# Thermal Performance of Traditional Windows and Low-Cost Energy-Saving Retrofits

PAUL BAKER, ROGER CURTIS, CRAIG KENNEDY, AND CHRIS WOOD

**Good thermal performance of traditional windows can be achieved using low-cost methods.**

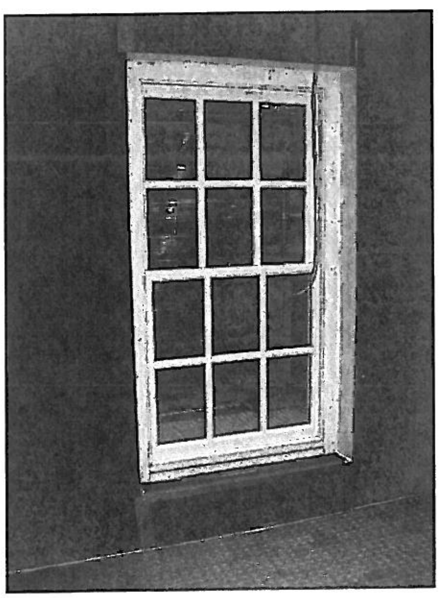

Fig. 1. The window provided for the study by Historic Scotland, manufactured in 1996 with a traditional-pattern sash and case, in as-received condition. Images by Paul Baker, unless otherwise noted.

## Introduction

In 2004 the United Kingdom's $CO_2$ emissions stood at 559 million tons per year, with 27 percent attributed to the energy used in people's homes. Scottish Government estimates suggest that approximately a third of the $CO_2$ emissions from the average home could be saved by adopting simple energy-saving measures.

However, achieving further reductions in carbon emissions from UK households to meet the UK government's target of an 80 percent reduction of 1990 $CO_2$ levels by the year 2050 is a major challenge. Some hold the opinion that traditionally constructed buildings are energy inefficient and should be replaced with new buildings rather than refurbished. However, while the operational carbon emissions of new buildings are lower than those of traditional buildings, the latter already embody carbon; energy is required to demolish them and dispose of the resulting waste, as well as to produce and transport new building materials. Existing buildings also have cultural and societal value. Improving the existing housing stock in response to climate change and reducing $CO_2$ emissions while maintaining our architectural heritage presents a challenge.

The options for upgrading thermal performance are particularly limited for pre-1919 dwellings with solid-wall construction. Replacement with modern double-glazed windows are often thought to be the easiest option for dealing with traditional single glazing. Traditional windows are often considered to be drafty, prone to condensation, and hard to maintain. On the other hand, with good care and maintenance traditional windows will outlast modern replacements and should be considered a sustainable resource. However, the heat lost through a single-glazed window is about double the loss through a double-glazed window that meets the current UK building-regulation targets (maximum U-value of 2 $W/m^2K$ for a timber or a PVC-u window). While secondary glazing (storm windows) may be effective as an option to preserve existing traditional windows, there is little information on the performance of more traditional (and cheaper) methods of reducing heat loss, such as draft-proofing or installing shutters, blinds, and curtains.

The work presented below quantifies the effectiveness of relatively simple measures to improve the thermal performance of traditional windows by draft-proofing and using blinds, curtains, shutters, and secondary glazing. Two typical traditional sash-and-casement windows with single glazing were provided for testing by Historic Scotland and English Heritage. The windows were mounted in an insulated panel between the two independently controlled rooms of an environmental chamber. Under a 68°F (20°C) temperature gradient, the heat flow through the glazing was measured using heat-flux sensors both for the glazing only and with the various improvement options. The reductions in heat loss and U-values were estimated. The improvements in the airtightness were assessed after the refurbishment of the joinery of the English Heritage window and draft-proofing of both windows. In addition, in-situ measurements of secondary glazing and shutters were performed in an early nineteenth-century building in Edinburgh.

