

RESEARCH INTO THE THERMAL PERFORMANCE
OF TRADITIONAL WINDOWS:
TIMBER SASH WINDOWS



EXECUTIVE SUMMARY



ENGLISH HERITAGE

RESEARCH REPORT



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RESEARCHING THE THERMAL PERFORMANCE OF TRADITIONAL BUILDINGS

The national and global imperative to improve energy security and reduce carbon emissions is turning the spotlight on the existing building stock. Traditional and historic buildings can often adopt modern technologies, such as more efficient boilers, lamps, control and management techniques, and low-carbon energy supplies. However, changing the building fabric is more difficult, particularly for walls, windows and doors, which give the building so much of its character. This is not just an aesthetic concern: changing balances between heat, air and moisture movement may also affect the integrity of the building and the health of its occupants.

There is often a presumption that old is bad and new is good. This is not necessarily so: historic and traditional buildings have stood the test of time, demonstrating their sustainability in an ever-changing world. With hindsight, many well-meaning interventions in the 20th Century have turned out to have been mistaken. For example, harder and less permeable paints, coatings, mortars and renders often accelerated the deterioration of the fabric they were expected to protect, while new windows and pointing have taken the character out of many well-loved buildings and streetscapes.

To better understand the performance of traditional and historic buildings and elements, and the scope for upgrading, English Heritage is commissioning a number of research projects, and will be reporting on these as soon as results come available. Each report will include a technical summary of the research, and an executive summary that puts the work into a broader context.

This is the first of the series, showing the results of laboratory tests of heat loss through a traditional double-hung sliding sash timber window. At the time of writing (October 2009), tests of a metal window are in progress, and *in-situ* measurements of the U-values of solid brick walls have begun.



This Executive Summary should be read in conjunction with the research report prepared for English Heritage by Dr Paul Baker, at Glasgow Caledonian University. It summarises the report's conclusions, and sets the timber sash window research into a broader context.

1. BACKGROUND

English Heritage supports national and global efforts to reduce energy consumption and greenhouse gas emissions, in which existing buildings are being asked to play an ever-increasing role. A few years ago large-scale reconstruction was widely advocated, but this is now seen to be impractical and the emphasis has moved towards refurbishment, with a presumption of window replacement. English Heritage is questioning the extent to which this is necessary or desirable, because:

- traditional windows can be very durable: many original Georgian and Victorian windows are still in place, whereas modern windows tend to be designed to have very much shorter lives (typically 20 years);
- current calculation methods may be pessimistic about the performance of traditional windows and the opportunities for improvement; and
- window replacement can easily destroy the character of a traditional building, as has been widely demonstrated over the past 30 to 40 years in nearly every part of the UK.

Consequently, English Heritage has funded research at Glasgow Caledonian University [GCU], carried out in conjunction with Historic Scotland, who commissioned similar work on a different timber window. The English Heritage work also included tests on condensation.

The results presented here are part of an ongoing programme of research into the thermal performance of traditional building materials and components. Testing of a steel and cast-iron windows with leaded lights is currently underway.

2. THE RESEARCH UNDERTAKEN

English Heritage provided GCU with a traditional 2 x 2 traditional double-hung vertical sliding sash window in poor condition. The window, which measured 1.77 x 1.16 m overall, was installed between two environmental chambers, one of which (“the cold room”) was maintained at 2°C to simulate outdoor winter conditions, whilst the other (“the hot room”) was held at 22°C to represent room conditions. Heat-flow tests were undertaken with the window as-found, after repair, and again after draughtproofing. The effects of adding curtains, blinds, shutters and secondary glazing were also evaluated. Formation of condensation was also monitored with and without secondary glazing, and with the window both open and shut.

3. HEAT TRANSFER THROUGH WINDOWS

Heat loss¹ from a room through a window during the heating season is complex, with three main mechanisms:

- By convection and conduction, from the warm room air to the colder surfaces of the glass and the frame.
- By the colder surface of the window absorbing infra-red radiation from the room.
- By uncontrolled air leakage, which can either bring in cold air from the exterior or take warm air out from the interior; often called *air infiltration*, this can occur even when the window is closed.



