Journal of Physics: Conference Series

PAPER • OPEN ACCESS

The Behaviour of Wood Fibre Insulation Systems for Solid Wall Buildings: Lessons from a Long-term Monitoring Study

To cite this article: Valentina Marincioni and Hector Altamirano-Medina 2023 *J. Phys.: Conf. Ser.* **2654** 012127

The Behaviour of Wood Fibre Insulation Systems for Solid Wall Buildings: Lessons from a Long-term Monitoring Study

Valentina Marincioni*, Hector Altamirano-Medina

UCL Institute for Environmental Design and Engineering, Central House, 14 Upper Woburn Place, London, WC1H 0NN, United Kingdom

*Corresponding author: v.marincioni@ucl.ac.uk

Abstract. The majority of the traditional building stock in the UK is made of solid brick walls. Internal wall insulation is one of the possible interventions to preserve the external appearance of a building while improving the energy efficiency of its walls. However, it can lead to moisture-related risks, such as excess moisture accumulation and mould growth. This paper presents an overview of the lessons learnt from the long-term monitoring of two case-study solid wall buildings, insulated with wood fibre-based systems and monitored for a year. The aim of this monitoring campaign was to provide evidence on the main moisture transfer and storage mechanisms occurring in solid walls insulated with wood fibre-based systems under actual environmental conditions. Results showed that the dynamic interaction between the insulated wall and moisture sources could be controlled by means of an appropriate specification of the insulation system, considering the influence of orientation, material properties and indoor moisture loads. It was also found that construction moisture influenced the initial conditions of the interface, but mitigation strategies can be considered to reduce mould growth risk during installation and before the drying of construction moisture.

1. Introduction

Historic buildings account for a large proportion of the building stock in many countries, and 30% in the UK, where such buildings are mainly made of solid masonry. Currently, only 11% of these buildings have been insulated [1]. The push for deep retrofit and carbon emission reduction to net zero by 2050 requires tackling those buildings. There is growing awareness on the hygrothermal performance of insulated buildings, although limited research has been carried out in walls without protection from wind-driven rain. This paper provides evidence of the leading moisture transfer and storage mechanisms occurring in two solid walls buildings insulated with a capillary-active insulation systems based on wood fibre systems. The two case study buildings were monitored for one year.

Capillary-active insulation systems have been developed for the internal insulation of solid walls, to allow walls to dry out when they are exposed to outdoor moisture sources. While other insulation systems work by opposing resistance to vapour diffusion through the system, capillary-active insulation systems work by redistributing any moisture that is accumulated within the system, particularly in the area near the existing wall-insulation interface. The definition of capillary-active systems is not clear-cut; however, the common trait of capillary-active systems is their ability to store moisture, redistribute it and eventually dry out. Dense wood fibre insulation is one of the examples of capillary-active systems, together with e.g. calcium silicate, autoclaved cellular concrete, cellulose insulation, hemp-lime or cork-lime insulating plasters.

To allow moisture redistribution from the critical interface, the insulation material must be capillary-active in the region surrounding the critical interface and in full contact with the existing wall. This usually requires the provision of an adhesive layer (called *bonding coat*) between the existing wall and the insulation; lime plaster can act as a bonding coat.

Capillary-active systems, when fully bonded to the wall, have other positive characteristics. First, the systems can inhibit mould growth at the wall-insulation interface, since mould requires a surface to grow [2] or very large pores, less common in building materials. Moreover, unwanted air flow behind the insulation is prevented. However, the presence of water in material pores can affect their durability and thermal resistance.

The literature presents various examples of in-situ monitoring of capillary-active systems. In-situ monitoring of capillary-active systems under actual environmental conditions showed low mould growth risk [3], and relative humidity levels below the thresholds for material degradation [4]. A comparative study was carried out in a stone wall in Ireland, where different insulation systems were installed in the same building. All capillary-active systems showed drying from initial conditions, low levels of relative humidity, and similar relative humidity and temperature profiles; on the other hand, a vapour-closed insulation system (i.e. foil-backed polyisocyanurate) showed a consistently high relative humidity [5]. This result is consistent with another comparative study, performed under a continental climate (in Poland), where the monitoring showed higher drying rates in capillary-active systems compared to expanded polystyrene insulation [6]. This paper presents an analysis of the hygrothermal performance of two different wood fibre internal wall insulation (IWI) systems installed onto solid walls with no additional protection to wind-driven rain.

