Monitoring Report on the SB&WRC Wall Prototype 2 at the Brighton WasteHouse

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Introduction

The SB&WRC project's wall prototype 2, consisting of two layers of waste duvet insulation, was installed in the downstairs office of the Brighton WasteHouse in November 2018. Monitoring of the wall was conducted from 8^{th} of November 2018 to $3^{rd}$of January 2019. Temperatures and humidities within and around the wall were monitored along with the heat flux at the interior surface of the wall. From this data U-value and condensation risk for the wall were assessed. The U-value for the wall was calculated to be 0.138W/m^{2}K, and the duvets to have a thermal conductivity of 0.069W/mK. No condensation risk was detected during this monitoring period.

Monitoring System

Within the WasteHouse downstairs office a wireless monitoring hub had already been installed as part of a previous university project. This monitoring hub accepts encrypted data from monitoring nodes on an 868Mhz frequency band using an RFM69 radio transceiver. This data is then stored by the hub and automatically emailed to the operator on a daily basis.

The hub accepts data of the form "2 h1234 t1234 c1234 v1234", where the initial integer number is the ID number of the data stream (the data ID number allocation is shown in table 1) and the letters prepending numerical values identifies the metric e.g. "h" signifies humidity.

Data ID	Data streams
4	External conditions (temperature, humidity & dew point)
5	Outer insulation (temperature, humidity & dew point)
6	Inner insulation (temperature, humidity & dew point)
7	Internal conditions (temperature, humidity & dew point)
8	Inner surface heat flux (heat flux)

Table 1: Data streams and their data IDs

The integer four digit numbers after the letter gives the data value. The nature of the data value depends on the metric: for humidity, temperature and heat flux the figure is 10x the value e.g. h0568 equals a humidity value of 56.8%; voltage it is 1000x the value e.g. 3300 equals 3.3V; CO2 it is a simple integer representation of the value e.g. 0858 equals 858ppm of CO_2.

As both condensation risk, which necessitated monitoring within the wall, and U-value measurements were required, it was decided to build a probe that could be built into the wall and monitor internal and external temperatures and humidities.

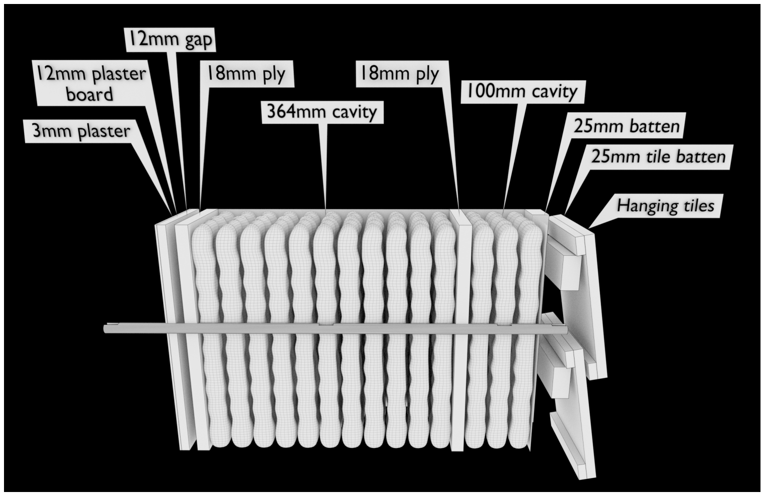
The probe consists of a 650mm length of 15mm diameter polyethylene pipe containing four SHT75 temperature and humidity sensors: one positioned in the room air; one positioned at the mid-point of the inner insulation layer comprising of folded polyester duvets with a density of 21.4 kg/m^3; one in the middle of the outer insulation layer also comprising of folded polyester duvets with a density of 11.3kg/m3; one in ambient air.

A schematic of the wall and the probe itself are shown in figure 1.

