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Risk analysis of biodeterioration of wooden beams embedded in internally insulated masonry walls

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HIGHLIGHTS

- Hygrothermal behavior of internally insulated masonry wall.
- Moisture of wood beam heads in internally insulated walls.
- Effects of retrofit interventions of historical buildings.

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ABSTRACT

Energy retrofit of the envelope of existing historical buildings, due to their historical and cultural value, often includes the addition of an interior insulation layer. The new wall configuration changes the hygrothermal performance of the structure leading to higher moisture contents that increase the risk of damage, especially in wooden components. The hygrothermal performance of different retrofitted masonry assemblies is studied through HAM (Heat Air and Moisture) numerical simulations, for different external renders. Simulation results are post-processed using a damage model for wooden materials to evaluate the risk of biological deterioration as a consequence of the addition of an interior insulation layer. The external render, and in particular the combination of its liquid and vapor transport properties, strongly influences the hygrothermal behavior of the wall and, thus, the risk of moisture related damage to embedded wooden structures as a consequence of addition of interior insulation.

1. Introduction and problem statement

A main challenge in reducing energy use and thus greenhouse gas emissions of the building sector comes from existing buildings and more specifically the older ones. The better performing solutions in terms of durability rely on the introduction of exterior insulation. However, when the architectural appearance of a building has to be maintained, due to historical and cultural values of the facades, interventions on the interior side are often the only possible solution to reduce thermal losses through the building walls. However, adding insulation at the interior side of solid walls may cause performance and durability problems, especially in cold and wet climates ([10,12,9,6]). A lot of the building insulation materials is vapor tight; this property can drastically change the hygrothermal performance of the structure, preventing moisture that eventually found its way in the wall to dry out. On the other hand, vapor-open insulation materials installed on the inside of the wall may increase the risk of interstitial condensation at the colder interfaces within the wall ([11,4]). Moisture accumulation increases the risks of damage due to freeze–thaw cycles, leading to structural materials deterioration. The long term performance of energy efficient renovation strategies must be assessed as moisture accumulation and interstitial condensation are difficult to detect and related damages costly to solve. HAM transfer numerical tools allow predicting hygrothermal changes in the different components according to the boundary climate conditions and the material properties. Thus, critical conditions for damages can be foreseen and safe solutions can be designed.

In the retrofit of historical buildings, a main risk of damage is the biodeterioration of wooden elements embedded in the masonry structure. The most common criterion applied in wood construction consists in considering wood to be safe when the moisture content (MC) is below 20%, independent of temperature and duration of moisture exposure where moisture content refers

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to the ratio of mass of moisture to the mass of dry wood. Wood at moisture content conditions below 20% does not undergo fungi growth, while in the range from 20% to fiber saturation point (approximately 27% MC), localized development of fungi is possible. Optimal conditions for rot fungi development lie above fiber saturation, i.e. typically above 28% MC and for temperatures in the 10–40 °C range e.g. (Trechsel [13]). The critical moisture content for decay fungi germination and growth is in the range between 25% and 28% MC, depending on wood species. These moisture content values correspond to environmental conditions equal to 94–96% RH, in a range of temperature between 5 °C and 20 °C. However for prediction of the risk of damage, a more complete model is needed. Comprehensive experimental studies on the fungi development in building materials have been done by Viitanen at the VTT institute ([15–17]) working mainly on pine and spruce. The rate of decay is dependent mainly on the relative humidity but also on the temperature, although temperatures higher than 38 °C are lethal for most decay fungi (FPL [2]). As variations in loading conditions are likely, the duration of exposure at certain conditions required for decay to be initialized must be taken into account. This initial work of Viitanen has been since further enriched with studies on more fungal, including mold fungal, other materials and environmental conditions. These data led to the development of models of fungi growth for building applications ([14]). As an example, Nofal et al. [8] studied the long-term performance of wall assemblies defining a biological damage-function model based on the theoretical mold growth index proposed by Hukka et al. [5].

This paper investigates the risks of biodeterioration in wooden elements embedded in masonry walls due to different hygrothermal conditions in walls with different internal insulation materials and exterior insulation renders.

2. Risk analysis methodology

In this work, 2D numerical simulations are performed to compare the behavior of the junction of wooden beams within the external wall. The simulations are performed with different types and combinations of external render and interior insulation to investigate the global performance of assemblies. The main varied parameters are the liquid and vapor transport properties. The model was validated against experimental results of an internally insulated test wall, as described in Guizzardi et al. [3].