## Laboratory Studies

The main objective of the laboratory investigations was to determine the

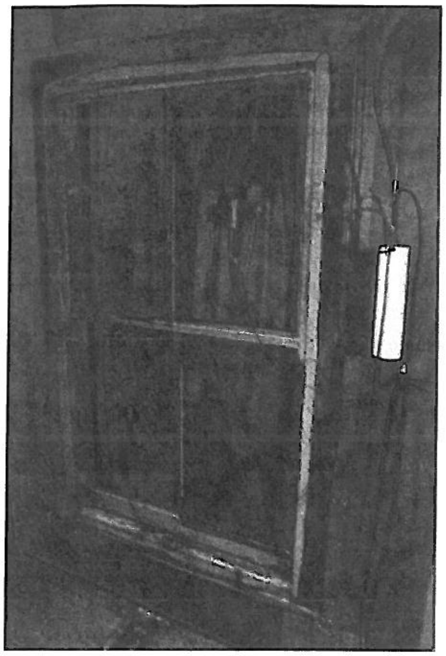

Fig. 2. Sash and case of the window provided for the study by English Heritage in as-received condition.

benefits of using methods such as the addition of shutters, blinds, and curtains on the reduction of heat loss through the glazing of two traditional sash-and-case windows. English Heritage (EH) and Historic Scotland (HS) each provided a sash-and-case test window. The HS window, which was 6 feet 2.4 inches (1.89m) high by 3 feet 5.7 inches (1.06m) wide and constructed in 1996, was received in good condition (Fig. 1). In contrast, the EH window, 5 feet 9.7 inches (1.77m) high by 3 feet 9.7 inches (1.16m) wide, dated from the 1880s and had been retrieved from scrappage; it was in poor condition (Figs. 2 through 4). The frame was out of true, with a visible gap between the upper sash and the frame. There was also evidence of timber decay in the sill and in the lower part of one of the vertical elements of the frame.

After testing the EH window in the as-received condition, the window was refurbished as follows:

- The frame was squared up.
- Part of the windowsill and part of the outer section of frame were replaced.
- A broken pane and putty were replaced.
- Gaps were filled with plastic wood.
- Sash boxes and top of window were sealed with plywood and sealant to prevent excessive air leakage.
- A coat of white primer was applied.

The repaired window is shown in Figures 3 and 4. Some thermal-performance tests were conducted on the window again after the repairs.

Each window was draft-proofed using a different system. The HS window was professionally draft-proofed by Ventrolla, Ltd.[1] This process involves some routing out of grooves in the frame to insert weather-stripping. The EH window was draft-proofed using the Quattro Seal system, which comprises a flexible sealant applied to the frame after careful preparation.[2] One surface is coated with a detergent solution to prevent the sealant from sticking. The sealant is then applied to the adjacent untreated surface. The sealant is allowed to cure, and the detergent removed. The sashes can then be opened as usual.

The windows were installed in an insulated panel that was 11.8 inches (300mm) thick and mounted between the two rooms of the Environmental Chamber at Glasgow Caledonian University (GCU). The windows were mounted in an insulated panel that divided the chamber. On one side of the chamber, conditions were set to mimic outdoor conditions, while the other was set to mimic indoor conditions, creating a 68°F (20°C) temperature gradient. A pressure gradient was applied to replicate air movements. Heat-flux sensors were then applied to the center of the glazed area to assess heat transfer, a standard research technique used by the UK's Building Research Establishment since the 1990s. Test conditions of 35.6°F (2°C) in the "exterior" room and 71.6°F (22°C) in the "interior" room were maintained. The heat flow was measured both for the glazing only and with the various improvement options using heat-flux sensors mounted on the glazing for two- to three-day measurement periods (Fig. 5). The in-situ heat-flux method was justified because guarded hot-box measurements on the HS window indicated that, while the glazed area is 55 percent of the total window area, approximately 72 percent of the heat is lost through the single glazing. Surface-temperature measurements were also made in order to determine U-values and the impact on thermal comfort using type-T thermocouples glued to the glazing surface using a bead of silicone sealant. On the curtains, blinds, and shutters the thermocouples were mounted with adhesive tape.

The airtightness of the windows was also measured before and after refurbishment of the EH window and draft-proofing of both windows, as well as after installation of secondary glazing.

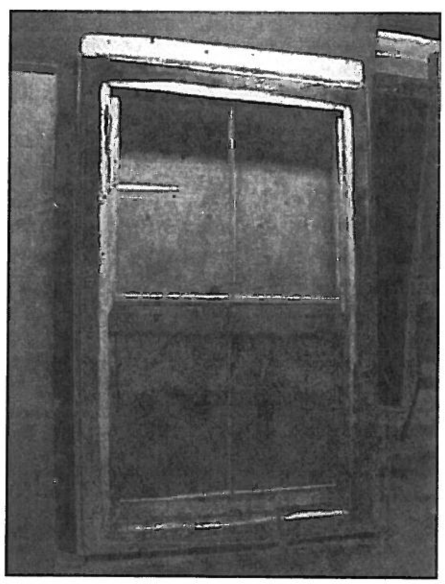

Fig. 3. English Heritage window with repaired joinery, before the second round of testing.

