

SCOTSTARVIT TOWER COTTAGE, CUPAR

THERMAL UPGRADES & INSTALLATION OF RADIANT HEATING



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Historic Scotland Refurbishment Case Study 7

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JESSICA SNOW

Contents

| | |
|---|----|
| 1. Introduction..... | 5 |
| 2. The site..... | 5 |
| 3. Pre-intervention thermal performance | 6 |
| 4. Delivery of the work..... | 7 |
| 5. Improvements to roof space | 7 |
| 6. Improvements to ceilings | 8 |
| 7. Improvements to rooflight and lightwell..... | 9 |
| 8. Improvements to windows | 9 |
| 9. Improvements to the floor | 10 |
| 10. Improvements to external walls | 11 |
| 11. Improvements to the chimney..... | 12 |
| 12. Redecoration..... | 13 |
| 13. Radiant heating..... | 13 |
| 14. Occupant feedback..... | 14 |
| 15. Post-intervention air leakage testing..... | 14 |
| 16. Ongoing monitoring..... | 14 |
| 17. Conclusion | 15 |
| 18. Appendices | 16 |

Acknowledgements

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1. Introduction

This case study forms part of the Historic Scotland *Refurbishment Case Study* series, detailing energy efficiency improvements to traditionally constructed buildings in Scotland. The property is owned by the National Trust for Scotland and the project was a collaboration between the National Trust for Scotland and Historic Scotland. The project demonstrates a range of energy efficiency upgrades that can be carried out in traditionally constructed buildings, with minimal or no loss of original fabric. The project involved the use of innovative materials, in particular loose-fill perlite wall insulation, and demonstrated the use of vapour-permeable materials and finishes.

2. The site

Scotstarvit Cottage is a late 19th century detached cottage located adjacent to Scotstarvit Tower, in an elevated location above the town of Cupar in Fife (Fig. 1). It is well sheltered by a belt of trees to three sides, with a open aspect to the south. The property is built of roughly-squared sandstone rubble bonded with lime mortar, with a slate roof. Internally it is lined with lath and lime plaster on timber battens with a timber suspended floor and single glazed timber sash and case windows. In some areas plasterboard had replaced the lath and plaster. Prior to works commencing, the property was in a semi-derelict state, having been vacated by the previous tenant some time earlier, and having suffered a leak which had caused the living room ceiling to collapse. The property was heated with an oil fired boiler, on a conventional wet system. Insulation was limited to around 200 mm mineral insulation in the roof, which had begun to slump in places.



Fig. 1. Scotstarvit Cottage

The accommodation is arranged on one floor, and consists of three bedrooms, a living room, and kitchen. A later flat roofed extension (c. 1925), built from a brick cavity wall with a lead roof, provides a bathroom and small front porch. There is a small timber and glazed lean-to sun porch at the rear entrance. While there are three chimneys on the building, there is only one open flue, within the living room, which has a fireplace and grate for an open fire.

3. Pre-intervention thermal performance

The thermal performance of the unimproved elements was measured prior to the works by Edinburgh Napier University and consisted of in situ U-value measurements of the floor, wall and the ceiling, using the standard heat flux plate and associated equipment (Fig. 2). As glazing of the type found at the cottage had been tested before, the windows were omitted from the testing process. The relative humidity value for the void behind the existing plasterboard was also tested. These measurements allowed a baseline pre-intervention figure to be calculated, from which the effectiveness of the upgrade works could be measured (Table 1). The techniques for measurement and analysis are described in Historic Scotland *Technical Papers 10 and 17*. The results are similar to other in situ measurements that Historic Scotland has monitored in traditional built fabric and as such need no discussion.



Fig. 2. The U-value of various elements being tested using heat-flux sensors

| Location of measurement (bedroom) | Pre-intervention U-value (W/m ² K) |
|---|---|
| Ceiling (lath and plaster, timber joists 200 mm mineral wool) | 0.7 |
| Floor (timber suspended) | 2.3 |
| Wall surface (lath and plaster, timber battens, 500 mm rubble stone wall) | 1.6 |

Table 1. Pre-intervention U-values

The property was also tested for air leakage, using a blower door test (Fig. 3). This returned a result of 16.9 m³h⁻¹m⁻² @50Pa. This level of air leakage can be compared with the *Scottish Building Standards Technical Handbook Domestic* for new dwellings which has a recommended maximum leakage rate of 10 m³h⁻¹m⁻² @50Pa (see section 6.2.4). The air leakage testing and results are described in full in Appendix 1.



