Development and thermal evaluation of a secondary glazing system

Report for

The Glass Shutter Company Ltd

Invest NI Innovation Voucher

Reference No. IV 0712066

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February 2013

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1.0 Introduction

With buildings accounting for approximately 40% of the total energy consumption in OECD countries, the development of low energy dwellings is seen as key to achieving energy reduction and carbon emission targets which EU member states have committed to – the so called 20-20-20 targets. Significant effort has been directed at developing techniques for low energy new builds however the thermal upgrading and retrofitting of existing housing stock must be considered as crucial in achieving carbon targets as over 70% of the buildings which will be around in 2050 already exist. In particular windows have long been recognised as a principle source of heat loss from buildings and are generally regarded as a problematic building element when it comes to improving thermal performance.

This problem is exacerbated in the case of historic buildings be they listed, non listed or complementing a townscape within a conservation area as they frequently comprise single glazed sliding sash windows which must be retained in order to maintain the architectural integrity of the building. This type of window system generally exhibits high rates of heat loss which can have a major impact on the energy efficiency of a building. Secondary glazing systems and a range of other alternatives methods may be employed to reduce this however most commercially available systems require some form of framing. In addition, many of the options available have horizontal transoms which make them obtrusive and detract from the aesthetics of the window.

A glass shutter has been designed which requires no additional framing, has no horizontal transoms and is quite discreet when in position on the window when viewed from outside the building. Internally the side fixing mechanisms are covered by curtains. They have a novel hinge system so they can be easily retracted for cleaning of both the window and the shutter; for ventilation purposes and access to an escape route via the window in the event of an emergency.

The following report describes the thermal test procedure for the glass shutters and provides an analysis of the improvement in thermal performance which could be achieved by their application to a traditional sliding sash window.

2.0 Window Sample and Shutters

A traditional wooden single glazed sliding sash window was constructed as shown in figures 1 and 2 below using a six over six configuration. To replicate what is commonly found in heritage buildings no draft excluders were included in the window though the window had rebated meeting rails as is common in windows of this type.

The glass shutters to be tested were manufactured from 6mm thick toughened, low-e coated glass. The low-e coating was set facing the window panes. The glass shutters comprised two side hung shutters and a top hung shutter.

An adhesive backed foam sealing strip (commonly used as a draught excluder) was also tested in conjunction with the glass shutter to minimize filtration losses between the edge of the shutter and the frame.

A simple wooden shutter was also tested along with the glass shutter and sealing strip.

Figure 1 Front view of sliding sash window

Figure 2 Sliding sash window with glass and wooden shutters

3.0 Experimental Procedure

3.1 Guarded hotbox

The U-value of the window and associated shutters was determined using a guarded hotbox calorimeter constructed in accordance with the requirements of the European and ISO standard EN ISO 8990 at the University of Ulster. A schematic diagram of the guarded hotbox calorimeter is shown in figure 3 and figure 4 illustrates the actual hotbox with controls.