2. Methodology

Two case studies were monitored to better understand the behaviour of capillary-active wood fibre insulation under actual environmental conditions. The case studies are characterised by different solid wall structures and located in the UK, which has a coastal maritime climate. Both case studies are in an area of moderate wind driven rain exposure and have a relatively high exposure to solar radiation, with a yearly sum of global irradiation between 1100 and 1200 kWh/m^2 [7].

In the first case study, two wood fibre insulation systems were installed on a solid stone wall and compared. The case study was devised to understand the in-situ hygrothermal performance of the two insulation systems, based on the same material but with different hygric properties.

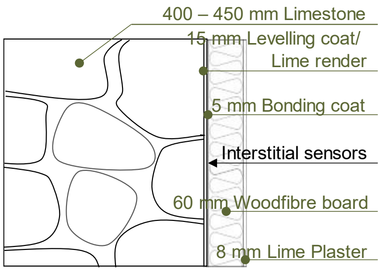

Figure 1. CS1 living room/ bedroom (IWI system 1)

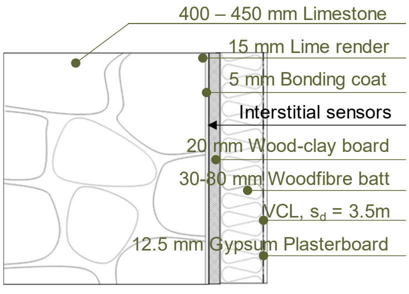

Figure 2. CS1 staircase (IWI system 2)

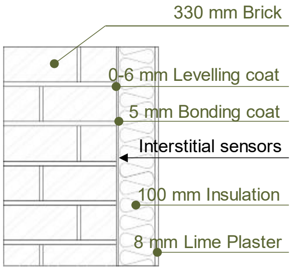

Figure 3. CS2 teaching area (IWI system 1)

Both systems included a fully bonded dense woodfibre board (of various thicknesses) at the monitored interface between existing wall and insulation, considered to be the critical interface for mould growth and condensation. However, IWI system 1 (Figures 1 and 3) has a vapour diffusion resistance (s_d) of 0.83 m to 1.03 m, while IWI system 2 (Figure 2) has a vapour control layer (VCL) with a s_d-value of 3.5 m (and a total s_d-value of 3.77 m). Other differences between IWI systems 1 and 2 are the use of lime plaster and gypsum plasterboard as interior finish respectively, and the addition of a wood fibre batt close to the interior environment in IWI system 2. In the second case study, one a thicker IWI system 1 was installed on two solid brick walls with different orientations and the same indoor environment. The case study was devised to understand the hygrothermal behaviour of two walls under different outdoor local climate. Both case studies had walls without external render or any water-repellent treatments.

2.1. Case study 1

This case study is a 19th century mid-terrace house in Oxfordshire, located in a conservation area. Un-rendered west-Oxfordshire limestone is the main material of the solid masonry wall, whose thickness is 450mm at the ground floor and 400mm at the first floor. Three rooms were tested: the living room on the ground floor, the staircase, and the first-floor bedroom. In the living room, prior to retrofit the wall was not plastered; a levelling coat made of sand and Natural Hydraulic Lime 3.5 was used to obtain an even surface before the application of insulation. In other rooms, the existing lime render was retained, but the paint was scratched to allow for moisture transfer. This is because paints can sometimes be vapour closed, inhibiting the transfer of moisture.