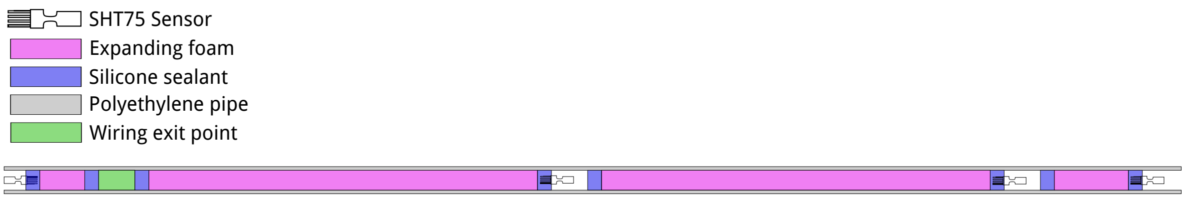
The SHT75 sensors are held in place with silicon sealant and the cavities within the tube filled with expanding foam to minimise air and heat transfer along the tube. The probe was built into the wall as the wall layers were constructed figure 2a. This was done on the 6^{th} November 2018. The junction points between the probe and the hard construction layers were also sealed to prevent vapour transfer via this route.

For the heat flux measurement a recently calibrated Hukseflux HP01 heat flux sensor has been used. The calibration certificate for the sensor states 61.18μV output voltage per W/m^2. This was positioned in-line and above the probe insertion point. The heat flux meter is attached to the wall and covered in masking tape to maintain a consistent emissivity with the rest of the wall (figure 2b).

As the heat flux mat produces voltage differentials in the μV range an analogue to digital converter is required to resolve these small differentials. An ADS1115 16-bit converter has been used here. The ADS1115 is programmed to use its lowest internal reference voltage of 0.256V. With 15bits of resolution (1 bit is used to sign the integer value) the ADS1115 can resolve down to 0.256/2^{15} or 7.8125μV. As the heat flux meter has been calibrated at 61.18μV

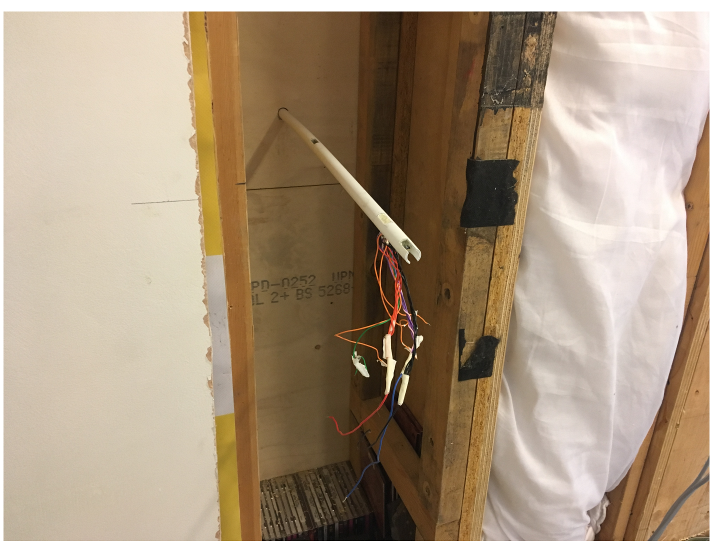


(a) Wall section

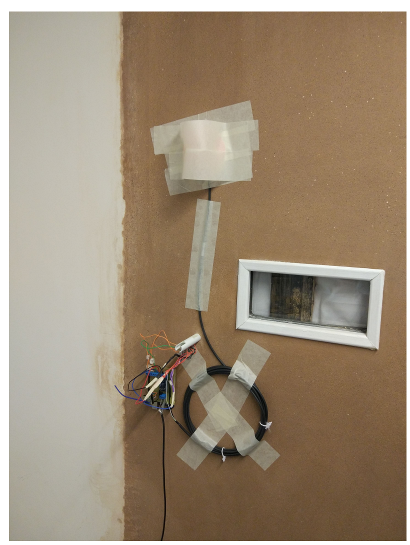


(b) Probe section

Figure 1: Wall and probe sections



(a) Probe installation



(b) Final installation

Figure 2: Probe installation and final equipment installation

per W/m^2 this delivers a heat flux resolution of 0.128W/m^2, or a U-value resolution of 0.0128W/m$^2 \cdot K$ at a 10°C temperature difference.