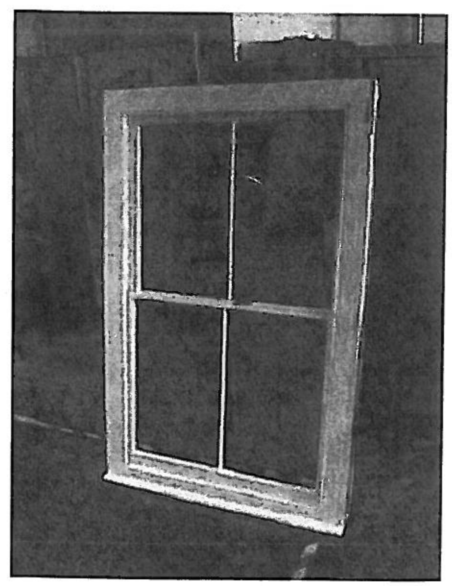

Fig. 4. English Heritage window after the gap between the upper sash and frame was filled and a coat of white primer was applied.

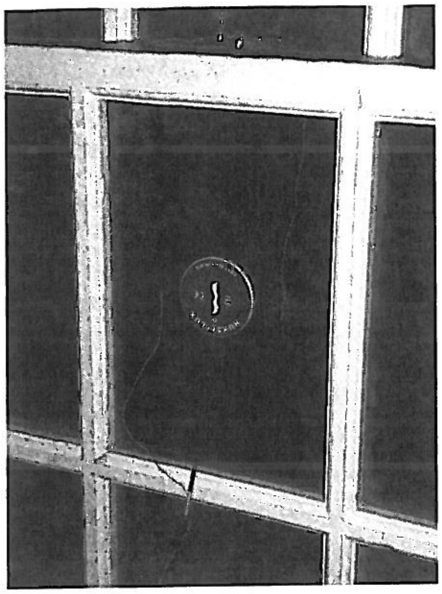

Fig. 5. Heat-flux sensor in position on the glazing of the English Heritage window.

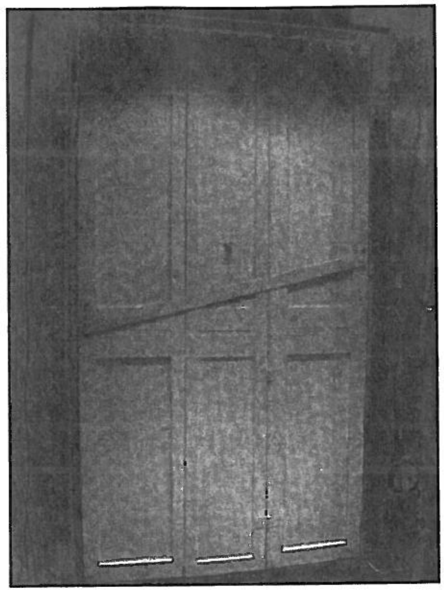

Fig. 6. Traditional shutters used with the Historic Scotland window.

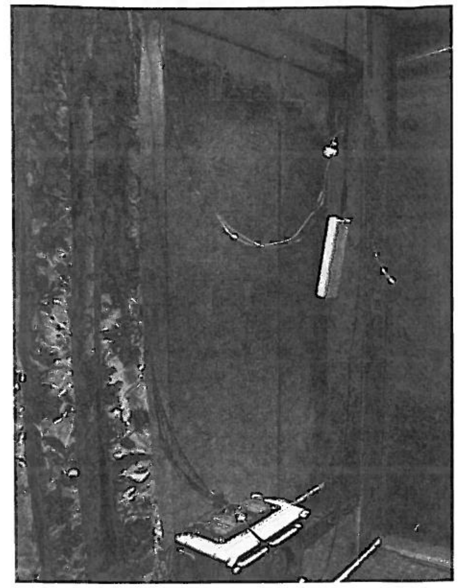

Fig. 7. Plywood shutters used with the English Heritage window (the curtains tested are at left of image).

