Energy Efficiency Case Study

# Top floor Flat, Bonnygate, Cupar

## Essential Repair, Maintenance and Thermal Upgrades

# Energy Efficiency Case Study: Flat in Bonnygate, Cupar


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## Acknowledgements

Fife Council would like to thank all partners participating in this case study.

## Background

Cupar has a superb architectural heritage, reflected in its many listed historic buildings and large conservation area. Maintaining the buildings and the charm of Cupar is vital to the success of the town.

Fife Council is working with Fife Historic Buildings Trust and local groups to invest in Cupar's historic properties and streets to support the town's future. Cupar CARS and THI is funded by Historic Environment Scotland (£1 million via its Conservation Area Regeneration Scheme) and the Heritage Lottery Fund (£550,000 via its Townscape Heritage Initiative). In total, at the end of the five-year programme, which runs from April 2014 to March 2019, approximately £7 million will be invested in Cupar.

The aim of the case study was to demonstrate that significant improvements can be achieve in enhancing the energy efficiency of traditional buildings through regular maintenance and low-cost improvements such as loft insulation and draught proofing.

## Summary

Throughout this report it is demonstrated that we can say that the energy used post-works was approximately 44% less than was used before the works. It is acknowledged that the temperature difference was approximately 3 °C less, on average, during the post-works monitoring period, and when adjusting for this, the energy used after the works was approximately 27.8% less.

It is therefore fair to conclude that by implementing these straightforward improvements, significant energy savings approaching 30% can be made.

## Introduction

This project set out to record the energy use of a flat in Bonnygate before and after the proposed repair works to the complete tenement, which were part funded as part of the Cupar CARS/THI initiative.

The property is of traditional construction, with mass masonry walls, a slated roof and single glazed timber sash and case windows. The building is category C-listed and within the Cupar Conservation Area. Access is via a narrow and busy section of the Bonnygate with a narrow pavement and pend through to the rear, all of which makes organising repairs and improvements a challenge. Prior to the works there were a number of issues identified, many of which are shown in Figures 1 to 17.

Water ingress through the roof was identified in two locations. A thin coat of cement render and significant areas of delaminating (flaking) stone were found on the front elevation. Extensive masonry pointing and localised stone repairs were required on the rear elevation. Most of the windows were in a fair to poor state of repair. Rainwater goods (guttering) needed to be cleared and re-fixed and some local vegetation needed to be removed.

The works included repairs to the roof and the guttering, reinstatement of the shop front, removal of cement and paint to the front, extensive masonry repairs, significant masonry pointing, window and door repairs and draught stripping and a top up of loft insulation. All work was carried out in line with the principles of conservation best practice, retaining original features and matching sandstone and slates to the original. Cement mortar was removed and replaced with traditional lime pointing.

## Construction Phase

The construction was carried out between May and November 2018 with pre-works monitoring running for six weeks from the beginning of March 2018 and post-works monitoring running from 1st November 2018.

The flat has electric storage heating and hot water cylinder and we recorded electric heating demand via weekly electric meter readings during the monitoring periods. We installed data log tags to monitor the internal temperature of the four main rooms in the flat and to monitor the relative humidity of the lounge, along with the ambient external temperature to allow for adjustments in conductive heat losses. We also recorded thermal images before and after the works to help illustrate where the heat losses were improved and conducted a user questionnaire to obtain soft feedback on the human impact of the works.

## Images of General Repairs and Improvements


Fig. 1. Front elevation before works

Fig. 2. Front elevation after works


Fig. 3. Front elevation before detail

Fig. 4. Front elevation after detail

Fig. 5. Existing rear window before overhaul

Fig. 6. Existing vegetation roots in masonry

Fig. 7. Vegetation resulting from rainwater leaks

Fig. 8. Water ingress through roof (note daylight)

Fig. 9. Attic insulation before works

Fig. 10. Attic insulation after top up

Fig. 11. Typical front window before works

Fig. 12. Typical front window after works

Fig. 13. Sash window repair

Fig. 14. Draught strips added to windows

Fig. 15a–c. Rear window shutters restored (inside of window in Fig. 5)

Fig. 16a–c. Front door draught strips

Fig. 17a–b. Loft hatch insulated and draught stripped

## Methodology

Electricity used for heating was recorded for a period of six weeks before and six weeks after the repair and restoration works. Internal and external temperatures during the test phase were also recorded to allow for any necessary adjustments in conductive heat loss. The data log tag in the living room also recoded relative humidity.