Fig. 3. Blower door testing to measure the air tightness of the unimproved building

4. Delivery of the work

The work was designed and specified by Historic Scotland in collaboration with the National Trust for Scotland, and delivered on site by an general building contractor, with some work subcontracted. The work was scheduled to be completed within six weeks, however this over-ran due in part to delays in delivery of materials, and technical problems with the installation of the perlite insulation. The work was carried out while the property was unoccupied. Downtakings were limited to the removal of the existing mineral wool insulation from the roof space, removal of degraded plasterboard linings and surface finishes (paper and paint).

5. Improvements to roof space

The property has a simple roof structure with a pitched, gabled roof over the main house, and a hipped roof over the later extension. The 1920's bathroom and porch extensions are flat-roofed and covered in zinc. The attic had been insulated with mineral wool in the past, to a depth of around 200 mm, and this was intact in some areas, although in others it was unevenly distributed, damaged or missing (Fig. 4). The old insulation and other debris were removed from site. With the attic clear, access was possible to the void behind the last and plaster, allowing the perlite wall insulation to be poured in. When this was complete, the roof was re-insulated with 270 mm flexible hemp batts between and across joists (Fig. 5). This was boarded over with loft boarding to allow a storage space and access to the other roof spaces.



Fig. 4. Attic filled with variable depths of mineral wool and other discarded items, prior to the improvement works



Fig. 5. Attic insulated with 270 mm flexible hemp batts

6. Improvements to ceilings

The property was finished with lath and plaster ceilings throughout, except in the living room which had been replaced with plasterboard nailed to the lath. Following a water leak from the loft, the ceiling in the living room had come down almost entirely and required replacement (Fig. 6). In addition, a small area of ceiling in the smaller bedroom had also been damaged. The opportunity was taken to repair the ceilings using existing lath and traditional haired lime plaster (Fig. 7). The ceilings were then finished with clay paint.



Fig. 6. Lath and plaster ceiling damaged by water leak



Fig. 7. The ceiling was repaired using haired lime plaster on lath

7. Improvements to rooflight and lightwell

The internal hall was provided with daylight from a lightwell connected to a cast iron rooflight in the pitched roof. This was a cold spot as the lightwell was un-insulated and the rooflight was single-glazed (Fig. 8). The lightwell was upgraded by fixing 18 mm wood fibreboard around the light shaft (Fig. 9), and replacing the single-glazed units in the existing rooflight with double-glazed units.



Fig. 8. The original iron rooflight was retained, but the glazing was replaced



Fig. 9. The lightwell was insulated with wood fibreboard

8. Improvements to windows

The timber sash and case windows were in a reasonable state of repair, although they had been neglected over the years and required some maintenance. To minimise costs, the windows were simply rubbed down and repainted and areas of decayed timber or missing putty were repaired. The windows were then fitted with proprietary secondary glazing, consisting of a strong polycarbonate sheet fixed to the window frame with a magnetic strip (Fig. 10).



Fig. 10. The windows were fitted with polycarbonate secondary glazing

The advantages of this type of secondary glazing are that it is relatively cheap, at around £100 a square metre; it is easy to install and it is seasonal, so it can be removed during the summer months when not required. It also requires minimal fixings or damage to the fabric. Its disadvantages are that when it is not in use it requires storage space; it can be unwieldy to lift off or replace and it can become scratched and soiled over time. In addition, there were a number of incidents where the glazing was unexpectedly 'blown' off by air pressure changes, which was potentially hazardous. To resolve this issue, additional fixings had to be made to secure the glazing to the window frame.

9. Improvements to the floor

The cottage was floored throughout with a timber suspended floor over a ventilated solum (Fig. 11), except for the modern porch areas which had a solid concrete floor. The floor was generally in good condition, although there were some localised areas of decay or damage. The decision was taken to insulate under the timber floor with hemp-fibre batts, lifting only enough floorboards to enable access, so as to minimise disruption. However, during a routine inspection for asbestos prior to work starting on site, traces of asbestos were discovered in the solum. This meant the floor works were required to be carried out by a trained asbestos contractor. During these works the contaminated area required to be sealed off, so unfortunately the entire floor was lifted, resulting in some further damage to the floorboards.

The solum was isolated using a geo-textile breathable membrane, after which the hemp batts were fitted between the floor joists, held in place by timber battens and supported by a breathable membrane wrapped around the floor joists (Fig. 12 and Fig. 13). The floorboards were then reinstated (Fig. 14). Some replacement of flooring was necessary, due to prior decay or damage caused during the asbestos works, but on the whole the replacement was kept to a minimum.



