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A comparison of the hygric performance of interior insulation systems: A hot box–cold box experiment

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ABSTRACT

To increase the thermal performance of massive masonry walls, exterior or interior insulation can be used. The latter insulation technique is the most risky, though forms for example in cases of historical buildings, buildings with a worth-preserving facade or buildings in the urban context the only solution to increase the thermal performance of the wall.

The current article compares the hygric performance of massive masonry walls provided with different interior insulation systems. To do so, small test walls are placed all together in a single hot box–cold box. The total moisture increase in the walls is measured by weighing the test walls. In addition, to investigate the working principle of the insulation systems the moisture distribution across the wall assemblies is investigated using the X-ray projection method. In the analysis capillary active as well as more standard non-capillary active insulation systems are investigated. For the imposed quasi steady-state winter condition, the increase of stored moisture inside walls with a capillary active system is found to be higher than for walls with a traditional vapour tight system.

1. Introduction

Climate and environmental changes, limited energy sources and rising energy prices made energy consumption a central concern all over the world. There seems to be no other option than to reduce our energy use and related CO_2-emission [1]. A large potential to obtain this reduction can be found in the existing building stock [2]. For example in Belgium still a quarter of the existing building stock contains hardly any insulation. In cases of single leaf masonry walls – the common construction technique of the outer walls in many European countries until the Second World War – the thermal performance can be increased by applying exterior or interior insulation. The latter technique is known as the most risky insulation technique due to potential interstitial condensation [3], frost damage, salt efflorescence, mould growth [4] and other damage patterns [5]. Though, in the urban context – where a strict building line often excludes exterior insulation – or in cases of buildings with a historical or worth-preserving facade [6,7], interior insulation is often the only possible solution to improve the thermal performance of massive masonry walls. Hence, a risk-free thermal upgrade of our culture heritage demands an in depth study of the working principle of interior insulation systems and its influence on the wall's hygrothermal performance. Especially during the heating season, interior insulation can change the hygrothermal wall performance significantly. By placing the insulation layer at the inner side of the wall, the temperature in the masonry wall strongly decreases. In addition, if the temperature at the brick-insulation interface drops below the dew point temperature, interstitial condensation may occur. To avoid the latter damage pattern, often a vapour tight insulation system is recommended. However, a vapour tight system avoids the drying out of the masonry wall towards the inside resulting in a potential risk on moisture related damage (e.g. frost damage, decay of wooden beam ends, etc.).

To exclude interstitial condensation while allowing the wall structure to dry out towards the inside, some innovative, especially capillary active, insulation systems [7–10] have been promoted. Capillary active systems consist of a capillary active insulation material in combination with a glue mortar. The capillary active insulation material can absorb liquid moisture and redistribute it towards the room. Hence, according to e.g. Scheffler and Grunewald [11], potential interstitial condensation can be avoided if a good contact between masonry wall and insulation is provided.

Abbreviations: ACC, autoclaved cellular concrete; CaSi, calcium silicate; CEL, cellulose; CC, cellular concrete; CG, cellular glass; EPS, expanded polystyrene; MP, Multipor®; MW, mineral wool; PAVA, Pavadentro®; SVR, smart vapour retarder; WFB, wood fibre board; XPS, extruded polystyrene.

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Nomenclature

Symbols

d	thickness (m)
I	attenuated X-ray intensity (–)
I_0	incident X-ray intensity (–)
RH	relative humidity (%)
T	temperature (°C)
V	volume (m^3)
w	moisture content (kg/m^3)

Greek symbols

μ	attenuation coefficient (–)
ρ	density (kg/m^3)
ρ	bulk density (kg/m^3)

Subscripts

cor	correction
w	water

In the current paper, the hygrothermal performance of massive masonry walls provided with different interior insulation systems and exposed to a (quasi) steady-state winter condition is studied. To this aim, different small test walls with interior insulation are placed all together in a single hot box–cold box. During the experiment, the total moisture increase in the walls is measured. In addition, to investigate the working principle of the insulation systems, the moisture distribution across the wall assembly is studied by means of the X-ray projection method. In the analysis, both capillary active and more standard non-capillary active insulation systems are tested. The applied methodology is described more in detail in a first section. Next, the results are discussed and some remarks are made. To end, the main conclusion is summarized.