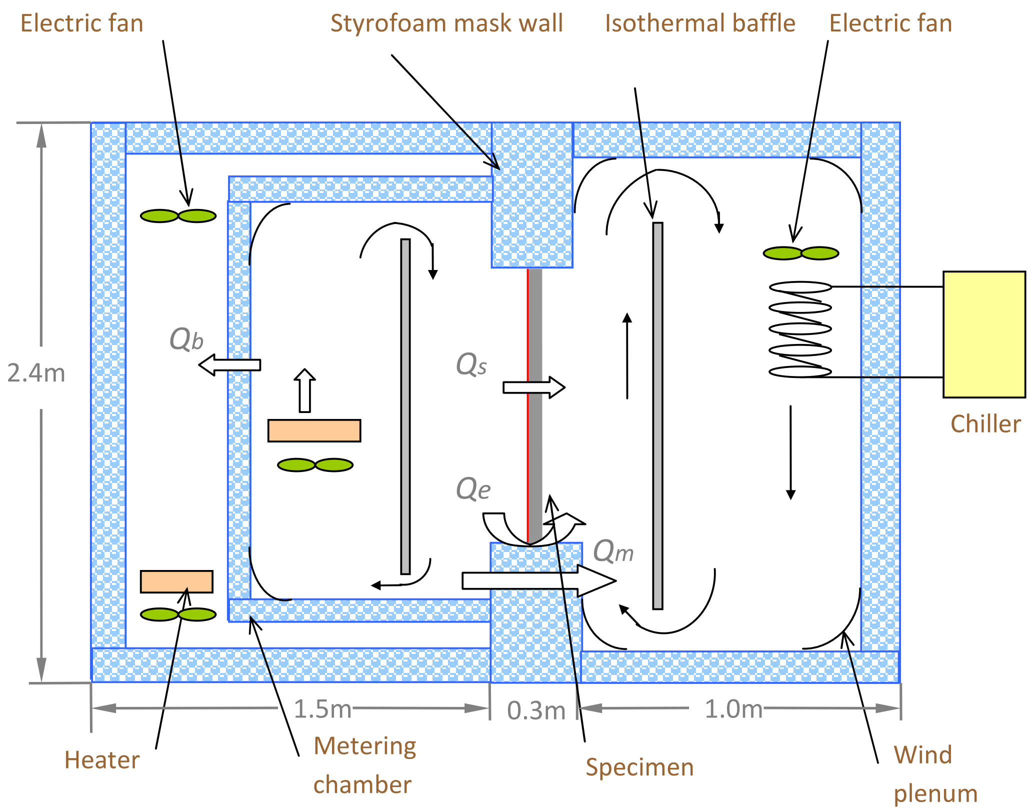

Figure 3 Schematic of guarded hotbox calorimeter

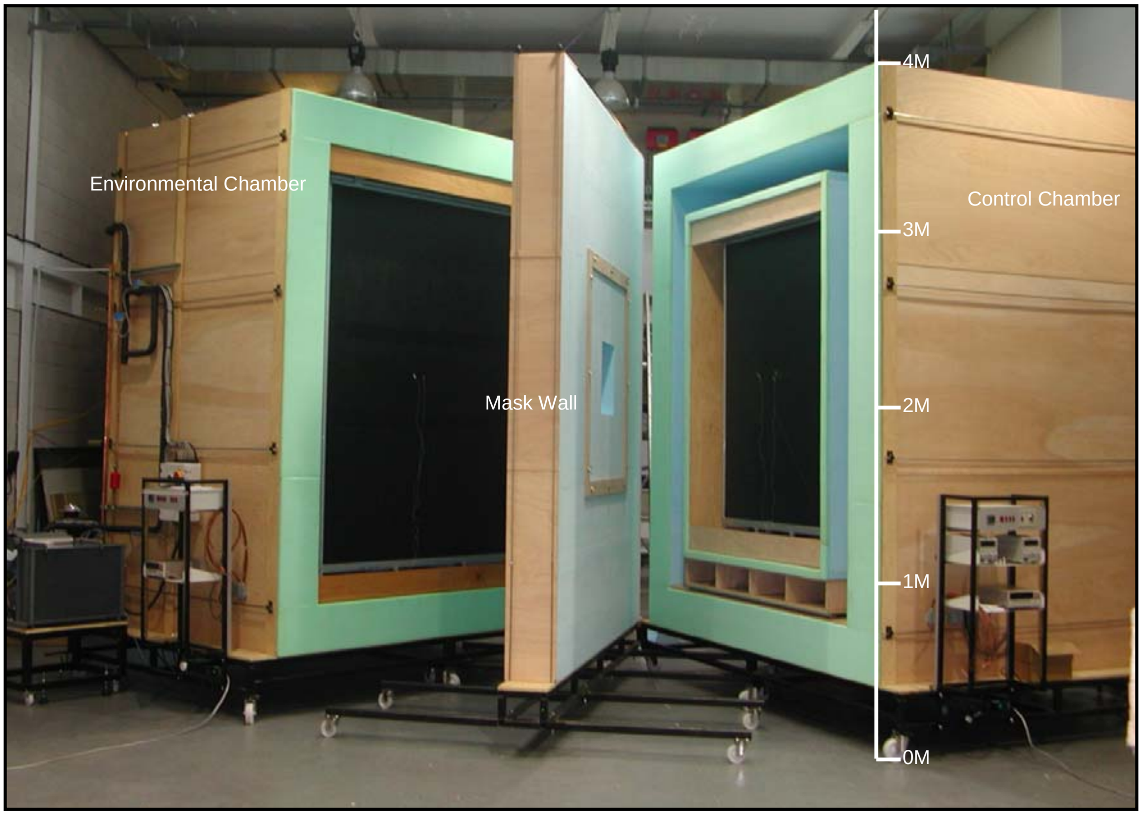

Figure 4 Guarded hotbox calorimeter

Heat transfer through the test sample located in the guarded hot box can be determined from:

$$Q_s = Q_{input} - Q_b - Q_m - Q_e \qquad (1)$$

Heat flow through the metering box, Q_b was controlled to be negligible by adjustment of the heater power. Heat transfer through the mask wall, Q_m was determined by measurement of mean mask wall surface temperatures in both the hot and cold chambers. The flanking loss, Q_e, i.e. the heat transfer through the edge area of the mask wall adjacent to the test sample, was determined experimentally using standard samples of known thermal properties.

