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The comparative in situ hygrothermal performance of Hemp and Stone Wool insulations in vapour open timber frame wall panels

Eshrar Latif[a,*], Mihaela Anca Ciupala[b], Devapriya Chitral Wijeyesekera[c]

[a] University of Bath, Bath, UK
[b] University of East London, London, UK
[c] University Tun Hussein Onn Malaysia, Johor, Malaysia

HIGHLIGHTS

- *U*-value of the Hemp and Stone Wool wall panels was lower than the calculated *U*-value.
- Increased *U*-value is plausibly due to moisture activity and variable heat capacity.
- Placement of heat flux sensors along the panels' depth influences *U*-value at high moisture load.
- Interstitial condensation is likely in the Stone Wool wall panel at high internal moisture load.
- Parametric prediction of mould growth in insulations is not supported by the in situ finding.

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ABSTRACT

An in situ experiment in a full scale timber frame test building was carried out to compare the hygrothermal performance of Hemp and Stone Wool insulations of identical thermal conductivity. Hemp and Stone Wool insulations were installed in timber frame wall panels without vapour barrier. The comparison was made in terms of heat transfer properties, likelihood of mould growth and condensation. Step changes in internal relative humidity were performed to explore the effect of high and normal internal moisture load on the wall panels. No significant difference between the average equivalent thermal transmittance (*U*-values) of the panels incorporating Hemp and Stone Wool insulations was observed. The average equivalent *U*-values of the panels were closer to the calculated *U*-values of the panels based on the manufacturers' declared thermal conductivity of Hemp and Stone Wool insulations. It was observed that the placement of heat flux sensor along the depth of the insulation had significant influence on the measured equivalent *U*-value of the panels during high internal moisture load. The frequency and likelihood of condensation was higher in the interface of Stone Wool and Oriented Strand Board (OSB). In terms of the parametric assessment of mould germination potential, relative humidity, temperature and exposure conditions in the insulation-OSB interfaces were found to be favourable to germination of mould spore. However, when the insulations were dismantled, no mould was visually detected.

1. Introduction

About 45% of the total carbon emissions in the UK is caused by the domestic and non-domestic buildings [1]. Since the highest amount of energy is used for space heating [1], improved thermal insulation standard remains one of the most cost effective means of reducing energy use [2] and thereby of reducing carbon emission. Most of the widely used thermal insulation materials are manufactured from either mineral or petro-chemical resources [3]. These resources are non-renewable and manufacturing processes of these insulation materials are energy intensive. In addition to reducing a building's operational energy use, there is also a conscious effort in the building industry to use natural, renewable and low-embodied energy building materials. Another trend in the building industry is to assess the applicability of walls that are hygroscopically active and do not require vapour barriers.

Hemp insulations are plant-based fibrous insulation materials. Limited amount of data is available on the hygrothermal performance of the Hemp insulations in a vapour open wall construction compared to that of any conventional insulation material. This paper aims to address this specific gap in knowledge. The

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* Corresponding author. Tel.: +44 7540606063.
E-mail address: e.latif@bath.ac.uk (E. Latif).

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comparisons between Hemp and Stone insulations are made in terms of equivalent thermal transmittance (*U*-value), likelihood of mould growth and condensation.

Research works on hygrothermal properties and performance of Hemp insulations are mostly based on experimental works in laboratories. Latif et al. [4] determined the hygric properties of five Hemp insulations and Collet et al. [5] determined the moisture adsorption and vapour transfer properties of two types of fibrous Hemp-Wool insulations. These data can be used as input in hygrothermal software to numerically simulate the hygrothermal performance of the building envelopes incorporating these insulation materials. Korjenic et al. [6] determined the moisture dependent thermal conductivity of Hemp insulation in steady state method by conditioning the insulations at a range of relative humidity conditions and then wrapping the insulations in foils before testing. However, in a vapour open construction during service conditions, moisture distribution in the insulation can be different from that obtained by wrapping insulations with impermeable membrane during laboratory tests. In terms of in situ performance monitoring, Nicolajsen [7] compared thermal transmittance of cellulose loose-fill insulation and Stone Wool insulation installed in a north facing timber frame wall in Denmark. In that test, the interior temperature and relative humidity were maintained at around 20 °C and 60%, respectively. Stone Wool insulation was tested in a wall panel with vapour retarder and cellulose insulation was tested in wall panels with and without vapour retarder. The thermal transmittance value of the panels with 285 mm cellulose insulation for both panels was 0.14 W/m^{2}K and the thermal transmittance value of Stone Wool was 0.12 W/m^{2}K. For both applications of cellulose insulations, the maximum moisture content was 18% which is regarded as being within the safe range.

