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Interior insulation for wall retrofitting – A probabilistic analysis of energy savings and hygrothermal risks

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ABSTRACT

Interior insulation is often the only possible post-insulation technique to improve the thermal performance of single leaf masonry walls. As a result of potential damage patterns such as frost damage, interstitial condensation and mould growth however, there is often some reluctance to adopt this technique. To fully exploit the capacity for energy savings offered by interior insulation while avoiding hygrothermal failure, a reliable risk assessment is extremely important. This requires a probabilistic approach, since the uncertainty of all influencing parameters might result in widely varying results.

As, so far, no real methodology is available to select the interior insulation system and thickness resulting in the best balance between energy savings and hygrothermal risks, this paper presents a decision tool based on a Monte Carlo analysis. Additionally, the influence of the rain load and some masonry characteristics is discussed. In the study, both vapour tight interior insulation systems and a capillary active insulation system are considered. Overall, vapour tight systems tend to be preferable for structures that are resistant to frost damage. For buildings sensitive to frost damage or when wooden beam ends are present, however, capillary active systems are shifted forward.

1. Introduction

The MURE overview [1] of energy efficiency policies and measures illustrates the growing efforts to reduce our energy consumption. The building sector is frequently mentioned in this respect, because of its large potential to contribute to that reduction. Indeed, buildings are responsible for approximately 40% of the world's primary energy use [2], a large share of which stems from our existing building stock. After all, in many countries, a large part of the existing building stock has been built before the first energy crisis. The growing awareness of their high energy use as well as poor comfort has led to a progressively increasing renovation and retrofitting of old buildings. And while upgrades of the (thermal) performance of roofs and windows are often the most cost-effective measures [3], the importance of the transmission losses through the walls should not be underestimated. After all, exterior walls cover a large part of the building envelope and therefore play an important role in reducing heat losses as well as in ensuring a healthy indoor environment and an acceptable occupant comfort.

To improve the thermal performance of single leaf masonry walls – in many West and Central European countries the most common construction technique until the Second World War – interior or exterior insulation can be applied. The latter technique is by far the most efficient measure. However, for buildings in an urban context, historical buildings or valuable facades [4,5], interior insulation remains the only feasible post-insulation technique. Applying interior insulation will however significantly modify the hygrothermal performance of the wall and, as a consequence, may induce a risk on interstitial condensation [6], frost damage, mould growth and other damage patterns [7]. To reduce the risk on these damage patterns, nowadays some more innovative interior insulation systems are promoted [5,8–10]. These systems aim at diminishing the moisture storage in the wall structure by still allowing an inward drying.

In the current study, two novel techniques – a capillary active insulation system [5] using calcium silicate board, and a mineral wool combined with a smart vapour retarder [8] – are compared to two standard systems – a vapour tight XPS-system and a mineral wool combined with a traditional vapour barrier. The analyses focuses on the hygrothermal performance of these systems during the heating season. With respect to capillary active interior

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insulation systems, Vereecken and Roels [11] revealed a higher sensitivity to small modifications of the boundary conditions than observed for a vapour tight system. Moisture in the calcium silicate board was found to result in a decrease in thermal resistance. Additionally, moisture could be redistributed inward resulting in a higher surface and indoor relative humidity. The study hence concluded that caution is required when the wall assembly is exposed to high wind-driven rain loads, and this particularly for thin masonry walls. These observations were however formulated based on a limited deterministic study, neglecting the inherent uncertainty and variability of involved input parameters. The question thus arises whether a generalisation of these conclusions is allowed. To that aim thus, a probabilistic approach is applied in the current paper, in which the uncertainties of the input parameters are explicitly propagated to the uncertainties of the studied performances. Probabilistic approaches are already frequently applied for energy studies [12–16], and can serve as a decision tool [17–21]. For hygrothermal analyses, however, only few studies are available [22,23]. In the current investigation, a probabilistic approach is applied to define the energy savings and the hygrothermal risks caused by interior insulation. To this aim, a hygrothermal model is used in a Monte Carlo analysis. Based on this probabilistic examination, recommendations on interior insulation are formulated, in particular on the choice between a vapour tight and a capillary active system.

In the following section, the case study is explained more in detail. The studied insulation options and the potential hygrothermal consequences are discussed and the wall characteristics and boundary conditions are specified. In the third section, the applied methodology is described. Here, both the hygrothermal model and the probabilistic assessment are addressed. After this, in a fourth section, the results are shown and discussed. Hereto, the hygrothermal performance and risk indicators are shown as a function of the dry thermal resistance of the insulation system. Additionally, the impact of the wind-driven rain load and of the masonry characteristics are discussed. In conclusion, the main findings are summarised and some remarks are drawn.

