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Technical Conservation Group

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In situ U-value measurements in traditional buildings – preliminary results

Prepared for Historic Scotland

GLASGOW CALEDONIAN UNIVERSITY

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Prepared for Historic Scotland by

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1 Introduction

This report summarises the results of *in situ* U-value measurements of walls carried out by the Centre for Research on Indoor Climate & Health, Glasgow Caledonian University (GCU) for Historic Scotland between November 2007 and April 2008 in a sample of buildings representing traditional masonry construction in Scotland. Measurements were made of the heat flow directly through each wall using heat flux sensors mounted on internal surfaces and room and outdoor temperatures.

The main objective of the study was to assess the actual thermal performance of traditional building envelopes, in order to provide guidance for energy performance assessments and implementing energy efficiency measures in such buildings.

2 Monitoring procedure

Campbell Scientific CR1000 data loggers [1] equipped with heat flux and temperature sensors were used. Hukseflux HFP01 [2] heat flux sensors were used to measure heat flows through selected walls (Figure 1). The sensors are 80mm in diameter and 5mm thick. The sensors were mounted by firstly applying a layer of double sided adhesive tape to the back of the sensor. Secondly, low tack masking tape was applied to the wall. Finally, the heat flux sensor was applied firmly to the masked area. This arrangement was generally satisfactory for two or more weeks monitoring on painted surfaces only. Wallpapered surfaces were not generally used in case of damage. Sensor locations were chosen to avoid probable thermal bridge locations near to windows, corners, etc., with the sensor ideally located about half-way between window and corner, and floor and ceiling (Figure 2).