The SHT75 sensors require a 3.3V power supply and both the SHT75 and the HP01 sensors require a platform to interpret the sensor values and to send them to the monitoring hub. For this an Arduino Uno has been used as it has native support for the I^{2}C protocol used by both the SHT75 sensors and ADS1115 converter and libraries are available to allow the Uno to interface with an RFM69 transceiver chip. In addition the Arduino supplies voltage (3.3V) and ground connections to the sensors. A custom circuit board was designed that interfaces the Uno's pin configuration with the ADS1115 and RFM69 chips. The schematic of the custom shield is shown in figure 3

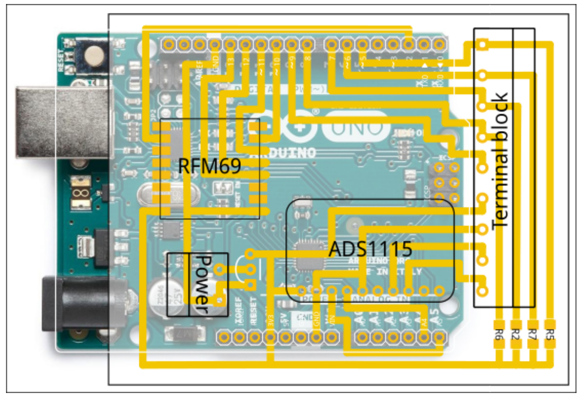


Figure 3: Custom Arduino Uno Shield

The monitoring system was connected up and started on the 8th November. Sensor readings since are taken approximately every 60 seconds and broadcast to the monitoring hub. Results are later hour averaged. The code, with annotation, that runs on the Uno to collect, process and send data to the monitoring hub is given in Appendix 2.

Results

U-value

Although the monitoring system was started on the 8th November and run continuously until the end of the calendar year, the general lack of heating (there is no dedicated heating system within the room) and occupancy in the space made a consistent and reliable U-value figure difficult to attain. Figure 4 shows the U-value over the entire monitoring period.

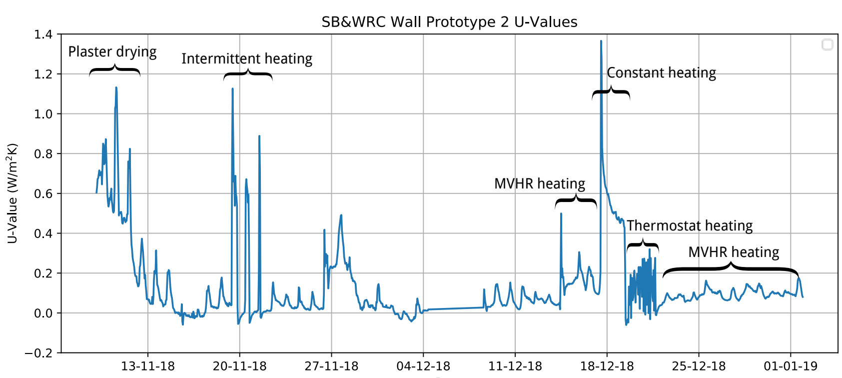


Figure 4: Prototype 2 U-values (entire monitoring period)

Initially, the wall plaster was still drying, causing the wall surface to absorb heat and inflate initial U-values. For the first 10 days the room temperature was allowed to free-float, i.e. no discrete heating was applied to the room, although occupancy was relatively high during the first few days. On the 19th, 20th and 21st of November a fan heater was installed in the room and the room heated constantly during working hours. Temperatures again free floated until the heating systems were turned on in the bathroom and upstairs room. As air to downstairs is supplied with an MVHR system, the heating in these other rooms was delivered to the downstairs office via the ventilation system. A dedicated convection heater was placed in the room and the room heated constantly from the 17th of December. This resulted in high room temperatures and resulted in a slow attainment of a thermal steady state within the room and wall constructions. The heating was therefore turned down on the 19^{th} of December and the room heated to a thermostatically controlled temperature for three days. Over the Christmas period the room reverted to heating by MVHR air supply.