Fig. 18. Electric Meter

Fig. 19. Typical electric storage heater and controls

Fig. 19. Bathroom electric convector

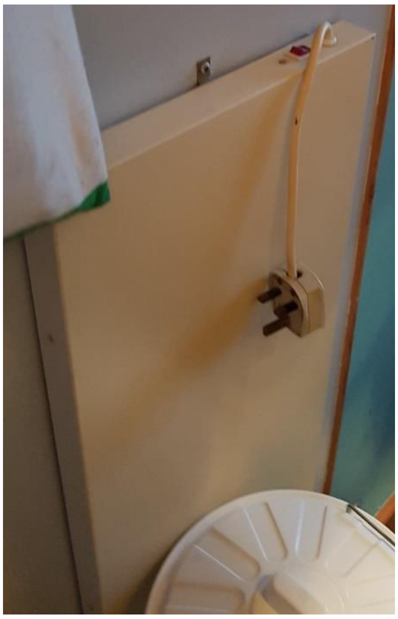

Fig. 20. Kitchen electric panel heater


Fig. 21. Data log tag on door frame in lounge

Some assumptions were made to enable calculations and performance assessment. It was assumed that there would be no heat losses to the neighbouring properties through the common walls and floor. It was assumed that all of the electrical energy was converted into heat through the storage heaters and that there was no thermal lag benefit from stored summer heat in the masonry before the initial test phase. We know that the occupant did not use the bathroom convector or kitchen panel heater during either test phase.

Electric heating demand was documented by recording high- and low-rate electric meter readings every week over both monitoring periods. The high rate applied to general electric use and the low rate applied for space heating and hot water. It was assumed that the hot water heating demand was constant during both test phases.

Credit-card-sized data log tags were used at consistent mid-height locations in the lounge, kitchen, front bedroom and rear bedroom. The data log tags recoded temperature every ten minutes for both six-week periods and found that the average internal temperature over both periods was similar.

The lounge log tag also recorded humidity and we found that the average relative humidity was 34% before the works and 46.5% after the works. The outside temperature was monitored during the periods using Met Office data and an external log tag and it was found that, on average, the ambient external temperature during the post-works period was 2.4 °C higher than during the pre-works measurement period.

The performance of the insulation is measured by the U-value, where a low U-value means that the rate of heat transfer through the building for a given temperature difference (between ambient (outside) and the internal temperature of the flat) is low, i.e. the flat stays warm.

U-values were calculated for the walls and ceiling and an estimated U-value was used for single glazed windows to work out the rate of heat loss through the building fabric. This was then multiplied by the duration (hours) of the test phase to approximate the effect of the temperature difference in kilowatt hours (kWh).

The total kWh used for heating energy in the pre-works phase was 2,964 kWh.

The total kWh used for heating energy in the post-works phase was 1,691 kWh.

There appears to be a 44% reduction in energy used. On average, the internal temperature remained approximately the same, but the external temperatures were 2.4 °C higher and the internal temperature was, on average, 0.6 °C lower in the post-works. From this, we can calculate that the temperature difference between inside and outside pre-construction was 21.6 °C – 4.6 °C = 17 °C, with the corresponding post-construction value being 21 °C – 7 °C = 14 °C. Therefore, the pre-construction phase temperature was 3 °C higher that that of the post-construction phase.