The test options examined in the GCU environmental chamber were as follows:

- heavy curtains: lined, tight-weave curtains that allowed no light penetration
- timber shutters: salvaged traditional panelled shutters fitting the HS window (Fig. 6) and plywood shutters constructed to fit the EH window (Fig. 7)
- modified traditional shutters fitting the HS window with .4 inch (9mm) aerogel insulation inserted into panels and covered with 6mm plywood (Fig. 8).[3] The insulation has a low thermal conductivity of 0.013W/mK. The insulated area of the shutters is 55 percent.
- modern roller blind
- modern roller blind, covered with a low emissivity (low-e) film (Fig. 9)
- Victorian roller blind (a blind dating to Victorian times, designed to cover the glazed area of the window and tightly fitted) fitted to the top of the recess formed by the window-case pulley stiles at the side of the upper sash of the HS window
- a "thermal" Duette honeycomb blind manufactured by Hunter Douglas Europe b.v.
- secondary glazing with low-e coating from two manufacturers. In the HS window the secondary glazing was mounted within the staff beads (the removable inner timber strips that hold the lower sash in place) of the window (Fig. 10). The secondary glazing was mounted in front of the EH window and sealed to the surrounding structure (Fig. 11).
- replacement of the single-glazed panes in the HS window with Slimlite low-e double-glazed units, manufactured and installed by Fountainbridge Windows, Ltd., Edinburgh.[4]

**Thermal performance.** All options that were applied to the HS window were tested after draft-proofing, whereas most of the options applied to the EH window were investigated with the window in the as-received condition. Some options were then re-tested after refurbishment and following draft-proofing of the EH window.

The effect of the various options on the heat loss through the glazing was then estimated. For each option, the heat flow through the glazing was compared with that measured during the test on the single glazing only. The percentage reduction in heat loss was calculated with an adjustment for the variation in the chamber air temperatures between the tests. The results are given in Table 1.

A U-value was calculated from the average heat-flux meter reading through the glazing and the surface-temperature difference between the outer glazing surface and the room-facing surface of each option, with a correction for the standardized internal and external surface resistances and the thermal resistance of the heat-flux meter:

$$U = \frac{1}{\left(\frac{T_{si} - T_{se}}{Q}\right) + 0.17 - 6.25 \times 10^{-3}} \text{W/m}^2\text{K}$$

where $T_{si}$ and $T_{se}$ are the internal and external surface temperatures, respectively, and Q is the heat flux. The term 0.17 is the sum of the standard internal and external surface resistances, and $6.25 \times 10^{-3}$ is the correction for the heat-flux meter.

The U-value estimates are shown in Table 2. The estimated uncertainty of the U-values is 0.3 W/m²K; this variation is largely due to temperature stratification down the window, confirmed by thermographic survey.

The results for the EH window generally indicate that the airtightness of the window has no significant effect on the conductive heat loss through the glazing with the various options. All the options have some impact on reducing the heat flow through the glazing. The most effective traditional solution is the

**Table 1. The Reduction in Heat Loss through the Glazing**

| | Reduction in Heat Loss through Glazing | | | |
|---|---|---|---|---|
| | HS window | EH window | | |
| | | As-received | Refurbished | Draft-proofed |
| Curtains | 14% | 19% | 22% | 15% |
| Victorian blind | 28% | - | - | - |
| Roller blind | 22% | 36% | 37% | 32% |
| Roller blind with low-e foil | 45% | 61% | - | - |
| Duette honeycomb blind | 36% | - | 56% | 55% |
| Roller blind with low-e foil and shutters | - | 82% | - | - |
| Shutters | 51% | 62% | 64% | 62% |
| Insulated shutters | 60% | - | - | - |
| Blind and shutters | 58% | - | - | - |
| Blind, shutters, and curtains | 62% | - | - | - |
| Secondary glazing | 63% | - | - | 63% |
| Secondary glazing and curtains | 66% | - | - | - |
| Secondary glazing and shutters | 75% | - | - | 72% |
| Secondary glazing and insulated shutters | 77% | - | - | - |
| Double glazing | 55% | - | - | - |

