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Improving the Thermal Performance of Traditional Windows: Metal-framed Windows

Prepared for Historic England by
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Front cover: Steel-frame pivot windows, *c.*1950 ©Historic England

FOREWORD

Understanding the energy performance of historic buildings and the effects of measures to reduce energy use and carbon emissions

The imperative to improve the energy performance of the built environment presents particular challenges for traditionally constructed and historic buildings. While modern technologies to reduce energy use and carbon emissions (efficient heating, hot water supply and lighting systems; better controls and management techniques to reduce waste; low-carbon energy supplies) are often easily incorporated, measures to increase the thermal performance of building fabric are more difficult. Walls, windows and doors – elements that contribute greatly to the heritage significance of a building – can be especially problematic. This is not solely an aesthetic concern: altering the balance between heat, air and moisture transfer can also affect the well-being of the building and the health of its occupants.

It is a widely held view that older buildings are not energy efficient and that radical upgrading is needed, starting with the building fabric. In reality, the situation is more complicated, and assumptions made about poor performance are not always justified. The research project described in this report forms part of a programme of investigation to understand better the performance of older buildings and the effects of energy efficiency measures. The aim is to provide information that will enable better-informed, evidence-based decisions to be made about improving the energy and carbon performance of the historic built environment.

SUMMARY

This report summarises the results of research to investigate the thermal performance of metal windows and methods of reducing heat loss. The project was carried out by the Centre for Research on Indoor Climate & Health, Glasgow Caledonian University (GCU) on behalf of Historic England (previously English Heritage). The testing programme aimed to quantify the thermal performance of the single-glazed metal-framed windows tested, and the benefits of simple improvements including curtains, blinds, draught-stripping, and secondary glazing options.

CONTRIBUTORS

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IMAGES

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1 INTRODUCTION

Many building owners are choosing to replace their traditional windows with modern replacements in the belief that this will bring about an improved thermal performance. This report summarises the results of research on the thermal performance of metal windows and methods of reducing heat loss carried out by the Centre for Research on Indoor Climate & Health, Glasgow Caledonian University (GCU) on behalf of Historic England. The testing programme aims to quantify the extent of the benefits offered to the thermal performance of single-glazed metal-framed windows by curtains, blinds, draught stripping, and secondary glazing options. The results of this research are intended to inform owners of options to enhance thermal performance without removing the historic building fabric.

Two metal-framed windows were mounted in an insulated panel between the two independently controlled rooms of an environmental chamber at GCU. Under a 20°C temperature gradient, the heat flow through the glazing was measured using heat flux sensors for the glazing only and with the various improvement options. The reduction in heat loss and U-values were estimated. The airtightness of each window was determined before and after draught-proofing using a proprietary sealing system. Condensation tests were also carried out on the windows, with emphasis on the use of secondary glazing options.

2 THE TEST WINDOWS AND OPTIONS

Historic England provided two metal-framed windows for testing. Both are out-swinging casement windows. The condition of the windows was fair. Both windows have approximately the same external frame size (90 cm x 48 cm). The white window has six panes, giving a glazed area of approx. 70% (Figure 1). The black window contains 12 panes, giving a glazed area of approx. 67% (Figure 2). Both windows were mounted within the reveal of a test panel (Figure 3).

Two new single glazed windows (Figure 4) were also provided by the manufacturer of a proprietary secondary glazing system (unsuitable for the Historic England windows, but appropriate for many post-war metal-framed windows). The windows were manufactured with the same external dimensions as the Historic England windows. One window has a fixed pane, the other is openable.


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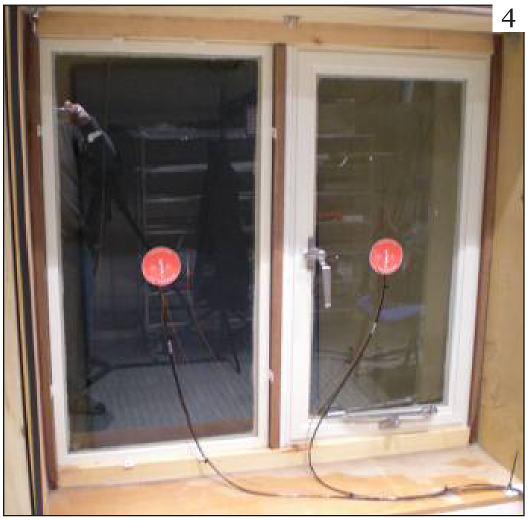
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Figure 1: White metal-framed window with removable acrylic secondary glazing.
Figure 2: Black metal window with leaded panes.
Figure 3: Windows mounted side-by-side in reveal of test panel.
Figure 4: New single glazed metal windows for secondary glazing system.

