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MOISTURE BUFFER POTENTIAL OF WALL ASSEMBLIES INCORPORATING HEMP-LIME

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Abstract
Experiments were carried out according to the NORDTEST protocol to study the moisture buffer value of various wall assemblies incorporating hemp-lime. The following assemblies were tested: a base-case assembly of hemp-lime without any coating, hemp-lime with lime plaster on the upper surface of the sample, hemp-lime with breather membrane, hemp-lime with breather membrane and air layer and plasterboard, hemp-lime with air layer and plaster board. Two tests were carried out with following two air velocities over the buffering surfaces during the moisture uptake cycles: 0.3 m/s and 0.6 m/s. It was observed that, while use of coatings and inner layers reduced the moisture buffer values of the assemblies, yet the reduced values were comparable with the moisture buffer values of some other best performing building materials in their exposed conditions. It was also observed that change of air velocity had higher impact on the moisture buffer values of the exposed hemp-lime and the hemp-lime with lime plaster than on that of the other assemblies.

Keywords:
Moisture buffer value; hemp-lime; air velocity.

1 INTRODUCTION

Hemp-lime is an innovative construction material consisting of hemp shiv and lime binder. For non-structural wall and roof applications, hemp-lime exhibits moderate thermal conductivity values ranging between 0.05 W/mK and 0.12 W/mK [Lawrence et al. 2012, Sutton et al. 2011] depending on the proportions of the constituents in the mix and density. However, in practical applications, due to its high thermal and hygric inertia, hemp-lime shows better thermal performance than what its thermal conductivity value indicates. High thermal and hygric inertia of hemp-lime help to moderate the effect of temperature and relative humidity fluctuations in the interior spaces [Evrard 2008]. In terms of energy use, Osanyintola et al. [Osanyintola and Simonson 2006]. Showed that hygroscopic materials reduced heating energy consumption during occupation while total heating energy consumption remained similar to that when non-hygroscopic materials were used. The Haverhill hemp-lime house demonstrated that heating fuel consumption in the hemp-lime house was no greater than that of a traditionally constructed house [Yates 2002].

One of the key properties of hemp-lime is its moisture buffer capacity. Moisture buffer capacity of a material in an enclosed space is the ability of the material to moderate the fluctuations in relative humidity of that space. In addition to moisture buffer capacity, moisture buffer performance of a material depends also on the exposure areas of the material, moisture load and ventilation rate. The moisture buffer value of hemp-lime samples are reported as either ‘Good’ or ‘Excellent’ by Collet et.al [Collet et al. 2013]. However, in real life, hemp-lime is used as a part of the building envelope system composed of more than one layer. The application of plaster or inner lining and the presence of service void or air layer between the hemp-lime and the inner line can potentially influence the moisture buffering ability of hemp-lime as the material in not in direct contact with the interior climate. The present study investigates the moisture buffer values of various wall assemblies containing hemp-lime compared to the moisture buffer value of exposed hemp-lime. The NORDTEST protocol [Rode 2005] is followed to determine the moisture buffer values of the assemblies.

2 THEORY

Moisture buffering capacity is a 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 buffering capacity such as the method developed by the NORDTEST protocol [Rode 2005], the Japanese Standards [Association 2002], the ISO standard [Standardization 2008] and the method proposed by Padfield [Padfield and Jensen 2010].

Among those, NORDTEST method is a commonly used method in Europe. The NORDTEST protocol expresses moisture buffer capacity in following three ways:

2.1 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 [Rode 2005]. The equation for moisture effusivity is:

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

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].

2.2 Ideal Moisture Buffer Value

Ideal Moisture Buffer Value, MBV_{ideal} is the theoretical determination of moisture buffer value based on its moisture effusivity, time period of moisture uptake-release and saturation vapour pressure. The equation for MBV_{ideal} is,

$$MBV_{ideal} \approx \frac{G(t)}{\Delta RH} = 0.568 \,.b_m.P_{s.}\sqrt{t_p} \quad [2]$$

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

2.3 Practical Moisture Buffer Value

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 variations in relative humidity of the surrounding air. The unit of $MBV_{practical}$ is [kg/m^2 %ΔRH] when moisture exchange is reported for unit surface area and unit % relative humidity variation, the cycle time is also mentioned in the result. For the present study, $MBV_{practical}$ of hemp-lime assemblies is determined. $MBV_{practical}$ can be expressed as,

$$MBV_{Practical} = \frac{\Delta m}{A.\left(RH_{high} - RH_{low}\right)} \quad [3]$$

Where $MBV_{practical}$ is moisture buffer value (Kg/(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 (%).