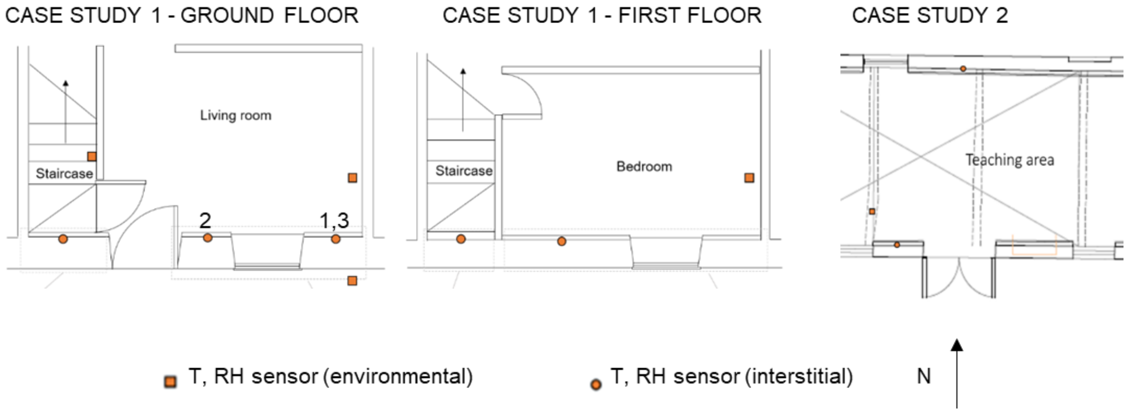

Figure 4. Sensors locations in Case Study 1 (left and centre) and Case study 2 (right)

2.2. Case study 2

This case study examines an 18th century barn in Berkshire, that has been refurbished and converted into an education centre. The building, which is grade II listed, is of special interest and every effort was made to preserve it during the refurbishment. Internal wall insulation was added to improve the energy efficiency of the building while retaining the appearance of its façade. The walls under evaluation are two solid brick walls facing north and south. The external surfaces of the brick walls were left unrendered and no gutters were installed on the south elevation, with the aim of preserving the external appearance of the building. The north elevation at the rear of the building had new gutters installed, and is also partially protected from the weather by a row of trees. The building has a large room used as teaching area, and is designed to accommodate 50 occupants at full capacity. The monitored walls are part of this teaching area and are exposed to the same indoor environment, while being subject to different external local climates, due to their different orientations.

2.3. Monitoring method

The environmental conditions of the buildings were monitored, together with temperature and relative humidity at the interface between insulation and existing wall. The temperature and relative humidity were monitored for at least one drying season – covering spring and summer – and one wetting season – in autumn and winter. In both cases, the monitoring started on the day of installation of the insulation system; the drying after installation was monitored and analysed.

The data loggers used were HOBO H08-003-02 for relative humidity and temperature, produced by Onset, modified to detach the sensing element from the datalogger. They have a thermocouple with accuracy 0.7 °C as temperature sensor and a resistive relative humidity sensor, with accuracy ±5%. The sampling interval was set at 1 hour. For the analysis of interstitial conditions, time series of monitored variables were plotted and the results for the different sensors locations were compared.

The analysed parameters were temperature and relative humidity, measured at the existing wall-insulation interface.

3. Results

3.1. Temperatures

In case study 1, at the wall-insulation interface, the interstitial temperature profile was found to be very similar for all the sensors. Figure 5 (left) shows the interstitial temperature recorded in the first year by the sensors in the three monitored rooms in case study 1. The existing stone wall on the first floor is 400 mm, 50 mm thinner than the ground floor wall, which is 450 mm. The living room and bedroom walls have been insulated with the same IWI system 1, with an insulation thickness of 60 mm; the insulation in IWI system 2 on the staircase wall is much thinner on the ground floor (*staircase low*, 50 mm-thick) than on the first floor (*staircase up*, 100 mm-thick). However, the interstitial temperatures recorded were very similar across the different rooms, with a slightly larger amplitude for the sensors located on the first floor (*bedroom* and *staircase up*). It is worth noting that there is variability across the three sensors installed on the living room wall, suggesting heterogeneity in the thermal properties of the existing wall.