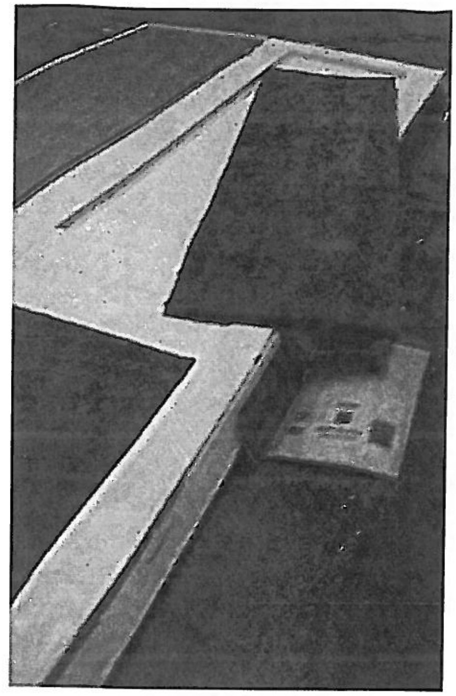

Fig. 8. Aerogel insulation of the traditional shutters used on the Historic Scotland window.

shutters. Figure 12 demonstrates the effect of closing the shutters, which reduce the heat flow through the glazing by about half. Insulating the panels of the shutters produces a U-value equivalent to low-e double glazing. The modern roller blind with the low-e foil and the honeycomb blind are also effective.

Installing the secondary glazing clearly improves thermal performance to a level that is comparable to the best of the options examined prior to its installation. However, the secondary glazing has the advantage that its benefits can be realized both day and night, as curtains and shutters will shut out daylight when closed and thus are only suitable for use at night. Augmenting the secondary glazing with the other options gives further improvement; however, the insulated shutters give only a small improvement over the uninsulated shutters. Replacing the single glazing with the Slimlite double-glazed panes also produces a significant improvement.

The study also demonstrated that the various options improved room-facing surface temperatures, 62.6 to 69.8°F (17 to 21°C), compared to about 53.6°F (12°C) for single glazing alone under the test conditions.

**Airtightness.** The airtightness of the windows was measured by a pressurization method with both test rooms at 71.6°F (22°C).

**Table 2. U-value Estimates for the Glazing**

| | U-value, W/m$^2$K | | | |
|---|---|---|---|---|
| | HS window | EH window | | |
| | | As-received | Refurbished | Draft-proofed |
| Center of glazing only | 5.2 | 5.2 | 5.2 | 5.2 |
| Curtains | 3.1 | 3.2 | 3.2 | 3.3 |
| Victorian blind | 3.1 | - | - | - |
| Roller blind | 3.0 | 3.1 | 3.1 | 3.2 |
| Roller blind with low-e foil | 2.2 | 1.8 | - | - |
| Duette honeycomb blind | 2.4 | | 2.2 | 2.3 |
| Roller blind with low-e foil and shutters | - | 0.9 | - | - |
| Shutters | 2.2 | 2.0 | 2.0 | 2.1 |
| Insulated shutters | 1.6 | - | - | - |
| Blind and shutters | 1.8 | - | - | - |
| Blind, shutters, and curtains | 1.6 | - | - | - |
| Secondary glazing | 1.7 | - | - | 2.0 |
| Secondary glazing and curtains | 1.3 | - | - | - |
| Secondary glazing and shutters | 1.1 | - | - | 1.4 |
| Secondary glazing and insulated shutters | 1.0 | - | - | - |
| Double glazing | 1.9 | - | - | - |

The HS window was measured before and after draft-proofing and after the installation of secondary glazing. The EH window was measured before and after refurbishment of the joinery to reduce gaps, etc., and after installation of the secondary glazing. The results are shown in Figures 13 and 14.

Draft-proofing the HS window reduced air leakage by more than 85 percent. While refurbishing the EH window resulted in some improvement, draft-proofing produced a reduction of 87 percent in air leakage. In order to give an estimate of the air leakage of the window under normal conditions, it is common to express the leakage as the air-flow rate at 50 Pa divided by 20 (V50/20). Before draft-proofing, this value is 11 feet 5.8 inches$^3$/h (3.5m$^3$/h), and afterwards it is 1 foot 7.7 inches$^3$/h (0.5m$^3$/h) for the HS window. Similarly, the values are 19 feet 8.2 inches$^3$/h (6.0m$^3$/h) before and 45 feet 10 inches$^3$/h (1.3m$^3$/h) after draft-proofing for the EH window. A Canadian study[5] measured the air-leakage characteristics of trickle vent with an area of 13 feet 1.5 inches$^2$ (4000mm$^2$) as recommended in Section 3.14 of the Scottish Building Standard 2007[6] for use in kitchens, bathrooms, toilets, and utility rooms.