We then worked out the best approximation of the U-values for the walls, windows and ceiling which, when multiplied by the relative areas, the 3 °C difference and the time in hours for the test phase (1,008 hrs) we get the number of kWh that relate to the 3 °C temperature difference. The calculation is detailed below.

| **Location** | **Calculation** | **Losses** |
|---|---|---|
| Walls | 52.9 $m^2$ × 1.78 $W/m^2/°C$ × 3 °C | 282.5 W |
| Windows | 10.5 $m^2$ × 5.8 $W/m^2/°C$ × 3 °C | 187.7 W |
| Ceiling | 68.6 $m^2$ × 0.72 $W/m^2/°C$ × 3 °C | 148.2 W |
| tW | 282.5 W + 187.7 W + 148.2 W | 618.4 W |
| Overall | 618.4 W × 1,008 hrs | 623.3 kWh |

So, if the heating energy used when the temperature difference was 3 °C more was 2,964 kWh, then we can subtract 623.3 kWh to adjust for this temperature difference before arriving at our final approximation of the total percentage energy saved by the improvements.

The total kWh used for heating energy in the pre-works phase minus the total kWh used for heating energy in the post-works phase and the adjustment calculated above for the 3 °C temperature difference gives us the adjusted pre-works heating energy.

2,964 kWh – 623.3 kWh = 2,340.7 kWh

As a percentage:

Post-works heating energy of 1,691 kWh / Pre-works heating energy of 2,340.7 kWh

= 72.2%

We can therefore define an approximate heating energy saving of:

100% – 72.2%

= **27.8%**

## Thermal Comfort

From log tag data, we can see that despite there only being a 0.6 °C difference (lower in the post-works phase) in the average internal temperature, there was a trend of steadier temperature (lesser extremes of high and low temperatures) with typical daily swings reducing from 5 °C to 3 °C as can be seen in the before and after graphs for the rear bedroom.