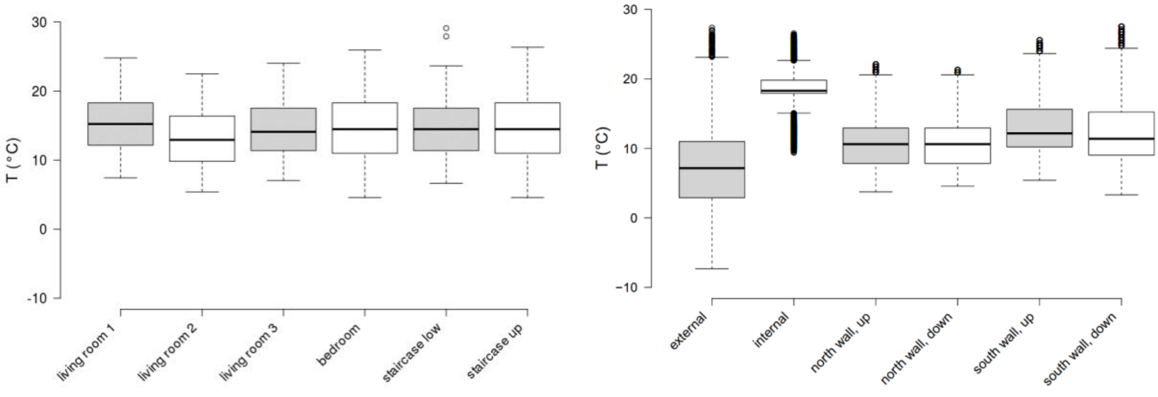

Figure 5. Boxplot of temperatures at the wall-insulation interface in all monitored rooms; case study 1 (left) and case study 2 (right)

The variation in thermal behaviour was also analysed in case study 2, where four sensors were installed in one room, but on walls that are exposed to two different orientations, north and south.

As shown in Figure 5 (right), the interstitial temperature profile was found to be very similar for sensors installed in the same wall, suggesting that the thermal transmittance of the wall is fairly constant. However, there were some differences in the temperature profile between the south façade and the north façade, with consistently higher interquartile ranges of temperature for the sensors in the south façade than in the north façade. More detailed analysis of temperature differences can be found in [8]. The paper identified that the discrepancy between temperatures in the north and south walls occurred only in the drying season, during periods with consistently high solar radiation intensity.

3.2. Relative humidity: construction moisture and drying

In both case studies, the disparity in relative humidity in the measured locations was found to be larger than the one found in the temperatures, although the trend after the drying season is similar among all sensors. The main difference in relative humidity across sensors was found in the first period after construction (see Figure 6). This is because the installation of dense wood fibre recommends the use of a wet bonding coat to ensure full contact between insulation and wall, which introduces moisture in the construction.

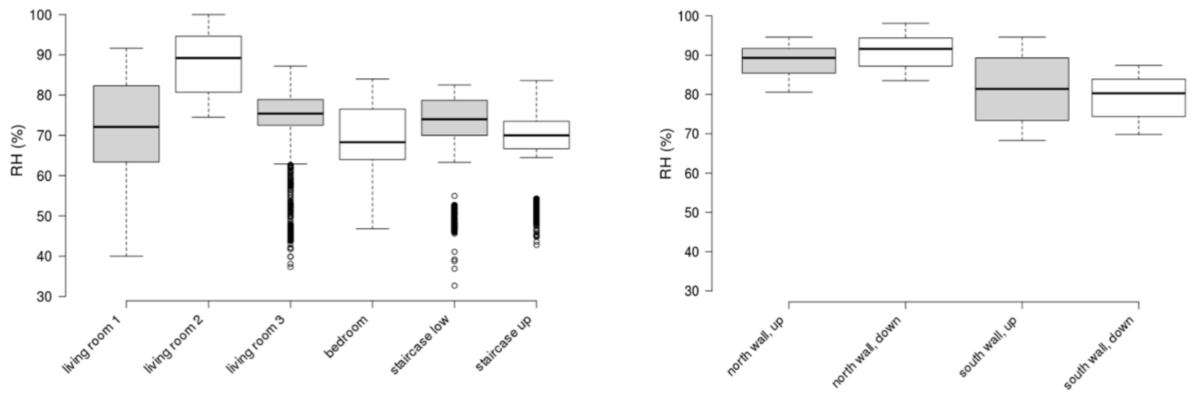

Figure 6 Box plots of relative humidity at the wall-insulation interface from installation to the end of the first drying season; case study 1 (left) and case study 2 (right).

In case study 1, construction moisture was found to be higher at one sensor (*living room 2*, see Figure 6, left), located in the lower end of the living room wall; this can be given by the proximity to the wet plaster used as bonding coat, which is difficult to control during the installation of sensors. Similarly, in case study 2, the relative humidity in the first period after the installation of insulation was high. In particular, the north wall sensors measured a relative humidity in the range between 80% and 98% from installation until the end of the drying season (see Figure 6, right). Also, the initial relative humidity varied between sensors even if they were on the same wall, which could have been caused by the proximity to the bonding coat.