The temperatures within and around the wall prototype for the entire monitoring period is shown in figure 5.

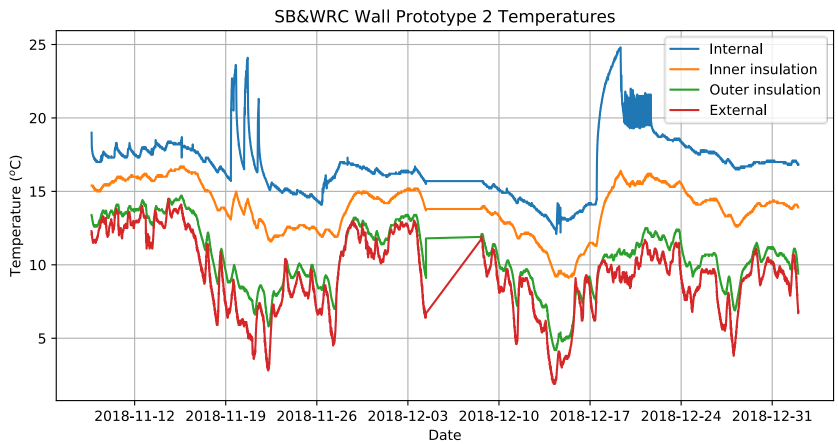


Figure 5: Wall temperatures (entire monitoring period)

The only period where the internal room temperature was consistent, was the thermostat controlled heating period between the 19^{th} and 21^{st} of December. It is this period that has been used to generate the wall U-value., the results for which are shown in figure 6.

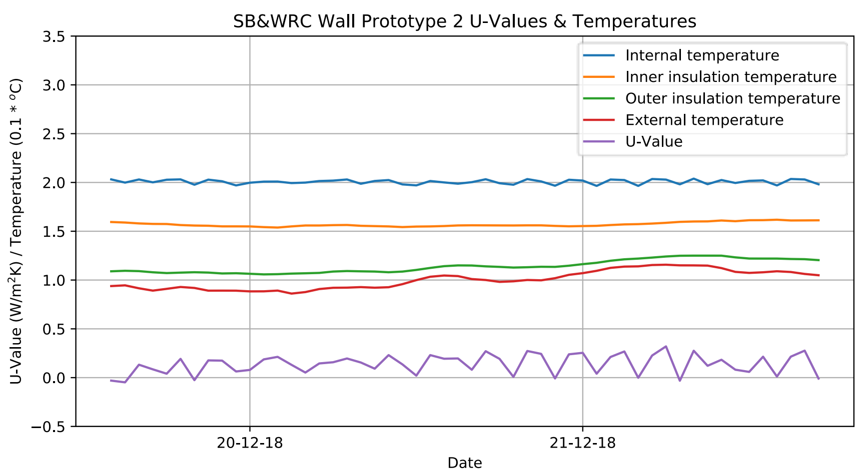


Figure 6: U-values and wall temperatures (calculation period)

Due to the intermittency of the thermostatically controlled heating, U-value still varies but this is to expected, and a U-value can be generated by averaging over the period. Although 72 hours is recommended in ISO 9869-1:2014 for the averaging in in-situ U-values compared to the 52 hours here, the strong heating of the room before this sampling period, and the subsequent consistency of the inner insulation temperature, coupled with the similarity between beginning and end of period external temperature would indicate that this period generates a valid U-value result as the overall heat content of the wall is does not change significantly. This average results in a final U-value of $0.138\text{W/m}^2\text{K}$. To put this in context, in cool/temperate climates the PassiveHaus standard for external walls is $0.15\text{W/m}^2 K$and the U-value of the Prototype 2 is a slight improvement on this and therefore represents what could be considered a good U-value.