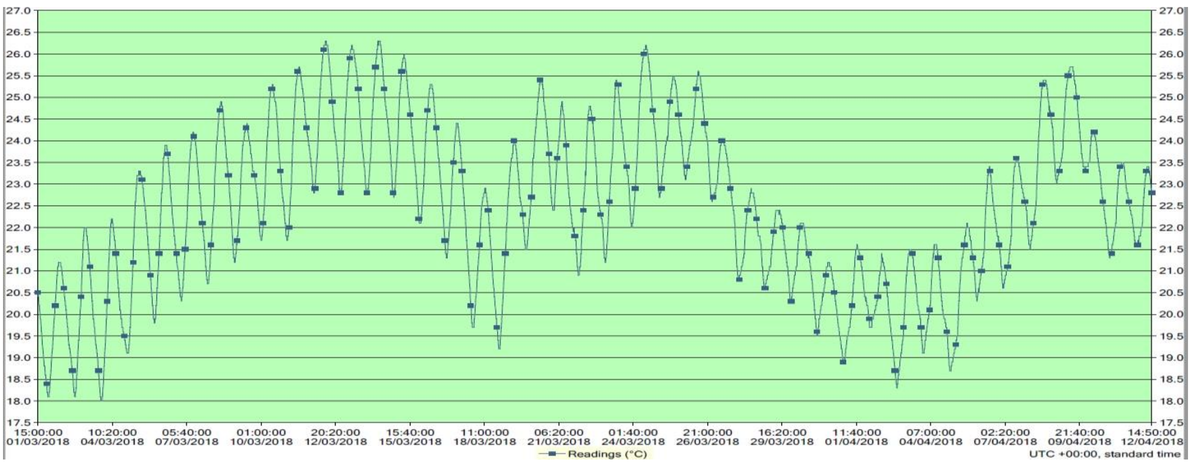


Fig. 22. Rear bedroom pre-works temperature

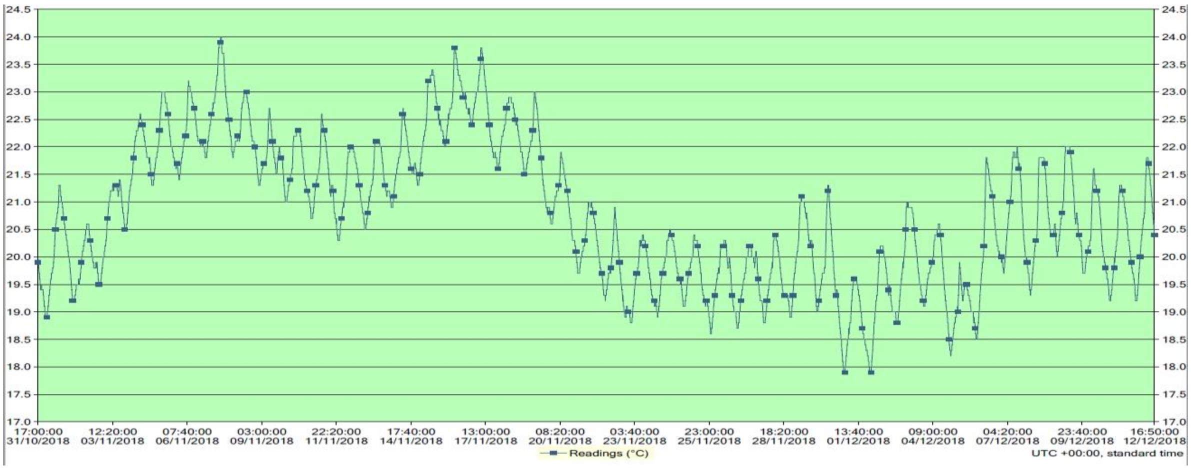


Fig. 23. Rear bedroom post-works temperature

It is worth noting that there seems to be a correlation between external weather and internal temperature, as the internal temperature seems to shift with a lag of a few days, following shifts in external temperatures. This can be seen on the post-works external Cupar temperature graph (Fig. 24) below. We note that internal temperature spikes could relate to solar gain but, as we did not record this data, we have no way of proving this.

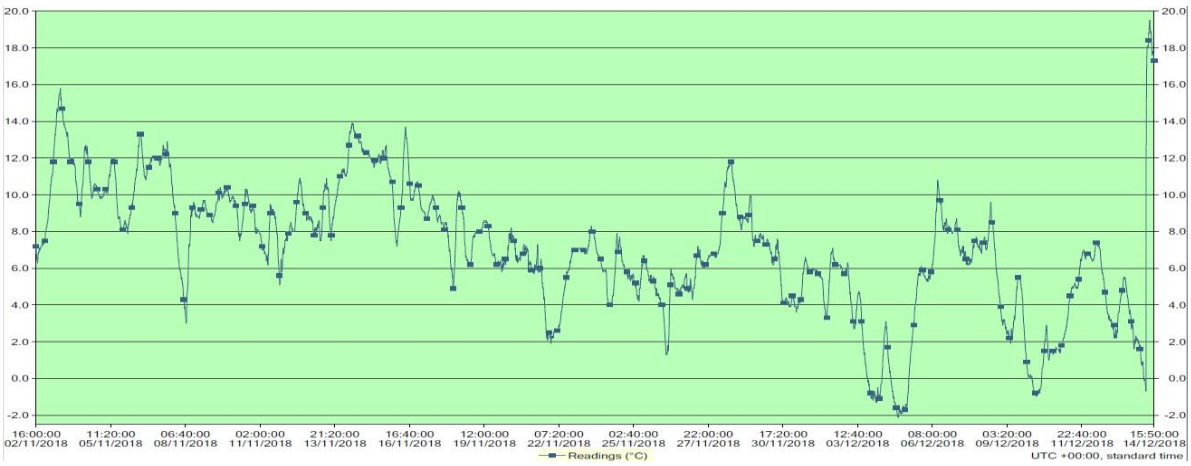


Fig. 24. Post-works external (Cupar) temperature

## Relative Humidity and Comfort

It is also worth noting that in the living room, relative humidity was markedly lower, with a range of 24–46% and average of 34% before the works, compared to a range of 36–60% and an average of 46% after the works. Given that a relative humidity of between 30% and 70% is best for human health and comfort, with 50–60% being the ideal, the post-works relative humidity has improved, which will help to improve comfort and minimise the potential to cause health issues associated with low relative humidity values such as respiratory problems, allergies and, in extreme cases, eye irritation.