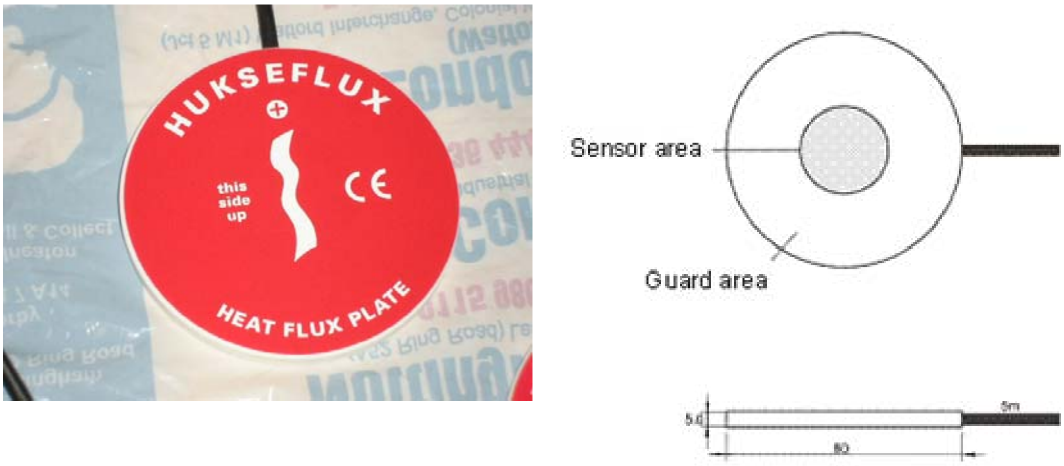


Figure 1: Heat flux sensor

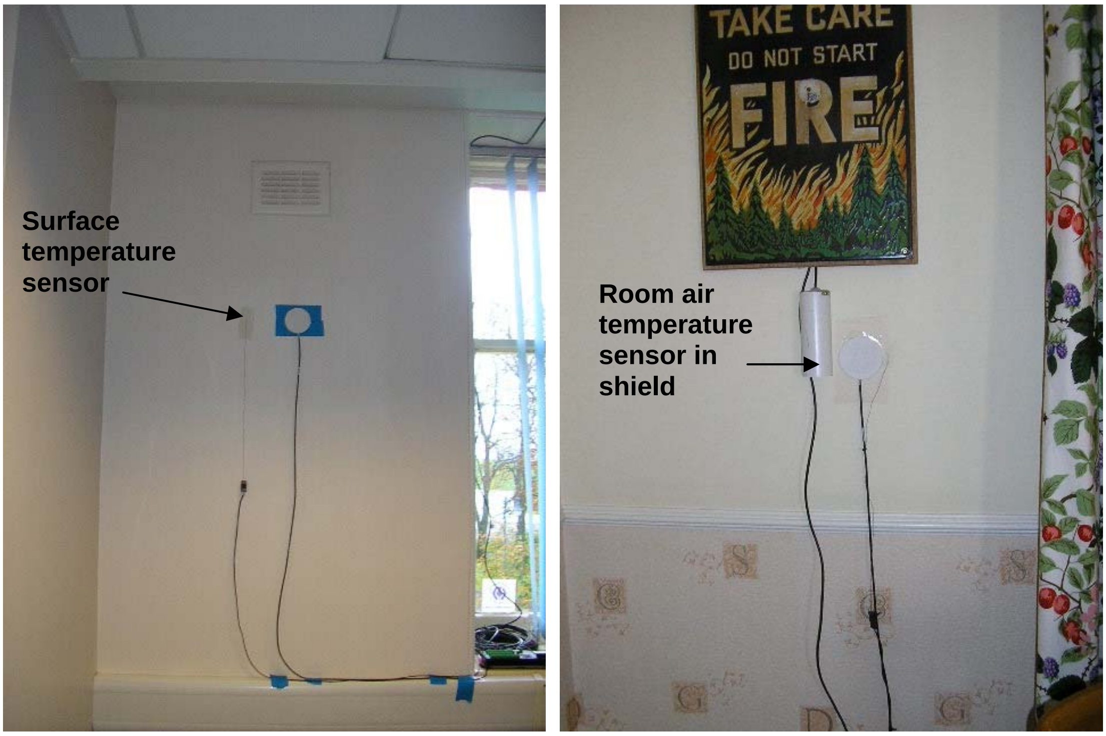


Figure 2: Typical heat flux sensor and room temperature measurement locations

Stainless steel-sheathed thermistors, Campbell Scientific type 107, were used internally and externally to measure temperature [3]. Internal sensors were mounted in a simple shield to minimise the influence of solar radiation, heat sources, etc. (Figure 2). Each external temperature sensor was placed in a radiation shield mounted onto the exterior wall surface using a bracket (Figure 3).

Figure 3: Mounting of shielded external temperature sensor

Internal (Figure 2) and external surface temperatures were also measured using type-T thermocouples. Figure 3 shows the method of mounting external surface temperature sensors.

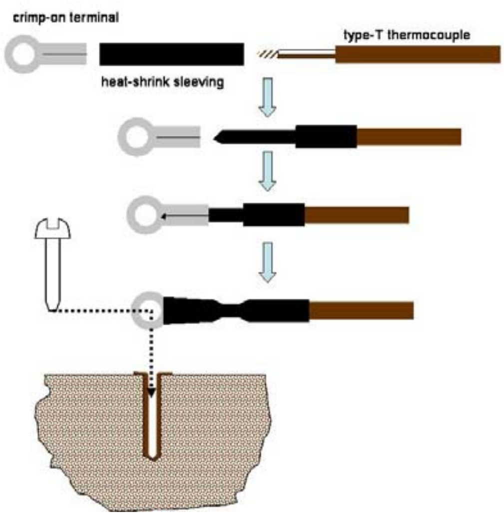


Figure 4: External surface temperature sensor

Sensors were logged at 5 second intervals and averaged over 10 minutes.

3 Data Analysis

Given that the monitoring conditions are non-steady state, it is considered necessary to monitor for about two weeks or, preferably longer, in order to collect sufficient data to estimate *in situ* U-values. For example, the U-value may be estimated by a simple averaging procedure as follows

$$U_t = \frac{\sum_{0}^{i=t} Q_i}{\sum_{0}^{i=t} Ti_i - \sum_{0}^{i=t} Te_i} \quad \text{W/m}^2\text{K} \qquad \text{Eqn. 1}$$

where U_t is the average U-value after t hours, Q_i, Ti_i and Te_i are, respectively the heat flux, room temperature and external temperature collected at intervals of i hours. Figure 5 shows the effect of increasing the length of the monitoring period on the estimate of the U-value. A period of at least a week is required before the U-value estimate stabilises to within ±5% of the final value determined from about 27 days data. The drawback of the averaging method is that, for short monitoring periods at least, the thermal capacity of the wall is not taken into account.