The options tested were as follows:

- The white window was supplied with a prototype secondary glazing system, which incorporated magnetic strips to hold an acrylic sheet to the edge of the openable section of the window (Figure 1). Desiccant strips were also applied to the metal frame to prevent condensation.
- Heavy curtains mounted outside the reveal.
- Honeycomb thermal blind mounted inside the reveal (Figure 5).
- Roller blind mounted outside the reveal.
- Roller blind mounted outside the reveal, backed with a low emissivity foil facing the window (Figure 6).
- Roller blind mounted inside the reveal (Figure 7).
- Roller blind mounted inside the reveal, backed with a low emissivity foil facing the window.
- A prototype transparent blind mounted outside the reveal (Figure 8). This blind incorporates a method of sealing to the surrounding wall surface.
- A prototype fabric blind with a low emissivity foil facing the window and incorporating the same method of sealing as Option 8.
- A conventional secondary glazing system with low emissivity glazing mounted inside the reveal (Figure 9).
- Secondary glazing was applied directly to the existing panes of the new metal-framed windows. The secondary glazing is applied by bonding a glazing spacer, as would be found in a conventional double glazed unit, onto the original pane. The spacer contains a desiccant. A second pane of glass is then bonded onto the spacer to form, effectively, a double glazed unit. Trim is then fixed to cover the exposed edges of the glass. One of the secondary glazed panes was low-e coated, the other plain glass.

Both the windows supplied by Historic England were draught-proofed using a proprietary system, which comprises a flexible sealant applied to the frame after careful preparation. 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 window can then be opened as usual.

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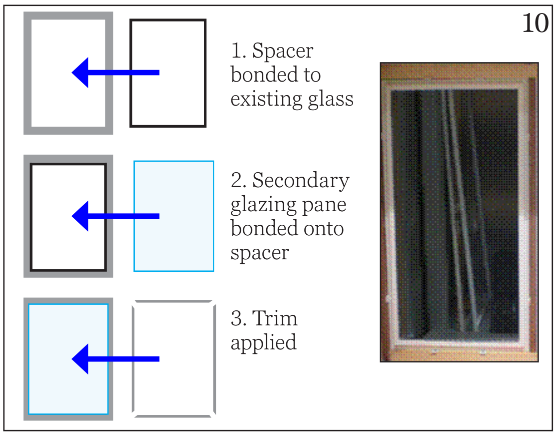

Figure 5: Honeycomb blind mounted within reveal.
Figure 6: Roller blind with low emissivity foil, mounted outside reveal.
Figure 7: Roller blind mounted inside reveal.
Figure 8: Transparent blind mounted outside reveal and sealed to edges of wall.
Figure 9: Secondary glazing system mounted in reveal in front of the Historic England windows.
Figure 10: Secondary glazing system applied to new metal-framed window.

3 THERMAL PERFORMANCE TESTS

3.1 Test procedure and analysis

The test windows were firstly mounted in a hard wood frame (Figure 3) and then installed in a 300 mm-thick insulated panel mounted between the two rooms of the GCU Environmental Chamber with the frame set flush with the cold face of the panel as recommended by *BS EN ISO 12567-1:2000* [1]. Sealant was used around the joints between the frame and the insulated panel in order to seal all gaps and hold the windows firmly in position.

The Environmental Chamber, the test procedure and analysis method have been previously described in Baker [2].

Most of the options were tested before and after draught-proofing, however in the case of the white metal-framed window the acrylic secondary glazing was retained throughout the test period before draught-proofing and tested in tandem with the other options, but removed after establishing its performance following draught-proofing.

The centre-of-pane U-value and the reduction in heat loss through the glazing due to each option are calculated fromthe heat flux through the glazing and the temperature difference across the glazing and the option.

3.2 Results

The test results are given in Table 1 for the black window, Table 2 for the white window and Table 3 for the new metal-framed windows. Note that most of the tests of the various options on the white window were carried out with the acrylic secondary glazing in place prior to draught-proofing.

Figure 11 and 12 show the options in ranked in order of effectiveness of the various options applied to the windows supplied by Historic England. The results for the white window with the acrylic secondary glazing with additional option are shown in Figure 13.

Given the level of uncertainty of the measurements, the results before and after draught-proofing are not significantly different.

The most effective options are the blind with low emissivity foil, the honeycomb blind and the low-e secondary glazing. Mounting the low emissivity blind within the reveal gives a better result than mounting the blind outside the reveal.

The acrylic secondary glazing applied to the white window and the plain glass secondary glazing applied to the new metal-framed window are about as effective as ordinary double glazing without a low-e coating.

Additional options with the acrylic secondary glazing give further improvements, particularly with the low emissivity blind.

Table 1: The effect of the various options on the centre-of-pane U-value and the reduction in heat loss through single glazing for the black metal-framed window

	Before draught-proofing		After draught-proofing	
	U-value W/m^{2}K	Reduction in heat loss through glazing	U-value W/m^{2}K	Reduction in heat loss through glazing
Single glazing only	5.2	–	5.2	–
with options as follows:				
+ curtains	3.0	43%	3.0	43%
+ honeycomb blind mounted in reveal	2.8	47%	2.5	53%
+ roller blind mounted outside reveal	3.3	36%	3.2	38%
+ roller blind mounted inside reveal	3.4	35%	3.3	37%
+ roller blind mounted outside reveal. Roller blind has low-e foil facing window	2.7	48%	2.5	51%
+ roller blind mounted inside reveal. Roller blind has low-e foil facing window	2.4	54%	2.3	55%
+ tight fitting transparent blind mounted outside reveal	2.7	48%	–	–
+ tight-fitting blind mounted outside reveal. Roller blind has low-e foil facing window	2.4	53%	–	–
+ secondary glazing with low-e glazing fitted into reveal in front of window	–	–	1.9	63%

Table 2: The effect of the various options on the centre-of-pane U-value and the reduction in heat loss through single glazing for the white metal-framed window