Fig. 11. Suspended timber floor showing 19th century staining at edges



Fig. 12. The hemp batts were supported with a breather membrane



Fig. 13. Hemp insulation prior to re-laying floorboards



Fig. 14. Floor re-laid following insulation, showing areas of repair

10. Improvements to external walls

The insulation of the walls was the most challenging element of the project. One of the main objects of this project was to demonstrate and test the installation of loose fill insulation into the cavity between the lath and plaster linings and the external stone walls. The challenge was to achieve a complete fill of the walls whilst causing minimum disruption to the existing linings. The insulation material chosen was perlite, a product designed to be free-flowing, and therefore well suited to giving a full fill to the spaces behind the wall linings.

Access to the void behind the lath and plaster was gained from the attic space. The contractor experimented with various methods, finding that a rigged up 'funnel' formed from a piece of plasterboard and some plastic sheeting was the most effective (Fig. 15). The perlite was poured in between all the uprights until a full fill was achieved (i.e. no more could be inserted).



Fig. 15. Perlite insulation poured into wall voids from the attic space

More difficult areas to be insulated were the window reveals and the sections underneath the windows. For the lower walls, part of the timber sill was removed to allow the insulation materials to be poured in, and then replaced in a fairly straightforward process. The window reveals were more difficult, but the contractor rigged up a suitable funnel and poured in the insulation through a 30 mm diameter hole drilled into the lining (Fig. 16).



Fig. 16. Insulation being poured into the window reveals

Whilst the benefit of the perlite was its free-flow characteristic, this also proved to be a problem as it was subsequently discovered that the insulation material had run into the window sash boxes and filled up the casings, causing an obstruction to the window opening. This meant that where the insulation had been installed, the window linings had to be removed in order to access and clear the sash boxes. The space around them was then blocked up using hemp-fibre to prevent the same thing happening again. Some of the window reveals were lath and plaster and some were plasterboard, but all were replaced with lath and haired lime plaster.

11. Improvements to the chimney

During the pre-intervention air-tightness testing it was found the chimney was accounting for approximately 7% of the air leakage from the property (Fig. 17), and, probably more importantly, was missing its pot and allowing water ingress into the chimney (Fig. 18). A Chinese lantern chimney pot was installed, allowing sufficient ventilation but preventing excessive draughts and air leakage.



Fig. 17. The adjustable baffle allowing chimney ventilation to be controlled



Fig. 18. The open chimney pot before refurbishment works

12. Redecoration

Whilst internal plaster and timber linings were retained, the finishes were stripped back to bare plaster, removing degraded layers of modern paint and paper. The property was then repainted throughout using vapour permeable clay based paint (Figs. 19 and 20). As well as being non-toxic and low in VOCs, a clay-based paint allows any moisture present within the fabric of the building to be dispersed into the internal atmosphere where it can be removed by ventilation.



Fig. 19. The redecorated living room showing radiant heated mirror above fireplace



Fig. 20. The property was redecorated with clay paint

13. Radiant heating

The cottage had previously been heated from a conventional system with an oil fired boiler. Oil is a high carbon fossil fuel and can be subject to price fluctuations and issues with delivery during periods of poor weather and high demand. Like many rural properties in Scotland, the cottage was off of the gas grid; therefore a solution was looked for to deliver low energy electric heating. The decision was made to trial a new type of infra-red radiant heating panel.

The theory behind radiant heating is that thermal comfort can be achieved at lower ambient air temperatures where occupants are subject to radiant heat. Occupants feel warmer and more comfortable physiologically, in the same way that one feels pleasantly warm when sitting in front of an open fire even in a cool room, or when sitting in a sheltered spot on a sunny day, even if the air temperature is cool. The heat delivered by radiant heating panels is much gentler than heat from a fire or from the sun, but nevertheless it quickly warms up the fabric of the room, and the people within in, before the heat is taken up by the air. This is a more efficient way of heating, as the occupants are heated first, and the air temperature rises more gradually, with the hope being that thermal comfort can be achieved at a lower air temperature, such as 17 or 18 C instead of the typical 18-22 C range normal for habitable living spaces.

The panels are slim, wall mounted panels, which can be supplied simply as matt white or grey panels, or as mirrors or even designed as prints or pictures. For the cottage refurbishment, simple matt white panels were specified for most of the rooms (Figs. 21

and 22), with a heated mirror selected for the living room and bathroom (see Fig. 19). Unfortunately the mirror is a smoked glass, so is not ideal as a bathroom vanity mirror, although it is adequate in most other situations.