In the first drying season after construction (spring-summer), drying occurred at all locations. In case study 1, the sensor with higher construction moisture dried out slower but the general trend showed drying until the end of September, as shown in Figure 7. Two drying events are noticeable: end of May and end of July. There, the relative humidity dropped by 5 to 15 %, with a more considerable drop in the bedroom wall.

In the wetting season (autumn-winter), the trend of relative humidity was more consistent among the sensors. Still, the three sensors located in the same living room wall showed different values of relative humidity, suggesting variability of the wall properties or local environmental conditions. The bedroom relative humidity increased at a higher rate than in the living room in the wetting season, probably due to higher indoor moisture loads in the bedroom compared to the living room.

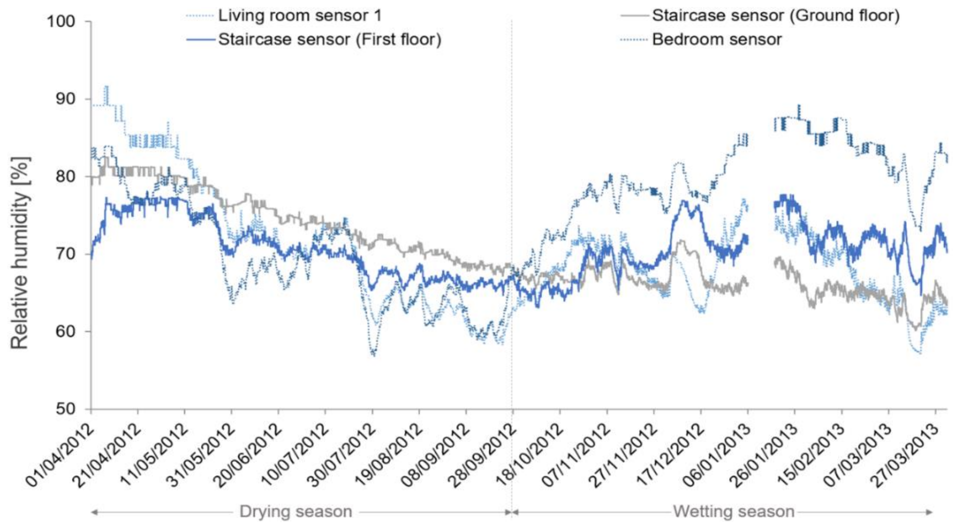

Figure 7 Case study 1: relative humidity at the wall-insulation interface; sensors in all monitored rooms (sensor 1 was shown for the living room)

Although temperature profiles are similar within each case study, there is a difference in the relative humidity profile of both case studies. In case study 1, the fluctuations in the relative humidity profile found in the staircase wall were less marked than in the other rooms, particularly in the first drying season (see Figure 7). This is thought to be associated with the fact that the insulation system installed on the staircase wall has a slightly higher vapour diffusion resistance than in the other walls, which allowed drying of construction moisture in the drying season but reduced moisture accumulation in the wetting season.

The pattern at the interface follows closely the indoor environment (if long term averages are considered); on the other hand, the relationship between the external environment and the interstitial conditions was not detected in this case study.