An alternative to Equation 1 is to use the surface temperature difference across the wall (ΔTs) to determine its thermal resistance and add the standard internal and external surface resistances, respectively r_{int} = 0.13m^2K/W and r_{ext}=0.04 m^2K/W, as follows.

$$U_t = \frac{1}{\frac{\sum_{0}^{i=t} \Delta Ts_i}{\sum_{0}^{i=t} Q_i} + r_{int} + r_{ext}} \quad \text{W/m}^2\text{K} \qquad \text{Eqn. 2}$$

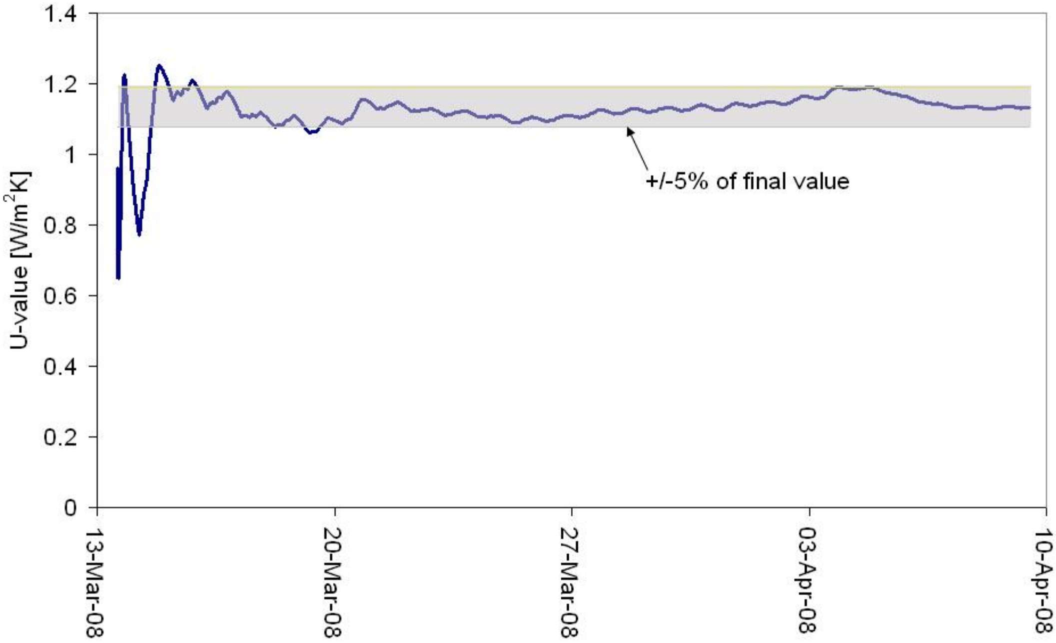


Figure 5: The effect of increasing the monitoring period

A small correction is applied for the thermal resistance of the heat flux sensor ($<6.25\times10^{3}$ m^2K/W). The uncertainty of the U-values estimates is about ±10%.

4 The buildings

Figure 6: Victorian Villa, Cathcart, Glasgow

N-W facing bedroom
Blonde sandstone
Wall thickness: 600mm
External face: rubble
Internal face: lath and plaster

Figure 7: Crichton Campus, Dumfries

Early 20th Century
Six measurement locations
Locharbriggs sandstone
Wall thickness: 600mm
External face: Ashlar
Internal face: lath and plaster
Vented walls!

Lauriston Place, Edinburgh

19th Century tenement
Stone - Craigleith

Five measurement locations with various wall finishes and thicknesses.
Additional test on basement floor

Figure 8: Lauriston Place
Front elevation (S), ground floor.

Wall thickness: 600mm
External face: Ashlar
Internal face: lath and plaster

Figure 9: Lauriston Place
Rear elevation (N), basement

Wall thickness: 600mm
External face: cement
Internal face: plasterboard

Castle Fraser
Kemnay Granite
Four measurement locations

Figure 10: Castle Fraser
Stables (N)
Wall thickness: ?
External face: rubble
Internal face: plasterboard

Figure 11: Castle Fraser
Stables/Turret (N)
Wall thickness: 350mm
External face: rubble
Internal face: hard

Figure 12: Castle Fraser
Gardeners' Bothy (N)
Wall thickness: ?
External face: rubble
Internal face: lath and plaster

Figure 13: Castle Fraser
Apartments (E)
Wall thickness: 600mm
External face: harling
Internal face: lath and plaster

Figure 14: Weens Cottage, Borders
Red sandstone & brick
Four measurement locations
Wall thickness: 400mm
External face: rubble (x3) and cement (x1)
Internal face: hard plastered

5 Additional tests

Laboratory measurements on a Locharbriggs sandstone wall

In situ U-value measurements were made on a Locharbriggs sandstone wall constructed within an environmental chamber at Glasgow Caledonian University. The wall thickness is 550mm and has an Ashlar exterior and a rubble interior face (Figure 15). A heat flux sensor was mounted in the centre of the interior face.