Fig. 21. Radiant heating panel in hallway

Fig. 22. Radiant heating panel in bedroom

14. Occupant feedback

At the time of writing this report a new tenant had only recently settled into the property. Whilst there were some teething problems with the radiant heating (which had been programmed incorrectly) and the secondary glazing (which on two occasions ‘blew off’ the windows), on the whole the tenant was very pleased with the internal appearance of the property.

15. Post-intervention air leakage testing

Following completion of the refurbishment works, the property was tested for air leakage using the standard blower door test. It was found that the air leakage had reduced by close to 50% to a level of $10.7 \text{ m}^3\text{h}^{-1}\text{m}^{-2} @50\text{Pa}$, which compares favourably to the recommended maximum air leakage of $10 \text{ m}^3\text{h}^{-1}\text{m}^{-2} @50\text{Pa}$. The results of the air leakage testing are found in Appendix 2.

16. Ongoing monitoring

The work was completed in June 2012, and a tenant moved in shortly afterwards. During the summer months heating was not used and the air temperature differential was not sufficient to undertake U-value testing using heat flux sensors. Testing to determine the U-values of the wall, floor and ceiling will be undertaken over the winter months (2012-13). In addition, thermal imaging will be carried out to evaluate the success of the wall insulation, and the heating costs will be monitored. The work to the property was completed in June 2012 and the new tenant moved in July. The future

monitoring of the property will also include indoor air quality monitoring (CO₂, RH and temperature) and feedback from the tenant on thermal comfort. The results of the monitoring will be reported as they become available.

17. Conclusion

The works to Scotstarvit Cottage demonstrate that significant upgrade works can be carried out to traditional buildings without requiring loss of internal linings or existing features. The success of the project will ultimately depend on showing that there has been a significant improvement in the thermal performance of the building, coupled with a reduction in heating bills and improved thermal comfort of the occupant. The process of carrying out the work has demonstrated that innovative methods can be successfully employed in retrofit works to traditional buildings, and that where the work is well specified, it can be carried out by competent contractors, without the need for specialist intervention.

18. Appendices

[Appendix 1: Air leakage testing report: pre-intervention](#)

[Appendix 2: Air leakage testing report: post-intervention](#)

Appendix 1: Air leakage testing report: Pre-intervention

Historic Scotland Refurbishment Case Study 7



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Air Permeability Investigation

Client: Historic Scotland
Address audited: Scotstarvit Tower Cottage, Cupar
Description: Stone built detached cottage awaiting refurbishment
Test equipment: Energy Conservatory Minneapolis Blower Door Model 3 Number 65982. Calibrated 8 Dec 2010; Ring – Open.
Date of Test: 29 July 2011 11am onwards
Prevailing weather conditions at time of test: Dry, reducing level of cloud through day, wind force 0-1.
Conditions inside dwelling: Unheated.
Mould evident in cupboards recessed in walls in bedrooms, living room and window reveal in living room.



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Air permeability testing

Infiltration is the unwanted ingress/egress of air from buildings through the building fabric, such as through leaks in floors, walls and windows. The rate of infiltration is often referred to as the air tightness of a building.

Air permeability testing is a way of quantifying infiltration.

Though air permeability testing does not fully represent the infiltration situation, it is the most favoured indicator for measuring it – reflected in the fact there is a requirement for new buildings to be tested using this method.

The test procedure has been carried out in accordance with ATTMA Technical Standard L1 (2010), with any permanent points of ventilation covered or closed, such as boiler flues, chimneys, extractor fans, mechanical ventilation points and trickle vents.

The pressure in the building was increased to 50Pascals (Pa) above the external air pressure. The volume of air flow through the testing fan was then measured and related to the complete surface area of the inhabited part of the building, giving a result in m^3 of air per hour per m^2 of surface area of the living space ($\text{m}^3\text{h}^{-1}\text{m}^{-2}$ @50Pa).



Right: Blower door in situ at Scotstarvit Tower Cottage

Below: Smoke pen in use on one of the windows at Scotstarvit Tower Cottage

Using the calculated building volume, the measured air flow can be converted to a figure of air changes per hour (ach @50Pa), which is easier to relate to.

The air permeability test is used not only to quantify these results, but also to help physically identify the paths for the air leakage. These are located by using a smoke pen or, less subtly, by using hands to detect air flow.

It is also possible to tape over some leakage paths, for example around an external door, in order to quantify the air leakage relating to that particular element.



The bulk of tests previously carried out on traditional dwellings by Green Footsteps have been with the building depressurised. However this was not possible in this instance, due to a large area of ceiling in Bedroom 3 (east side of dwelling) and most of the plasterboard ceiling in the living room having been removed (as shown in the photograph). These areas were temporarily sealed with plastic, which would have probably not remained in place if depressurisation had taken place and this would have resulted in the test having to be abandoned.