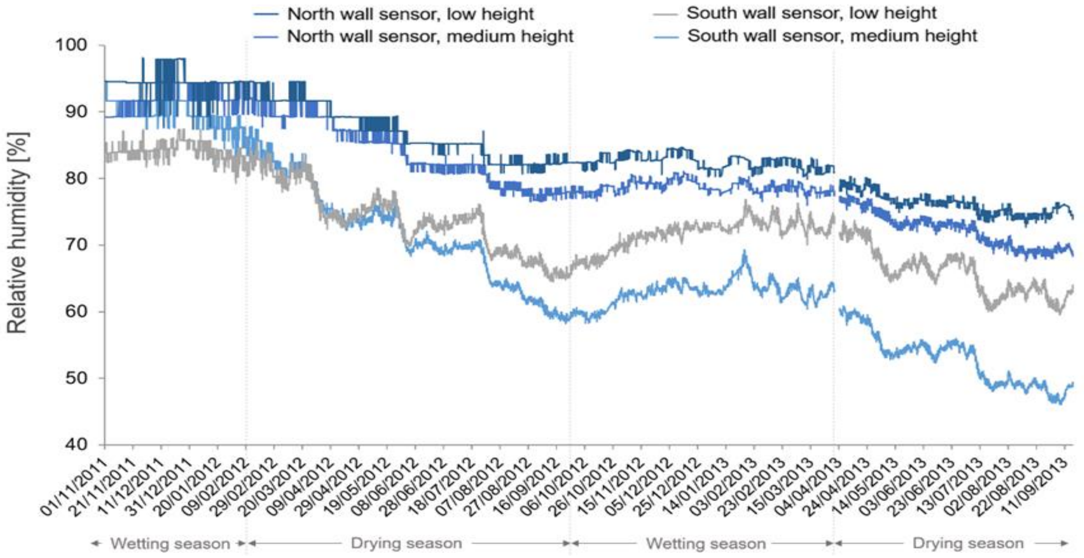

Figure 8 Case study 2: relative humidity at the wall-insulation interface; all monitored locations

Figure 8 shows the interstitial relative humidity in case study 2, for all monitored locations, where the influence of the external environment on interstitial conditions was investigated.

Relative humidity only started decreasing in the first drying period after the installation of internal wall insulation. In the south wall, drying started after two months from installation; in the north wall it started after five months, in the following spring.

After two to five months, the construction moisture introduced by the bonding coat started drying out; at the end of the drying season, the relative humidity at the north wall had a reduction of around 17% and the relative humidity at the south wall was reduced by 23% to 36%.

In the drying season of the first year, three major drying events could be noticed, in March, May and July; a similar behaviour was found in the second year, in April-May and July and, to a lesser extent, in June and August. These events are related to the periods with consistently high solar radiation intensity identified in the analysis of interstitial temperatures.

In the wetting season, the south wall showed higher moisture accumulation than the north wall. The relative humidity at the south wall had an increase of around 12% and the relative humidity at the north wall increased by 4%. Overall, both sensors in the south wall show lower relative humidity than the sensors in the north wall.

4. Discussion

Both cases showed an influence of construction moisture on the initial conditions at the wall-insulation interface. In these cases, construction moisture was introduced by the bonding coat, in the process of fully bonding the insulation to the existing wall. Construction moisture led to high initial relative humidity after installation; since installation, a reduction of relative humidity was noticed during the first drying season. Therefore, if the installation of insulation involves wet processes, these results suggest that it is safer to install insulation prior to the drying season,. It is also important to note that the drying process of lime-based materials (i.e. carbonation) produces an alkaline environment, which inhibits the growth of organisms. Therefore, lime-based materials are better suited as bonding coats.

In case study 1, while the temperature profile at the wall-insulation interface was very similar for all monitored locations, the relative humidity varied visibly. This also occurred for sensors that were installed in different locations of the same wall. Three sensors located on the same wall in the living room, under the same boundary conditions and wall construction, showed different relative humidity profiles. This suggests that the thermal properties of the insulated walls being monitored are comparable, although there seems to be more variability associated to the hygric properties of the insulated walls.

The relative humidity profiles associated with the two different insulation systems installed in case study 1 were found to be slightly different, although both systems were based on capillary active wood fibre. This suggests that insulation systems with the same thermal properties can have different hygric properties, although made of the same raw material.

Regarding case study 2, the interstitial temperature at the north and south elevations showed a very similar profile in autumn and winter, suggesting a fairly constant thermal transmittance throughout the wall. However, solar radiation was found to have an influence on interstitial temperatures, as shown in a previous paper [8]. Temperature differences were found between north and south walls, particularly between temperature peaks, due to the local outdoor environmental conditions. As in case study 1, relative humidity in case study 2 exhibited more variations than temperature. However, there was a smaller difference in relative humidity across sensors located in the same wall, suggesting that the spatial variation of hygric properties of the walls in case study 2 is less than in case study 1. Also, case study 2 showed differences between walls at different orientations: the south wall was found to be consistently at lower interstitial relative humidity levels than the north wall. Although the south wall accumulated more moisture than the north wall in the wetting season, drying was more marked in the south wall. The different wetting profiles can be related to orientation and rainwater protection. Firstly, the south wall is likely to receive more wind-driven rain due to its orientation. Secondly, the walls have different rainwater goods installed. On the other hand, the difference in drying is likely to be associated with higher solar radiation intensity on the south wall, as drying was found to occur in conjunction with periods of high solar irradiation [8].

