SB&WRC Project

Facility Presentation Sheet:

Brighton Waste House Pilot Site

April 2019

1. Presentation of the facility

Figure 1: The Waste House (pilot site for prototype 2) in Brighton.

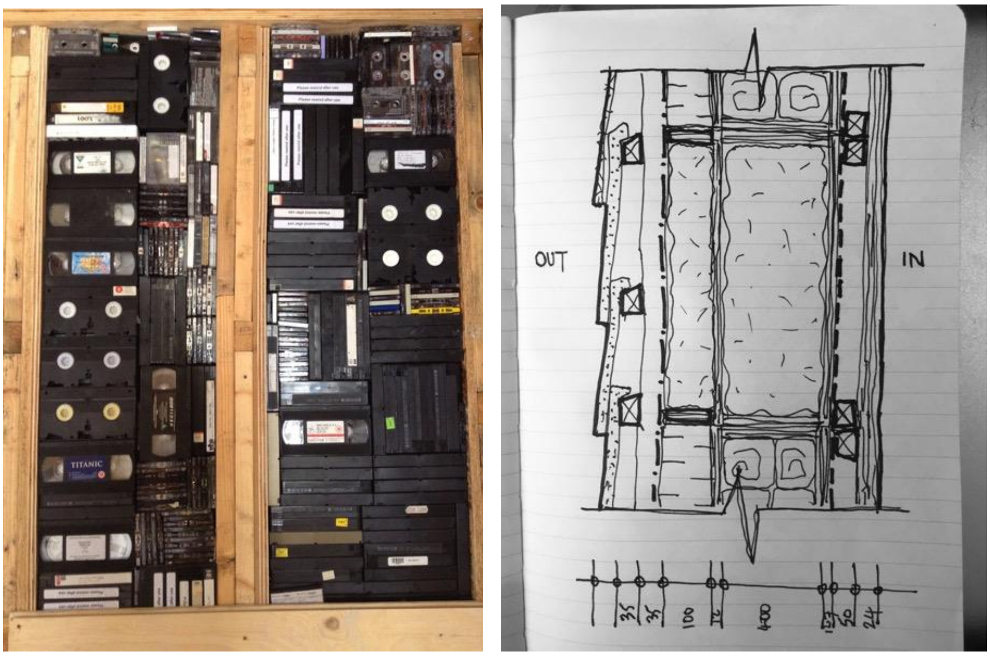

Figure 2: Left: Typical wall section before it was emptied, Right: Typical Waste House wall section drawn in section occupied by Prototype 2 at the Brighton Waste House

1.1 Description of the facility

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 Waste House in November 2018. Monitoring of the wall was conducted from 8th of November 2018 to 3rd 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 $0.138W.m^{-2}.K^{-1}$, and the duvets to have a thermal conductivity of $0.069W.m^{-1}K^{-1}$. No condensation risk was detected during this monitoring period.

1.2 Monitoring System

Within the Waste House 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 below) and the letters prepending numerical values identifies the metric e.g. "h" signifies humidity.

Table 1: Data streams and respective ID

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)

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; CO_2 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 $11.3kg.m^{-3}$; one in ambient air. The average density of the duvet material across both layers is $19.2kg.m^{-3}$.

The specific heat capacity (SHC) of the two insulated layers was calculated by taking a standard values for the density of polyester and air of 1390 $kg.m^{-3}$ and $1kg.m^{-3}$ respectively. The proportion of polyester in the cavities by volume is derived by the insulation density divided by the polyester material density; with the rest of the cavity being air. This gives a proportion by volume of polyester of 1.5% and 0.8% for the inner and out cavity respectively. The proportion of the polyester in each cavity by mass is given by the mass of polyester divided by the total mass, which comes to 95.6% for the inner cavity and 91.9% for the outer. Taking standard values for the SHC of polyester and air of 1300J.kg^{-1}.K^{-1} and 1000J.kg^{-1}.K^{-1} respectively, this gives an inner layer SHC of 1287J.kg^{-1}.K^{-1} and the outer of 1276J.kg^{-1}.K^{-1} with an average across the two layers of 1285J.kg^{-1}.K^{-1}.

A schematic of the wall and the probe itself are shown in Figure 3 below.