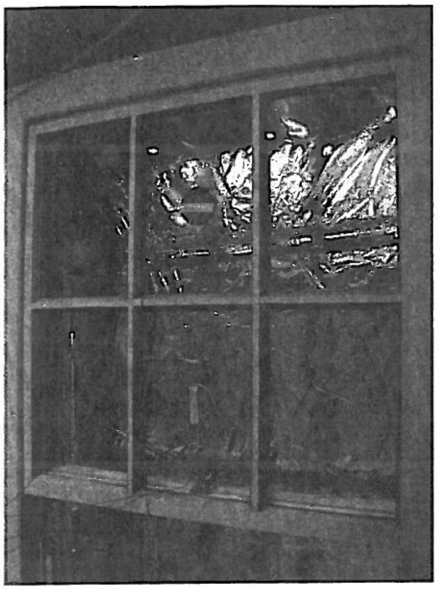

Fig. 9. Low-e foil on the side of the roller blind facing the Historic Scotland window.

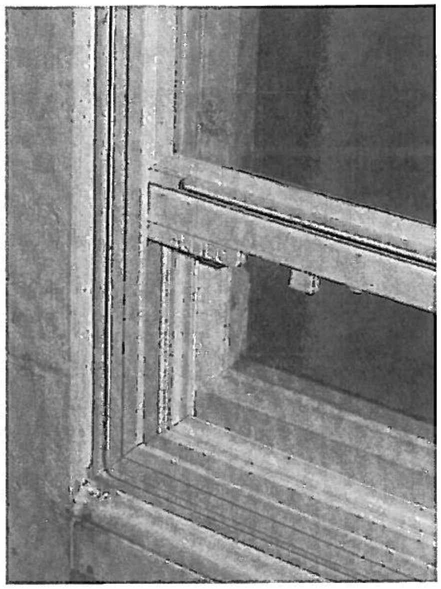

Fig. 10. Secondary glazing system installed within the staff beads of the Historic Scotland window.

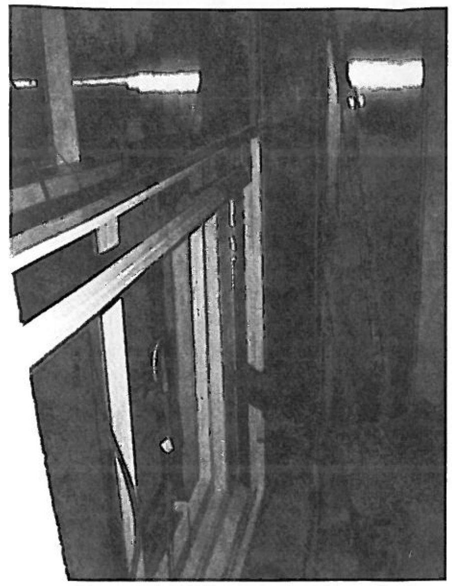

Fig. 11. Secondary glazing system mounted in front of the English Heritage window.

The V50/20 value is 7 feet 6.6 inches$^3$/h (2.3m$^3$/h), which is somewhat higher than the draft-proofed sash-and-case windows.

The carefully sealed secondary-glazing systems provide further reduction in air leakage with V50/20 values of 3.9 inches$^3$/h (0.1m$^3$/h) and 1 foot 3.7 inches$^3$/h (0.4m$^3$/h) for the HS and EH windows, respectively. Since both secondary-glazing systems can be opened, it is possible to ventilate through the window when required.

### In-situ Measurements

In-situ U-value measurements were made during the winter of 2007-2008 on the glazing of windows in the early-nineteenth-century apartments and offices known as Lauriston Place in Edinburgh, in order to assess the effect of secondary glazing with low-e glazing and shutters. The basic methodology used is the same as that for the thermal-performance tests carried out in the GCU environmental chamber; however, under real climate conditions a longer monitoring period of at least two weeks is required to obtain satisfactory results. The occupants of the apartment with shutters were asked to open and close the shutters as normal practice. Typical measurements from the shutter test are shown in Figure 15, which demonstrate the effectiveness of the shutters. The estimated U-values are given in Table 3.

