Technical Paper 20

HISTORIC SCOTLAND
ALBA AOSMHOR

Slim-profile double-glazing in listed buildings

Re-measuring the thermal performance

Nicholas Heath & Paul Baker

CHANGEWORKS

GCU Glasgow Caledonian University

The views expressed in the research report(s) presented in this Historic Scotland Technical Paper are those of the authors and do not necessarily represent the views of Historic Scotland or the Scottish Government.

This Technical Paper is available as web publication for free download from the Historic Scotland website:
www.historic-scotland.gov.uk/technicalpapers

This Technical Paper should be quoted as:
Historic Scotland Technical Paper 20

ISBN 978 1 84917 133 5

This paper was published by Historic Scotland, an executive agency of the Scottish Government.

You can contact us at:

Historic Scotland
Conservation Directorate
Longmore House
Salisbury Place
Edinburgh EH9 1SH

Phone 0131 668 8600
Email hs.conservationgroup@scotland.gsi.gov.uk
Web www.historic-scotland.gov.uk/conservation

We welcome your comments

If you have any comments or queries about our Technical Papers or would like to suggest topics for future papers, please do get in touch with us either by email at hs.conservationgroup@scot.gov.uk or by phone on 0131 668 8660.

Historic Scotland Technical Paper 20

Slim-profile double-glazing in listed buildings

Re-measuring the thermal performance

Nicholas Heath & Paul Baker

1. Contents

2. Introduction

by Historic Scotland

Improving the thermal performance of building envelopes is an important measure to make buildings energy efficient. Windows are often the building component which performs worst thermally, compared to the rest of the envelope. This is particularly the case for single-glazed windows. However, such windows are often located in historic buildings. The outright replacement in such buildings is, thereby, generally considered inappropriate, for conservation reasons. Nevertheless, there are various options to improve the thermal performance of such windows, as has been shown in Historic Scotland Technical Papers 1 and 9: from installing draught-proofing and using curtains and shutter to fitting secondary glazing / windows and replacing single-glazing with slim-profile double-glazing. The latter solution is a form of double-glazing with a cavity between the two glass panes thinner than that in conventional double-glazing units. Slim-profile double-glazing has generally a poorer thermal performance than conventional double-glazing, but performs thermally significantly better than single-glazing. Furthermore, such solutions can be fitted, due to their slimness, in most existing window sashes, thereby allowing for the retention of the existing window casements and/or sashes. This is an important conservation aspect, as the installation of double-glazing in historic buildings may be more acceptable in situations where it can be incorporated within the original joinery or within new joinery which matches the original.

In 2009/10 Changeworks, a sustainable development organisation, led a project in Edinburgh, in which single-glazing in historic buildings in Edinburgh was replaced with a variety of slim-profile double-glazing products and their thermal performance was measured in situ by Glasgow Caledonian University. The project was funded by the City of Edinburgh Council and Historic Scotland and supported by the Edinburgh World Heritage Trust and Lister Housing Co-Operative. The project results showed that replacing single-glazing with slim-profile double-glazing can significantly improve the thermal performance of historic timber windows, whilst retaining their joinery work. The project's findings, published in a project report for the city council and in Historic Scotland Technical Paper 9, led to a change in Edinburgh's planning guidelines for listed buildings in 2012, which now allow for the installation of slim-profile double-glazing in listed buildings, except where historically important glass is extant. (The installation of such glazing systems still requires Listed Building Consent prior to commencement of works.)

Improving the thermal performance of a window can help to reduce the energy used in the concerned building, i.e. to reduce the building's future operational energy. To properly assess a building's sustainability, however, requires factoring into (life-cycle) assessments also the embodied energy associated with the retrofit, e.g. the energy used to produce and install the glazing products. This has also been investigated in the previous Changeworks project by a report from Heriot-Watt University, Edinburgh, published as part of Historic Scotland Technical Paper 9.