2. Experimental test setup

2.1. Wall assemblies

The hygrothermal behaviour of single leaf masonry assemblies with different interior insulation systems is studied. To do so, different small scale test walls are placed simultaneously in a hot box–cold box. Each test wall is provided with a different interior insulation system (Table 1). The studied insulation systems are commercially available and represent the different types of systems, i.e. vapour open non-capillary active, vapour tight and vapour open capillary active system. The small scale test walls are 30 cm high and 3 cm thick (Fig. 1a), where the latter dimension was chosen to enable an investigation of the moisture distribution using the X-ray projection method. Plexiglas glued at all sides – except the inner and outer surface – of each test wall promotes a one-dimensional moisture transport through the test walls. Temperature (T-) and relative humidity (RH-) sensors are placed between the different material layers and at the interior and exterior wall surface. To keep the middle part free for the X-ray measurements these sensors are placed at approximately one-third height of the test walls. Since the contact between the (capillary active) insulation systems can be of crucial importance for the working principle [11,12], air spaces between the different material layers due to the sensor thickness are avoided by embedding the sensors in a narrow groove in the insulation (Fig. 1b and c). In addition, a glue mortar was used to stick the hard insulation materials at the masonry wall. An exception to this can be found for Wall G, which makes an investigation of the effect of the glue mortar possible.

2.2. Hot box–cold box

To investigate the hygrothermal performance of the test walls, a hot box–cold box experiment was performed (Fig. 2a and b). The different test walls were positioned in a frame (Fig. 2e) which was fixed between a hot box (Fig. 2c) and a cold box (Fig. 2d). The gypsum board was facing towards the hot box, the brick towards the cold box. To promote one-dimensional heat transport, XPS-insulation boards were placed between the different test walls. Air leaks, and consequently heat and vapour leaks, were minimized by taping all the edges between the test walls, the XPS-insulation boards and the connecting frame. In the boxes saturated salt solutions were used to control the relative humidity. In the hot box (Fig. 2c) a saturated KCl-solution was placed to achieve a relative humidity of approximately 85%. The relative humidity in the cold box (Fig. 2d) was approximately 45% and was obtained by $Mg(NO_3)_2{\cdot}6H_2O$ and $MgCl_2{\cdot}6H_2O$. In the cold box a temperature of approximately 2 °C was implemented, using a cooling unit. In the hot box, infrared bulbs were used to obtain a temperature of 35 °C. Obviously, these conditions do not confirm with realistic boundary conditions, but were selected to obtain in a short time span a clearly detectable increase in moisture content when using the X-ray projection method. Because of this difference to reality, the aim of the current study is limited to the investigation of the working mechanism of the different interior insulation systems. No quantitative comparison is intended.

2.3. Microfocus X-ray radiography

Microfocus X-ray radiography, a technique evolved from medical science, has proven to be also extremely valuable in material science ([14–17], among others). Roels and Carmeliet [16] showed the X-ray projection method as an accurate technique to measure the moisture content in materials. In the current analysis, this non-destructive technique is used to study the moisture content in the wall assemblies exposed to the conditions in the hot box–cold box. For reasons of completeness, before the experimental methodology applied to the test walls will be described, firstly the crucial elements of X-ray radiography will be reiterated.

The X-ray projection method is based on the attenuation of materials. When X-ray beams are sent through a material, the beams will attenuate. For monochromatic X-rays, the relationship between the incident (I_0) and attenuated (I) X-rays is expressed by Beer's law:

$$\frac{I}{I_0} = \exp(-\mu d) \tag{1}$$

with I_0 and I are the incident and attenuated intensity, respectively, and μ (–) and d (m) are the material attenuation coefficient and the material thickness, respectively. Hence, the attenuated intensity for a dry (I_{dry}) and a wet (I_{wet}) sample can be expressed, respectively, as:

$$I_{dry} = I_0 \exp(-\mu d) \tag{2}$$

$$I_{wet} = I_0 \exp(-\mu d - \mu_w d_w) \tag{3}$$

with μ_w (–) and d_w (m) are the attenuation coefficient and the thickness of a fictitious water (or in general, liquid) layer corresponding to the moisture content in the material. The moisture content w (kg/m^3) is given by:

$$w = \frac{\rho_w V_w}{V} = \frac{\rho_w d_w}{d} \tag{4}$$