## Noise and Air Quality Comfort

Despite being beyond the remit of this report, it is worth noting that the tenant has reported that, other than the improved thermal comfort, there was a marked improvement in acoustic and air comfort. The flat is located on a busy A-class road and the noise level in the flat has been improved through the work done to the external seals and the installation of draught strips. We should point out that thermal and acoustic comfort could be further improved with provision of secondary glazing. Below is an extract from the owner occupant questionnaire.

> *My comforts levels have increased dramatically since the works. The noise levels are at least 25 to 40% less. There are much fewer draughts coming in the windows and front door and the insulation in the attic has made my flat much warmer and, hopefully, less expensive to heat.*

Furthermore, it is also worth noting that the property is in an air quality management area because of the poor air quality in relation to traffic. Given the improvements in noise and draughts, it would logically follow that the flat’s air quality will also have improved as a result of the improvements.

## Infra-red Thermal Images

The following images were taken using a thermal imaging camera. The dark blue areas show where cold spots are through heat loss, whereas the lighter, warmer colours indicate the retention of the heat within the property.

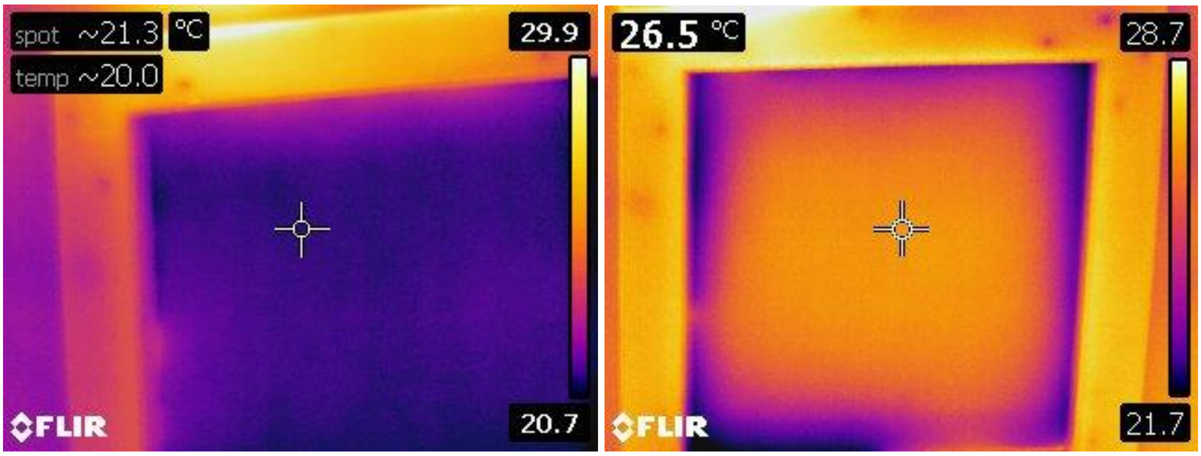


Fig. 25a–b. Before (left) and after (right) thermal images of the flat's loft hatch, showing significantly less cold (dark)

