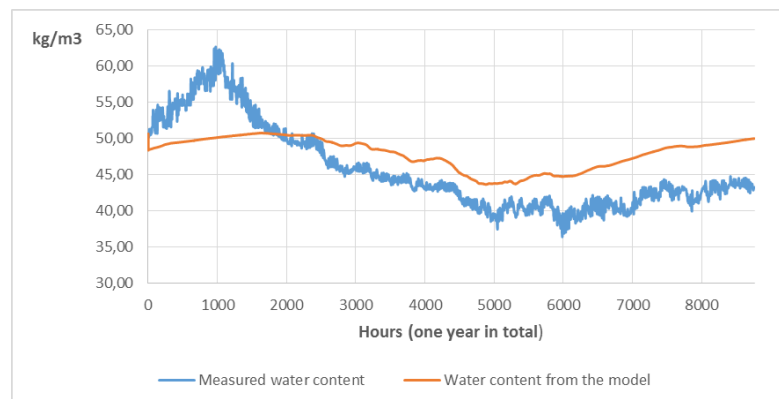


Figure 5: Confrontation of the model and the measurements in the daub and straw of the southern wall of the house C: Water content in the first year after the retrofit.

On the house B, simulations considering mineral wool, wood fibre board or expanded polystyrene in place of cellulose wadding have been performed and the result validate the choice of the architect. It is with the cellulose wadding and the smart vapour barrier that the original walls (bricks, lime mortar and wood) has the lowest water content in the simulation results. These simulations have been performed with a source terms in the model to represent flaws in the continuity of the barrier. The hypotheses for these sources can be found in [10]. It represents a hole of $0.26 \text{ cm}^2/\text{m}^2$ of vapour barrier. A warning can be issued for house B because of a freezing risk on the external coating: a temperature of 0°C on this coating was recorded.

4. CONCLUSION

In this study, three houses have been monitored to assess the durability of the associated retrofitting projects. The interior or exterior insulation with hydrophilic, capillarity active and vapour opened material has been investigated. With the studied cases and with the considered indoor and outdoor climate, no hygrothermal risk could be revealed but a list of warnings need to be highlighted. The freezing risk is always present with interior insulation and the external coating have to be well preserved and replaced or repaired when needed. The simulation considering flaw in the smart vapour barrier has shown a good resilience of the hydrophilic solutions even with accidental situations such as holes in the barrier. The investigations have to be continued with other realistic parameters such as rising damp to assess the limit of the use of the different insulation materials.

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