Figure 15: Locharbriggs sandstone wall in test chamber. Left: internal rubble face; right: Ashlar external face.

Temperatures of 23°C on the warm side and 8°C on the cold side of the wall were maintained. The U-value was determined from 10 days data, which are sufficient under steady conditions.

Following the test on the solid wall, timber studs were fixed to the sides of the wall and a sheet of plasterboard added. The cavity formed was sealed off. A second heat flux sensor was mounted on the plasterboard. The U-value of the wall was re-measured with the plasterboard finish.

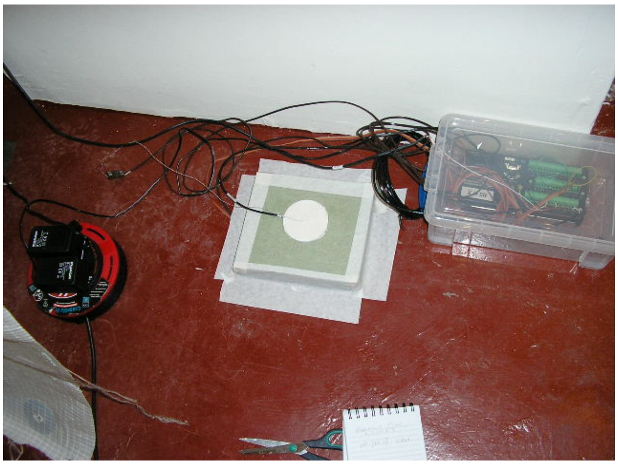
***In situ* measurements of basement floor at Lauriston Place, Edinburgh**

In situ U-value measurements of the concrete floor in the unoccupied basement at Lauriston Place, Edinburgh were carried out before and after the introduction of a sample of a composite insulation material consisting of 21mm Spacetherm [4] backed with 9mm particleboard (Figure 16). The composite had been used to up-grade occupied basement flats at Lauriston Place as part of a Changeworks project [5]. During a previous refurbishment in the 1970's, the basement flats had their original solid ground floors replaced with concrete laid on aggregate.

Prior to testing, a 100mm diameter core was cut from the floor, a thermocouple placed at the base of the hole thus formed, and the core replaced and sealed into the hole. The concrete core depth was approximately 150mm. The cement had been laid over a dpc covering aggregate.

Figure 16: Lauriston Place basement floor – testing of insulation on concrete floor

The U-value of the 150mm floor was measured before and after applying a sample of novel Spacetherm insulation.



6 Results and discussion

The wall descriptions and results are given in Table 1. The results are also summarised by internal wall finish (i.e. plastered on the hard, lath and plaster, plasterboard) in Figure 17 and masonry type in Figure 18. All wall finished with plasterboard have an air cavity behind the plasterboard.

Given the small sample size, the results indicate the following:

- For the walls plastered on the hard there is some correlation between wall thickness and U-value: generally the greater the wall thickness, the lower the U-value.
- The walls with lath and plasterboard finishes have lower U-values than those plastered on the hard.
- It is not possible to distinguish between the different masonry types. In the case of the Crichton Campus building (Locharbriggs sandstone), the six measurements show a greater range than those made in the other buildings with lath and plaster finishes. However, the ventilated walls in the Crichton Campus building have some influence on the U-value estimates, particularly on the top floor of the building.