What was, for practical reasons, not considered at the time, though, was the long-term performance of the replacement glazing. If the thermal performance of a glazing unit deteriorates over time, it will obviously impact on the (operational) energy use and the life cycle assessments. Therefore, in 2011/12, after the new glazing units have been in situ for only two years, it was decided to re-measure thermal performance of the replacement units and to compare these measurements with the results of the previous project. Although two years is only a short period of time, this will allow at least a first (preliminary) assessment and highlight any major short-term performance failures. The re-measuring project was again funded by Historic Scotland and managed by Changeworks, with the field measurements carried out by Glasgow Caledonian University. This paper, Historic Scotland Technical Paper 20, presents the findings of this re-measuring project.

3. Executive Summary

by Changeworks

During the winter 2009/10, Changeworks led a pilot project, *Double Glazing In Listed Buildings*, installing a range of slim-profile double-glazing systems into category 'B' listed, Georgian tenement buildings in Edinburgh's Old Town, a Conservation Area and part of the UNESCO World Heritage Site. As part of this project, Historic Scotland funded research to measure the thermal performance of and investigate the embodied energy associated with all the glazing units. The project led to a city-wide planning-policy change by the City of Edinburgh Council.

This project answered most of the questions surrounding double-glazing in listed buildings, except for the longevity of the glazing units: In most cases, the thermal performance of double-glazing is largely dependent on the durability of the seals within the units, as these retain the inert gases generally needed to create a low U-value. In 2011, therefore, it was decided to re-measure the thermal performance of the units in situ, which by then would have been in place for two years.

Of the ten glazing systems originally measured, eight were re-measured during the winter 2011/12. This report, Historic Scotland Technical Paper 20, presents, and draws conclusions from, the comparison of the U-value results measured in the winters of 2009/10 and 2011/12.

From the conducted thermal-performance re-measurements, it is, unfortunately, not possible to draw any significant conclusions, as most of the measurement results are within the margins of error of the measurement. However, applying the median figures, some deterioration in performance may be seen in the majority of the gas-filled glazing units. The Slenderglaze xenon-krypton-filled unit is the only one to show a level of deterioration outside the margins of error. The air-filled Slimlite unit and the Spacia vacuum unit show no significant deterioration in performance.

Further re-measurements of the units over time should provide more conclusive evidence of their longevity and thermal performance.

Research Report

Slim-profile double-glazing in listed buildings

Re-measuring the thermal performance

Nicholas Heath & Paul Baker

CHANGEWORKS

GCU Glasgow Caledonian University

About the authors

Nicholas Heath is Associate Consultant at Changeworks, where he worked between 2006 and 2013, before founding NDM Heath Ltd. Energy Consulting Services. He has developed and led award-winning research and demonstration projects on energy efficiency and renewable energy in traditional and historic buildings across Scotland and presented his work with Changeworks internationally. Project partners have included Historic Scotland, the Energy Saving Trust, Consumer Focus Scotland, the Joseph Rowntree Foundation and various local authorities, housing associations and community organisations. With a background in social housing and sustainable energy, the main focus of his current work is energy performance, retrofit and behavioural issues surrounding older, traditionally built, hard-to-treat housing.

Paul Baker is a Senior Lecturer and Researcher at Glasgow Caledonian University. He has over 25 years of experience in building science research, including air-infiltration measurements and ventilation issues, passive solar-energy use and moisture-related problems in buildings. He has been a task leader in international and European research projects, concerned with the assessment, measurement and analysis of the performance of building envelopes and building components. He has been involved in various research projects for English Heritage, Historic Scotland and the Society for the Protection of Ancient Buildings, investigating the hygrothermal performance of building envelopes of traditional buildings. He is currently participating in a major European FP7 project *Climate for Culture* concerned with the assessment of climate change on damage risk, macroeconomic impact and mitigation strategies for sustainable preservation of cultural heritage.

Acknowledgements

We would like to thank Lister Housing Co-Operative and their tenants for their continued support, by allowing us to measure their window glazing.

CHANGEWORKS
RESOURCES FOR LIFE

36 Newhaven Road Edinburgh EH6 5PY
T 0131 555 4010 W www.changeworks.org.uk
F 0131 555 2768 E ask@changeworks.org.uk

Slim-profile double-glazing in listed buildings: Re-measuring the thermal performance

Changeworks & Glasgow Caledonian University, March 2013

During the winter 2009/10, Changeworks led a pilot project, *Double Glazing In Listed Buildings*, installing a range of slim-profile double-glazing systems into category 'B' listed, Georgian tenement buildings in Edinburgh's Old Town, a Conservation Area and part of the UNESCO World Heritage Site. As part of this project, Historic Scotland funded research to measure the thermal performance of and investigate the embodied energy associated with all the units. The project led to a city-wide planning-policy change by the City of Edinburgh Council.

