APPLICATION OF HEMP-LIME RENDERS TO IMPROVE INSULATION OF WALLS.

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Abstract
This paper measures the variation of thermal transmittance of solid brick walls triggered by the application of hemp-lime renders in an effort to enhance the insulating properties of buildings. Six renders with different proportions of hemp and lime were fabricated and two selected based on their workability and adhesion. They were applied to the walls and their thermal transmittance measured using the hot box method. Thermal imaging was used to control thermal bridges in the masonry assemblies. When compared to commercial mixes such diathomite and expanded polystyrene, the hemp-lime renders display similar thermal properties that qualify them as good insulators. It was evidenced that the application of a hemp-lime render can halve the thermal transmittance of a solid brick wall. The renders notably increased the resistance to heat transfer of the brick wall. Render 5 [a 1.25: 1 - hemp: NHL3.5 mix applied in a 21 mm depth] nearly doubles the thermal resistance and halves the thermal transmittance of the wall, reducing the U-value from 6.99 to 3.65 W/m^{2}K therefore doubling the insulation provided by the solid brick wall.
It was also noted that the 21 mm hemp-lime renders improved the thermal properties of stone walls, but the improvement is not as notable as in the brick walls. However, a thicker render [40 mm] would greatly improve the thermal performance of the stone walls reducing U-values by c.40%.
The outstanding insulating ability of air gaps was exposed when the hemp-lime renders were applied on a metal lath/mesh set with a 20 mm gap off the wall: here, the U-values lowered by over 30%. Also, it was demonstrated that the hemp-lime renders improve the thermal performance of solid walls to a much greater extent than cavity walls.

Keywords:
Lime-hemp renders; thermal resistance; thermal conductivity; U-value.

1 INTRODUCTION

Applying a render to an existing fabric is probably the most simple and economic retrofit method that can be used to improve building energy performance.

Retroffiting measures to improve energy performance are of particular relevance as there is a need to improve building energy efficiency across the housing stock. The construction sector consumes a vast amount of energy. It is responsible for c. 40% of total energy consumption in Europe and 32% worldwide [Wang et al. 2014] Energy consumption would lower if buildings were energy efficient. In Ireland, the residential sector was the third largest consumer of primary energy [after industry and transport] [SEI, 2013]. A typical Irish house produces 8.1 tonnes of CO_2 emissions per year [SEI, 2008], one of the highest in Europe. Since Ireland's adoption of the European Directive on the Energy Performance of Buildings [2002/91/EC] in 2006, the Government has strived for building efficiency in both new and existing structures to reduce energy use and CO_2 emissions. Most new builds include energy efficient measures. However, there are thousands of buildings that appeared before building regulations were introduced and need upgrades to lower their energy consumption.

This paper experimentally measures the impact of hemp-lime renders on the thermal properties of solid brick walls. It then extrapolates the result to solid stone walls and cavity wall construction. The performance of the hemp-lime renders is compared with lime-based and commercial renders.

Solid walls are typical of historic and traditional construction however, they are also very common in pre-1920's buildings. Most solid walls of c.200 mm are assigned a single default U-value of 2.1 W/m^{2}K [BRE 2016] however, it is known that their performance can be underestimated as evidenced by experimental studies [Baker 2011]. In theory, there is not a great difference between the thermal conductivity of different solid units such fired-clay brick, concrete block or calcium silicate brick however, experimental measurements show more differences than theoretical values sometimes due to gaps in the walls or varying densities of the material components.

Natural materials including hemp and particularly lime, have been used in historic and traditional buildings. As any other vegetal tissue, hemp is very porous and therefore has an inherent insulating ability. Limes were used historically as binders in masonry mortars and are used for new building and repairs today. One of the outstanding properties of lime is the high water vapour permeability which makes lime-based materials compatible with historic and traditional fabrics such as solid masonry walls.

Although the thermal transmittance across a structure or building component [U-value] does not fully define thermal performance, it quantifies the rate at which heat passes through. Most heat loss in buildings takes place through walls so, knowing the U-value of a given wall is important. However, U-values neglect the significance of heat capacity and ignore other properties such as thermal diffusivity and thermal inertia, therefore they fail to fully assess the ability of the concretes to store heat and release it over time. As a result, hemp concrete buildings usually perform better than predicted by their U-value calculations [BRE 2002]. Despite these shortcomings, U-values offer a simplified method which addresses thermal behaviour under steady boundary conditions and it is widely accepted as a parameter to measure the thermal properties of fabrics.