By rearranging the standard U-value equation and solving for duvet thermal conductivity, by assuming standard values for the other wall layers, a value of 0.069W/mK is attained. To put this in context many conventional insulation materials have a thermal conductivity of 0.04W/mK, and the duvets therefore overall achieve a conductivity 72.5% higher than this conventional value. Although the thermal conductivity is relatively high it is the high overall thickness of the insulation layers that result in the overall good U-value figure. Reasons for the higher thermal conductivity could include air circulation within and around the duvet layers and the relatively low density of the duvet installation compared to conventional insulation materials.

All the temperature and heat flux data generated for the SB&WRC project is available for download from https://drive.google.com/drive/folders/1LVwFBVkMf5Fm5qgADbbomWf2vQEoOLIz. An explanation of the data format of the monitoring files is given in Appendix 1.

Condensation risk

Relative humidities for the whole monitoring period are shown in figure 7.

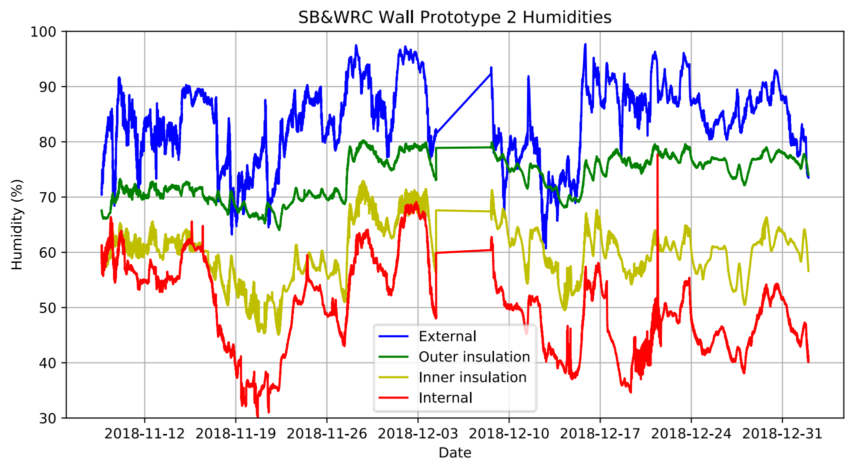


Figure 7: Humidity readings (entire monitoring period)