Two years later, in the winter 2011/12, the thermal performance of the units was re-measured, again funded by Historic Scotland. This report provides the results of this follow-up project.

Contents

1. Introduction

During the winter 2009/10, Changeworks led a pilot project, *Double Glazing In Listed Buildings*, installing a range of slim-profile double-glazing systems into category 'B' listed, Georgian tenement buildings in Edinburgh's Old Town, a Conservation Area and part of the UNESCO World Heritage Site. As part of this project, Historic Scotland funded research to measure the thermal performance of and investigate the embodied energy associated with all the glazing units. The project led to a city-wide planning-policy change by the City of Edinburgh Council (CEC). Details of the revised policy are available online (CEC, 2010 & 2012). This policy change has led to a considerable uptake of slim-profile double-glazing in listed buildings across Edinburgh.

As well as a detailed project report, prepared for CEC to inform their policy change, Changeworks also prepared a *Technical Paper* for Historic Scotland incorporating the findings of the thermal performance measurements and embodied-energy investigations (Changeworks, 2010, and Heath et al., 2010, respectively).

The above reports answered most of the questions surrounding double-glazing in listed buildings. The only real question that remained was the longevity of the glazing units: In most cases the thermal performance of double-glazing is largely dependent on the durability of the seals within the units, as these retain the inert gases generally needed to create a low U-value. In 2011, therefore, it was decided to re-measure the thermal performance of the units in situ, which by then would have been in place for two years.

The re-measuring was conducted by the Centre for Research on Indoor Climate and Health, School of Engineering and the Built Environment, Glasgow Caledonian University, on behalf of Changeworks, with funding provided by Historic Scotland as part of their on-going technical research into energy efficiency of traditional buildings.

2. Context

Full details of the different double-glazed units installed are available in the original project report (Changeworks, 2010). Table 1 below provides a summary of the products used. Website details of the products' manufacturers are listed in Appendix A.

As part of the 2009/10 pilot project, these products were installed throughout an entire, category 'B' listed tenement building in Edinburgh's Old Town Conservation Area (at 1 Archibald Place and 37 Lauriston Place), comprising nine flats and owned by Lister Housing Co-operative. One of the products was also installed in a single window in a category 'A' listed building in Edinburgh's New Town Conservation Area (at 5 Charlotte Square), the former offices of the Edinburgh World Heritage Trust.

The re-measuring project in 2011/12 aimed to measure as far as possible the same individual glazing units that were measured in 2009/10, to provide as much consistency as possible The measurements were also conducted at the same time of year (December to January).

The measurement method is described in the previous report and was used to determine the *centre-of-pane* U-values of the double-glazed replacement units.

Table 2 below gives the locations and specifications of the different units measured in 2009/2010.

Table 1 Overview of the replacement products used

Manufacturer	Glazing system		Cavity fill	Comments
Histoglass	Histoglass	D10	krypton	
		D11	krypton	
Sash Window Consultancy	Slenderglaze		xenon & krypton	
Slimlite Glass	Slimlite		air	
			xenon & krypton	
Peter Noble Glazing	Supalite		argon	
			xenon & krypton	
Sashworks	Sashworks		argon	
NSG Pilkington	Spacia		vacuum	formerly energiKare Legacy
Colour coding for cavity fills:	air	inert gas	vacuum	