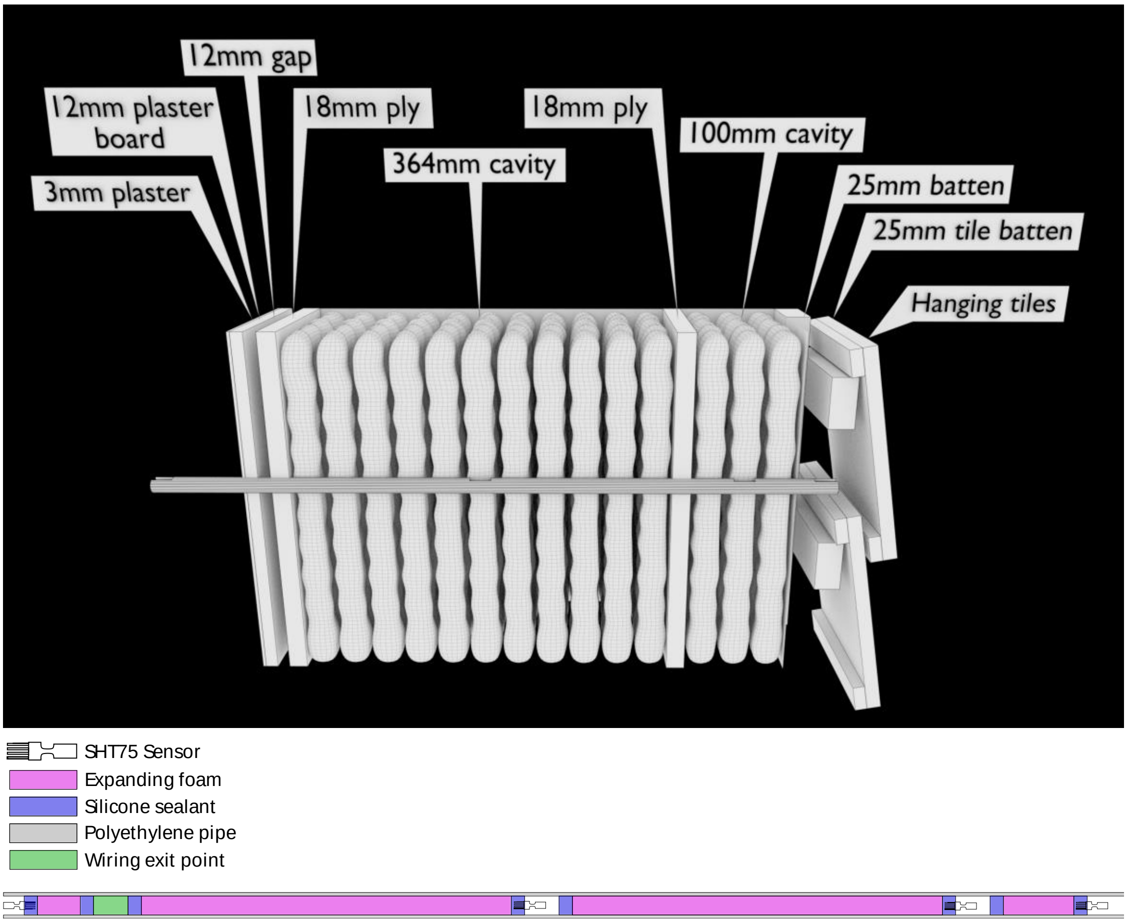

Figure 3: Wall and probe sections

2. Prototype 2 performance measurement

2.1 Measurement procedure

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, as shown in Figure 4. This was done on the 6th of November 2018. The junction points between the probe and the hard construction layers were also sealed to minimise vapour transfer via this route.