	Before draught-proofing		After draught-proofing	
	U-value W/m^{2}K	Reduction in heat loss through glazing	U-value W/m^{2}K	Reduction in heat loss through glazing
Single glazing only	5.2	–	5.1	–
with options as follows:				
+ curtains	3.0	43%	3.0	42%
+ honeycomb blind mounted in reveal	–	–	2.3	54%
+ roller blind mounted outside reveal	–	–	3.2	38%
+ roller blind mounted inside reveal	–	–	3.2	38%
+ roller blind mounted outside reveal. Roller blind has low-e foil facing window	–	–	2.4	53%
+ roller blind mounted inside reveal. Roller blind has low-e foil facing window	–	–	2.0	61%
+ tight fitting transparent blind mounted outside reveal	2.9	45%	–	–
+ tight-fitting blind mounted outside reveal. Roller blind has low-e foil facing window	2.6	50%	–	–
+ secondary glazing A with low-e glazing	–	–	1.8	64%
+ acrylic secondary glazing	2.8	47%	2.8	45%
+ acrylic secondary glazing & curtains	1.9	63%	–	–
+ acrylic secondary glazing & honeycomb blind mounted in reveal	1.8	66%	–	–
+ acrylic secondary glazing & honeycomb blind mounted outside reveal	2.2	57%	–	–
+ acrylic secondary glazing & roller blind mounted inside reveal	2.2	58%	–	–
+ acrylic secondary glazing & roller blind mounted outside reveal. Roller blind has low-e foil facing window	1.5	71%		
+ acrylic secondary glazing & roller blind mounted inside reveal. Roller blind has low-e foil facing window	1.5	71%		

Table 3: The effect of the two secondary glazing options on the new metal-framed window

	Single glazing only	With secondary glazing	
	Centre-of-pane U-value W/m^2K	Centre-of-pane U-value W/m^2K	Reduction in heat loss through glazing
Left (fixed) with low-e secondary glazing	5.3	1.6	69%
Right (openable) with plain secondary glazing	5.3	2.8	46%

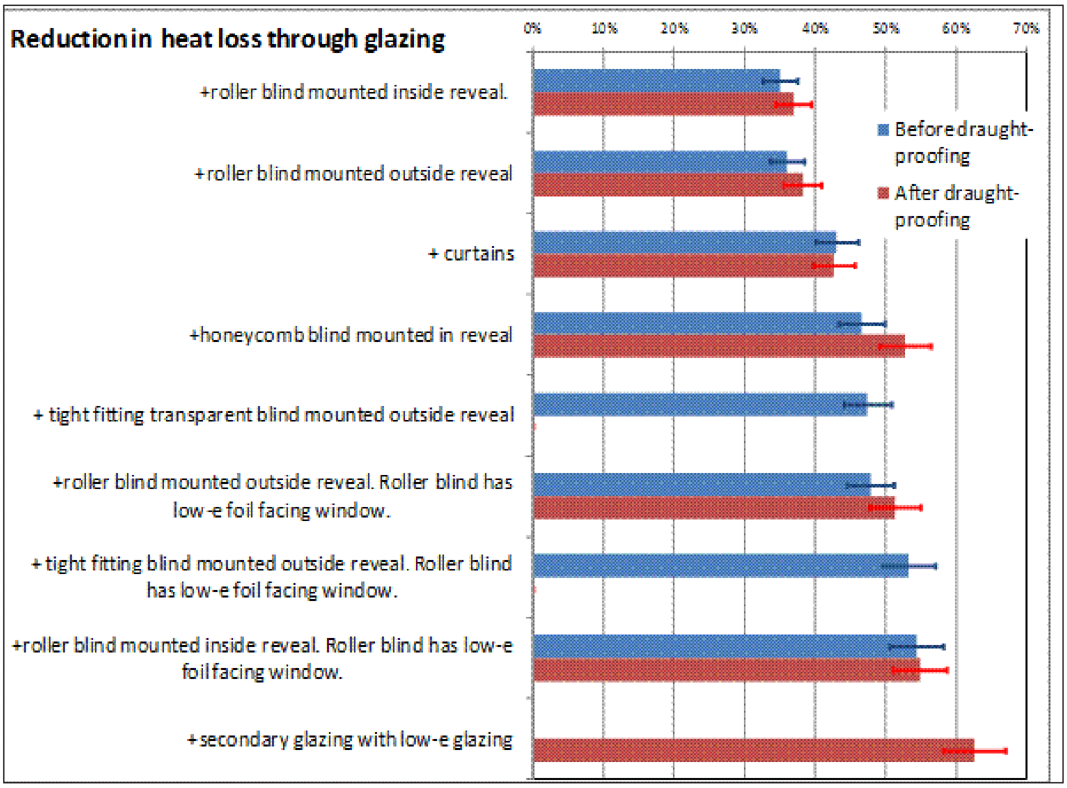

Figure 11: The options in ranked in order of effectiveness of the various options applied to the black window supplied by Historic England.