Table 2 Locations and specifications of the replacement glazing-units

Address	Glazing system	Glazing configuration (inner pane - cavity - outer pane) [mm]	Glass type of inner pane	Cavity fill	Notes	U-value provided by manufacturer (upper limit) [W/(m^2·K)]
1/1 Archibald Pl.	Sash-works	4 - 8 - 4	low-E	argon	new sashes†	1.8
1/2 Archibald Pl.	Histoglass D11	3 - 4 - 4	low-E	krypton		1.9
1/3 Archibald Pl.	Histoglass D10	3 - 4 - 5	low-E	krypton	Crown effect*	1.9
1/4 Archibald Pl.	Spacia	4 - 0.2 - 3	low-E	vacuum		1.3
1/5 Archibald Pl.	Slimlite	3 - 3 - 3	low-E	air		2.6
1/6 Archibald Pl.	Slimlite	3 - 3 - 4	low-E	xenon & krypton	Crown effect*	2.1
1/7 Archibald Pl.	Slender-glaze	4 - 3.9 - 4	low-E	xenon & krypton		2.1
1/8 Archibald Pl.	Slimlite	3 - 3 - 3	low-E	xenon & krypton		2.1
37 Lauriston Pl.	Supalite	4 - 4.8 - 3	low-E	argon	new sashes†	2.5
5 Charlotte Sq.	Slimlite	3 - 3 - 3	low-E	xenon & krypton	new sashes†	2.1
Notes	* Crown-effect glass was used as outer glass pane. † Existing window sashes were replaced with new sashes.					

It was not possible to repeat the measurements at 5 Charlotte Square and 37 Lauriston Place, as access to these properties was no longer available. However, eight out of the nine systems installed were successfully re-measured, all of them in the flats at 1 Archibald Place.

This report compares the results of the two series of measurements, to assess whether there has been any deterioration of the thermal performance of the units since installation.

3. Results

Table 3 below details the results of the in-situ re-measurements, providing *centre-of-pane* U-value estimates for both measurement series (winter 2009/10 and winter 2011/12) together with the change in U-value. Also tabled are the uncertainties associated with these in-situ measurements.

It is important to look at the uncertainty margins together with all figures.

The results are also illustrated in Figure 1 below, again together with their uncertainties. The product details (Table 1 and Table 2 above and Table 3 below) and the measurement results are also more fully tabled in Appendix B below at the end of this report.

Table 3 Comparison of U-value measurement results with uncertainties [W/(m^2·K)]

Flat no.	Glazing system	Cavity fill	U-value with uncertainties		Change in U-value*	
			Winter 2009/10	Winter 2010/11	U-value	Percentage
1	Sashworks	Ar	2.0 ±0.2	2.1 ±0.2	+0.1	+5%
2	Histoglass D11	Kr	2.7 ±0.2	2.7 ±0.2	±0.0	±0%
3	Histoglass D10	Kr	2.3 ±0.2	2.5 ±0.2	+0.3	+12%
4	Spacia	vacuum	1.0 ±0.1	0.9 ±0.1	-0.1	-6% †
5	Slimlite	air	2.8 ±0.2	2.9 ±0.2	+0.1	4%
6	Slimlite	Xe & Kr	2.3 ±0.1	2.6 ±0.3	+0.3	15%
7	Slenderglaze	Xe & Kr	1.7 ±0.1	2.0 ±0.1	+0.3	19%
8	Slimlite	Xe & Kr	2.3 ±0.2	2.5 ±0.2	+0.2	9%

Notes

* Figures showing the *Change in U-value* between 2009/10 and 2011/12 do not take account of the uncertainty margins. Colour coding: red colour shows an increase in U-value, i.e. a deterioration of the thermal performance; green colour shows a decrease in U-value, i.e. an improvement of the thermal performance.

† In flat 1/4, the re-measurement was carried out in a location different from that in January 2012.

N.B. Increased U-values represent a reduced thermal performance.

