Monitoring report on the SB&WRC wall prototype at the Brighton WasteHouse

10th December 2018

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 4 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.

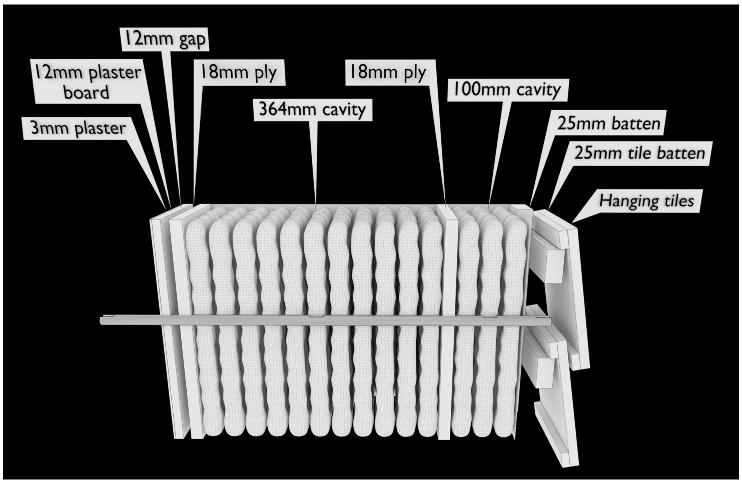
A schematic of the wall and the probe itself are shown in figure 1.

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.

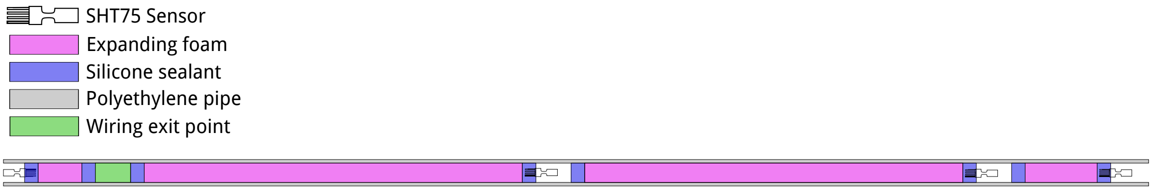
The Sensirion SHT75 sensors communicate via the I^2C protocol and each therefore requires a data (SDA) and clock (SCL) connection to the Arduino. In addition the Arduino, via the custom shield, supplies voltage (3.3V) and ground connections to the sensors.

For the heat flux measurement a recently calibrated ($61.18\mu V$ per W/m$^2 \cdot K$) Hukseflux HP01 heat flux sensor has been used. 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 also uses the I^2C

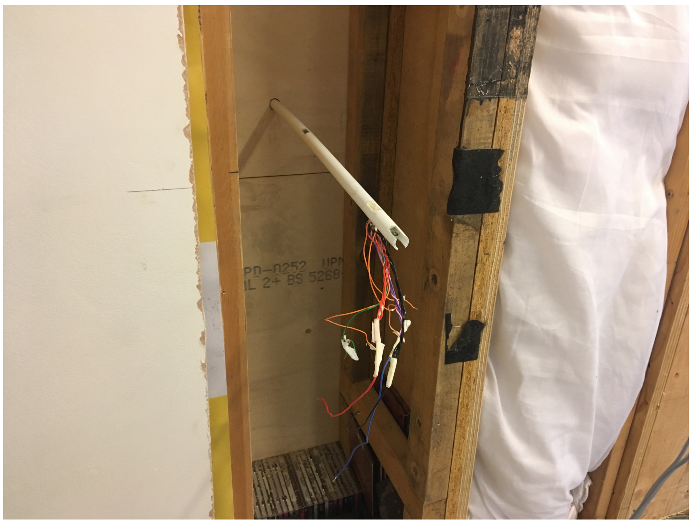


(a) Wall section

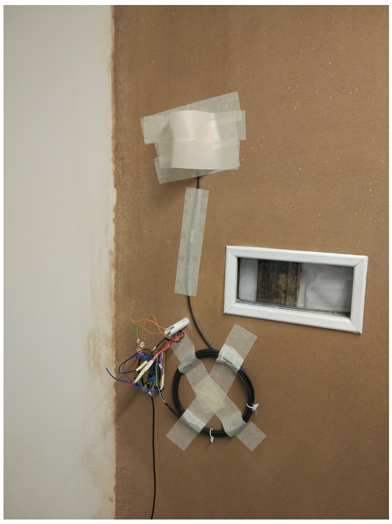


(b) Probe section

Figure 1: Wall and probe sections



(a) Probe installation



(b) Final installation

Figure 2: Probe installation and final equipment installation

protocol and shares the clock pin with the SHT75 sensors. The ADS1115 is placed in differential voltage mode to reduce noise and the ground and VDD connections from the heat flux mat are connected to analogue inputs 1 & 2. 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 $7.8125\mu V$. As the heat flux meter has been calibrated at $61.18\mu V$ per W/m^{2}K this delivers a heat flux resolution of 0.128W/m$^2\cdot$K.