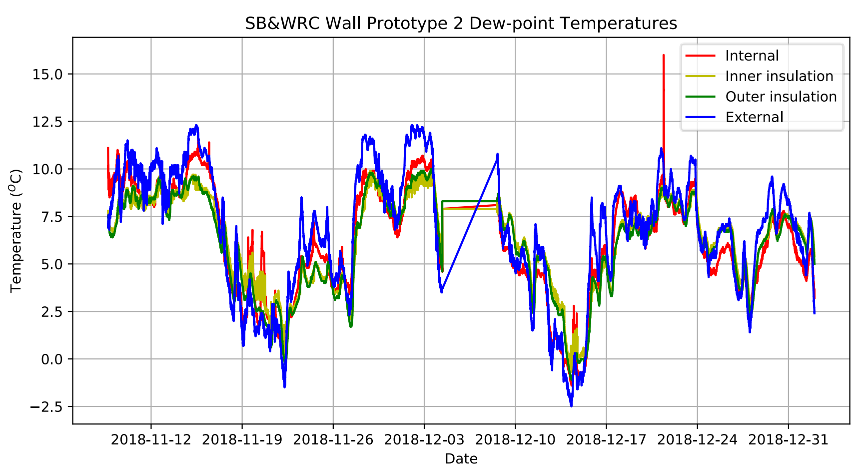
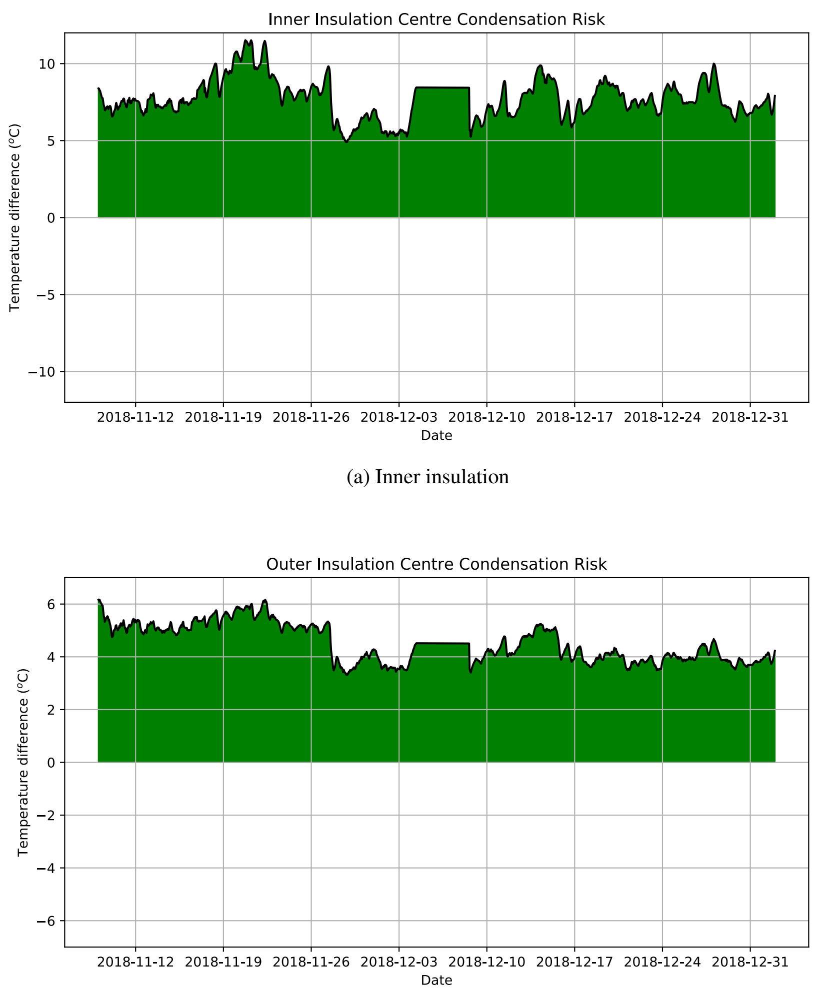


Figure 8: Dew-point readings (entire monitoring period)

Relative humidities are generally higher towards the outside of the building, which is to be expected in the UK climate in Winter. Relative humidities within the wall, although different from the internal and external environments, do follow the trends of the internal and external environments. This suggests that water vapour is relatively free to move from either the outside or the inside of the building into both insulated sections of the wall. This is confirmed by looking at the dew-point temperatures within and around the prototype wall (figure 8).

Dew-point temperatures with the two insulated layers not only vary significantly over time (if the moisture content within the layers were constant dew-point should be constant), but they also follow the dew-points of the internal and external environments quite closely. Water vapour does appear therefore to be able to move quite freely into both the insulated layers from either the internal or external environment. Raising the humidity within the room for a significant period of time could determine which.

A basic assessment of whether condensation is likely to form at the centre point of the insulation layers (where the sensors are placed) can be made by comparing the temperature and dew-point temperatures. If the temperature is greater that the dew-point temperature condensation is unlikely to form and vice versa. Graphs in figure 9 are filled green where the temperature difference is positive, and red where negative. The temperature difference at the centre of each layer is positive at all times, indicating that there has been no condensation risk up to these points.