3 MATERIAL AND ASSEMBLY

3.1 Material preparation

Hemp-lime

Hemp-lime for the present study is prepared from 5 Kg of hemp shiv, 8.25 kg of Tradical PF70 lime and 10 litres of water providing the weight-based ratio of hemp shiv to lime to water of 1:1.7:2. Initially, 5 kg of hemp shiv was placed into a 200 litre drum mixer and 2 litres of water was added. After the content was mixed for 2 minutes, 8.25 kg of lime binder was added to the mix. After the contents were dry-mixed for 3 minutes, 8 litres of water was added and the contents were mixed for another 4 minutes. Finally, 1 extra litre of water was added and the contents were mixed for 2 minutes.

The mix was cast into the wooden moulds of the internal dimension of 100 mm X 100 mm X 100 mm. Once placed into the moulds, the mix was compacted lightly by tapping the base of the moulds on the ground 3 times and this was repeated until the moulds were full.

After 24 hours, the base of the mould was removed to allow more air to the samples. After further 24 hours, the samples were removed from the mould completely and left for further 24 hours. The samples were then oven dried for 24 hours at 45˚C. The dry density of the hemp-lime was 248 kg/m^3.

Lime plaster

Tradical® Batir lime was mixed with fine sand at a ratio of 1:5 and water was added to required workability. A 5 mm layer of lime plaster was applied to some hemp samples depending on the assembly preparation as discussed in subsection 3.2.

3.2 Assembly preparation

The following five hemp-lime assemblies (Fig. 1) were prepared for the experiment:

- Assembly 1: it is the base-case assembly where no inner layer or surface finishing was added to the hemp-lime surface. Hemp-lime cube is covered in 5 sides with aluminium foil tape.
- Assembly 2: 5 mm lime plaster is applied to the upper surface of the base-case hemp-lime cube and other 5 surfaces are covered with aluminium foil tape.
- Assembly 3: Breathable membrane is added to the upper surface of the base-case hemp-lime cube and other 5 surfaces are covered with aluminium foil tape. While the breather membrane does not represent a complete set of inner linings, the MBV value obtained from this assembly will help understand the effect of adding breather membrane to the hemp-lime surface.
- Assembly 4: The following layers are added to the upper surface of the base-case hemp-lime cube: breather membrane, 25 mm air void and paper backed 12.5 mm gypsum plasterboard. The other 5 surfaces of the assembly are covered with aluminium foil tape.
- Assembly 5: The following layers are added to the upper surface of the base-case hemp-lime cube: 25 mm air void and paper backed 12.5 mm gypsum plasterboard. The other 5 surfaces of the assembly are covered with aluminium foil tape.

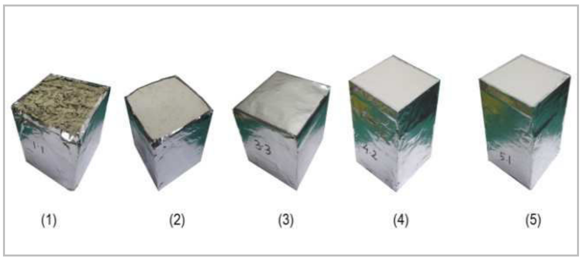

Fig. 1 : The assembly types (1) assembly 1, (2) assembly 2, (3) assembly 3, (4) assembly 4. (5) assembly 5.

Fig. 2 and 3 show the vertical cross sections of assembly 4 and assembly 5 where air void was included.