**Table 3. In-situ Results from Lauriston Place, Edinburgh**

| | U-value W/m$^2$K |
|---|---|
| Single glazing only | 5.5 |
| Single glazing with secondary glazing | 2.3 |
| Single glazing with shutters | 2.2 |

The shutter results show good agreement with the laboratory study, although the secondary-glazing result is higher than anticipated from the laboratory tests with the similar system fitted to the HS window.

### Conclusions

All of the options tested in the GCU Environmental Chamber reduce the heat loss through the glazing. Shutters are the most effective of the traditional methods. Further improvements can be made by insulating the shutters. Improved blind designs also have the potential to reduce heat loss. High-performance secondary glazing and replacement double-glazed panes offer improved thermal performance throughout the day.

All of the options offer improved thermal comfort due to higher surface temperatures compared to single glazing alone. The in-situ U-value measurements confirm in practice the performance of traditional shutters and show the potential benefits of low-e glazing in a secondary-glazing system.

The results for the EH window generally indicate that the airtightness of the window has no significant effect on the conductive heat loss through the glazing with the various options.

The pressurization tests demonstrate the effectiveness of two draft-proofing systems in reducing air leakage by about 85 percent. Well-sealed secondary-glazing systems further improve airtightness.

These results demonstrate that traditional methods can be used to improve the thermal performance of windows and, in turn, the thermal comfort of a room. In many cases, traditional windows are targeted for replacement due to their poor thermal performance. This study demonstrates that good thermal performance can be achieved by relatively low-cost methods, such as employing shutters, blinds, and curtains. Further performance gain is achievable by using sensitive methods such as secondary glazing, which allow the historic character of the window to be retained.

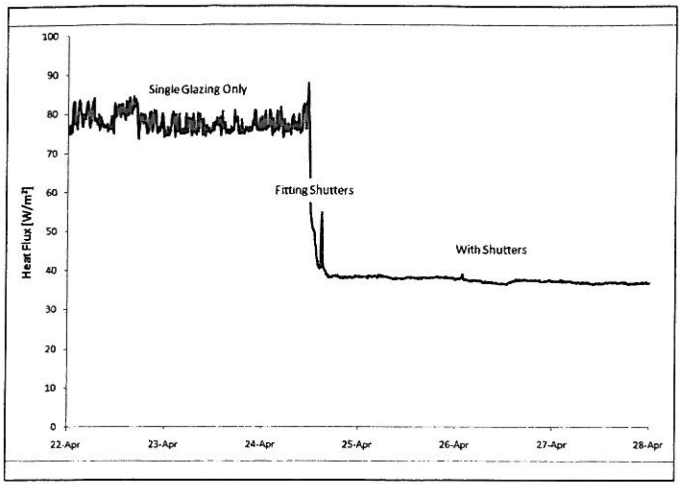


Fig. 12. Graph showing the effect of closing the shutters on the heat flux of the Historic Scotland window. Courtesy of Historic Scotland.

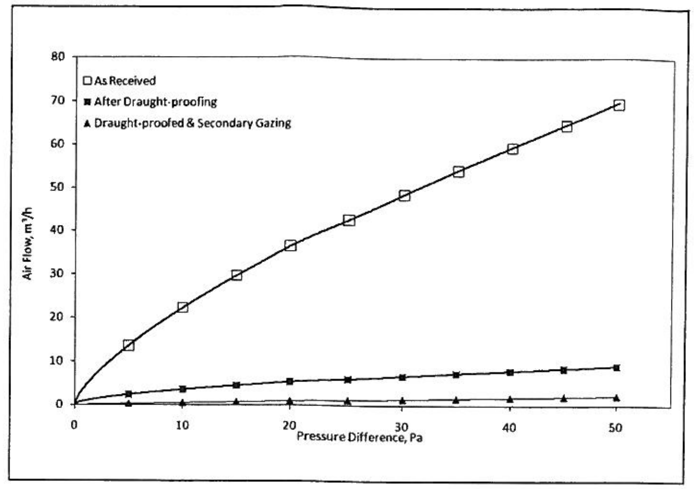


Fig. 13. Graph showing the air-leakage characteristics of the Historic Scotland window before and after draft-proofing by Ventrolla and after fitting with secondary glazing.