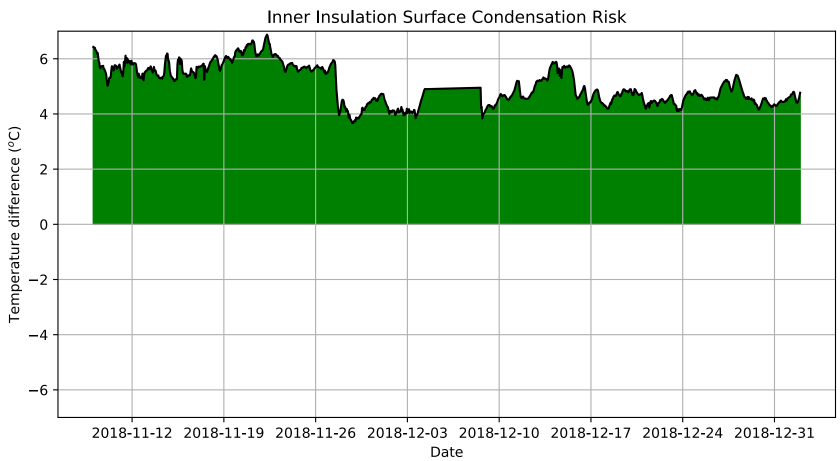


(a) Inner insulation

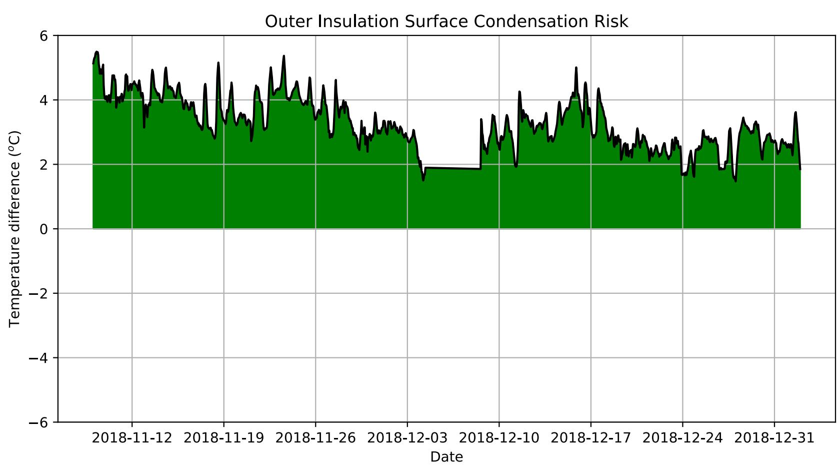
(b) Outer insulation

Figure 9: Centre of insulation condensation risk

As the duvets are permeable to moisture vapour, and the dew-point temperatures at all sensor points is similar, it is reasonable to assume that the moisture content at any point within each layer is similar. The worst case scenario for condensation risk is therefore at the coldest point, or exterior surface, of each layer. To asses this worse case scenario condensation risk the temperature at the external surface must be known. If the thermal conductivity of each of the insulated layers is similar then the temperature gradient between the mid-points of the inner and outer insulation will be linear. By taking into the account the thicknesses to the two insulation layers the temperature at the boundary point between the two layers can be estimated. If the temperature of this point is below the dew-point temperature of the inner insulation layer then condensation may form at this exterior surface point. For the outer insulation layer the outside surface can be considered to be at or near the external temperature and therefore if this external temperature is below the dew-point temperature of the outer insulation condensation may again form at this outer surface. The results of these two analyses are shown in figure 10.



(a) Inner insulation condensation risk



(b) Outer insulation condensation risk

Figure 10: Exterior surface of insulation condensation risk

Again, there appears to be no risk of condensation at these exterior surfaces. As the water vapour content within the insulation layers is equalising with the external/internal environments, and the insulation layers are always warmer than the external environment, this is as expected. This relatively free movement of water vapour between the insulation layers and the external/internal environments could however indicate enough air movement between the layers to increase the thermal conductivity of the insulation layers to the relatively high value calculated in the U-value section.

Conclusions

The dew-point temperature data suggests that the two insulation cavities are both able to exchange water vapour with either the external/internal environment. If this exchange is occurring with the external environment it may indicate enough air exchange with the outside to increase the effective thermal conductivity of the duvet layers and partly account for the relatively high thermal conductivity measured. Other potential reasons are the relatively low density of the of the duvet installation compared to conventional insulation materials, and the possibility of air circulation within the cavities. This exchange of water vapour has however ensured that there is no detectable condensation risk within the wall.

Despite the relatively high thermal conductivity the thickness of the wall, comprising a total of 464mm of insulation, has ensured a good U-value of 0.138W/m^{2}K, a figure better than would be required by, for example, by the PassivHaus standard.