Radiant and air temperatures can be combined into a single environmental temperature T_n, which represents the appropriate weighting of air and radiant temperatures for the purpose of determining the heat flow to the surface, given by:

$$T_n = \frac{T_a \frac{Q_s}{A} + \varepsilon h_r (T_a - T_r) T_s}{\frac{Q_s}{A} + \varepsilon h_r (T_a - T_r)} \quad (2)$$

where $$h_r = 4\sigma T_m^3 \quad (3)$$

$$T_m = \frac{T_r^{'} + T_s}{2} \quad (4)$$

Where $T_r^{'}$ is the mean temperature of the copper baffle; T_s is the mean temperature of the window surface. Using equation 2, the environmental temperatures in the hot and cold chambers, T_{n1} and T_{n2} can be calculated. The overall heat transfer coefficient is then given by:

$$U = \frac{Q_s}{A(T_{n1} - T_{n2})} \quad (5)$$

3.2 Test procedure

In order to determine the effectiveness of the shutters the tests were undertaken in four stages as follows:

Test 1: Window with no shutters

Test 2: Window with low-e glass shutter

Test 3: Window with low-e glass shutter and sealing strip

Test 4: Window with low-e glass shutter, sealing strip and wooden shutters

During testing the window sample was located in the central mask wall. Insulation fillers were used to ensure there were no gaps between the window frame and the mask wall to minimize heat transfer due to air infiltration as shown in Figure 5. A series of thermocouple sensors were used to monitor glass and frame surface temperatures as shown in Figure 6.

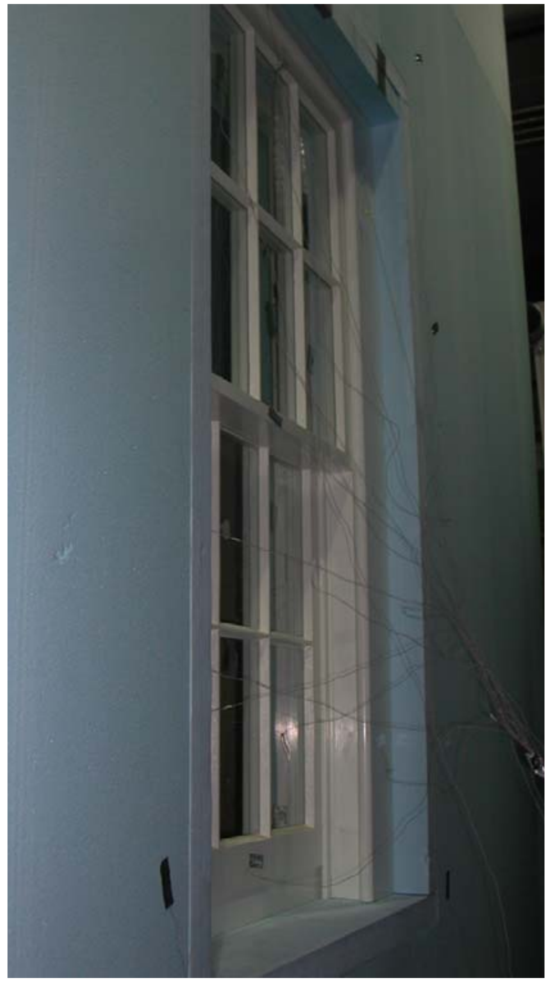

Figure 5 Window located in central mask wall of guarded hot box

Figure 6 Thermocouples attached to window under test

The temperature sensors were positioned on the glass, the top/bottom and meeting rails and the surrounding frame. These surface temperatures were used for the determination of the overall U-value of the window.

For the second test the glass shutters were added as shown in figures 7 and 8. Again temperature sensors were positioned on the glass shutters and on the surrounding frame.

Figure 7 Low-e glass shutters under test

Figure 8 Location of temperature sensors on the window under test

The next test involved using a sealing strip around the periphery of the glass shutters to minimise heat loss through infiltration between the edge of the glass shutter and the surrounding frame. Figure 9 shows the window with the sealing strip applied and Figure 10 shows the glass shutters with sealing strip and sensors attached.