During the day, windows are also a source of heat gain through direct and diffuse solar radiation, but this study was concerned with heat losses only.

4. HEAT LOSS THROUGH THE GLASS AND FRAMES

Whether it leaves the room by convection, conduction or radiation, the lost heat all passes through the glass and the frame as conduction. GCU measured the flow through the glass by averaging the results from two heat flux meters attached to the centres of the top right and bottom left panes. These results are summarised in Table 1, with the measured heat transfer rates² converted into U-values³ for the glass.

The glass is the most conductive part of the window, but heat is also lost through the frame, albeit at a lower rate. The complex frame geometry makes it impossible to measure these losses accurately using heat flux sensors. The contribution of the frame to overall heat loss was therefore estimated by comparison with tests at the National Physical Laboratory, as discussed below.

TABLE 1: CONDUCTION HEAT LOSSES THROUGH THE GLASS AND WINDOW						
	For glass only: Directly measured			For glass & frame: Using FRAME model		
DETAILS OF THE TEST ASSEMBLY	U-value of glass (W/m ² K)	Reduction in heat loss through glazing only	Temperature of innermost surface (°C)	U-value of whole window, (W/m ² K)	Reduction in heat loss through whole window	COMMENTS
Window as found	5.3	—	12 (glass)	4.3	—	
Joinery repaired	5.3	—	12 (glass)	4.3	—	This also reduced air infiltration by 34%
Heavy curtains	3.3	39%	21 (curtain)	2.5	41%	
Well-fitting shutters	2.0	64%	17 (shutter)	1.7	58%	
Plain roller blind	3.4	37%	18 (blind)	2.7	38%	When the blind was tightly fitted, the U-values fell by about 0.3
Reflective roller blind	1.8	66%	19 (blind)	1.9	57%	Reflective side facing towards the outside
Honeycomb blind	2.1	60%	20 (blind)	2.1	51%	Insulating blind
Low-emissivity secondary glazing	2.0	63%	19 (glass)	1.8	58%	Aluminium frame secondary system with spring balances
Low-emissivity secondary glazing and shutters	1.4	73%	20 (shutter)	1.6	62%	With both the glazing and the shutters closed

NB: the experimental error in the tests is equivalent to an uncertainty of ± 0.3 in the U-values above⁴



From the first two columns of Table 1, it can be seen that relatively simple methods of insulation can substantially reduce heat loss through the glass of single-glazed windows. In addition, the increased internal surface temperature of curtains, blinds, shutters and secondary glazing (shown in the third column) will limit draughts and reduce radiation losses, which may make the room feel more comfortable at a given temperature.

The effects of the frame were estimated by relating the measured U-values for the glass of the single glazed window to those from sophisticated hot-box tests of a similar traditional window at the National Physical Laboratory. This then allowed the two-dimensional heat conduction model FRAME to be calibrated and used with the empirical values to estimate the overall conduction heat loss of the window assembly. The results are summarised in the fourth and fifth columns of Table 1, which show that estimated heat losses by conduction and radiation through the window as a whole can be reduced by:

- 40 to 50%, simply by closing curtains or lowering plain blinds;
- 50 to 60%, by using shutters or insulating blinds with reflective surfaces facing outdoors;
- over 60%, by using secondary glazing with a low-emissivity coating; and
- even more where curtains, blinds or shutters are used alongside secondary glazing.

The results show that a traditional window with low emissivity (“low-e”) secondary glazing is perfectly capable of meeting the regulatory requirements for new buildings during the day, and can do still better at night, when the blinds and shutters are closed. Further savings could be made, for example, if the secondary glazing used insulating frames (made for example of timber), or if it were to incorporate double glazing, as is widespread practice in northern Europe.

5. HEAT LOSS BY AIR LEAKAGE

Heat loss by air infiltration was inferred by setting up air-pressure differences across the window assembly and determining the relationship between air flow and pressure. At a 50 Pa pressure, the leakage rate through the window as-received was 183 m³/hour. Repairs cut leakage to 120 m³/h, and *in-situ* draughtproofing (which still left the window operable) to 26 m³/h with the window closed. With secondary glazing installed as well, leakage fell to 8 m³/h.