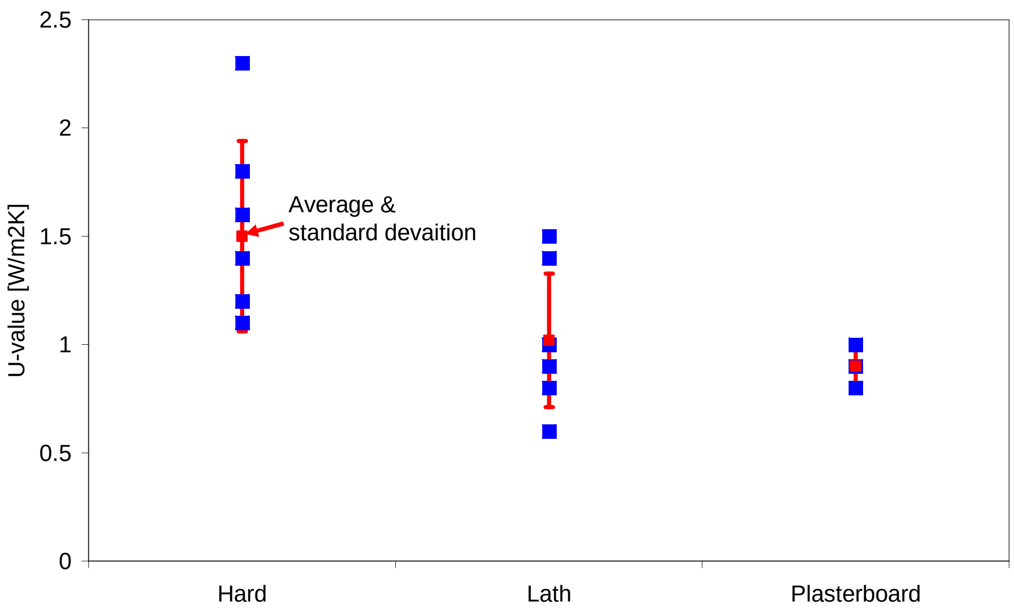


Figure 17: Wall U-values by internal finish.

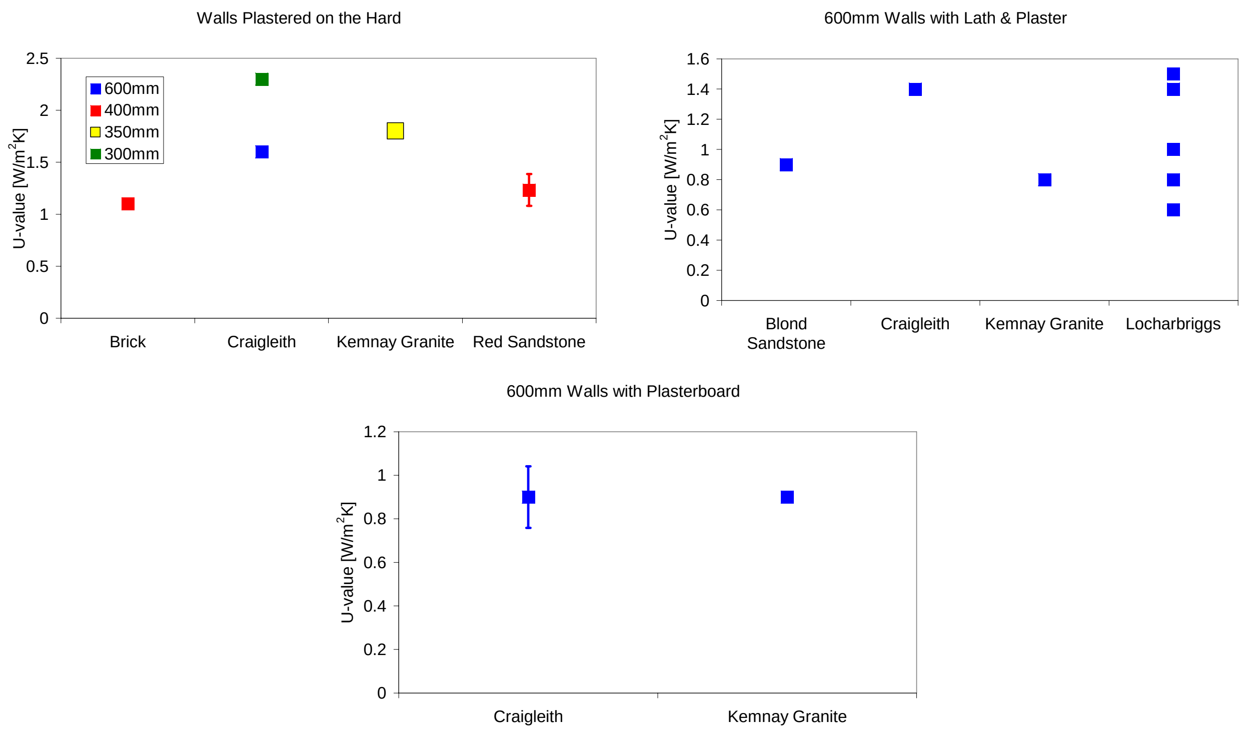


Figure 18: Wall U-values by masonry type

Generally the *in situ* U-values are lower than expected from standard values of the thermal conductivity of “stone”. For example, the Scottish Buildings Standards gives a value of 2.3 W/mK for sandstone; which results in calculated U-values of 2.2 W/m^{2}K for a 600mm sandstone wall plaster on the hard, and 1.5 W/m^{2}K for a 600mm wall with plasterboard. However, the calculated values do not account for the effect of mortar, voids, etc. which are included in the *in situ* measurements.