The thermal conductivity values of lime–hemp concretes range between 0.05 and 0.12 W/m K depending on composition and density [Daly et al. 2010]. It is well known that the presence of moisture enhances thermal conductivity of materials. However, the thermal conductivity of hemp lime concretes depends primarily on the density of the material and increases in a quasi linear manner in relation to it [Cerezo 2005, Elfordy et al 2008, Nguyen 2010, Shea et al 2012]. The hemp aggregate is a highly porous wooden tissue including substantial air therefore, increasing hemp in the concrete reduces thermal conductivity [Evrard 2003]. The binder is the most thermally conductive component [Tronet et al. 2011] consequently, a rise in binder content increases thermal conductivity.

Thermal bridging [which occurs at gaps in the fabric or when materials of very different thermal conductivity are in contact] accounts for significant unwanted heat loss and local condensation problems therefore it plunders thermal performance. The presence of thermal bridges can become clear with thermal imaging and was used in this investigation to validate results.

2 MATERIALS AND METHODS

Walls of 1x1 m were built with pre-soaked fired-clay bricks 215 mm x 102.5 mm x 65 mm [length x depth x height] and a [3:1 sand: lime] mortar made with a NHL 3.5 complying with EN459-1. They were left to cure under wet hessian cloth for one month during which they were soaked with water every three days to encourage hydration. A scud coat [1: 1 lime: sand] was first applied to even the wall and provide a key. It was left overnight to dry. The renders were applied on top in one or two coats and cured in laboratory conditions over four months [Fig. 1]. The two coat render was an approximately 12 mm thick scratch coat [applied to the walls previously wetted and cured overnight] followed by a 9 mm thick finishing coat [also on the wet wall].

The aggregate used for the hemp renders is industrial hemp shiv supplied by La Chanvriere De L'aube, France. Hemp properties vary with growing conditions and harvesting, and this influences the properties of the concrete. The water content of the hemp was measured at c.12.4% prior to mixing.The mixes in table 1 were initially trailed on hemp concrete and concrete block walls and the most suitable selected based on their workability and adhesion. The volume of hemp within the mix was increased in an effort to enhance the insulating properties of the material. The amount of water was adjusted based on workability and ranged from 1: 2: 3.5 to 1.25: 1: 3 [hemp: NHL3.5: water]-table 1. From the trials Mix 1 and Mix 5 were selected as the best performers. It was noted that increasing the amount of hemp raised the water demand and made the render unworkable, not being possible to apply the mix as a thin coat.

Each render was applied to one half of one of the brick walls, with the other brick wall being left un-rendered to act as a control. The hemp-lime renders were applied directly to the wall surface with no air cavity. Mix 5 was applied in one single coat of 21mm due to workability. This is not expected to affect thermal properties. Infrared thermal imaging was used on the assemblies to identify thermal bridges that would affect the thermal resistance and transmittance readings.

Fig. 1: A solid brick wall with hemp-lime render mix 5 applied.

The thermal resistance and thermal transmittance were measured with the guarded hot box method [GHB] in EN ISO 8990:2013. The central heater in the hot box was set at 30°C providing a consistent ΔT at c.10°C. The thermal sensors [HFM] and temperature sensors were fixed to the walls. The temperature sensors were thin thermocouples fixed to the wall using a compound silicone so that the sensors do not change the temperature at the measuring point. Data was collected using data logger software at 10-minute and 19-hour intervals. As aforementioned, the renders were cured in laboratory conditions for over four months therefore, no interference from residual moisture was apparent in the measurements.

Surface temperature readings were taken, both inside and outside the hot box, and the transfer rate of heat energy through the walls measured with a heat flow meter [HFM- a transducer giving an electrical signal which is a direct function of the heat flow transmitted through it] and a set of temperature sensors. The average of several measurements sampled at shorter time intervals were used for analysis as recommended by the standard. As no large variations occurred in the experiment temperatures, the data were analysed using the average method in ISO 9869-1 which assumes that the conductance or transmittance can be obtained by dividing the mean density of the heat low rate by the mean temperature difference, the average being taken over a long enough period of time.

Tab. 1: Mixes by trial.

Mix No.	Parts by volume		Render properties
	Lime	Hemp	
1	2	1	Standard mix commonly used in industry. Good workability. Smooth finish.
2	1	2	Dry. Poor workability. Lacks adhesion, crumbly surface.
3	1	1	Good consistency and good workability. Good bond. Slightly crumbly when dry.
4	1	1.5	Low workability. Difficult to achieve a consistent mix.
5	1	1.25	Good workability, achieves a consistent mix. Good adhesion and bond to wall.
6	2	1	Contained pre-soaked hemp fibres. Poor workability [too wet]. Lack of bond to wall.