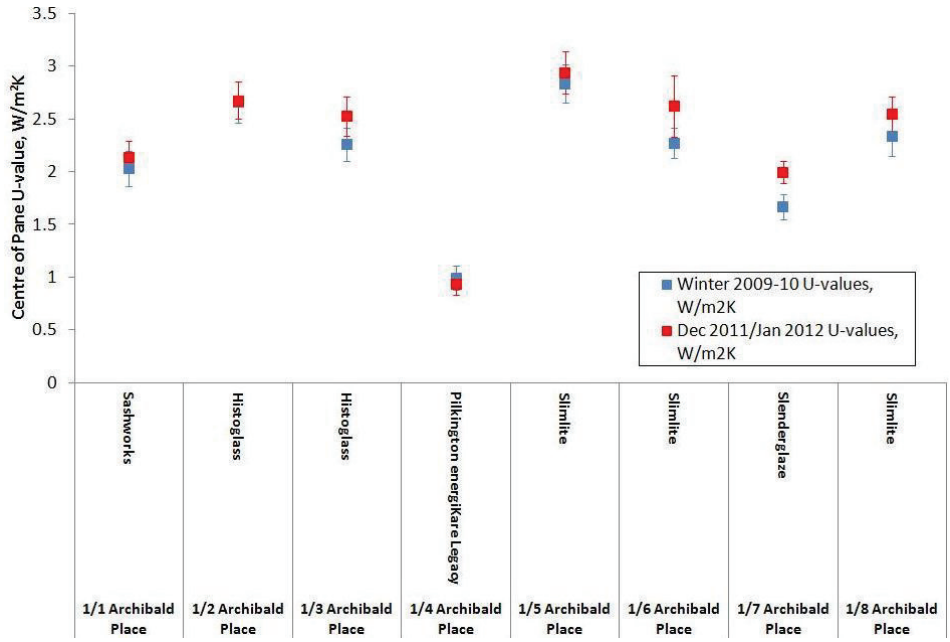

Figure 1 Comparison of the two series of *centre-of-pane* U-values with their uncertainties

4. Discussion

In most cases, the re-measured U-values are within the stated margins of error. While the above table and graph would appear to show some deterioration in performance over time, this cannot be stated absolutely.

The changes in calculated U-values may, therefore, be viewed in different lights, depending on how the margins of error are applied. Viewed in the most positive light (i.e. within the error margins, assuming the worst possible performance for the 2009/10 figures and the best possible performance for the re-measured figures), none of the systems shows any deterioration apart from the Slenderglaze system (at 1/7 Archibald Place) which shows a deterioration of 0.2 W/(m^2·K), from 1.7 to 1.9 W/(m^2·K) or 12%, as shown Table 4 below.

Table 4 Measurement results applying best-case scenario [W/(m^2·K)]

Flat no.	Glazing system	Cavity fill	U-values		Change in U-value*	
			Winter 2009/10	Winter 2010/11	U-value	Percentage
1	Sashworks	Ar	2.0	2.0	±0.0	±0%
2	Histoglass D11	Kr	2.7	2.7	±0.0	±0%
3	Histoglass D10	Kr	2.3	2.3	±0.0	±0%
4	Spacia	vacuum	1.0	1.0	±0.0	±0% †
5	Slimlite	air	2.8	2.8	±0.0	±0%
6	Slimlite	Xe & Kr	2.3	2.3	±0.0	±0%
7	Slenderglaze	Xe & Kr	1.7	1.9	+0.2	+12%
8	Slimlite	Xe & Kr	2.3	2.3	±0.0	±0%
Notes: see Table 3						

However, viewed in the most negative light (i.e. within the error margins, assuming the best possible performance for the 2009/10 figures and the worst possible performance for the re-measured figures), all systems show some deterioration and some are marked, as the Table 5 below shows.

Table 5 Measurement results applying worst-case scenario [W/(m^2·K)]

Flat no.	Glazing system	Cavity fill	U-values		Change in U-value*	
			Winter 2009/10	Winter 2010/11	U-value	Percentage
1	Sashworks	Ar	1.8	2.3	+0.5	+28%
2	Histoglass D11	Kr	2.5	2.9	+0.4	+16%
3	Histoglass D10	Kr	2.1	2.7	+0.6	+29%
4	Spacia	vacuum	0.9	1.0	+0.1	+11% †
5	Slimlite	air	2.6	3.1	+0.5	+19%
6	Slimlite	Xe & Kr	2.2	2.9	+0.7	+32%
7	Slenderglaze	Xe & Kr	1.6	2.1	+0.5	+31%
8	Slimlite	Xe & Kr	2.1	2.7	+0.6	+29%
Notes: see Table 3						

It is not possible to determine the absolute figures, as stated previously. However, applying the median figures (as per Table 3 and Figure 1) a number of observations may be made:

