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Hygrothermal behavior of a massive wall with interior insulation during wetting

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ABSTRACT

To improve the energy efficiency of historical buildings, the introduction of an interior insulation is often the only possible solution in order to preserve their valuable external facades. However, this intervention changes the wall hygrothermal conditions and can negatively affect its hygrothermal performance. Furthermore, interior insulation is often difficult to apply due to practical problems of irregularities in geometry and heterogeneity of materials. A newly developed high insulating render is used as interior insulation on a masonry test wall and is exposed to controlled but severe wetting conditions, while the hygrothermal parameters in its different components have been recorded. In addition to provide a well-documented dataset for model validation, this investigation highlights the hygrothermal behavior of a masonry wall internally insulated with a new developed highly insulating render. The experimental work described in the present paper is designed in order to record data to be used for the validation of a numerical model for the parametric study of the hygrothermal behavior of internally insulated masonry walls.

1. Introduction

To improve the energy efficiency of historical buildings, the introduction of an interior insulation is often the only possible solution in order to preserve their valuable external facades. One of the main issues to be considered in insulating solid walls consists in finding equilibrium between the reduction of heat loss and the preservation of the wall integrity through the careful choice of materials, installation techniques and assembly design. The long term performance of energy efficient renovation strategies must be assessed as moisture accumulation and interstitial condensation are difficult to detect. Moisture related damages can be costly to solve and can compromise the structural stability as in the case of some bricks sensitive to freeze-thaw cycles [27,28,45], although sound test procedures have been developed to assess the freeze-thaw resistance of brick and brick/mortar systems [17]. Thus, the choice of the insulation material to be applied is crucial for a safe long term performance of the retrofitted wall.

Furthermore, in historical buildings, interior insulation is often difficult to apply due to irregularities in the geometry of the wall, heterogeneity of materials, different interventions, damages and repairs during the building life, etc. For example, insulation under the form of rigid panels requires flat surfaces to attach the panels, while old walls can present surface irregularities. For this reason, the use of an insulating interior render is often a more suitable solution. The application of a wet layer has the advantages of requiring a lower number of construction steps, thus making the construction method simpler, of providing flexibility in the presence of unevenness of the wall, and of allowing gap filling in order to get a continuous contact between the insulation layer and the substrate. However the components of the render must be inert and thus chemically suited to the old materials of the structure. In addition, as often the exterior finishing cannot be modified, it is important to avoid the use of vapor tight insulation solutions in order to allow moisture drying from the wall to the indoor environment if needed. For these specific interventions, an insulating render has been developed [37].

Moisture is known to be one of the main causes of damage in building facades and wind-driven rain a main external moisture source for exterior walls [4,23,24]. Different experimental measurements have been performed with different types of structures

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and loadings in order to evaluate the hygrothermal performance of building envelopes exposed to wind-driven rain. Pioneer work on rain penetration [12,13,40] has opened to way for more advanced hygrothermal evaluation methods of envelope systems exposed to environmental loading, both in North America [5,6,14] or in Europe [21] or [18]. Several field measurements recorded hygrothermal data from real buildings, such as Künzel (1998a) [26], Künzel (1998b) [26] Abuku et al. (2009) [1], Sass et al. (2010) [36] or Straube et al. (2011) [39]. Other experiments have been performed using wall samples and large-scale testing facilities that allow the application of controlled environmental loads. Many of these studies refer to wood framed walls as in Derome et at. (2008) [10], Maref et al. (2001) [29] Maref et al. (2002) [30], or Teasdale-St-Hilaire et al. (2005) or [41] while a more limited number deals with large-scale experiments of solid walls [2,34,19]. In the work of Teasdale-St-Hilaire et al. (2006) [42]; wood-framed walls are studied and the percentage of rain water infiltration through an intentional defect is determined. Piaia et al. (2013) [34] analyzed water penetration through a wall of concrete block. Other studies have been performed to investigate retrofitted masonry walls with an additional internal insulation layer [32,38,46] and the presence or not of vapor barriers [11,7,8]. Johansson et al. (2013) [19] performed an experimental campaign similar to that exposed in the present paper, for the analysis of the hygrothermal performance of masonry envelopes with an interior insulation layer of vacuum insulation panels. In this study, the conditions of wooden beams embedded in the wall are recorded. Wood members, in fact, are seen to undergo risky conditions after retrofit, as assessed in Morelli et al. (2010) [33], with a risk for corrosion of fasteners due to changes in hygrothermal conditions [47] In many cases these measurements have been used to validate numerical models that are currently used in building physics calculations and design [20,35]. Despite these numerous studies, very little has been done to document rain water movement within massive masonry walls. Such studies under realistic conditions would require very long monitoring efforts. As a result, the behavior of reinsulated massive masonry walls during wetting conditions as yet to be assessed.