Figure 9 Low-e glass shutters with sealing strip between shutters and frame

Figure 10 Glass shutters with sealing strip

The final test involved positioning simple wooden shutters over the glass shutters as shown in figure 11. They comprised two side hung shutters which were not insulated or rebated.

Figure 11 Wooden shutter under test with temperature sensors attached

4.0 Thermal transmittance test results

4.1 Determination of U-value

The schematic diagram of the projected areas of the tested window and the thermocouple locations are shown in Fig. 12. T_1 is assumed to be the mean temperature of the external frame area A_1 with hatched lines, T_2 the mean temperature of the area A_2 of the internal frame, T_3 is the mean temperature of the glass area. The mean surface temperature of the window is determined by:

$$T_s = \frac{T_1 A_1 + T_2 A_2 + T_3 A_3}{A_1 + A_2 + A_3} \quad (6)$$

The U-value of the window is determined by equations 1 to 5.

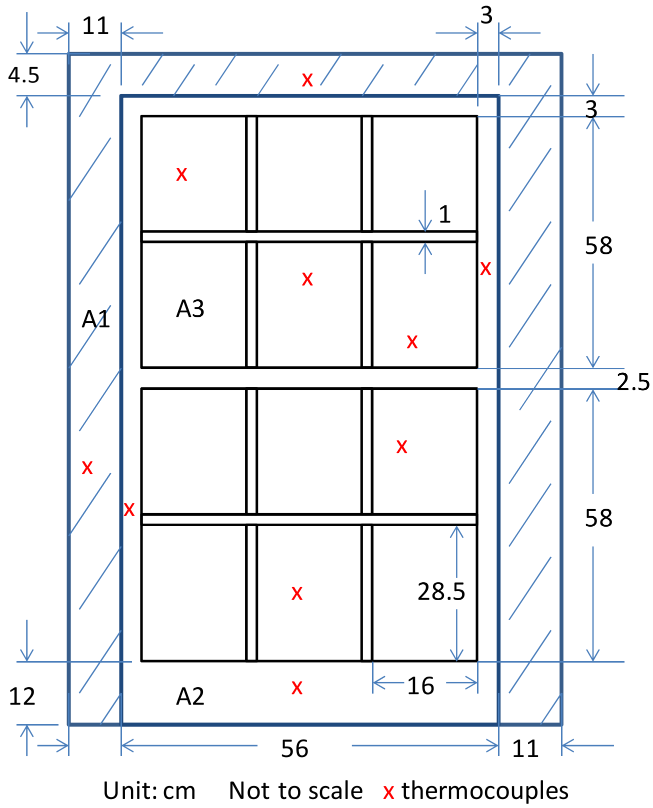

Figure 12 Schematic of the projected areas of the tested window.

Table 1 below gives the results of the guarded hotbox tests. The heat conductance U-value was calculated by assuming standard surface heat transfer coefficients. Typical indoor and outdoor air temperature would be 20 ^{o}C and 0 ^{o}C; surface heat transfer coefficients: 7.7 $Wm^{-2}K^{-1}$ and 25 $Wm^{-2}K^{-1}$ respectively (British/European standard: BS EN 674). The system error of the guarded hot box calorimeter is 5%.

Table 1 Results of the guarded hot box calorimeter

Sample type	U-value ($Wm^{-2}K^{-1}$)	Improvement* ($Wm^{-2}K^{-1}$)	Improvement* %
Window only (as manufactured)	4.45	-	-
Window plus glass shutter	2.64	1.81	40.7%
Window, glass shutter plus sealing strip	2.57	1.88	42.2%
Window, glass shutter, sealing strip plus wooden shutter	1.89	2.56	57.5%

* Over original window as manufactured

4.2 Analysis of test results

Figure 13 shows the relationship of the various improvements to the original sliding sash window system. The overall thermal transmittance for the window as manufactured was 4.45 $Wm^{-2}K^{-1}$ for the entire window i.e. glass and frame combined. This figure can be compared to a U-value of 5.6 $Wm^{-2}K^{-1}$ which is the generally accepted figure for a single pane of glass. The difference therefore of 1.15 $Wm^{-2}K^{-1}$ between the U-value of the overall window tested and a single piece of glass can be attributed to the higher insulation afforded by the frame, meeting and side rails and the glazing bars.