5. Conclusions

This paper analysed the conditions at the wall-insulation interface of two internally-insulated solid wall buildings, with a focus on their hygrothermal properties, construction moisture and drying. First, although the thermal behaviour across each wall is fairly homogeneous, higher variability was found to be associated to the hygric properties of the insulated walls. Construction moisture was found to lead to high relative humidity, but both case studies showed drying, although the extent of it depends on many factors, particularly the wall orientation. The analysis of these case studies suggests that capillary-active wood fibre insulation is affected both by indoor and outdoor moisture sources, aligning with simulation studies concerning other capillary-active insulation systems (e.g. [9]). Specifically, the case studies highlight the impact of wind-driven rain and solar radiation on the more porous external surfaces.

Capillary-active insulation systems are likely to interact more with the indoor environment than non-capillary active insulation due to their low vapour diffusion resistance. However, all internal insulation systems are exposed to the same outdoor moisture loads. This paper found an influence of outdoor sources in both case studies, suggesting that a moisture risk assessment for any internal wall insulation must consider the impact of the outdoor environment, justifying the need for hygrothermal simulations for exposed solid masonry walls, regardless the insulation system. The data presented in this paper could be used for calibration of hygrothermal simulations in the British Isles and similar temperate maritime climates.

6. References

[1] HM Department for Levelling Up Housing and Communities, ‘English Housing Survey. Headline report 2021-22.’, 2022. Accessed: Mar. 15, 2023. [Online]. Available: https://www.gov.uk/government/statistics/english-housing-survey-2021-to-2022-headline-report/english-housing-survey-2021-to-2022-headline-report

[2] J. Singh, *Building Mycology - Management of decay and health in buildings*. Taylor & Francis, 1994.

[3] P. Wegerer, ‘Long-term Measurement and Hygrothermal Simulation of an Interior Insulation Consisting of Reed Panels and Clay Plaster’, in *9th Nordic Symposium on Building Physics*, 2011, vol. 1, pp. 331–338.

[4] T. Odgaard, S. P. Bjarløv, and C. Rode, ‘Influence of hydrophobation and deliberate thermal bridge on hygrothermal conditions of internally insulated historic solid masonry walls with built-in wood’, *Energy Build*, 2018, doi: 10.1016/j.enbuild.2018.05.053.

[5] R. Walker and S. Pavía, ‘Thermal and moisture monitoring of an internally insulated historic brick wall’, *Build Environ*, vol. 133, no. February, pp. 178–186, 2018, doi: 10.1016/j.buildenv.2018.02.020.

[6] B. Orlik-Kozdoń and T. Steidl, ‘Impact of internal insulation on the hygrothermal performance of brick wall’, *J Build Phys*, vol. 41, no. 2, pp. 120–134, 2017, doi: 10.1177/1744259116671322.

[7] M. Šúri, T. A. Huld, E. D. Dunlop, and H. A. Ossenbrink, ‘Potential of solar electricity generation in the European Union member states and candidate countries’, *Solar Energy*, vol. 81, no. 10, pp. 1295–1305, 2007.

[8] V. Marincioni and H. Altamirano-Medina, ‘Effect of orientation on the hygrothermal behaviour of a capillary active internal wall insulation system’, in *10th Nordic Symposium on Building Physics*, 2014, pp. 1238–1243.

[9] E. Vereecken and S. Roels, ‘Capillary active interior insulation: do the advantages really offset potential disadvantages?’, *Mater Struct*, vol. 48, no. 9, pp. 3009–3021, Jul. 2014, doi: 10.1617/s11527-014-0373-9.

Acknowledgments

The authors acknowledge the financial support provided by the UK Engineering and Physical Sciences Research Council and Natural Building Technologies Ltd. for the doctoral research presented in this paper. The research was conducted by the main author within the EngD Centre in Virtual Environments, Imaging and Visualisation (EP/G037159/1). More information on the EngD thesis can be found at https://discovery.ucl.ac.uk/id/eprint/10098519/1/EngD_MarincioniV_Final.pdf