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Moisture buffer potential of experimental wall assemblies incorporating formulated hemp-lime

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ABSTRACT

Experiments were carried out according to the Nordtest protocol to study the moisture buffer potential of hemp-lime walls with a range of different internal linings and surface treatments. It was observed that the moisture buffer value was 'Excellent' when the inner surface of hemp-lime was exposed. 'Excellent' moisture buffer values were also obtained for hemp-lime with lime plaster. All other assemblies demonstrated 'Good' moisture buffer value. Moisture buffer values of the assemblies, after application of paint on the upper surfaces, were also determined. It was observed that application of synthetic pigment based trade paint could reduce the moisture buffer performance of the assembly consisting of hemp-lime and lime-plaster from 'Excellent' to 'Good' while between 61 and 69% reduction of moisture buffer value was observed for the other assemblies. However, the reduced buffer values of the assemblies are still comparable with other moisture buffering building materials. It was further observed that moisture buffer performance was improved when clay based organic paint was used instead of trade paint.

1. Introduction

Hemp-lime is a bio-composite material comprised of hemp shiv, the woody core of hemp plant, and a lime based binder [1]. The composite can be cast into any rigid form and can be used as a floor, wall or roofing material. Hemp-lime is a carbon-negative and low embodied energy material [2,3]. Hemp shiv comes from renewable sources and lime is a flexible, reusable and breathable material with significantly lower embodied energy than conventional masonry materials [4]. Because of its low compressive strength [5–8], hemp-lime is typically used as an insulating infill material between structural framework [9].

Hemp-lime possesses excellent hygric and moderate thermal properties. The dry thermal conductivity of hemp-lime varies between 0.06 and 0.12 W/m K [1,10,11]. It is observed that the thermal performance of hemp-lime is better than what its U-value or thermal conductivity value suggests [4]. This is may be because of the low thermal diffusivity of hemp-lime resulting from its high specific heat capacity [12], varying between 1300 and 1700 J/Kg.K [3], combined with its high density, ranging between 220 and 950 kg/m^3 [13]. Since the external boundary conditions are dynamic, the high thermal mass of hemp-lime means that variations in changes in temperature can be dampened and the peak energy load can be reduced [14].

In terms of hygric properties, hemp-lime, like other cellulose materials [15], works as an effective hygric mass because of its 'Excellent' moisture buffer capacity in its exposed condition [16–18]. Moisture buffer capacity of a hygroscopic material enables the material to moderate the fluctuations in relative humidity of an enclosed space by utilising the adsorption and desorption properties of the material [19,20]. Moisture buffering properties of the material also helps to reduce condensation in the building envelope [21–24] and maintain indoor air quality [25,26]. In addition to the moisture buffer capacity, moisture buffer performance of a material depends also on the exposure area, vapour permeability, surface treatment of the material, moisture load [27,28], ventilation rate [28–32], volume rate [31] and initial humidity condition [33]. The moisture buffer value can be classified within the 'practical moisture buffer value classes', consisting of the following ranges: negligible, limited, moderate, good and excellent [19]. The moisture buffer value of exposed hemp-lime samples are reported as either 'Good' or 'Excellent' by a number of authors [16,17].

Moisture buffering can directly and indirectly reduce the energy consumption of buildings [34]. In terms of energy use, hygroscopic materials in general can reduce heating energy requirements by 2–3% and cooling energy requirements by 5–30% if integrated with

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a well-controlled HVAC system [34].

High thermal and hygric inertia of hemp-lime can potentially help to moderate the effect of temperature and relative humidity fluctuations in an interior space [35]. However, in practical applications, hemp-lime is used as a part of the building envelope system incorporating a combination of surface lining and surface treatment. The application of plaster or surface treated inner lining and the presence of a service void or air layer between the hemp-lime and the inner lining can potentially influence the moisture buffering ability of hemp-lime since the material is no longer in direct contact with the interior boundary conditions. Furthermore, use of coating or inner layers may delay and reduce vapour diffusion [36]. The aim of the present study is to compare the moisture buffer values of vapour-open wall assemblies containing hemp-lime and inner linings and surface treatments with that of the exposed hemp-lime. The Nordtest [9] protocol is followed to determine the moisture buffer values of the assembly. The experiments described in this article are part of the experiments being carried out in the EPSRC-funded HIVE building situated in the Building Research Park at Wroughton, UK.