6. THE COMBINED EFFECTS OF CONDUCTION AND AIR LEAKAGE

None of the results for conduction heat loss shown in Table 1 are significantly affected by the measures to reduce air leakage discussed in Section 5. To get the best performance it is important to tackle both aspects. Indeed, we estimate that if the window tested had been installed in a typical house, air leakage would have been responsible for:

- over 60% of the overall heat loss through the window in its as-received state;
- about half its overall heat loss after the joinery was repaired but the window was not draughtproofed; and
- less than 20% of the heat loss if the window were fully draughtproofed but not insulated.

By combining repair with draughtproofed secondary glazing, total heat loss could be reduced to one-quarter of that of the window in its original state; and by even more at night with shutters, curtains or blinds in place. Thus it is certainly not essential to replace existing windows to obtain levels of improvement in thermal performance that make traditional timber sash windows comparable with standard modern windows⁵.

7. PROVIDING VENTILATION AND AVOIDING CONDENSATION

The original window was so leaky that air infiltration would have met most wintertime ventilation requirements for occupied rooms, even when it was closed. The refurbished window would likewise have allowed sufficient ventilation, but draughtproofing reduced the measured air infiltration rate to about 60% of that achieved by a standard trickle ventilator (such as those often fitted to modern windows).

At this stage, one needs to reconcile heat retention with ventilation⁶ and moisture removal. In some rooms, it may be possible to leave some windows tightly closed, because sufficient air can be provided elsewhere (e.g. via other windows, ventilators, or mechanical systems). In other cases – especially where there is only one window per room – the window will need to provide ventilation as well. With secondary glazing, the simplest approach is to open the inner window by a small amount, and rely on infiltration through the original window; if necessary this original window can be opened slightly too. The risk is that this might cause condensation problems, so to study the possible outcomes GCU undertook some tests of condensation with secondary glazing.

8. THE CONDENSATION TESTS

While occasional condensation is acceptable, persistent condensation is unslightly and can lead to decay of materials and mould growth. The condensation tests involved collecting and weighing the amount of water deposited on the inside of the original window over a 5-hour period, with the warm room at 22°C with a relative humidity of 60%⁷, and the cold room at 2°C as usual.

The results for condensation on the inside of the original window were as below. No condensation was found on the secondary glazing itself.

When the secondary glazing was closed and reasonably well sealed (as in the tests), it protected the primary window from condensation. With the secondary glazing slightly opened, the presence and amount of condensation on the original window depended on the direction of air movement:

Single glazed window, closed, no secondary glazing	33 g
Added secondary glazing, both windows closed or with primary window open	0 g
Added secondary glazing, slightly open; primary window closed	36 g
Added secondary glazing, slightly open; primary window slightly open	48 g
As above, but with hot room at small positive pressure to cold room	69 g
As above, but with hot room at small negative pressure to cold room	0 g

- if the outside air flowed inwards to the room, there was no problem; however
- if there was little or no flow, condensation on the original window increased; and
- if the flow was outwards and the main window was also open, condensation increased further.

The results demonstrate that there will be a risk of condensation in cold weather if the indoor air is humid and the secondary glazing is left open for ventilation, unless the flow of air can be controlled to be always, or at least nearly always, inwards from the exterior to the interior. These risks will be highest in rooms where there are high rates of moisture generation, or low rates of ventilation.



9. CONCLUSIONS

The timber sash window tests at Glasgow Caledonian University suggest that:

- There are major opportunities for improving the thermal performance of existing windows by relatively simple methods, including traditional curtains, blinds and shutters.
- There is a good potential for improvement from draughtproofing, with air infiltration through the repaired and draughtproofed window being somewhat less than through a standard trickle ventilator.
- There is potential for further improvement where secondary glazing with a low-emissivity coating is used as well. This gives good performance in the daytime, and better still at night when curtains, blinds and shutters can be closed.