The 2-dimensional computational domain reproduces the geometry and dimensions of a wooden floor beam, which dimensions in the model are 15 × 80 cm, inserted in a massive 2-white brick masonry wall. An air space of 1 cm separates the end of the beam and the external brick withe. The exterior side of the wall is finished with an unpainted render with a thickness of 3 cm, while, at the interior side, different insulation solutions are considered. For the analysis of results, five reference positions are selected (see Fig. 1): four of them are wood portions in contact with the masonry respectively close to the most interior brick (1), in the corner of the beam (2), in the middle of the head surface towards the air gap (3) and close to the interior insulation layer (4). An additional reference position is selected from the interior brick in contact with the interior insulation (5).

2.1. Material properties

Material properties used in the calculations are the bulk density, porosity, heat capacity, heat conductivity, vapor diffusion resistance factor, sorption and liquid transport coefficients for suction and redistribution. For the masonry structure, the brick and the mortar properties have been measured in laboratory and are kept constant in the parametric analysis. The wood properties are taken from literature (Zillig [18]). All properties and the sorption isotherms are summarized in Table 1 and Fig. 2a.

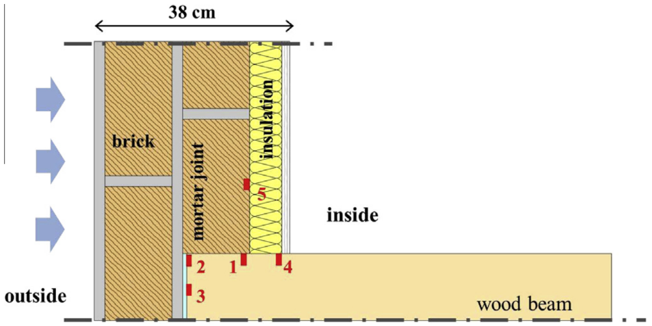

Fig. 1. Horizontal cross section of the wall as modeled for the 2D simulations.

For the parametric analysis, six types of renders are selected from the material database included in the software database, that collects data measured on real building materials. The selection is done in order to cover a wide range of possible materials that can be applied as exterior layer of building envelopes. The renders are selected taking into consideration the combination of their capillary absorption coefficients and vapor diffusion resistance values, as these two parameters describe the behavior of the material in relation to two different moisture transport mechanisms: in liquid and vapor state. LP (lime plaster) is the render with the highest capillary absorption value ($A_{cap} = 0.047\ \mathrm{kg/m^2\ s^{0.5}}$), i.e. the render that absorbs the highest amount of liquid water in the shortest time, when it is in contact with a liquid source. Renders CLP (cement lime plaster) and LCP (lime cement plaster) have a similar A_{cap} in the 0.017–0.047 $\mathrm{kg/m^2\ s^{0.5}}$ range and the same vapor diffusion resistance factor ($\mu = 19$), while the render LP (lime plaster) is characterized by a low vapor resistance factor ($\mu = 7$) compared to the two previous ones. The last render selected, CP (cement plaster), has very low capillary uptake capacity ($A_{cap} = 0.0076\ \mathrm{kg/m^2\ s^{0.5}}$) associated with a very high μ-value ($\mu = 25$). The hygrothermal characteristics of the selected renders are summarized in Table 2 and in Fig. 2b. The graph in Fig. 3 gives a comparison between the A_{cap} and μ-values of the selected renders. To emphasize the intrinsic effect of the different renders on the moisture transport, the exterior surface of the wall is modeled as unpainted.

The effect of three different interior insulation materials on the hygrothermal behavior of the wall is investigated. The performance of the non-insulated wall is taken as a reference and its results are compared with the results from the assemblies internally insulated with a layer of 6 cm of aerogel plaster, with a 6 cm layer of calcium silicate boards, that is a very capillary active insulation material, or with vacuum insulation panel (VIP). The aerogel plaster properties are measured in the laboratory, values for VIP are taken from literature and for calcium silicate the values in the software database are selected. All properties are summarized in Table 3 and Fig. 2c. The different thicknesses of the interior insulation layer are chosen to obtain walls with comparable *U*-values, as shown in Table 4.

2.2. Boundary conditions

The external boundary conditions are provided with a climatic file for Zürich of hourly relative humidity, temperature, wind driven rain loads, wind direction and sun radiation for a period of one year, summarized in Fig. 4. A west orientation of the wall is selected, as it has been assessed to be most critical in terms of rain