Results of air permeability testing

The results of the test are as follows:

| | Units | Results | Comments |
|--|---|---------|---|
| Internal floor area | m ² | 79 | |
| Habitable building volume | m ³ | 225 | |
| Dwelling envelope area i.e. surface area of living space | m ² | 286 | |
| Air permeability test result at 50Pa | m ³ h ⁻¹ m ⁻² @50 Pa | 16.9 | m ³ of air per hour per m ² of surface area of the living space at the test pressure. Test is with the front door, loft hatch and living room windows untaped. |
| Air changes per hour at 50Pa | ach@50 Pa | 21.5 | The number of times the complete volume of air in the property is changed per hour at the test pressure. |

The air permeability figure of 16.9 m³h⁻¹m⁻² @50Pa for Scotstarvit Tower Cottage can be compared with the Scottish Building Standards Technical Handbook Domestic for new dwellings which has a recommended maximum leakage rate of 10 m³h⁻¹m⁻² @50Pa (section 6.2.4).

In order to relate the test results to infiltration figure in terms of air changes per hour, a widely used approximation is to divide the result by 20¹; however this figure should be adjusted for the level of exposure of the building tested². Though Scotstarvit Tower Cottage is in an exposed location, there is tree cover to three sides of the property and so the 1/20 approximation is still likely to be valid. This gives an air change rate under normal conditions of more than 1 ach, which is excessive³.



There are two vents in the external wall of the kitchen (shown in photograph) - one to the LHS of the chimney and the other vent under the window. There was no obvious evidence of any vents inside the kitchen, but a large amount of the wall area is currently obscured by kitchen units.

One vent was assumed to be related to the old flue and the other to ventilate the cavity behind the lining. Both of these were taped up from the outside as a precautionary measure as most of this wall had kitchen units fitted. On completion of the test, the tape had been displaced on both, indicating air flow through this route during the test (the tape on the boiler exhaust remained undisturbed).

¹ From Sherman e.g. Ridley, I. et al citing Sherman in The impact of replacement windows on air infiltration and indoor air quality in buildings. International Journal of Ventilation 1(3) pp209-218.

² CIBSE, *Heating, ventilating, air conditioning and refrigeration: CIBSE Guide B*. London: CIBSE (2005).

³ From personal research and literature review – “normal ventilation” is of the order of 0.4 – 0.5 ach.

In addition to the standard test, the level of infiltration due to certain elements was identified:

| | Additional $\text{m}^3 \text{h}^{-1}$ |
|--|--|
| Living room windows (x 2) | 31 |
| Loft hatch and areas of cut floor boards | 61 |
| Front door (into open porch area) | 358 |

In order to try and establish the level of leakage through the window in their current condition, the living room windows were temporarily taped over. Extrapolating the result to the dwelling as a whole, the windows represent less than 5% of the total leakage.

The front door, from the vestibule was tested in a similar manner and the lack of draught proofing on this door accounted for more than 7% of the building leakage.

Under the standard test procedure, chimneys and flues in the dwelling are excluded from the results. However, the air flows were measured following the main test. Though the flue vent from Bedroom 1 had little noticeable air flow whilst the blower door was in operation, the flow@50Pa for the fireplace in the living room was $343\text{m}^3\text{h}^{-1}$. Though this will not directly relate to the air flow through the flue when in use / not in use, it increased the flow of air for the building as a whole during the test by just over 7%.

Infiltration points identified

Infiltration points were identified by locating air flows under the test conditions and through the use of smoke pen. The key items were as follows:

- Kitchen – this was significant, but locations cannot be specifically identified because of the units obscuring walls – needs further inspection
- Bathroom floor /wall junction
- Front door

The suspended floors generally were not as leaky as perhaps expected, but they appeared to be in good condition, apart from in a few locations. There were no specific areas of leakage at the joint of floor and skirting board on the external walls in the original part of the building, where you might normally expect to see leakage. This may be explained by how the lining is fitted.