However, when designing secondary glazing to avoid heat losses, it is important to ensure that ventilation is sufficient, and that the risk of condensation is minimised. The box below provides some simple guidelines for this.

SOME COMMENTS ON CONDENSATION AND SECONDARY GLAZING

As discussed above, draughtproof secondary glazing⁸ with a clean low-emissivity hard coating facing the outside offers major reductions in heat loss through existing windows by controlling conduction, radiation and air leakage. There are potentially further opportunities to reduce conduction losses if double or vacuum glazed secondary units can be accommodated, and by improving the thermal insulation of the frames.

However, secondary glazing can be relatively airtight, so other means of ventilation may need to be considered. Condensation on the primary system may arise if the secondary system is opened for ventilation in cold weather and/or where rooms are relatively humid, (typically owing to high rates of indoor moisture production and/or low ventilation rates), and the air leakage is outwards⁹.

These condensation risks will be minimised where the secondary glazing is either:

- able to be kept closed in cold weather, because there are alternative means of ventilation¹⁰;
- located where the normal direction of air flow is from outside to inside, e.g. on the windward side of a building, on the lower floors, or where a designed natural or mechanical extraction system helps to ensure inward airflow¹¹;
- fitted with devices which avoid reverse airflow in adverse circumstances, e.g. a one-way trickle ventilator or a small fan incorporated in the window¹²; or
- where the primary and secondary window assemblies incorporate some alternative means of ventilating between the exterior and the room interior, but bypassing the cavity between the primary and secondary glazing (e.g. a bypass trickle ventilator on the secondary glazed unit).



NOTES:

1. During the day, windows also gain heat from outside by direct and diffuse radiation, but these effects are not dealt with here.
2. The climate chamber air conditioning initially created high air velocities over the window surfaces, leading to high rates of convection heat transfer between the rooms and the glazing, and anomalously high initial U-values. Baffles were fitted to avoid this.
3. A U-value is the heat loss through a square metre of a building element – here the window glass – for each degree of temperature difference between inside and outside. It is normally expressed as $\text{W/m}^2\text{K}$ (watts per metre squared kelvin). Typical values in buildings range from as low as $0.1 \text{ W/m}^2\text{K}$ for a very highly insulated wall, to $7 \text{ W/m}^2\text{K}$ for a single-glazed roof light; the smaller the U-value the less the heat loss.
4. The 2006 CIBSE Guide A quotes U-values for vertical single glazing of $5.75 \text{ W/m}^2\text{K}$ for windows under normal exposure, and $5.16 \text{ W/m}^2\text{K}$ for windows in sheltered conditions (Table 3.23).
5. Sometimes even approaching those of more advanced designs.
6. The saying “build tight, ventilate right” is widely used in new construction.
7. These interior conditions are relatively humid, representing a dew-point temperature of 14°C , an absolute moisture content of 10.0 g/kg of dry air, and a water-vapour pressure of 1.68 kPa . At 2°C , air will have a moisture content of no more than 4.4 g/kg of dry air and a water vapour pressure of 0.71 kPa , even when conditions are very wet. In a traditional building with leaky windows (such as the test window as-found or as-repaired), and an exterior temperature of 2°C , the room test conditions could occur only transiently (for example during cooking, bathing, washing and drying clothes, or during a party, when there were many people present). On the other hand, if the window were closely draughtproofed and the sole source of ventilation, one sedentary occupant could produce enough moisture for the room to reach the test humidities.
8. Where draughtproof secondary glazing is fitted, it is neither necessary nor desirable to draughtproof the primary windows, because a small amount of ventilation of the gap by the outside air will actually help prevent condensation.
9. Particular care is needed when reviewing the condensation risk in the upper floors of naturally-ventilated buildings, where air leakage will tend to be outwards especially on the lee side.
10. For example, through a segregated trickle ventilator leading directly to the outside, through other windows or ventilators, via a mechanical system, or perhaps through existing chimneys.
11. Normally this would use extractor fans, but natural ‘passive stack’ extraction systems are also available.
12. These also offer opportunities for recovering some of the heat which would otherwise be lost to the outside through the space between the primary and secondary windows.