- Of all the measurements:
  - Half the units measured showed no significant change, i.e. the re-measured U-values are well within the uncertainty of the measurement.
  - The units at 1/3 Archibald Place (Histoglass), 1/6 Archibald Place (Slimlite) and 1/8 Archibald Place (Slimlite) showed a larger change, but these are still within the margins of error and are, therefore, not statistically significant.
  - The Slenderglaze unit at 1/7 Archibald Place shows a marked difference, with a 19% increase in U-value over 2 years.
  - The Spacia unit at 1/4 Archibald Place showed no deterioration in performance. (A different unit was measured, and its performance was actually better than that of the originally measured unit.)
- Most of the gas-filled units show some deterioration in performance, but the majority are within the margins of error.
- While the 100% krypton-filled unit (1/2 Archibald Place) showed no real deterioration, its performance is similar to that of the air-filled unit (1/5 Archibald Place).

Applying the median figures, the results may indicate that there is a general deterioration of the units' edge seals. (Spacia vacuum glazing units do not have edge seals, as the two glass panes are welded together at their edges.) This may, in some instances, be caused by in-compatibility with the putty used to fix units in the sashes. However, this cannot be verified without further measurements, and other causes (e.g. diffusion) may also contribute. It is expected that the U-values will tend towards that of an air-filled unit over time. In the longer term, visible evidence of this may be seen as condensation within the units, as moist air enters and replaces the gas fill, and the desiccant in the edge spacer bars fails.

5. Conclusions

The in-situ *centre-of-pane* U-values of various replacement slim-profile double-glazing units have been re-measured two years since installation and the first measurement series in winter 2009/10.

Unfortunately, it is not possible to draw any significant conclusions from this re-measuring, as most figures are within the margins of error of the measurement. However, applying the median figures, some deterioration in performance may be seen in the majority of the gas-filled glazing units. The Slenderglaze xenon-krypton-filled unit is the only one to show a level of deterioration outside the margins of error; and this unit may merit further investigation. The air-filled Slimlite unit and the Spacia vacuum unit show no significant deterioration in performance.

A hypothesis exists suggesting that the incompatibility of edge seal materials and putty may in some cases be a cause of deterioration. Further deterioration may be identified if condensation becomes evident in the units. Periodic visual checks of the units are recommended to identify this problem.

Further re-measurements of the units over time should provide more conclusive evidence of their longevity and thermal performance.

Appendices

Appendix A - Website details of manufacturers of glazing units measured

Histoglass	D10 and D11	www.histoglass.co.uk
NSG Pilkington	Spacia	www.pilkington.com/spacia
Sashworks		www.sashworks.co.uk/conservation.htm
Sash Window Consultancy	Slenderglaze	www.sashconsultancy.co.uk
Slimlite Glass	Slimlite	www.sashconsultancy.co.uk/index.cfm?page=51
Peter Noble Glazing	Supalite	www.peternobleglazing.com

Appendix B – Summary of glazing units measured and comparison of U-values [W/(m^2·K)]

Address	Glazing system	Glazing details				Window details	U-values provided	Measured U-value with uncertainties		Change in U-value*[6]	
		Glazing configuration*[1]	Inner pane*[2]	Cavity fill *[3]	Outer pane*[4]	Sashes *[5]	by manufacturer	Winter 2009/10	Winter 2010/11	U-value	Percentage
1/1 Archibald Pl.	Sashworks	4 - 8 - 4	Low-E	Ar		New	1.8	2.0 ±0.2	2.1 ±0.2	+0.1	+5%
1/2 Archibald Pl.	Histoglass D11	3 - 4 - 4	Low-E	Kr		New	1.9	2.7 ±0.2	2.7 ±0.2	±0.0	±0%
1/3 Archibald Pl.	Histoglass D10	3 - 4 - 5	Low-E	Kr	Crown effect	Existing	1.9	2.3 ±0.2	2.5 ±0.2	+0.3	+12%
1/4 Archibald Pl.	Spacia	4 - 0.2 - 3	Low-E	vacuum		Existing	1.3	1.0 ±0.1	0.9 ±0.1	-0.1	-6% †
1/5 Archibald Pl.	Slimlite	3 - 3 - 3	Low-E	air		Existing	2.6	2.8 ±0.2	2.9 ±0.2	+0.1	4%
1/6 Archibald Pl.	Slimlite	3 - 3 - 4	Low-E	Xe & Kr	Crown effect	Existing	2.1	2.3 ±0.1	2.6 ±0.3	+0.3	15%
1/7 Archibald Pl.	Slenderglaze	4 - 3.9 - 4	Low-E	Xe & Kr		Existing	2.1	1.7 ±0.1	2.0 ±0.1	+0.3	19%
1/8 Archibald Pl.	Slimlite	3 - 3 - 3	Low-E	Xe & Kr		Existing	2.1	2.3 ±0.2	2.5 ±0.2	+0.2	9%
37 Lauriston Pl.	Slimlite	4 - 4.8 - 3	Low-E	Xe & Kr		New	2.5	2.3 ±0.2	Not re-measured		
5 Charlotte Sq.	Slimlite	3 - 3 - 3	Low-E	Xe & Kr		New	2.1	2.3 ±0.2	Not re-measured		