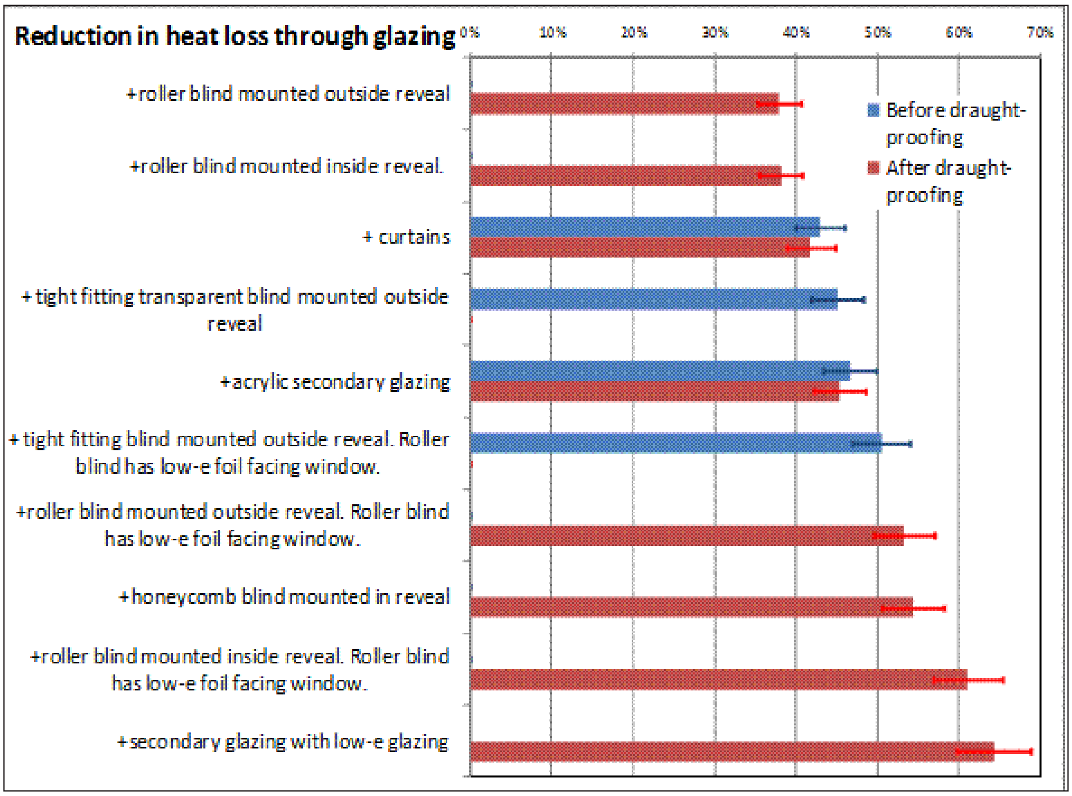

Figure 12: The options in ranked in order of effectiveness of the various options applied to the white window supplied by Historic England.

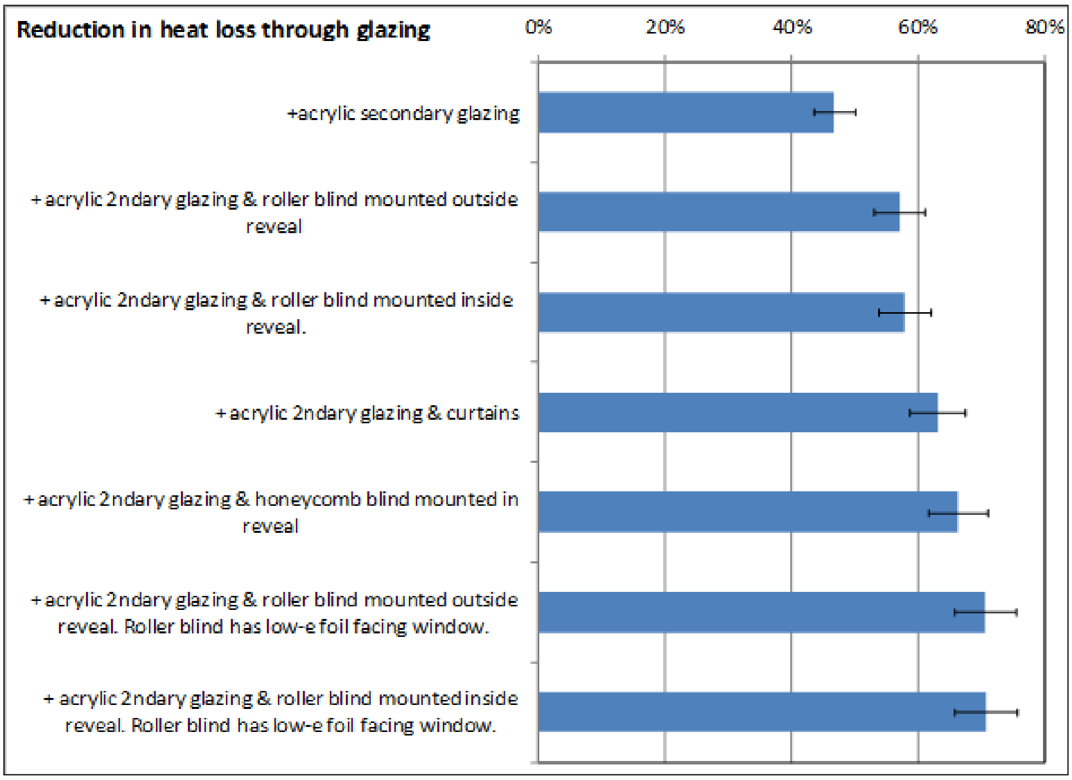

Figure 13: The effectiveness of the acrylic secondary glazing in conjunction with other options.