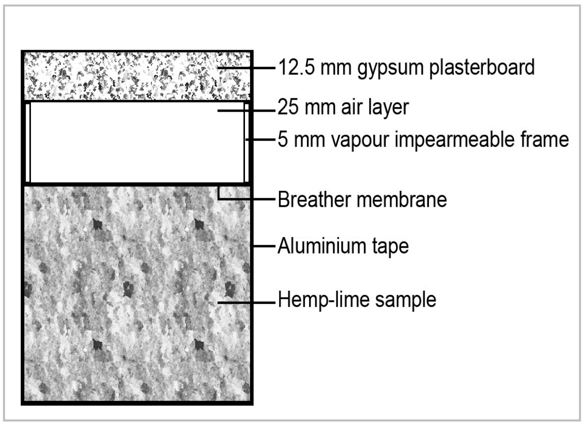

Fig. 2 : Vertical cross section of assembly 4

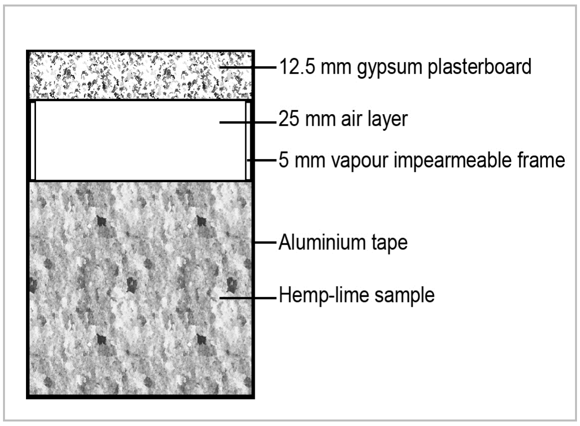

Fig. 3 : Vertical cross section of assembly 5.

4 TEST METHOD

NORDTEST protocol was used to determine the moisture buffering values ($MBV_{Practical}$) of the assemblies. According to this method, the test assemblies were subject to following step changes of relative humidity: 8 hours at 75% relative humidity and 16 hours at 33% relative humidity. The temperature was kept constant at 23° C. Two tests were performed, test-1 and test-2. Test-1 was performed in two climate chambers (TAS and Espec) and test-2 was carried out in one climate chamber (TAS). Tab. 1 shows the duration of the relative humidity exposures, use of climate chambers and average air velocity inside the climate chambers during test-1 and test-2.

Tab.1: The test protocol.

	Exposure to 33% relative humidity			Exposure to 75% relative humidity		
Test	Duration (Hour)	Climate chamber	Internal air velocity (m/s)	Duration (Hour)	Climate chamber	Internal air velocity (m/s)
Test-1	16	TAS	0.6	8	Espec	0.3
Test-2	16	TAS	0.6	8	TAS	0.6

4.1 Experimental equipment

Two climate chambers were used in test-1: TAS climate chamber for low relative humidity (33%) exposure and Espec climate chamber for high relative humidity (75%) exposure. For test-2, only TAS climate chamber was used by setting a cyclic relative humidity profile of 8 hours of 75% and 16 hours of 33%.

Analytical weighing scale with a resolution of 0.1 g was used to measure weight gain by moisture uptake and weight loss by moisture release at the end of each conditioning step.

4.2 Test specimens

Test specimens/assemblies are described in subsection 2.2. The dimension of the exposed surfaces of the test assemblies is 100 mm X 100 mm. The thickness of the specimens is 100 mm.

The cubic test assemblies were sealed on 5 out of 6 sides with aluminium tape and the test surface of each of the assemblies was kept exposed. For each assembly type, 3 specimens are tested.

4.3 Conditioning of the tests assemblies

The MBV test started 14 days after the casting of the samples and the test lasted for 9 days. At the beginning of the MBV test, the assemblies were conditioned to 23° C temperature and 50% relative to reach equilibrium moisture content.

4.4 Test conditions and procedure

The test assemblies were exposed to 75% relative humidity for 8 hours and 33% relative humidity for 16 hours. In each cycle, mass of the assemblies were measured at the end of each exposure. Change in moisture mass, Δm, was determined as the average of the mass gain during the moisture uptake branch of the cycle, and the mass loss during moisture release. The moisture buffer value ($MBV_{practical}$) was calculated as mass change, Δm, per m^2 and per ΔRH (relative humidity), based on the mean of last three cycles.