3 RESULTS

The experimental values below were obtained every 19-hour time interval during the hot box testing. When considering Mix 5, the first value recorded [R = -21.04 m^2K/W] displays the sensor's initial settling period and is not considered in the calculations. The thermal resistance of the solid brick wall rendered with hemp-lime render 1, as an arithmetic mean of 9 measurements taken every 19 hours during 7 days is 0.259 m^2K/W while render 5 achieved 0.274 m^2K/W. The results appear in tables 2-3 and Figs 2-3.

The thermal imaging did not evidence any thermal bridges in the masonry assemblies and made clear the difference in heat flow between the cooler, rendered brick wall at 13.9°C and the un-rendered brick wall at c. 18.2°C [Fig. 4]. According to the results [tables 2-3], the hemp renders significantly increase the resistance to heat transfer in the solid brick wall. Render 5 nearly doubles the thermal resistance and halves the thermal transmittance of the wall reducing the U-value from 6.99 to 3.65 W/m^2K therefore, the hemp render doubles the insulation ability of the solid brick wall.

According to the experimental results, the thermal resistances of the hemp renders are c. 0.10 and 0.11 m^2K/W for mixes 1 and 5 respectively. The values compare well with those previously reported for thicker [50 mm] hemp lime renders of conductivity 0.13 to 0.14 W/mK [R=0.05/0.13=0.38 m^2K/W] [St.Astier/CESA, 2018] and 40mm hemp renders [hemp:NHL2:water-1:2.9:3.5 -by weight] of conductivity 0.09 [R= 0.44] [Walker and Pavia 2016].

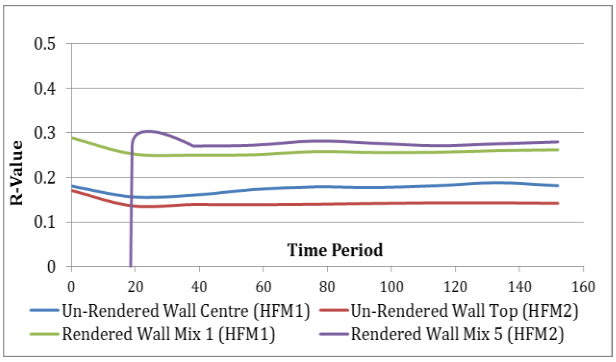

Fig. 2: Thermal resistance of one of the brick walls over time.

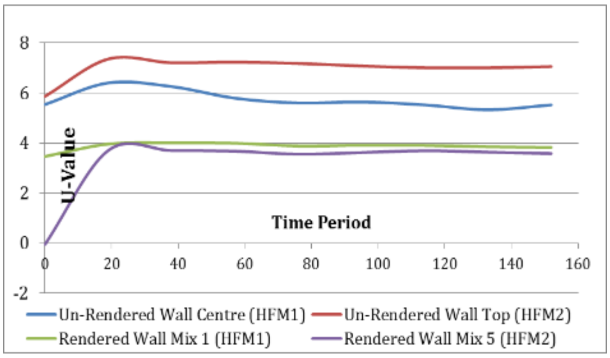

Fig. 3: Thermal transmittance of one of the brick walls over time.

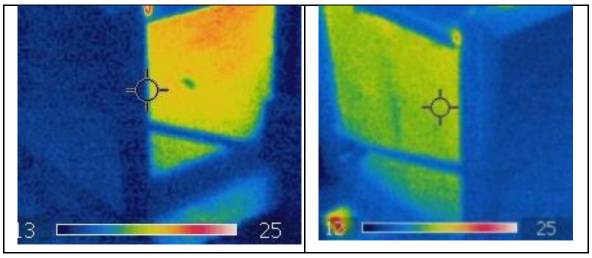

Fig. 4: Infrared thermography showing the absence of thermal bridges and the temperature differential between the hotter, un-rendered [left] at c. 18.2°C and the cooler, rendered brick wall [right] at 13.9°C.

In table 4, the experimental values are applied to stone walls whose thermal properties were measured in the field by Historic Scotland. As it can be seen from the results, the 21 mm hemp-lime renders in this paper would improve the thermal properties of the stone walls however, the improvement is not as notable as in the solid brick walls. However, a render twice the thickness [40 mm] would greatly improve the thermal performance of the solid stone walls reducing U-values by c.40%. The results also highlight the improved thermal performance when the walls are lined with plasterboard inside.