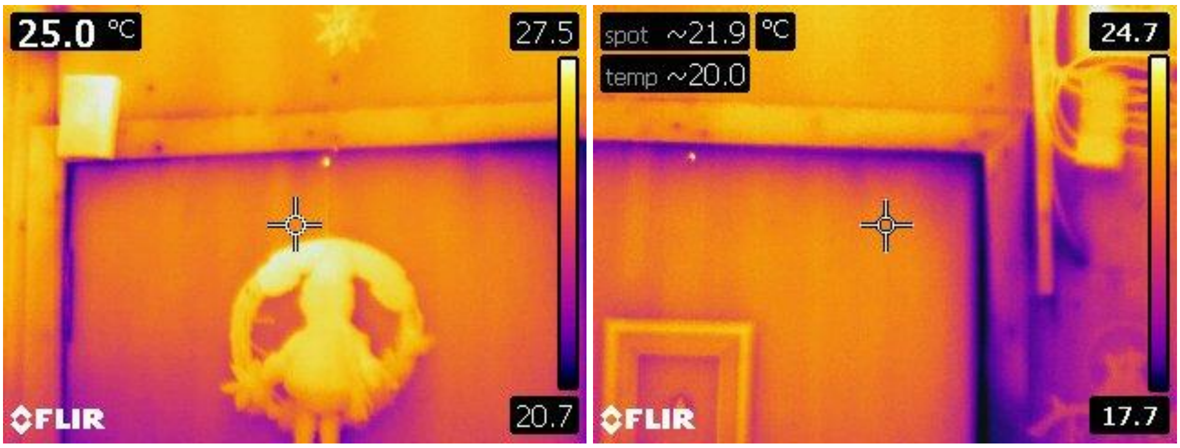


Fig. 26a–b. Before (left) and after (right) thermal images of the flat's front door, showing slight improvement in cold tracking into flat (dark)

## Summary

We can say that the energy used post-works was approximately 44% less than was used before the works but that the temperature difference was approximately 3 °C less, on average, during the post-works monitoring period. When we adjust for this, the energy used after the works was approximately 27.8% less.

The flat owner has confirmed that the flat is significantly less draughty and that the storage heater electrical demand has been less, as the owner stated at the end of January 2019:

> *I have not had to turn my heaters up to the maximum setting as of yet and they would have been on max for a while by this time.*

It is therefore fair to conclude that by implementing straightforward improvements such as draught stripping doors and windows, fixing window panes and topping up loft insulation, significant energy savings approaching 30% can be made. It is also important to note that these improvements were aided by the overall repair work to the building. By rectifying damaging work previously carried out and repairing the damage caused through lack of maintenance, the building structure can now perform as it was originally designed to against the elements. Regular maintenance work, using traditional techniques and materials, will ensure that this, and the benefits to the occupants, continues.

For further reading on this subject, please refer to the following documents produced by Historic Environment Scotland, available at https://www.engineshed.scot/publications/

Short Guide 1 (Fabric Improvements for Energy Efficiency in Traditional Buildings)

Short Guide 9 (Maintaining Your Home)

Short Guide 11 (Climate Change Adaptation for Traditional Buildings)

Inform Guide (Maintaining Sash & Case Windows

Inform Guide (Improving Energy Efficiency in Traditional Buildings)

## APPENDIX 1: Meter and Log Tag Data Summary

Bonnygate Meter Readings

PRE WORKS

| Meter readings | high rate | low rate | | total |
|---|---|---|---|---|
| | kWh | kWh | | kWh |
| 2018.03.01 | 952 | 6997 | | 7950 |
| 2018.03.08 | 1024 | 7557 | 560 | 8586 |
| 2018.03.15 | 1096 | 8104 | 547 | 9200 |
| 2018.03.27 | 1213 | 8988 | 884 | 10201 |
| 2018.03.29 | 1234 | 9102 | 114 | 10337 |
| 2018.04.05 | 1310 | 9604 | 502 | 10914 |
| 2018.04.12 | 1376 | 9961 | 357 | 11338 |
| TkWh | 424 | 2964 | | 3388 |
| kWh/d | 10 | 71 | | 81 |

POST WORKS

| Meter readings | high rate | low rate | | total |
|---|---|---|---|---|
| | kWh | kWh | | kWh |
| 2018.10.31 | 3108 | 11888 | | 14996 |
| 2018.11.07 | 3194 | 12172 | 284 | 15367 |
| 2018.11.14 | 3265 | 12385 | 213 | 15650 |
| 2018.11.22 | 3356 | 12669 | 284 | 16025 |
| 2018.11.28 | 3425 | 12891 | 222 | 16316 |
| 2018.12.06 | 3510 | 13258 | 367 | 16768 |
| 2018.12.12 | 3580 | 13579 | 321 | 17160 |
| TkWh | 472 | 1691 | | 2164 |
| kWh/d | 11 | 40 | | 52 |