5 RESULTS AND DISCUSSION

The results of the test-1 and test-2 are shown in Fig. 4. Fig. 5 shows the results of test-1 in the background of moisture buffer value classes. Both tests show that the $MBV_{PracticaL}$ values of assembly 1 and assembly 2 are 'Excellent' while the $MBV_{Practical}$ values of assembly 3, assembly 4 and assembly 5 are 'Good'. The test assemblies maintained similar hierarchy of $MBV_{Practical}$ values for both tests. However the $MBV_{Practical}$ values of assemblies differed between the two tests. Compared to test-1, the moisture buffer values increased by 24%, 58% and 13% for assembly 1, assembly 2 and assembly 5, respectively, in test-2. For assembly 3 and assembly 4, the moisture buffer values decreased by 20% and 21%, respectively.

It can be assumed that 24% and 58% increase in moisture buffer values in assembly 1 and assembly 2, respectively, is due to the 100% increase in air velocity over the exposed surface of the assemblies. It is plausible that, during the moisture uptake cycle of test-2, the availability of moist air increased over the exposed surface of the assemblies due to increased air velocity. At the same time the surface film resistance also changed due to the change in air velocity. For assembly 5, the increase in moisture buffer value is relatively lower as the exposed hemp surface was covered with 25 mm layer of air and 12.5 mm plasterboard.

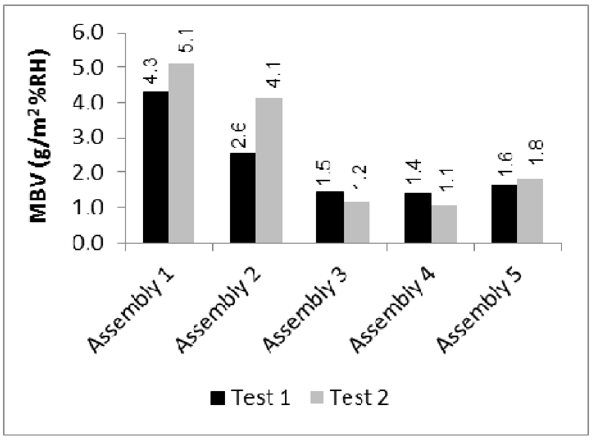

Fig. 4 : MBV of the assemblies.

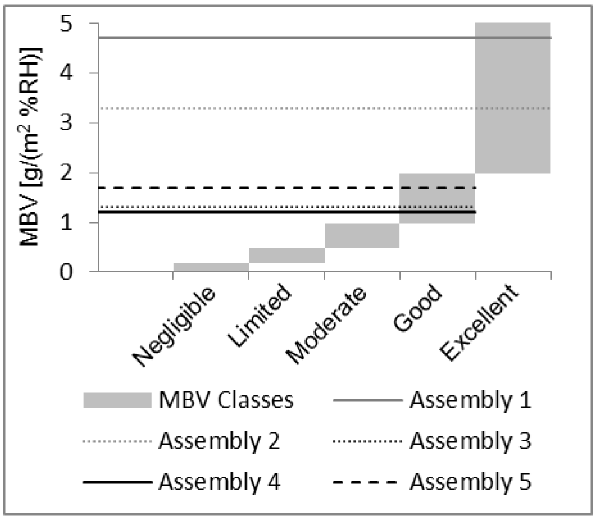

Fig.5: Moisture Buffer Classes of the assemblies.

It can be noted that both assembly 3 and assembly 4 incorporated breather membrane on the surface of the hemp-lime and their moisture buffer value declined, although in reduced magnitude than that of the rest of the assemblies, when the moisture uptake cycle was performed in 100% higher air velocity. It is plausible that increased moisture movement potentially increased the vapour diffusion resistance factor of the breather membrane by partially covering the microscopic holes in the breather membrane.