2. Case study

The probabilistic analysis is performed for a single leaf massive masonry wall outfitted with an interior insulation system. The study will be performed for different wall thicknesses and the walls will be exposed to different exterior and interior climatic conditions. Traditional vapour tight interior insulation systems and two novel systems, i.e. capillary active systems and a mineral wool combined with a vapour retarder, will be compared based on their hygrothermal response. Therefore, for each of these systems, all inherent uncertain variables will be taken into account in a Monte Carlo design approach using the hygrothermal model. Both the model and the design approach will be described in Section 3. Such a design approach quantifies the probabilistic distributions of the considered performances for each of the design options by repeating the simulation several times while varying the values of the uncertain variables according to their probability. This study limits to a typical cross section of the wall. So, no construction details such as corners or embedded wooden beam ends are considered. Furthermore, the brick mortar composition of the masonry wall is simplified to a single isotropic brick layer. Hence, the analysis can be completed based on one-dimensional simulations. As shown by Vereecken and Roels [24] this approach is acceptable if the wall is exposed to realistic climatic conditions.

In what follows the potential hygrothermal risks and the wall performances (Section 2.1), the studied interior insulation systems (Section 2.2) and the characteristics and boundary conditions (Sections 2.3 and 2.4) are described.

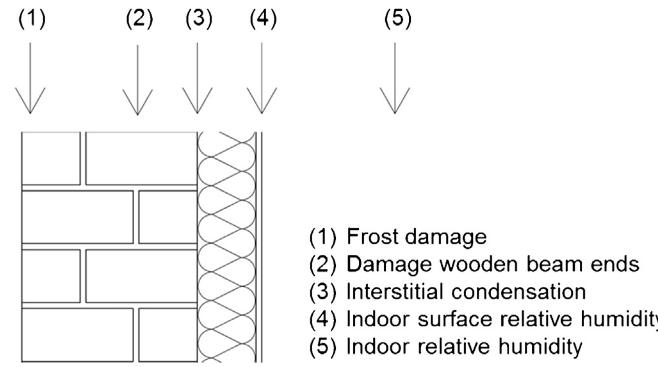

Fig. 1. Wall composition with hazardous planes indicated.

2.1. Hygrothermal risks and performances

Applying interior insulation will reduce the heat loss through the wall. However, it will also significantly modify the hygrothermal performance of the wall assembly, which might result in a number of hygrothermal risks. Fig. 1 schematically indicates the different interfaces and surfaces for a wall assembly with interior insulation together with the corresponding potential hygrothermal risks. A brief description of the different damage patterns for which the risks are analysed in the current study is given in what follows.

2.1.1. Frost damage (1)

The extra vapour diffusion resistance caused by the interior insulation system hinders an inward drying of the wall. Additionally, the lower temperature of the original wall structure results in a decreased drying potential towards the exterior. Hence, by applying interior insulation, the moisture content in the original wall structure will increase. This in combination with the lower temperature results in an enlarged risk on frost damage [25]. In the current study, the risk on frost damage will be evaluated based on the number of moist freeze-thaw cycles per year at 0.5 cm from the exterior brick surface. Such 'moist freeze-thaw cycles' are freeze-thaw cycles that occur in combination with a moisture content in the brick (in this case at 0.5 cm from the exterior surface) that is high enough to induce frost damage. In this study, a moisture content higher than 25% of the saturated moisture content is assumed to be critical and thus to entail a risk on frost damage. Note that this percentage is lower than 91.7%, which is often mentioned as the critical degree of saturation [26]. Measurements performed by Mensinga et al. [27] showed, however, potential failure due to freeze-thaw cycles starting from a critical degree of saturation equal to 25%. The freezing and thawing point is assumed to be −2 °C (because of, for instance, dissolved salts).

2.1.2. Relative humidity in the construction (2) (3)

The increased moisture content in the masonry wall might damage wooden beam ends in the construction [28–30]. In the current study, an indication of this risk is made based on the number of hours that the relative humidity in the masonry at 5 cm from the insulation system exceeds the critical relative humidity for wood decay, and this in January. For the critical relative humidity for wood decay, a relative humidity equal to 95% is assumed, which corresponds to the lower limit mentioned in [31]. Note, however, that in the present study solely a rough indication of the risk is made, as a one-dimensional approach – without a wooden beam end – is applied and potential air rotations are neglected. Furthermore, a quantitative analysis of the risk on wood decay