In this work, the behavior of a massive masonry wall, insulated on its interior surface with the insulating aerogel render and exposed to controlled environmental loading, is documented. In order to maximize the wetting rate and the moisture penetration through the different layer, freezing temperatures are avoided and a weathering is used to expose the wall sample to temperatures in the range between 20 °C and 50 °C. The large-scale wall assembly consists in a load-bearing two-width brick masonry without any cavity or air space, finished with an external lime-based render and the internal insulating layer, and is fitted with two wooden beams. The monitoring protocol focuses on documenting with a high number of sensors the moisture transport in the wall, with focus on liquid moisture using specially developed sensors, in order to give a complete description of the wetting process in all layers. As many other large-scale experiment, as described in Maref (2004) [15], Geving et al. (1996) [31] or Teasdale-St-Hilaire et al. (2007) [43] the results of the experimental campaign that is described in this paper have been used for the validation of a numerical model for the calculation of hygrothermal performance of building facades [16].

2. Experimental set up

2.1. Material description

The materials used for the construction of the wall sample (Fig. 1) have been selected to represent an average assembly as found in Swiss residential buildings dating from the 1850—-1920 period. The choice of materials for the test wall has been made to match material properties measured on samples taken from different historical reference buildings from the Zurich area. However, for the external layer, an exterior render with a high capillary absorption coefficient has been selected in order to reduce the experimental duration. For the same reason, no paint has been applied at the exterior surface of the wall. The selected render is a mixture of hydraulic lime, white slaked lime and cement, with crushed and round limestone or sand grains with a dimension of 0–4 mm (mortar F 662, available on the market and produced by Fixit). Some water and air-retaining additives are present in the mixture. As mentioned, the value of the capillary absorption coefficient, A_{cap}, of the render is higher than the average of the historical renders while other hygrothermal properties, that have been measured in laboratory and are presented in Table 1, are consistent with those of the material samples from the reference buildings.

For the choice of the clay bricks to build the masonry, full bricks have been preferred because holes can affect moisture transport. The full clay brick chosen has properties similar to the ones of site samples. For the mortar to be used in the masonry joints, as no samples from reference buildings were available, the IBP database for historical materials, as available in the software Wufi, has been taken as reference. For mortars, the A_{cap} values lie in the range between 0.001 kg/m^{2}s$^{0.5}$ and 0.127 kg/m^{2}s$^{0.5}$ and the retained mortar value lies in the middle of this range. To get a good contact between the render and the masonry, and between the masonry and the internal insulation, a thin rough layer of mortar has been applied on the interior and exterior surfaces of the masonry, after the wall had dried.

On the internal side of the wall, a layer of 6 cm of the high insulation render, mentioned above, has been applied. The material is a lightweight mortar (200 kg/m^3) that can be applied both as

Table 1
Table of properties of the materials used for the test wall construction.

	External render		Clay brick		Cement mortar		Aerogel render		Wood	
Density	1668 kg/m^3		1553 kg/m^3		1623 kg/m^3		200 kg/m^3		455 kg/m^3	
Thermal conductivity	0.464 W/mK		0.684 W/mK		0.633 W/mK		0.027 W/mK		0.23 W/mK	
μ-value	11 -		14–15 -		17–21 -		4 -		3.8 -	
A_{cap}	0.077 kg/m^{2}s$^{0.5}$		0.115 kg/m^{2}s$^{0.5}$		0.023 kg/m^{2}s$^{0.5}$		0.032 kg/m^{2}s$^{0.5}$		(longit.) 0.007 kg/m^{2}s$^{0.5}$ (trans.) 0.032 kg/m^{2}s$^{0.5}$	
Sorption isotherm	RH	w [kg/m^3]	RH	w [kg/m^3]	RH	w [kg/m^3]	RH	w [kg/m^3]	RH	w [kg/m^3]
	0	0	0	0	0	0	0	0	0	0
	0.3	4.2	0.3	1.4	0.3	2.44	0.3	1.1	0.3	45
	0.5	17.9	0.5	1.9	0.5	5.56	0.5	2.55	0.5	53
	0.8	50.5	0.8	10.5	0.8	20	0.8	10	0.8	73
	0.95	59.7	0.95	17.1	0.95	113.2	0.95	43.4	0.95	107
w_{sat}	286.8 [kg/m^3]		303.8 [kg/m^3]		148 [kg/m^3]		400 [kg/m^3]		534 [kg/m^3]	