The velocity of air in the indoor spaces can range between 0.1 m/s to 2 m/s [Heerwagen]. However, for thermal comfort, the upper range of air velocity during the summer is 0.9m/s and the lower range of air velocity during the winter is 0.115 m/s [Orosa and Oliveira 2012]. Thus both air velocities of 0.3m/s and 0.6m/s are realistic in an indoor condition. The results of both test-1 and test-2 will, therefore, be useful in understanding the moisture buffer of hemp-lime in an indoor space.

The moisture buffer values of the aforementioned assemblies can be better appreciated if compared with that of other hygroscopic building materials as shown in Fig. 6. The MBV data of the other hygroscopic building materials were taken from the NORDTEST round robin tests [Rode 2005]. Among the materials used in the NORDTEST, the best performing materials were spruce and birch panel. The $MBV_{PRACTICAL}$ values of spruce and birch panel are lower than the poorest performing assembly of the present test.

It is to be noted that, during the NORDTEST round robin tests, the exposed surfaces of the building materials were tested without having any coating or inner layer. On the other hand, it is also to be noted that the air velocity over the exposed surfaces of the samples was 0.1 m/s during the NORDTEST tests compared to the air velocity of 0.3 m/s during the moisture uptake cycle of the tests-1. Thus compared to the NORDTEST tests, the moisture buffer values of the assemblies of the present tests may show higher values because of higher air velocity and may also show decreased performance as a result of the application of coating or layers.

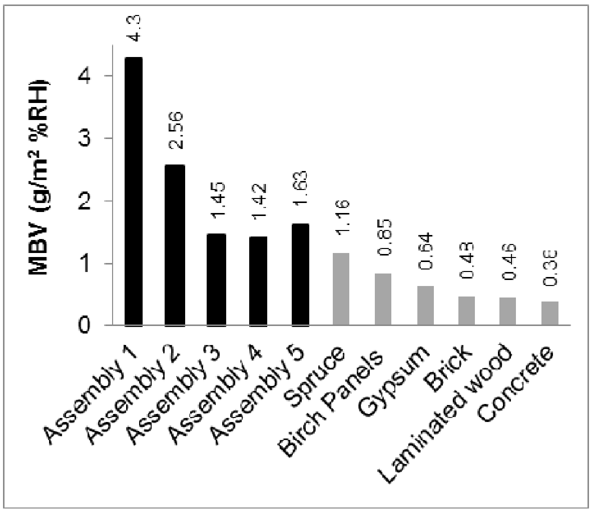

Fig. 6 : Comparison of moisture buffer value of the assemblies of the present test with that of other building materials determined by NORDTEST.

6 CONCLUSION

The moisture buffer capacity of hemp-lime is most utilised when the hemp-lime surface is exposed to the internal hygrothermal boundary conditions. However, this does not seem to be a viable option for practical applications. The next preferable option, to utilise most of the moisture buffer capacity of hemp-lime, is the direct application of lime plaster on hemp-lime surface. Experimental results for both options show 'Excellent' moisture buffer value of those hemp-lime assemblies. The assembly 5, where the hemp-lime surface was covered with 25 mm air layer and 12.5 mm gypsum plasterboard, showed 'Good' moisture buffer performance. In the hierarchy of moisture buffer performance, the less performing assemblies are assembly 3 and assembly 4 where breather membrane was used. It is assumed that the moisture buffer values were lower in these two assemblies due to the partial blocking of breather membrane cavities in high humidity conditions resulting in higher vapour diffusion resistance of the membrane combines with air resistance. Nonetheless, these two assemblies also showed 'Good' moisture buffer performance. Both 'Excellent' and 'Good' moisture buffer classes denote significant moisture buffering capacity compared to 'Negligible' 'Limited' and 'Moderate' moisture buffer classes.

Variations are observed between test-1 and test-2 with reference to the moisture buffer value of each assembly. The reason for the variations seem to be the differences in the surface film resistance due to the change of the air velocity over the surfaces of the assemblies during the moisture uptake cycles of test-1 and test-2. However, while the magnitude of moisture buffer values changed, the hierarchy of material in terms of moisture buffer value was same and the assemblies fell into similar moisture buffer classes during both tests.

7 AKNOWLEDGEMENT

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