2. Theory

2.1. Moisture buffer capacity

Moisture buffer capacity is a hygric property by which hygroscopic materials in touch with surrounding air adsorb and desorb moisture to create equilibrium with the relative humidity of the surrounding space. A number of methods are available to determine moisture buffer capacity such as the Nordtest protocol [19], the Japanese Standards [37], the ISO standard [38], the method proposed by Padfield [39] and the Ultimate Moisture Buffer Value concept [40]. Among those, Nordtest method is the pioneering method and is mostly used in the European context. The Nordtest protocol expresses moisture buffer capacity in following three ways:

2.1.1. Moisture effusivity

Moisture effusivity (b_m) is the measure of the ability of the material to exchange moisture with its surroundings when the surface of the material is exposed to sudden change in humidity [19] The equation for moisture effusivity is:

$$b_m = \sqrt{\frac{\delta_p \cdot \rho_0 \cdot \frac{\partial u}{\partial \varphi}}{P_s}} \tag{1}$$

where, b_m is moisture effusivity [kg/(m^2.Pa.s$^{1/2}$)], δ_p is water vapour permeability [kg/(m.s.Pa)], ρ_o is the dry density of the material (Kg/m^3), u is moisture content (kg/kg), ϕ is relative humidity (−), P_s is saturation vapour pressure (Pa).

2.1.2. Ideal moisture buffer value (MBV_{ideal})

Ideal Moisture Buffer Value is the theoretical determination of moisture buffer value (MBV) based on its moisture effusivity, time period of moisture uptake and saturation vapour pressure. Ideal Moisture Buffer Value expresses the upper limit of the moisture buffer capacity [41]. The equation for Ideal Moisture Buffer Value is,

$$MBV_{ideal} \approx \frac{G(t)}{\Delta RH} = 0.00568 \cdot b_m \cdot P_s \cdot \sqrt{t_p} \tag{2}$$

where G(t) is accumulated moisture uptake (kg/m^2) and the corresponding moisture release during a time period t_p (s). The ideal moisture buffer value is measured in [g/(m^2.% RH)].

2.1.3. Practical moisture buffer value ($MBV_{practical}$)

Practical moisture buffer value, $MBV_{practical}$, is defined as the amount of moisture content that passes through the unit open surface of the material when the material is exposed to variation in relative humidity of the surrounding air. MBV can be expressed as [42]:

$$MBV_{Practical} = \frac{\Delta m}{A \cdot \left(RH_{high} - RH_{low}\right)} \tag{3}$$

where $MBV_{practical}$ is practical moisture buffer value [g/(m^2.%RH)], Δm is moisture uptake/release during the period (g), A is open surface area (m^2), $RH_{high/low}$ is high/low relative humidity level (%). For the present study, $MBV_{practical}$ values of hemp-lime assemblies are determined.

2.1.4. True moisture penetration depth

The true moisture penetration depth (also described as ‘moisture penetration depth’), $d_{p1\%}$, is the depth at which the amplitude of moisture variation is 1% of the variation on the surface of the material [19,41,43] and is expressed as,

$$d_{p1\%} = 4.61 * \sqrt{\frac{D_w \cdot t_p}{\pi}} \tag{4}$$

where D_w (m^2/s) is the moisture diffusivity and is expressed as,

$$Dw = \frac{\delta_p P_s}{\rho \xi_u} \tag{5}$$

where ξ_u is the specific moisture capacity (kg/kg) and expressed as,

$$\xi_u = \frac{\partial u}{\partial \varphi} \tag{6}$$

2.1.5. Moisture buffer classes

In addition to the direct comparison of moisture buffer values of the assemblies, moisture buffer capacity of the materials can also be categorised in terms of their moisture buffer classes [19]. As shown in Fig. 1, the moisture buffer values of the materials are classified in to following categories: Negligible (MBV: 0.0–0.2), Limited (MBV: 0.2–0.5), Moderate (MBV: 0.5–1.0), Good (MBV: 1.0–2.0), Excellent (MBV: 2.0-upwards).

2.2. Vapour diffusion resistance factor

Moisture transfer occurs through porous materials when there is vapour pressure difference between two opposite surfaces. Fick's law [44] expresses isothermal moisture transfer by the following equation:

$$g_v = -\delta \cdot \nabla \rho_v \tag{7}$$

where g_v is the vapour/moisture flux [kg/(m^2.s)], δ is the vapour permeability of the porous system in the material [kg/(m.s.Pa)], ρ_v is the water vapour partial pressure (Pa).

Vapour diffusion resistance factor of a material, μ, is the ratio of vapour permeability of air and the material. The equation for the vapour diffusion resistance factor is expressed as:

$$\mu = \frac{\delta_a}{\delta} \tag{8}$$

where μ is the vapour diffusion resistance factor (-), δ_a is the vapour permeability of air [kg/(m.s.Pa)].