3.3 Whole-window conductive heat loss

The results above show the effect of the various options on reducing the conductive heat loss through the glazing of the metal-framed windows. The impact of the measures on the whole window (frame and glazing) was estimated for the white metal-framed window using a 2-D finite element model, FRAME [3] specifically designed for windows. FRAME models the window in three zones (Figure 14):

- the centre of glazing
- the edge of glazing: a 63.5mm-wide zone which accounts for the thermal bridging between the frame and glazing
- the frame: in the case of the metal window Section A-A (Figure 14) is the main frame and Section B-B is the glazing bar.

FRAME was used to calculate the U-values of window with single glazing only, and the addition of (a) curtains as a typical option and (b) low-e secondary glazing as the best option tested in the study. The curtains and the secondary glazing were added as extra layers with an air gap between the original primary window and the option (Figure 15).

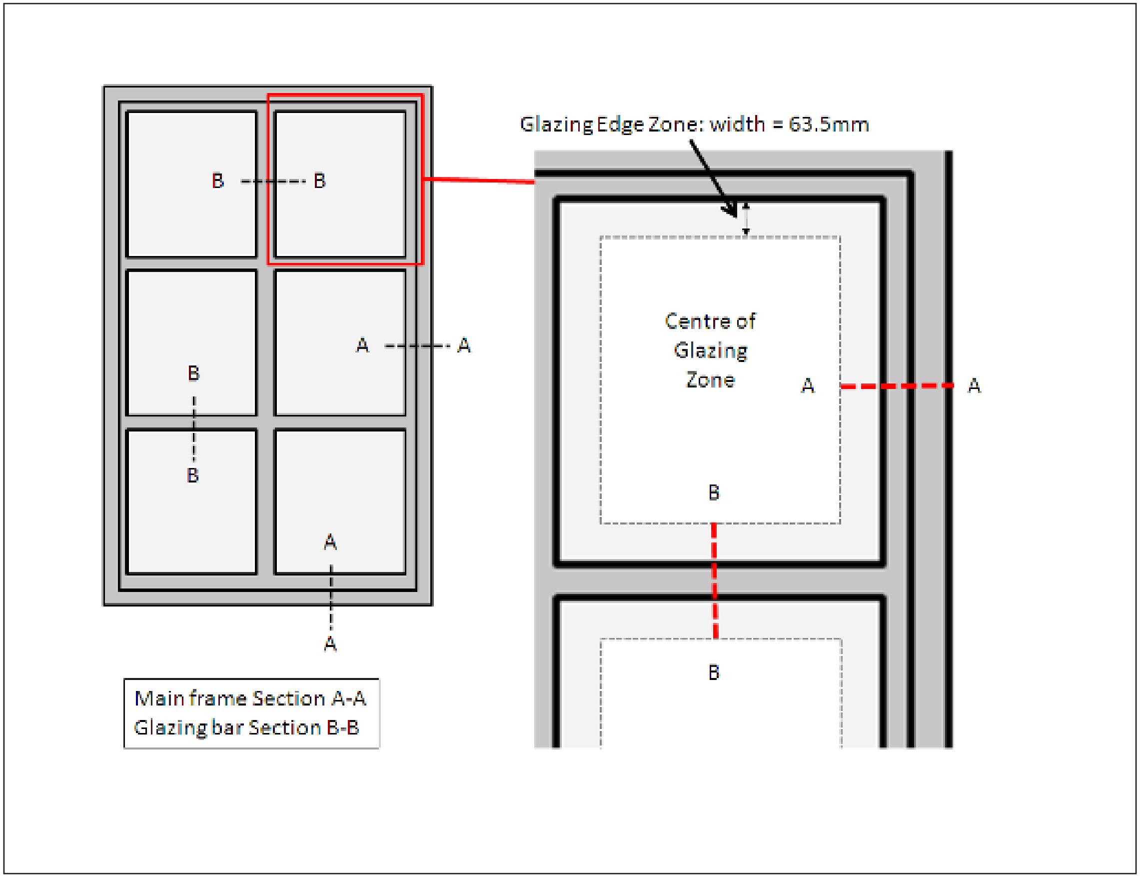

Figure 14: FRAME modelling of the metal window – schematic diagram of the window and the zones and cross-sections modelled.