Bonnygate Temperature and Humidity Data

PRE WORKS PHASE 01/03/2018 - 12/04/18

| Week beginning | Outside Temp C | | Temp Lounge C | | Temp Front Bed C | | Temp Rear Bed C | | Temp Kitchen C | | Temp Average Flat C | RH Lounge C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | high | low | high | low | high | low | high | low | high | low | | high | low |
| 2018.03.01 | 5 | 1 | 24.5 | 16 | 23 | 15.5 | 24 | 18 | 21.5 | 17 | | 40 | 26 |
| 2018.03.08 | 9 | 0 | 27.5 | 20 | 25 | 19.5 | 26 | 21 | 23 | 19.5 | | 41 | 29 |
| 2018.03.15 | 9 | 0 | 26 | 17.5 | 24 | 17 | 26 | 19.5 | 23 | 18.5 | | 43 | 24 |
| 2018.03.27 | 9 | -1 | 27.5 | 21 | 25 | 20 | 26 | 20.5 | 23.5 | 19.5 | | 41 | 29 |
| 2018.03.29 | 8 | -1 | 23 | 16.5 | 22 | 16.5 | 22 | 18.5 | 21 | 17.5 | | 46 | 31 |
| 2018.04.05 | 8 | -1 | 27 | 18 | 25 | 19 | 25.5 | 20.5 | 23 | 18 | | 43 | 31 |
| | average | 4.6 | average | 22.4 | average | 21.0 | average | 22.5 | average | 20.5 | 21.6 | average | 34.0 |
| | high | 9 | high | 27.6 | high | 25 | high | 26.3 | high | 23.8 | 27.6 | high | 46.3 |
| | low | -1 | low | 16 | low | 15.6 | low | 18 | low | 17 | 15.6 | low | 24 |

POST WORKS PHASE 01/11/18 - 12/12/18

| Week beginning | Outside Temp C | | Temp Lounge C | | Temp Front Bed C | | Temp Rear Bed C | | Temp Kitchen C | | Temp Average Flat C | RH Lounge C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | high | low | high | low | high | low | high | low | high | low | | high | low |
| 2018.10.31 | 14 | 7 | 24.5 | 19 | 23 | 19.5 | 23 | 19 | 23.5 | 19 | | 54.5 | 42.5 |
| 2018.11.07 | 15.5 | 3.5 | 25 | 20.5 | 23.5 | 20.5 | 24 | 20.5 | 23.5 | 20 | | 56.5 | 44.5 |
| 2018.11.14 | 14 | 5 | 25 | 19 | 23.5 | 20.5 | 23.5 | 19.5 | 24.5 | 20 | | 59.5 | 43.5 |
| 2018.11.22 | 13.5 | 2 | 22 | 18.5 | 20.5 | 19 | 21 | 18.5 | 21.5 | 18.5 | | 56.5 | 42.5 |
| 2018.11.28 | 11.5 | 1.5 | 22 | 18 | 22 | 18 | 21 | 18 | 23 | 17.5 | | 54.5 | 38.5 |
| 2018.12.06 | 10.5 | -2 | 24 | 20 | 23 | 19.5 | 22 | 18.5 | 23.5 | 18.5 | | 50.5 | 36.5 |
| | average | 7.0 | average | 21.4 | average | 21.2 | average | 20.8 | average | 20.7 | 21.0 | average | 46.5 |
| | high | 15.5 | high | 25.4 | high | 23.7 | high | 24 | high | 24.8 | 25.4 | high | 59.9 |
| | low | -2.1 | low | 17.8 | low | 18 | low | 17.9 | low | 17.2 | 17.2 | low | 35.7 |

## APPENDIX 2: U-Value Calculations

# ELEMENTAL U-VALUE CALCULATION

## Energy Design Tools

Prepared by: Gary Paterson for G Paterson Architect Ltd

**Bonnygate - External wall**

**<u>This is a External wall construction</u>**

There are 5 layers:

| Layer | Thickness (mm) | λ (layer) | λ (bridge) | Bridge % |
|---|---|---|---|---|
| 1. Internal Surface Resistance | - | 0.130 | | |
| 2. Lath and plaster | 25.0 | 0.480 | - | - |
| 3. Sandstone | 525.0 | 2.300 | - | - |
| 4. Slightly ventilated air layer | 50.0 | 0.000 | 0.130 | 8.33 |
| 5. External Surface Resistance | - | 0.040 | | |