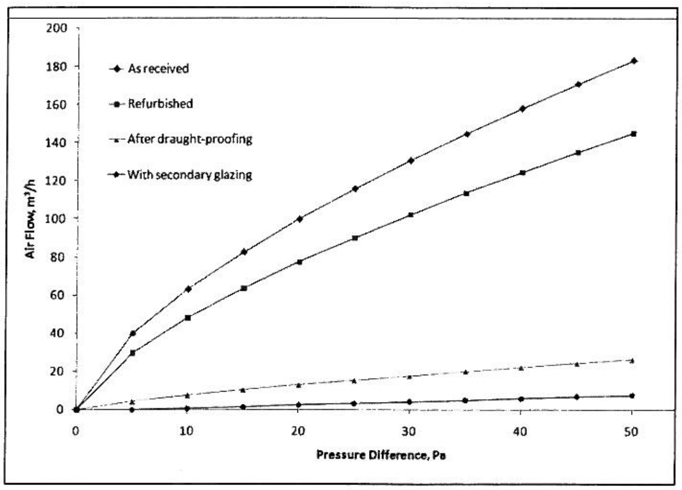


Fig. 14. Graph showing the air-leakage characteristics of the English Heritage window in as-received condition and after refurbishment, draft-proofing, and installation of secondary glazing.

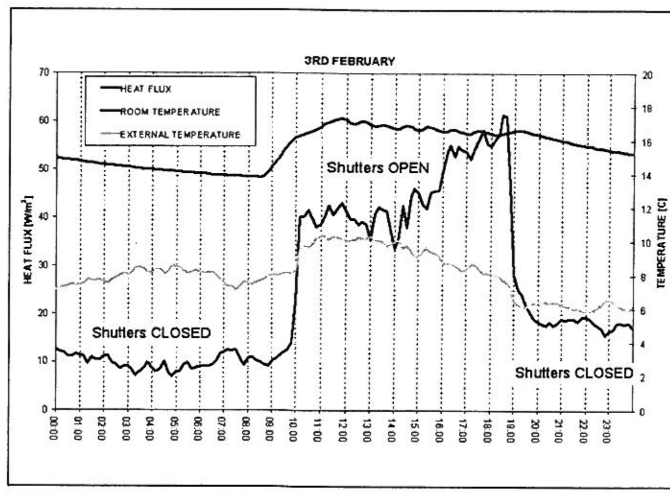


Fig. 15. Graph showing the effect of opening and closing the shutters at Lauriston Place, Edinburgh.

PAUL BAKER has 25 years of experience working in building physics at the Building Research Establishment (BRE) and subsequently in academia. He has been researching improving energy efficiency in buildings and working with Historic Scotland on the evaluation of the thermal performance of traditionally built structures and interventions to improve energy efficiency.

ROGER CURTIS worked on restoration and consolidation projects in Scotland before moving to Historic Scotland's Technical Conservation Group in 2006 and has been head of technical research since 2008. He completed an MS in building conservation in 2003 at Heriot Watt University in Edinburgh and manages projects concerning traditional structures and materials.

CRAIG KENNEDY obtained a PhD from Cardiff University working on examining the deterioration of collagen within historic parchment. Further work at Cardiff included analyzing the structure of cellulose microfibrils, as well as historical materials. He then joined Historic Scotland and became head of science in 2007, working on historic-building deterioration.

CHRIS WOOD is head of the building conservation and research team at English Heritage, where he has worked for the last 16 years. He is responsible for running a number of research programs, including ones that seek to benignly improve energy efficiency in historic buildings.

## Notes

1. See www.ventrolla.co.uk/theventrollaservice/perimetre-sealing-system--7.

2. See www.quattroseal.com/seal-information.htm.

3. See www.spacetherm.com/pdf/apg5738%20spacetherm%20v5.pdf.

4. See www.fountainbridgewindowrenovations.co.uk/double_glazing.htm.

5. P. Karava, A. Athienitis, and T. Stathopoulos, "Investigation of the Performance of Trickle Ventilators," *Building and Environment* 38, no. 8 (Aug. 2003): 981–993.

6. Scottish Building Standards Domestic Handbook 2007, www.sbsa.gov.uk/tech_handbooks/tbooks2007.htm.