Table 5 is also based on the experimental values however, it considers the hemp-lime renders applied on a metal lath or mesh set with a 20 mm gap off the wall. The thermal resistance of the air gap - given the thermal conductivity of the air at 0.11W/[m·K] - is R=0.02/0.11= 0.18 m^2K/W. As it can be seen from the results, the 21 mm hemp-lime renders applied on the 20 mm gap greatly improve the U-values of the walls lowering it by over 30%. They perform significantly better than the hemp-lime renders applied directly on the wall.

Tabl. 2: Thermal properties of the rendered solid brick walls measured experimentally.

Time Period	Render Mix 1 Heat Flux W/m^2	ΔT ºC or K	R m^{2}K/W	Render Mix 5 Heat Flux W/m2	ΔT ºC or K	R m^{2}K/W
0	34.74	10.03	0.288	-0.538	11.32	-21.040
19	34.88	8.81	0.252	35.94	9.70	0.269
38	36.41	9.09	0.249	37.33	10.09	0.270
57	36.14	9.05	0.250	37.53	10.21	0.272
76	34.86	8.98	0.257	35.69	10.04	0.281
95	36.54	9.34	0.255	37.28	10.30	0.276
114	38.74	9.92	0.256	39.61	10.73	0.270
133	38.94	10.11	0.259	40.21	11.06	0.275
152	37.29	9.75	0.261	38.31	10.70	0.279
	R = 0.259 m^{2}K/W; U-Value = 3.86 W/m^{2}K			R = 0.274 m^{2}K/W; U-Value = 3.65 W/m^{2}K		
	Heat Flow [q] = 36.5 W			Heat Flow [q] = 37.74 W		

Tabl. 3: Thermal properties in the solid brick wall un-rendered. R=0.159 and U-Value= 6.36 arithmetic mean.

Time Period	Centre of un-rendered wall Heat Flux W/m^2	ΔT ºC or K	R m^{2}K/W	Top of un-rendered wall Heat Flux W/m^2	ΔT ºC or K	R m^{2}K/W
0	45.00	8.12	0.180	50.50	8.610	0.170
19	48.59	7.58	0.156	55.33	7.521	0.135
38	51.05	8.16	0.159	55.85	7.749	0.138
57	49.70	8.58	0.172	55.37	7.655	0.138
76	47.66	8.51	0.178	53.69	7.477	0.139
95	49.58	8.79	0.177	54.29	7.672	0.141
114	49.77	9.01	0.181	55.21	7.879	0.142
133	46.57	8.74	0.187	53.59	7.649	0.142
152	47.27	8.56	0.181	53.07	7.522	0.141
	R = 0.175 m^{2}K/W; U-Value = 5.73 W/m^{2}K			R = 0.143 m^{2}K/W; U-Value = 6.99 W/m^{2}K		
	Heat Flow [q] = 48.35 W			Heat Flow [q] = 54.1 W		

Tabl. 4: Experimental values extrapolated to onsite values by Historic Scotland on solid stone walls. Renders are applied to the wall with no cavity. Proportions by weight. R [m^{2}K/W] U-Value [W/m^{2}K]. Walker and Pavia [2015].*

Stone masonry wall		No render		21 mm hemp-render 1, R= 0.10		21 mm hemp-render 5, R= 0.11		40 mm hemp render of conductivity 0.09,R= 0.44*	
Width, material, internal finish		R	U-Value	R	U-value	R	U-value	R	U- value
600mm Craigleith Sandstone	Plaster on stone	0.66	1.50	0.76	1.31	0.77	1.29	1.10	0.90
	Lined with plasterboard	1.11	0.90	1.21	0.82	1.22	0.81	1.55	0.64
Kemnay Granite	Plaster on 350mm wall	0.58	1.70	0.68	1.47	0.69	1.44	1.02	0.98
	600mm wall lined with plasterboard	1.11	0.90	1.21	0.82	1.22	0.81	1.55	0.64

Tabl. 5: Hemp-lime renders applied on a metal lath leaving a 20 mm gap [R=0.18 m^{2}K/W] off the wall. As both tested hemp-lime renders produce similar results, render 5 is used.