When the low-e coated glass shutters were attached to the window the U-value reduced by 1.81 $Wm^{-2}K^{-1}$ to 2.64 $Wm^{-2}K^{-1}$ representing an improvement of almost 41% in thermal performance compared to the original window as manufactured.

When the sealing strip was applied around the edge of the glass shutters abutting the frame reveal the U-value was reduced by a further 0.07 $Wm^{-2}K^{-1}$. Thus the glass shutter and sealing strip combined gave an improvement of just over 42% over the original window.

In the final test wooden shutters were added to the window in combination with the glass shutters and sealing strip which reduced the overall window U-value to 1.89 $Wm^{-2}K^{-1}$. Thus the combined effect of the wooden shutters, glass shutters and sealing strip gives an improvement of over 57% over the original window.

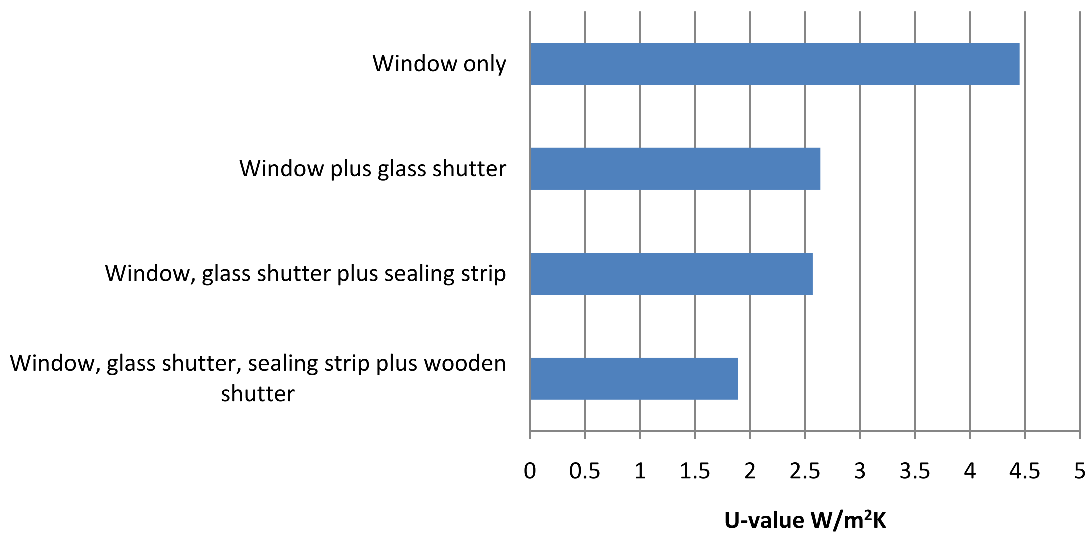

Figure 13: Change in U-value for various improvements to window

The window tested had an overall size of approximately 1380 by 780mm. In terms of period windows for a heritage building, window sizes are frequently in excess of this size. For these larger windows the framing sections would remain fairly constant with an increase in glass pane size. This would have the effect of increasing the glass to framing ratio therefore the overall U-value of the window by itself would be higher. Thus it could be assumed that for larger windows the percentage improvement in thermal performance due to the glass shutters would be more pronounced. In addition, the larger the glass shutter the smaller the percentage of linear opening around the shutter therefore the better the improvement in thermal performance over the original window

As can be seen in Figures 7 and 8 the shutters tested were fabricated in three pieces, two side hung shutters and one top hung shutter. The top hung shutter is to accommodate a curtain pelmet which would otherwise prevent the side shutters from opening. The top hung shutter increases the length of linear gap where the shutters meet, therefore if only a two piece shutter were used there would also be a slight improvement in thermal performance.

5.0 Conclusions

The sliding sash window tested in the guarded hotbox calorimeter had an overall thermal transmittance U-value of 4.45 $Wm^{-2}K^{-1}$. With the addition of low-e coated glass shutters this was reduced to 2.64 $Wm^{-2}K^{-1}$ which represents approximately a 41% improvement in thermal performance over the original window as manufactured. With the addition of the sealing strip around the edge of the glass shutters the U-value was reduced to 2.57 $Wm^{-2}K^{-1}$ which represents a 42% improvement over the original window. When the wooden shutters were added the U-value was reduced to 1.89 $Wm^{-2}K^{-1}$ representing an overall improvement of almost 58% over the original window.

It must be remembered the wooden shutters were not the focus of this study and therefore were not optimised for thermal performance. With careful design a greater improvement in thermal performance would be possible.