The custom Arduino shield also supplies the ADS1115 and RFM69 chips with 3.3V power and ground connections. The schematic of the custom shield is shown in figure 3

The monitoring system was connected up and started on the 8^{th} 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, running on the Arduino is given in Appendix 1.

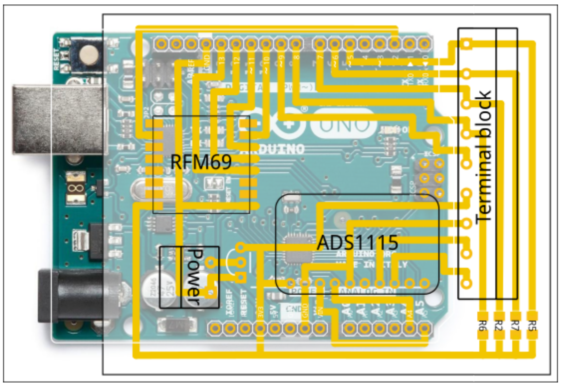


Figure 3: Custom Arduino Uno Shield

Results

U-Value

The monitoring system was started on the 8^{th} November but as the inner plaster skim on the wall was initially still damp, data from the first few days should probably be superseded by later data when it becomes available.

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 19^{th}, 20^{th} and 21^{st} of November a fan heater was installed in the room and the room heated during working hours. The hourly temperatures within and around the wall construction are shown in figure 4.

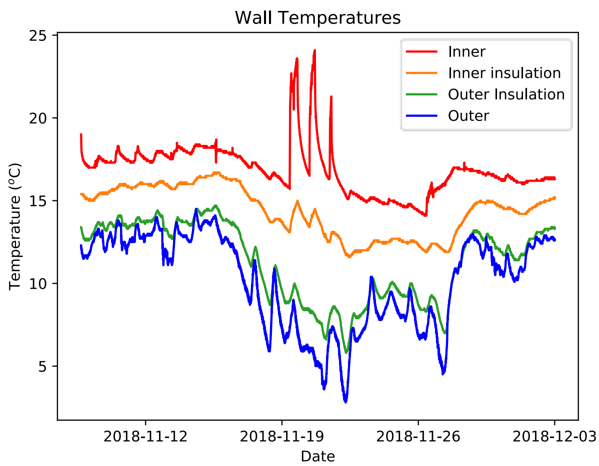


Figure 4: Wall temperatures

The three days where heating was applied to the room can be clearly seen in the middle of the data period. With the fan heater used, heating purely during working hours did not manage to achieve a steady state internal temperature as the internal temperature was still rising at the end of the working day albeit more slowly. This was also the case with the inner insulation layer where temperatures were still rising strongly by the end of the day, and the outer insulation layer where temperature increases had not begun to tail off by days end. In order for the room and wall layers heating for a longer period will be required.

When heating is not applied the internal temperature free floats between 14 and 18°C.

The wall U-value for the complete period is shown in figure 5. The effect of the drying plaster at the beginning of the period can be clearly seen as the evaporation of water lowers the internal wall temperature and increases the heat flow measured from the room to the wall, increasing the calculated U-value. The effect of the heating period in the