102.5 mm Solid brick wall						600mm sandstone wall					
un-rendered		hemp- render 5		render 5 on metal lath with air gap		un-rendered [no plasterboard]		rendered with hemp- render 5		render 5 on metal lath with air gap	
R	U-Value	R	U-Value	R	U-Value	R	U-Value	R	U-Value	R	U-Value
0.16	6.36	0.27	3.65	0.45	2.22	0.66	1.50	0.77	1.29	0.95	1.05

Finally, the hemp renders are compared with commercial mixes including diathomite and expanded polystyrene [EPS]. The diatomite is a spray-on render comprising cork, resins and diatomaceous earth [a fine siliceous sedimentary rock that is chemically inert, very porous and has a low density]. The EPS is a multi-layer arrangement commercialised as a single coat of mineral render which can be applied externally with a machine pump and fibre mesh placed between wet passes. The properties of these renders are included in table 6.

Tabl. 6. Thermal properties of the commercial renders.

	Thickness [m]	Conductivity [W/mK]	Resistance [m^{2}K/W]
Diathomite	0.019	0.086	0.221
EPS	0.019	0.032	0.594

To establish a comparison, the commercial and the hemp lime renders investigated are theoretically applied to a standard concrete-block, cavity wall [Fig. 5, table 7] where the standard external render is replaced with the same thickness of hemp-lime renders, diatomite and EPS successively [table 8].

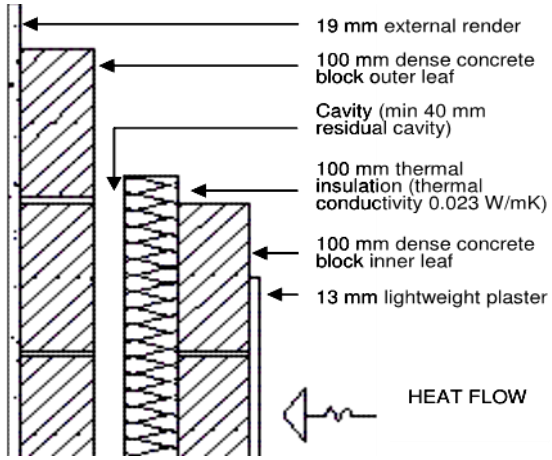

Fig. 5: Standard concrete-block cavity wall [Building Regulations 2017].

Tabl. 7. U-value W/m^{2}K of the cavity wall in Fig. 5.

Layer	Thickness [m]	Conductivity [W/mK]	Resistance [m^{2}K/W]
external surface	-	-	0.040
19 mm external standard render	0.019	1.00	0.019
100 mm dense concrete block	0.100	1.33	0.075
40 mm air cavity	0.100	-	0.180
insulation	0.100	0.023	4.348
100 mm dense concrete block	0.100	1.33	0.075
13mm plaster	0.013	0.18	0.072
internal surface	-	-	0.130
Resistance			4.939
U-Value			0.202

It can be seen from the results [table 8] that the hemp-lime renders significantly improve the thermal performance of solid walls however they have a much lower impact on the thermal performance of cavity walls. The results suggest that air gaps in a built fabric are amongst the best and more economic solutions to lower thermal conductivity.

Tabl. 8. Alteration of the U-value of the cavity wall [W/m^{2}K] by the renders.

Standard cavity wall	0.202
with 21 mm hemp renders 5 and 1	0.198 and 0.199
with 40 mm hemp render	0.186
with diatomite render	0.194
with EPS	0.181

4 CONCLUSIONS

The mere application of a hemp-lime render can halve the thermal transmittance of a solid brick wall. The renders investigated significantly increase the resistance to heat transfer of the solid brick walls. Render 5 [a 1.25: 1 - hemp: NHL3.5 mix applied in a 21 mm depth] nearly doubles the thermal resistance and halves the thermal transmittance of the wall, reducing the U-value from 6.99 to 3.65 W/m^{2}K therefore doubling the insulation provided by the solid brick wall.

When the experimental values were combined with stone walls whose thermal properties were measured on site, it was evidenced that the 21 mm hemp-lime renders also improve the thermal properties of stone walls however, the improvement is not as notable as in the solid brick walls. However, it was noted that a render approximately twice the thickness [40 mm] would greatly improve the thermal performance of the stone walls reducing U-values by c.40%.

The outstanding insulating ability of air gaps was exposed by including a 20 mm gap between the renders and the wall: when the hemp-lime renders were applied on a metal lath or mesh set with a 20 mm gap off the wall, the U-values of the walls lowered by over 30%.

When compared to commercial mixes such diathomite and expanded polystyrene, it was seen that the hemp-lime renders display similar thermal properties that qualify them as good insulators. Also, it was finally demonstrated that the hemp-lime renders improve the thermal performance of solid walls to a much greater extent than cavity walls.

5 ACKNOWLEDGMENTS

The authors thank David McAuley, Michael Grimes, Eoin Dunne and Mark Gilligan for their assistance with the laboratory testing.

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