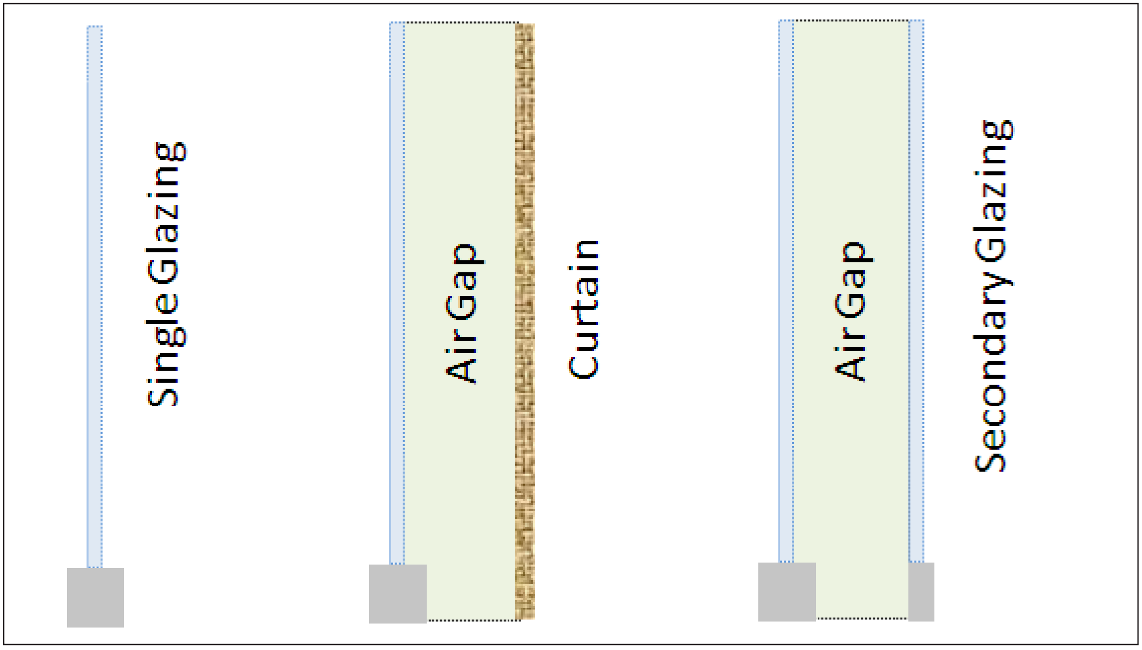

Figure 15: Modelling the addition of curtains and secondary glazing.

The resulting U-values were area-weighted to give an overall U-value for the window. The window frame U-values were also derived, which includes the main and glazing bars (Section A-A and B-B). The calculated values for the window with single glazing only, and the addition of (a) curtains and (b) low-e secondary glazing are given in Table 4. Note that the glazing U-value given in the table includes the edge effects.

The FRAME calculations indicate that whilst low-e secondary glazing has the greater impact on reducing heat loss through the whole window, curtains are an effective option. The benefit of both options is not only in reducing the heat loss through the glazing, but also making a significant reduction through the window frame. The secondary glazing option is less effective than the curtains at reducing heat loss through the window frame, since the system has an aluminium frame.

Table 4: Calculated whole-window U-values and reduction due to addition of (a) curtains and (b) low-e secondary glazing

	Whole-window U-value W/m²K	Reduction compared with single glazed window	Frame U-value W/m²K	Glazing U-value W/m²K
Single glazing only	6.6		8.2	5.8
(a) Single glazing + curtains	2.5	63%	2.4	2.5
(b) Single glazing + low-e secondary glazing	2.1	68%	2.8	1.8

4 AIRTIGHTNESS TESTS

The airtightness of the windows as-received and after draught-proofing was measured by a pressurisation method with both test rooms at 22°C [2]. The test is carried out in two parts, (i) with potential air leakage paths taped over (Figure 16), to determine the background air leakage of the test room and (ii) without the window covered to determine the total air leakage of the room and window at each pressure difference. The background leakage at each pressure difference is subtracted from the total leakage to estimate the window leakage.

The results are plotted and a power law relationship is usually fitted to the data. The results for the window before and after draught-proofing are shown in Figures 17 and 18.

The draught-proofing system results in over a 95% reduction in air leakage through both windows.

Figure 16: Potential air leakage paths taped over for the measurement of background leakage.

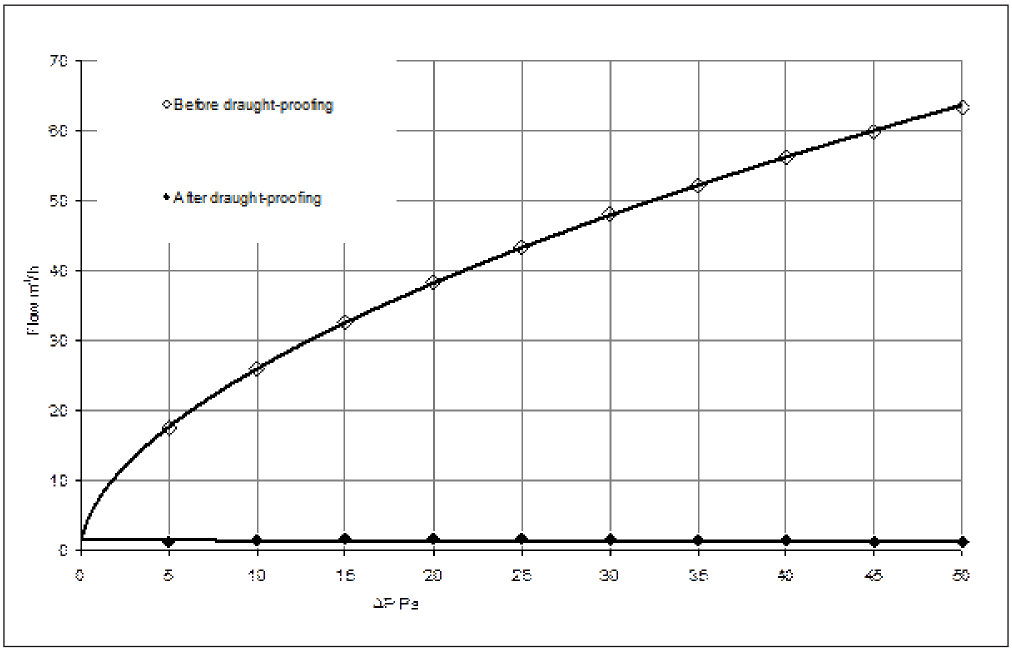

Figure 17: Air leakage characteristics of the black window before and after draught-proofing.