While Nicolajsen's study focusing on the exposure to 60% interior relative humidity is useful, it is also important to include the effect of changes in internal relative humidity on heat flux and interstitial relative humidity of wall panels in full scale tests. There are spaces in a house, such as the kitchen and bathroom that are subject to sudden fluctuation of relative humidity. It is useful therefore to assess the effect of different ranges of internal relative humidity on average heat flux through thermal envelopes and on the likelihood of increased moisture content and mould growth in the thermal envelopes.

In terms of mould growth in Hemp insulations, Nykter [8] found that bast fibres of the Hemp insulations contained microbes from the very beginning of the fibre processing and, since the fibres contained nutrient, it was not possible to completely eliminate microbes.

There is not adequate information available on any full scale test in relation to the study of the in situ hygrothermal performance and parametric assessment of mould growth in the Hemp insulation. The present paper attempted to address this gap in knowledge by assessing the in situ hygrothermal performance of Hemp and Stone Wool insulations in a full scale timber frame test building. The experimental test compared the hygrothermal performance of Hemp and Stone Wool insulations in vapour open wall panels in the internal boundary conditions incorporating very high (90%) and moderate interior relative humidity (50–60%). Additionally, the in situ test assessed the effect of the critical positioning of heat flux sensors along the depth of the wall panels on the equivalent *U*-values of the panels.

2. Theory

This section briefly describes the theories of determining thermal transmittance and assessing the likelihood of mould spore germination.

2.1. Thermal properties

2.1.1. Method for numerical determination of U-value

The calculations of *U*-value of the wall panels are based on BS EN ISO 6946:2007 [9]. The method is detailed below.

2.1.1.1. Calculation of the U-value of the panels consisting of homogeneous layers. The total thermal resistance, R_T, of a plane building component consisting of thermally homogeneous layers perpendicular to the heat flow is given by the following expression:

$$R_T = R_{si} + R_1 + R_2 + \ldots + R_n + R_{se} \tag{1}$$

where R_{si} is the internal surface thermal resistance; R_1, R_2,…R_n are the design thermal resistance of each layer; R_{se} is the external surface thermal resistance.

2.1.1.2. Calculation of the U-value of the panels consisting of homogeneous and inhomogeneous layers. The total thermal resistance, R_T, of a building component consisting of homogeneous and inhomogeneous layers parallel to the surface is calculated as the arithmetic mean of the upper and lower limits of the resistance:

$$R_T = (R'_T + R''_T)/2 \tag{2}$$

where R'_T is the upper limit of total thermal resistance and R''_T is the lower limit of total thermal resistance. The upper limit of resistance, R'_T, is determined by assuming one-dimensional heat flow perpendicular to the surface of the component. It is given by the following expression:

$$1/R'_T = f_a/R_{Ta} + f_b/R_{Tb} + \ldots + f_q/R_{Tq} \tag{3}$$

where R_{Ta}, R_{Tb},…R_{Tq} are the thermal resistances from environment to environment for each section, calculated using Eq. (1); f_a, f_b,…f_q are the fractional areas of each section.

Fig. 1 shows the horizontal cross-section of a notional wall panel, where *a*, *b* and *c* are the width of each perpendicular section, d1, d2 and d3 are the thickness of layer 1, layer 2 and layer 3, respectively.

The lower limit of total thermal resistance, R''_T, is determined by assuming that all planes parallel to the surfaces of the components are isothermal surfaces. The equivalent thermal resistance, R_j, for each thermally inhomogeneous layer is calculated using the following equation:

$$1/R_j = f_a/R_{aj} + f_b/R_{bj} + \ldots + f_q/R_{qj} \tag{4}$$

where R_{aj}, R_{bj},… R_{qj} are the thermal resistance of fractional areas f_a, f_b,… f_q of layer *j*.

The lower limit of thermal conductivity is determined by using Eq. (1),

$$R''_T = R_{si} + R_1 + R_2 + \ldots + R_n + R_{se} \tag{5}$$

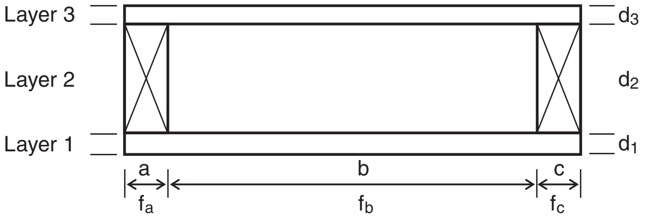

Fig. 1. Horizontal cross-section of a notional wall panel.