Layer 4 is bridged with 50 mm Timbers at 600 mm Centres, proportion 8.330, thickness 50.0 mm, λ: 0.130

Upper resistance limit of Construction = 0.560 $m^2K/W$
Lower resistance limit of Construction = 0.560 $m^2K/W$

Total Resistance = ( 0.560 + 0.560 ) / 2 = 0.560 $m^2K/W$

**U-value of construction = 1.78W/$m^2$K (1.785)**

**<u>System properties:</u>**

NB Calculation performed with a greater number of decimal places than shown, so rounding error may be apparent

# ELEMENTAL U-VALUE CALCULATION

## Energy Design Tools

Prepared by: Gary Paterson for G Paterson Architect Ltd

**Bonnygate _Copy R3531 - Pitched roof**

**This is a Pitched roof construction**

There are 8 layers:

| Layer | Thickness (mm) | λ (layer) | λ (bridge) | Bridge % |
|---|---|---|---|---|
| 1. Internal Surface Resistance | - | 0.100 | | |
| 2. Lath and plaster | 25.0 | 0.480 | - | - |
| 3. Glasswool | 50.0 | 0.040 | 0.130 | 8.33 |
| 4. Slightly ventilated air layer | 2,000.0 | 0.000 | - | - |
| 5. Timber sarking board | 20.0 | 0.130 | - | - |
| 6. Sarking felt | 3.0 | 0.230 | - | - |
| 7. Roof slates | 20.0 | 1.440 | - | - |
| 8. External Surface Resistance | - | 0.040 | | |

Layer 3 is bridged with 50 mm Timbers at 600 mm Centres, proportion 8.330, thickness 50.0 mm, λ: 0.130

Upper resistance limit of Construction = 1.405 $m^2K/W$
Lower resistance limit of Construction = 1.355 $m^2K/W$

Total Resistance = ( 1.405 + 1.355 ) / 2 = 1.380 $m^2K/W$

**U-value of construction = 0.72W/$m^2$K (0.725)**

**System properties:**

NB Calculation performed with a greater number of decimal places than shown, so rounding error may be apparent

# ELEMENTAL U-VALUE CALCULATION

## Energy Design Tools

Prepared by: Gary Paterson for G Paterson Architect Ltd

**Bonnygate _Copy R3531 - Pitched roof**

**<u>This is a Pitched roof construction</u>**

There are 9 layers:

| Layer | Thickness (mm) | λ (layer) | λ (bridge) | Bridge % |
|---|---|---|---|---|
| 1. Internal Surface Resistance | - | 0.100 | | |
| 2. Lath and plaster | 25.0 | 0.480 | - | - |
| 3. Glasswool | 150.0 | 0.040 | 0.130 | 8.33 |
| 4. Glasswool | 120.0 | 0.040 | - | - |
| 5. Slightly ventilated air layer | 2,000.0 | 0.000 | - | - |
| 6. Timber sarking board | 20.0 | 0.130 | - | - |
| 7. Sarking felt | 3.0 | 0.230 | - | - |
| 8. Roof slates | 20.0 | 1.440 | - | - |
| 9. External Surface Resistance | - | 0.040 | | |

Layer 3 is bridged with 50 mm Timbers at 600 mm Centres, proportion 8.330, thickness 150.0 mm, λ: 0.130

Upper resistance limit of Construction = 6.726 $m^2K/W$
Lower resistance limit of Construction = 6.460 $m^2K/W$

Total Resistance = ( 6.726 + 6.460 ) / 2 = 6.593 $m^2K/W$

**U-value of construction = 0.15W/$m^2$K (0.152)**

**System properties:**

NB Calculation performed with a greater number of decimal places than shown, so rounding error may be apparent

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