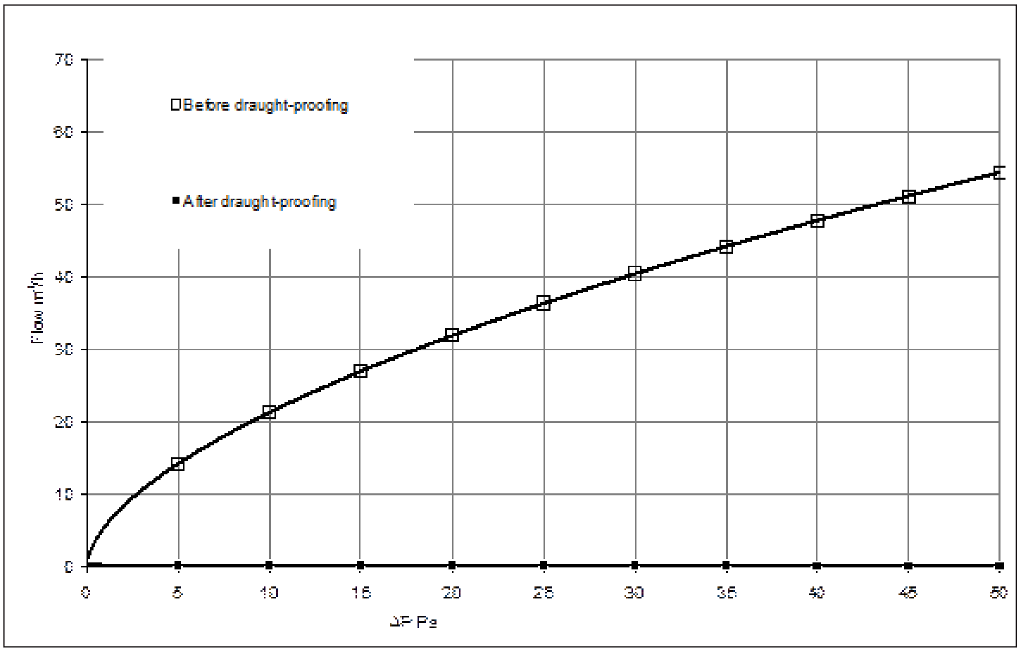

Figure 18: Air leakage characteristics of the white window before and after draught-proofing (note that the tests were carried out with the acrylic secondary glazing removed).

5 CONDENSATION TESTING

The warm room of the chamber was usually maintained at 30% relative humidity (RH) in order to prevent condensation on the glazing, whilst the recommended range of relative humidity in dwelling is 45-60%. The relative humidity was raised to 60% with a warm room temperature of 22°C and the cold room at 2°C. After six hours any condensation on the window, including the metal frame, was mopped up using absorbent paper and weighed.

Two studies were carried out: before draught-proofing, and with the conventional secondary glazing (Option 10).

5.1 Before draught-proofing

The black was as-received with single glazing only. The white window was secondary glazed with the acrylic system.

18 grams of condensate were collected from the black window including the metal frame (Figure 19).

5 grams of condensate were collected from the metal frame of the white window, with no condensation on the surface of the acrylic secondary glazing. However, some condensation occurred on the single glazing, probably due to the difficulty of sealing the acrylic secondary glazing around the window opening mechanism (Figure 20).

Generally, during the tests with the different options some condensation was observed, noticeably on the frames. Figure 21 shows a thermographic image of the two windows. The frame temperature is about 6°C, which is slightly lower than the temperature of the single glazing of the black window (right hand side). The surface temperature of the secondary glazing (left hand side) is considerable warmer, about 14°C, compared with the frame temperature.

Figure 19 (left): Condensation on the black window.
Figure 20 (right): Condensation occurring on the single glazing of the white window with secondary glazing.