Overview of issues identified:

| Part of building | Room | Area | Description | Comments |
|------------------|-----------------------|-------------------|---|--|
| General | | Windows | Gaps around windows and via sash box | Visible air leakage using smoke pen. Draught proofing or other improvement required. |
| | | Radiators | Entry and exit points through floor boards | |
| | Vestibule | Front door | Gaps between door and surround | Scope for draught proofing existing door |
| | Bedroom 3 (East) | Floor | Area where boards have been cut | General repairs required |
| | | Window | | Broken window was taped over to exclude from test results. |
| | Living Room | Floor | By door into vestibule - hole in boards | General repairs required |
| | | | Area where boards have been cut | General repairs required |
| | | Recessed cupboard | Leakage into void from bottom RHS | |
| | Passageway | Rooflight | Leakage at lower end | Roof light in poor condition |
| | Kitchen (solid floor) | N wall | To LHS of gap for washing machine -just under work surface | |
| | | | Noticeable air movement to RHS of boiler at work surface level | Unable to be more specific because kitchen units obscuring. Boiler exhaust was securely taped. |
| | | | Pipe entry at ceiling level | |
| | Bathroom | N wall | Joint of skirting board to floor | Very noticeable on both exposed external walls |
| | | E Wall | | |
| | | Floor | Through floor boards | |
| Entrance | | | Not possible to adequately check this area, due to location of test equipment | |

Conclusion

The results of the air permeability test at Scotstarvit Tower Cottage should be treated with caution, specifically with respect to the holes in the ceiling and the external vents to the kitchen, both of which may have affected the results. The result of $16.9 \text{ m}^3\text{h}^{-1}\text{m}^{-2}$ @50Pa is relatively high compared to the recommendations under the Scottish Building Standards for new dwellings. It is also high in comparison to the results from a limited range of tests which have been carried out on un-refurbished traditional dwellings – to date the mean result is just under $12 \text{ m}^3\text{h}^{-1}\text{m}^{-2}$ @50Pa (13 properties).

It is suggested particular attention is paid to investigating the air leakage in the kitchen and issues relating to ingress through the floor / wall joint on the extension. Draught proofing the external doors of the property will definitely prove worthwhile.

Though the measured air flow from these areas is not currently high in relation to the building as a whole, it will become of more significance as the infiltration from other sources is reduced by repairs and improvement to the fabric.

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29 September 2011.

Appendix 2: Air leakage testing report: Post-intervention

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Air Permeability Investigation

Client: Historic Scotland
Address audited: Scotstarvit Tower Cottage, Cupar
Description: Post-refurbishment test.
Stone built detached cottage.
Refurbishment included wall, floor and loft insulation and secondary glazing.
Test equipment: Energy Conservatory Minneapolis Blower Door Model 3 Number 24802. Ring A.
Calibrated 8 February 2012
DG700 Pressure and flow gauge serial number 27774.4.700 calibrated 6 February 2012
Date of Test: 26 June 2012 1100 onwards
Prevailing weather conditions at time of test: Sunny, 20% cloud cover, dry. Wind speed maximum 5.5ms^{-1} , mean 2.0ms^{-1}
Conditions inside dwelling: 19.4°C 67% RH (approx. 1445)
 17.1°C 75% RH (approx.1230)



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Air permeability testing

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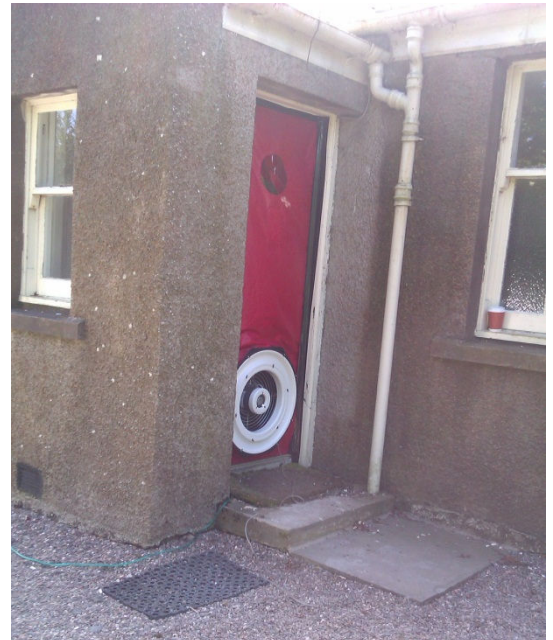
Air permeability testing is a way of quantifying infiltration.

Though air permeability testing does not fully represent the infiltration situation, it is the most favoured indicator for measuring it – reflected in the fact there is a requirement for new buildings to be tested using this method.

The test procedure has been carried out in accordance with ATTMA Technical Standard L1 (2010), with any permanent points of ventilation covered or closed, such as boiler flues, chimneys, extractor fans, mechanical ventilation points and trickle vents.