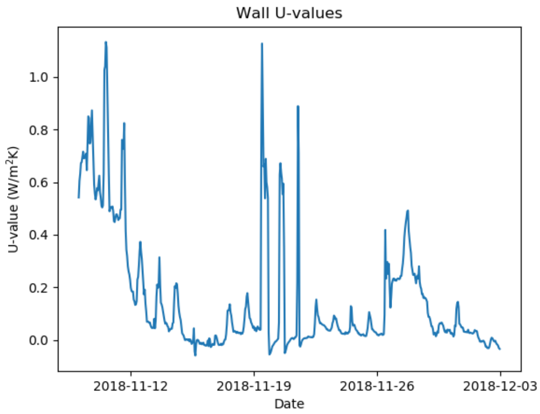


Figure 5: Wall U-values

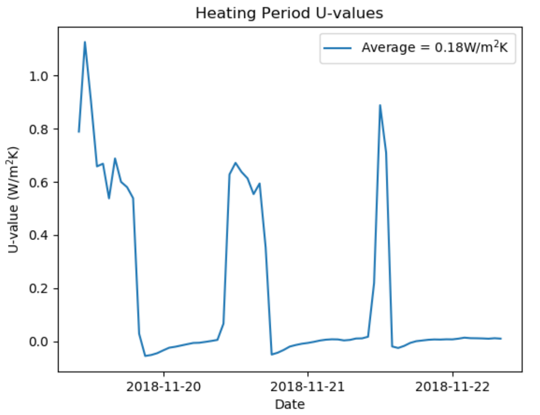


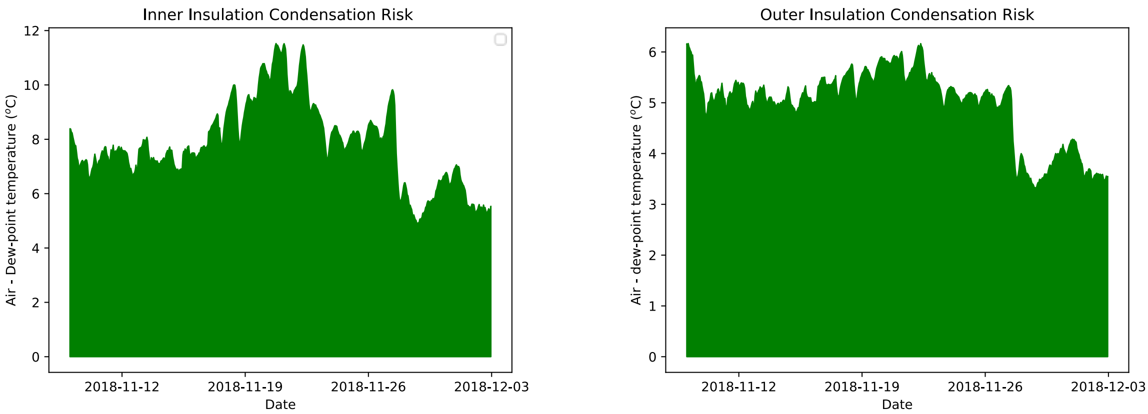
Figure 6: Heating period U-values

middle of the period can also be seen with the resulting very high U-values. As the U-value does not decrease until the heating is turned off, this again indicates that the wall construction had not completely heated up by the time the heating was turned off. At other times the calculated U-value is usually very low, as there is no heat input into the system. Between the $27^{th}$and $30^{th}$of November U-values are more indicative of a realistic value but this corresponds to a period of rising internal temperature due to a strongly rising external temperature.

Although a U-value can be gained by averaging in-situ values over at least a 72 hour period (ISO 9869-1:2014) the very low heating applied to the space, and the very transient nature of the heating that could so far be applied, makes it difficult to derive a definitive U-value with any confidence so far. An indicative value may be construed by averaging the U-value over the period of the three days where heating was applied (figure 6). This delivers a U-value of 0.18W/m^{2}K (corresponding to a thermal conductivity for the duvets of 0.1W/mK across both the insulation layers). This value is probably high, as some heat would have moved laterally within the wall construction to colder parts of the building mass, but maybe provides an upper limit for the ultimate value. The two duvet layers were also installed with very different densities, with the inner denser layer probably having a lower thermal conductivity than the less dense outer layer.

Condensation risk

The difference between the air and dew-point temperatures at the centre of each of the insulation layers is shown in figure 7 for the entire current data set. While the temperature difference is positive condensation will not form at this



(a) Inner insulation

(b) Outer insulation

Figure 7: Insulation condensation risk

point. Graphs in figure 7 are filled green where the temperature difference is positive, and red where negative. The temperature difference is positive in both layers at all times indicating that there has been no condensation risk up to this point.

Additional Notes

On the morning of the 20^{th} of November 2018 the analogue ground of the heat flux mat was connected to ground on the custom shield. This may impact on the heat flux results, especially at low heat fluxes, and should be checked.

On the 19^{th}, 20^{th} and 21^{st} of November 2018 discrete heating was applied to the room during working hours.