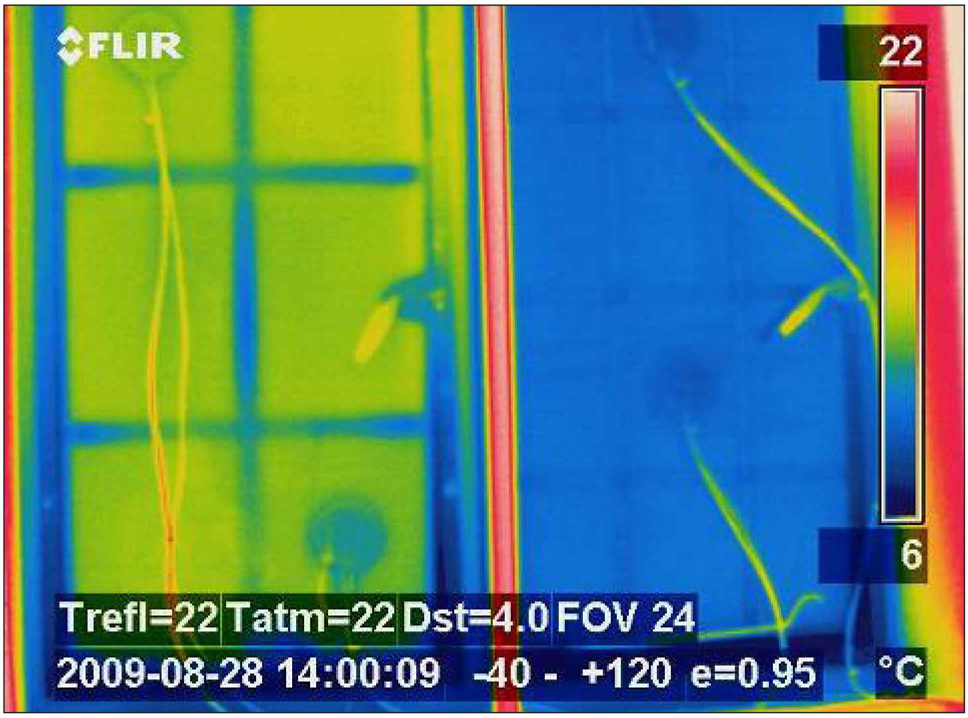

Figure 21: Thermographic image of the two windows. Left hand side: white window with acrylic secondary glazing. Right hand side: black window.

5.2 Tests with secondary glazing

Four options were tested to investigate the influence on condensation risk of draught-proofing the windows and the tightness of the seal of the secondary glazing. Test were carried out with the draught-proofing in place and then removed, and the secondary glazing tightly sealed and with a slight gap formed by wedging a thin spacer between the sash and frame of the secondary glazing system (Figure 22). The results are shown in Table 5 for the primary window.

Generally, the secondary glazing itself was largely unaffected, except in case A, which showed slight misting after 6 hours. Cases A and C with the secondary glazing tightly closed showed no evidence of condensation on the primary window. However, with the secondary glazing slightly open, significant quantities of condensate were collected. Observations showed the following over the course of the test:

- After about one hour misting was observed.
- After two hours small droplets were noted - the ‘orange peel’ effect.
- After three hours the droplet size increases.
- After about four hours of testing significant runs of condensation occur as larger droplets coalesce.

Figure 22: Condensation test with secondary glazing slightly open.

About 30% more condensation forms on the black window compared to the white window. The most likely explanation is that the black window has 12 smaller panes, which increases thermal bridging due to the higher glass/metal perimeter area. The condensation risk is therefore greater since this area is probably cooler than the centre of the panes.

Draught-proofing (Case B) appear to reduce the amount of condensate formed by about 25% compared to Case D with the draught-proofing removed, however the risk is still high. Allowing a continuously flow of warm air to the outside, as in Case D, may result in a higher condensation rate.

Comparing the results for the black window with secondary glazing (Case D) to the same window without secondary glazing indicates that the condensation risk is higher with leaky secondary glazing. The explanation is that the primary window temperature is lower with secondary glazing and therefore warm, moist air passing through the gap in the secondary glazing system will cool further below its dew point releasing more condensate on the window surface.

Table 5: Condensation on primary window (frame + glazing) after 6 hours at 60% RH & 22°C with 2°C 'outdoor' temperature

		Black window	White window	Comment
A	Window draught-proofed + secondary glazing tightly sealed	No noticeable Condensation	No noticeable Condensation	Misting occurred on primary glazing when opening secondary glazing. Misting on frame (0.5g) and lower corner of secondary glazing (<0.1g)
B	Window draught-proofed + gap introduced between secondary glazing and its frame	19.5g	28.4g	
C	Window with draught-proofing removed + secondary glazing tightly sealed	No noticeable condensation	No noticeable condensation	Misting occurred on primary glazing when opening secondary glazing after test
D	Window with draught-proofing removed+ gap introduced between secondary glazing and its frame	24.4g	35.7g	

6 CONCLUSIONS

All the options tested in the GCU Environmental Chamber reduce the heat loss through the glazing. The more effective options are secondary glazing systems which use low-e glazing.The prototype blinds with low emissivity foils and a commercially available honeycomb blind are the most effective“non-fixed” options. A prototype acrylic secondary glazing system, whilst giving reasonable performance is difficult to seal due to the opening mechanism of the window.

2-D finite element modelling of the window was carried to estimate whole window conductive heat loss of a metal-framed window with single glazing only, and the addition of curtains as a typical option and low-e secondary glazing as the best option tested in the study. The results indicate that whilst low-e secondary glazing has the greater impact on reducing heat loss through the whole window (68% reduction in heat loss), curtains are also an effective option (63%). The benefit of both options is not only in reducing the heat loss through the glazing, but also making a significant reduction through the window frame. The secondary glazing option is less effective than the curtains at reducing heat loss through the frame, since the system has an aluminium frame.

The air tightness of the windows can be improved considerably using a proprietary draught-proofing system.

The condensation tests on the windows show that the risk of condensation is high at the upper end of the range for domestic humidity conditions (60% RH). Cold bridging of the metal window frame leads to increased condensation risk compared to a timber framed window.

With secondary glazing in place, the risk of condensation forming on the primary window is low if the secondary glazing is well sealed, but the risk is high if the secondary glazing is not tightly closed.

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