The laboratory test results

The laboratory test results show reasonable agreement with the site measurements:

– Solid wall: 1.4 W/m^{2}K
– Wall with plasterboard: 1.1 W/m^{2}K

Lauriston Place, basement floor test results

Insulating the floor in the basement of Lauriston Place with 21mm Spacetherm/9mm particleboard composite resulted in a U-value of 0.6 W/m^{2}K compared to 3.5 W/m^{2}K for the concrete floor alone. These values agree well with calculated U-values, assuming the manufacturer’s thermal conductivity of 0.13 W/mK for Spacetherm.

7 Conclusions

The *in situ* U-values of twenty walls have been carried out covering part of the range of traditional Scottish masonry constructions and internal finishes.

Given the sample size it is not possible to differentiate between different masonry materials.

For walls plastered on the hard, increasing wall thickness improves the U-value.

Walls with lath and plasterboard finishes have lower U-values than those plastered on the hard. This demonstrates the insulating effect of an air cavity.

Further *in situ* measurement will be carried out during winter 2008/09, with the aims of extending the geographical range of masonry types within Scotland and also measuring the U-values of floors and roofs.

Thus far, indicative U-values for 600mm masonry walls are as follows:

- Wall plastered on the hard: 1.5 ±0.4 W/m^2K
- Wall with lath and plaster: 1.0 ±0.3 W/m^2K
- Wall with plasterboard: 0.9 ±0.1 W/m^2K

8 References

1. www.campbellsci.com/documents/manuals/cr1000-ov.pdf
2. www.hukseflux.com/heat%20flux/hfp01.pdf
3. ftp.campbellsci.com/pub/csl/outgoing/uk/leaflets/107_108_105t_109_apr07.pdf
4. www.spacetherm.com/pdf/apg5738%20spacetherm%20v5.pdf
5. www.changeworks.org.uk/uploads/83096-EnergyHeritage_online1.pdf

Table 1: Wall descriptions and in situ U-value estimates

Location	Stone Type	Wall thickness	Outside Face	Inside Face	U-Value W/m^{2}K	Monitoring Period
Victorian Villa, Glasgow						
Bedroom N-W	Blond Sandstone	600mm	Rubble	Lath	0.9	April-Dec 07
Crichton Campus						
Ground floor South	Locharbriggs	600mm	Ashlar	Lath	1.0	Nov-Dec 07
Ground Floor North	Locharbriggs	600mm	Ashlar	Lath	1.4	Nov-Dec 07
First floor South	Locharbriggs	600mm	Ashlar	Lath	1.5	Nov-Dec 07
First floor North	Locharbriggs	600mm	Ashlar	Lath	1.0	Nov-Dec 07
Second floor South	Locharbriggs	600mm	Ashlar	Lath	0.6	Nov-Dec 07
Second floor North	Locharbriggs	600mm	Ashlar	Lath	0.8	Nov-Dec 07
Lauriston Place, Edinburgh						
Ground floor front elevation	Craigleith	600mm	Ashlar	Lath	1.4	Dec 07
Basement front wall	Craigleith	600mm	Ashlar	Hard	1.6	Dec 07
Basement rear wall	Craigleith	600mm	Cement	Plasterboard	1.0	Dec 07
No 28 Rear wall 1st floor	Craigleith	600mm	Rubble	Plasterboard	0.8	Jan 08
Front wall, below window	Craigleith	300mm	Ashlar	Hard	2.3	Jan 08
Castle Fraser						
1st floor bedroom	Kemnay Granite	600mm	Rubble	Lath	0.8	Mar 08
Ground floor turret	Kemnay Granite	350mm	Rubble	Hard	1.8	Mar 08
Ground floor stable office	Kemnay Granite	?	Rubble	Plasterboard	0.9	Mar 08
Gardner's Bothy	Kemnay Granite	?	Rubble	Lath	0.8	Mar 08
Weens Cottage, Borders						
Ground floor, East elevation	Red Sandstone	400mm	Rubble	Hard	1.2	Mar - Apr 08
North gable, ground floor	Red Sandstone	400mm	Rubble	Hard	1.1	Mar - Apr 08
West wall	Brick	400mm	Rubble	Hard	1.1	Mar - Apr 08
Bathroom wall, West elevation	Red Sandstone	400mm	Rubble	Hard	1.4	Mar - Apr 08

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