The building was initially depressurised to 50 Pascals (Pa) below external air pressure. The volume of air flow through the testing fan was then measured and related to the complete surface area of the inhabited part of the building, giving a result in m^3 of air per hour per m^2 of surface area of the living space ($\text{m}^3\text{h}^{-1}\text{m}^{-2}$ @50Pa).

The pressure in the building was also increased to 50 Pascals (Pa) above the external air pressure in order to cross- reference the results.



Using the calculated building volume, the measured air flow can be converted to a figure of air changes per hour (ach @50Pa), which is easier to relate to.

The air permeability test is used not only to quantify these results, but also to help physically identify the paths for the air leakage, which in this instance were detected using manually. It is also possible to tape over some leakage paths, for example around an external door, in order to quantify the air leakage relating to that particular element.

Results of air permeability testing

The results of the test are as follows:

| | Units | Post refurbishment results 26 June 2012 | Pre-refurbishment results 29 July 2011 | Comments |
|---|--|--|---|--|
| Internal floor area | m ² | 79 | | |
| Habitable building volume | m ³ | 225 | | |
| Dwelling envelope area i.e. surface area of living space | m ² | 286 | | |
| Measured air flow @ 50 Pa | m ³ h ⁻¹ @50 Pa | 3057 | 4847 | Both tests were carried out with the front door and loft hatch un-taped and the outer porch door open. For the post-refurbishment test, the secondary glazing was installed. Pre-refurbishment test was pressurisation only. |
| Air permeability test result at 50Pa | m ³ h ⁻¹ m ⁻² @50 Pa | 10.7 | 16.9 | m ³ of air per hour per m ² of surface area of the living space at the test pressure. |
| Air changes per hour at 50Pa | ach@50 Pa | 13.6 | 21.5 | The number of times the complete volume of air in the property is changed per hour at the test pressure. |

The post-refurbishment air permeability figure of 10.7 m³h⁻¹m⁻² @50Pa for Scotstarvit Tower Cottage is slightly above the recommended maximum leakage rate of 10 m³h⁻¹m⁻² @50Pa specified in the Scottish Building Standards Technical Handbook Domestic for new dwellings (section 6.2.4), but significantly below the pre-refurbishment result of 16.9 m³h⁻¹m⁻² @50Pa.

In order to relate the test results to infiltration figure in terms of air changes per hour, a widely used approximation is to divide the result by 20¹; however this figure should be adjusted for the level of exposure of the building tested². Though Scotstarvit Tower Cottage is in an exposed location, there is tree cover to three sides of the property and so the 1/20 approximation is still likely to be valid. This gives an air change rate under normal conditions of just under 0.7 ach, slightly more than the orthodox view of 0.4 - 0.5 ach as an acceptable air change rate to maintain good indoor air quality³.

¹ From Sherman e.g. Ridley, I. et al citing Sherman in The impact of replacement windows on air infiltration and indoor air quality in buildings. International Journal of Ventilation 1(3) pp209-218.

² CIBSE, *Heating, ventilating, air conditioning and refrigeration: CIBSE Guide B*. London: CIBSE (2005).

³ From personal research and literature review – “normal ventilation” is of the order of 0.4 – 0.5 ach.

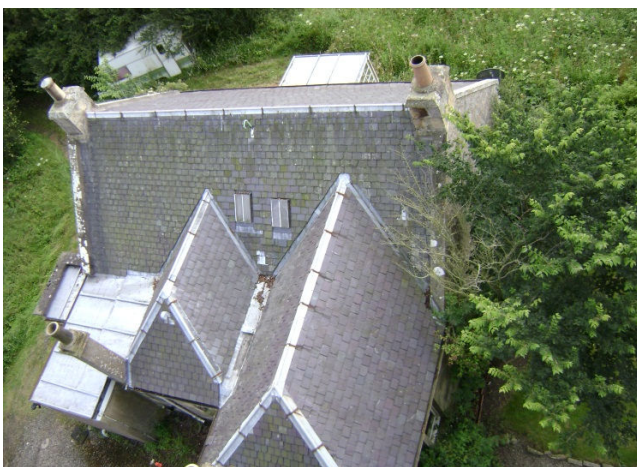
The air permeability test result of $10.6 \text{ m}^3\text{h}^{-1}\text{m}^{-2}$ @50Pa was with the inner front door of the property closed (but un-taped) and the outer porch door open, which complies to the standard test method (ATTMA TSL1 2010) as the porch is outside the heated envelope of the building. However, when the outer porch door was closed, the measured air flow through the property reduced to $2692 \text{ m}^3\text{h}^{-1}$ @50Pa, giving an air permeability result of $9.4 \text{ m}^3\text{h}^{-1}\text{m}^{-2}$ @50Pa and 11.9 ach @50Pa (a reduction of around 15%). With the porch being an unheated space, it would be ideal if the door immediately into the dwelling was draught proofed to minimise convective losses and reduce the risk of condensation in the porch.