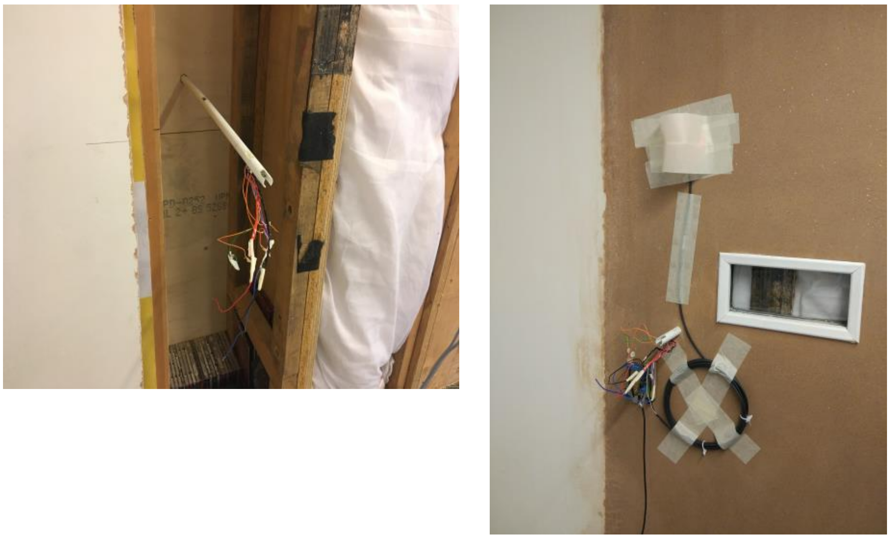

Figure 4: Probe installation and final equipment installation

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.

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}V or 7.8125μV. As the heat flux meter has been calibrated at 61.18μV 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}.K^{-1} at a 10°C temperature difference.

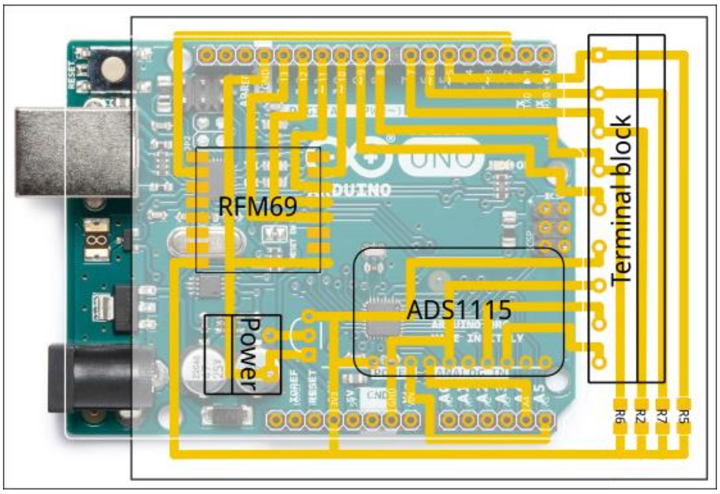

Figure 5: custom Arduino module

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 5.

2.2 Measurement calendar for Prototype 2

The monitoring system was connected up and started on the 8th of November. Sensor readings since were taken approximately every 60 seconds and broadcasted to the monitoring hub. Results are later hour averaged.

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 6 shows the U-value over the entire monitoring period.

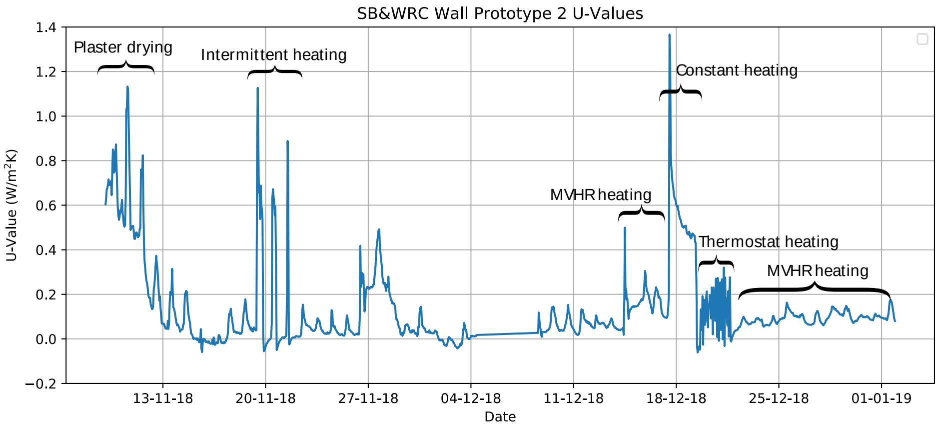

Figure 6 : Prototype 2 U-values (entire monitoring period)

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. After this 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 by proxy via the ventilation system. On the 17th of December a dedicated convection heater was placed in the room and the room heated constantly. 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 19th 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 are shown in Figure 7.