The air flow around the loft hatch was also examined. An additional air flow of $48 \text{ m}^3\text{h}^{-1}$ @50Pa was noted, amounting to 1.6% of the total measured air flow under the test conditions and would merit draught proofing.

Both of the above results are comparable to the 2011 pre-refurbishment test.

Following the main tests, the impact on the measured air flow of the secondary glazing was explored, with the secondary glazing panels being removed apart from the panel on the small window in the rear hall which was inaccessible due to the test equipment. When the secondary glazing had been removed, an additional air flow of $574 \text{ m}^3\text{h}^{-1}$ @50Pa was noted, with just over 40% of the amount attributable to the window in Bedroom 1. The installation of the secondary glazing has reduced the air flow through the building significantly (by about 19%). However, it should be noted that Stephen⁴ indicated that losses through windows under blower door test conditions may be exaggerated compared to normal conditions.

Under the standard test procedure, chimneys and flues in the dwelling are excluded from the results. During the pre-refurbishment test, when the fireplace in the living room was uncovered an increase in air flow of $343 \text{ m}^3\text{h}^{-1}$ @ 50Pa was noted with the damper in place. However, during the post-refurbishment test, an additional air flow of only $112 \text{ m}^3\text{h}^{-1}$ @ 50Pa was recorded when the damper was in place and $134 \text{ m}^3\text{h}^{-1}$ @ 50Pa with the fireplace fully open. Subsequent investigation identified the flue has been capped (shown in photographs).



Photograph taken at time of 2011 pre-refurbishment air permeability testing showing open chimney pot to living room



Photograph taken 26 June 2012, showing capping to flue from living room

⁴ Stephen, R.K. *Airtightness in UK dwellings: BRE's test results and their significance*. BRE Report 359. Garston, 1998.

Infiltration points identified

Infiltration points were identified by locating air flows under the test conditions. The most significant item was the air flow around the front door (discussed above). It was not possible to assess the leakage from the exterior door adjacent to the bathroom, since the blower door test equipment was located in this opening.

It was noted that a small amount of fine grain vermiculite wall insulation displaced during the testing process onto the kitchen floor, but no further investigation could be carried out due to the area being obscured by the kitchen units.



Overview of ingress identified under test conditions (please note that on this occasion, the air flow around skylight in the passage was not checked). Most of the air flows were relatively minor:

| Room | Area | Description |
|------------------|-------------------------------|--|
| Vestibule | Front door | Gaps between door and surround |
| | | Opening top light |
| | Storage area | Hatch into loft |
| Bedroom 3 (East) | Floor | Junction of skirting board to floor under window |
| Bedroom 2 (East) | Cupboard | Around truncated cables in cupboard |
| Living Room | Floor | Replacement floor boarding approx.30cm from east wall of room. |
| | Floor skirting board junction | Area of wall adjoining B1 to LSH of door into Bedroom 1 |
| Kitchen | N wall | Around Water pipes coming down from loft (boxed in) |
| Bathroom | N wall | Bathroom around toilet soil pipe. |
| | | Bath outflow? (air movement felt around bath panel) |
| | Floor | Floor boards to RHS of sink |
| Entrance | Floor | Hole and junction of skirting adjacent to door to Bedroom 3. It was not possible to fully check this area, due to location of test equipment |

Conclusion

The post-refurbishment air permeability result for Scotstarvit Tower Cottage of $10.7 \text{ m}^3\text{h}^{-1}\text{m}^{-2}$ @50Pa has scope for further improvement to around $9 \text{ m}^3\text{h}^{-1}\text{m}^{-2}$ @50Pa with draught proofing the front door and loft hatch, which would compare favourably to above the recommended maximum leakage rate of $10 \text{ m}^3\text{h}^{-1}\text{m}^{-2}$ @50Pa specified in the Scottish Building Standards Technical Handbook Domestic for new dwellings (section 6.2.4). The results achieved with this test are significantly better than the pre-refurbishment result of $16.9 \text{ m}^3\text{h}^{-1}\text{m}^{-2}$ @50Pa. The secondary glazing installed at Scotstarvit Tower Cottage has provided a sizeable reduction in air flow through the dwelling under the test conditions.

Though a number of ingress points were identified under the test conditions, most of these were relatively minor.

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Historic Scotland Refurbishment Case Study 7

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