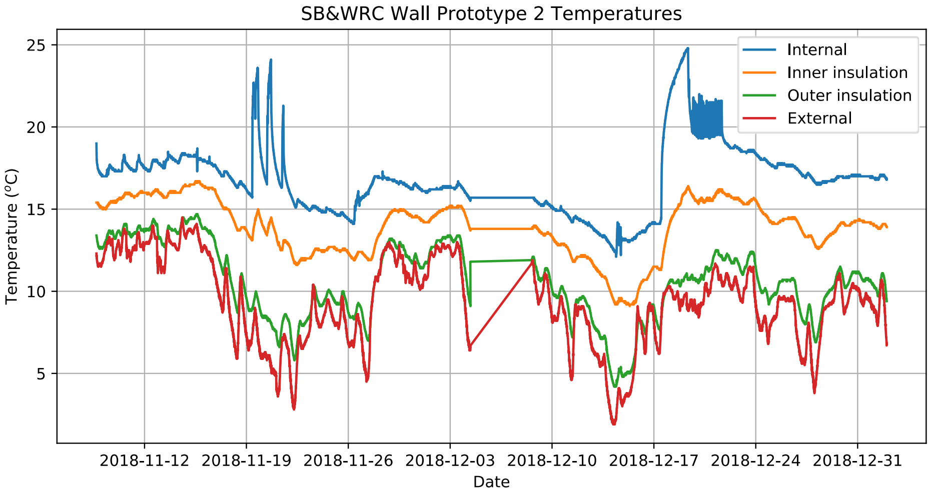

Figure 7: Wall temperatures (entire monitoring period)

The only period where the internal room temperature was controlled and relatively stable was the thermostat controlled heating period between the 19th and 21st of December. It is therefore this period that has been used to generate the wall U-value, the results for which are shown in Figure 8.

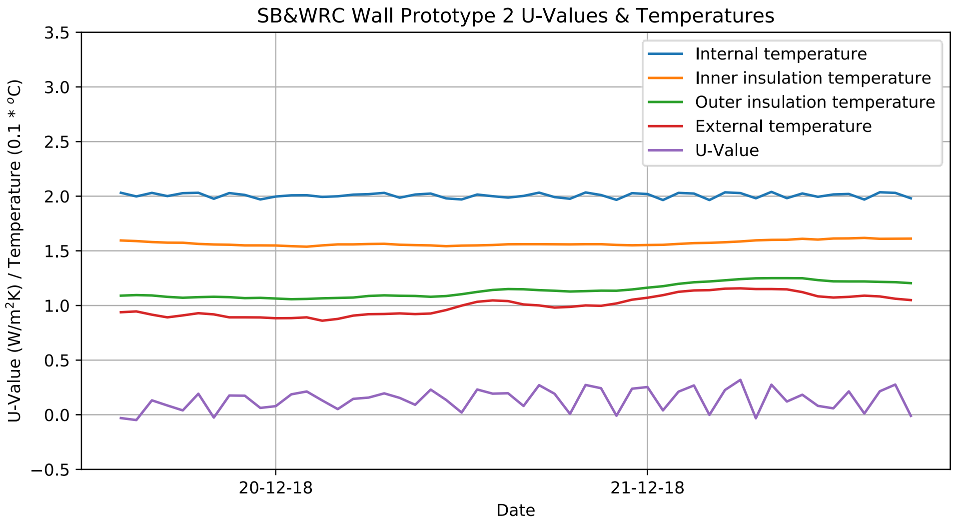

Figure 8: U-values and wall temperatures (calculation period)

Due to the intermittency of the thermostatically controlled heating, heat flux at the interior surface, and hence resultant U-value, still varies. This is however to be 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 $0.138 W.m^{-2}K^{-1}$.

To put this in context, in cool/temperate climates the PassiveHaus standard for external walls is 0.15 $W.m^{-2}K^{-1}$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 0.069$W.m^{-1}K^{-1}$ is attained. To put this in context many conventional insulation materials have a thermal conductivity of 0.04$W.m^{-1}K^{-1}$, and the duvets therefore overall achieve a conductivity 72.5% higher than this conventional value. Although the thermal conductivity is relatively high, the generous thickness of the insulation layers deliver 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.

A raw U-Value for the duvet material itself can be derived by dividing a chosen duvet thickness by the thermal conductivity. For 100mm of material this would result in a raw U-Value of 0.69$W.m^{-2}K^{-1}$, and at 150mm 0.46$W.m^{-2}K^{-1}$.

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.

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