Notes

*[1] Glazing configuration: inner pane – cavity – outer pane [mm]

*[2] Inner pane: all inner glass panes have a low-emissivity coating / film.

*[3] Cavity fills: colour coding: air | inert gas | vacuum

*[4] Outer pane: Crown-effect glass was used as outer glass pane.

*[5] Sashes: glazing units installed into existing or new windows sashes

*[6] Figures showing the *Change in U-value* between 2009/10 and 2011/12 do not take account of the uncertainty margins. Colour coding: red colour shows an increase in U-value, i.e. a deterioration of the thermal performance; green colour shows a decrease in U-value, i.e. an improvement of the thermal performance.

† In flat 1/4, the re-measurement was carried out in a location different from that in January 2012.

Bibliography

Changeworks, 2010. *Double glazing in listed buildings: Project report*. [PDF] Edinburgh, UK: Changeworks.
Available at: Changeworks
http://consultancy.changeworks.org.uk/assets/uploads/Double_Glazing_In_Listed_Building_-_Project_Report_(Changeworks_2010).pdf

City of Edinburgh Council, 2010. *Edinburgh planning guidelines: Replacement windows and doors*. Finalised version, [PDF] Edinburgh, UK: City of Edinburgh Council.
Available at: City of Edinburgh Council
www.edinburgh.gov.uk/download/meetings/id/18445/edinburgh_planning_guidance_replacement_windows_and_doors-finalised_version

City of Edinburgh Council, 2012. *Listed buildings and conservation areas*. [PDF] Edinburgh, UK: City of Edinburgh Council.
Available at: City of Edinburgh Council
http://www.edinburgh.gov.uk/download/downloads/id/9581/listed_buildings_and_conservation_areas_2012

Heath, N. Baker, P. & Menzies, G., 2010. *Slim-profile double glazing: Thermal performance and embodied energy*. (Historic Scotland Technical Paper 9) [PDF] Edinburgh, UK: Historic Scotland.
Available at: Historic Scotland
https://www.historic-scotland.gov.uk/slim-profile_double_glazing_2010.pdf

Historic Scotland Technical Papers

Available at www.historic-scotland.gov.uk/technicalpapers

1 Thermal performance of traditional windows
2 In situ U-value measurements in traditional buildings – *Preliminary results*
3 Energy modelling analysis of a traditionally built Scottish tenement flat
4 Energy modelling in traditional Scottish Houses (EMITSH)
5 Energy modelling of a mid 19th century villa
6 Indoor air quality and energy efficiency in traditional buildings
7 Embodied energy in natural building stone in Scotland
8 Energy modelling of the Garden Bothy, Dumfries House
9 Slim-profile double glazing – *Thermal performance and embodied energy*
10 U-values and traditional buildings – *In situ measurements and their comparison to calculated values*
11 Scottish Renaissance interiors – *Facings and adhesives for size-tempera painted wood*
12 Indoor environmental quality in refurbishment
13 Embodied energy considerations for existing buildings
14 Keeping warm in a cooler house – *Creating thermal comfort with background heating and locally used supplementary warmth*
15 Assessing insulation retrofits with hygrothermal simulations – *Heat and moisture transfer in insulated solid stone walls*
16 Green Deal financial modelling of a traditional cottage and tenement flat
17 Green Deal, Energy Company Obligations and traditional buildings
18 Evaluating energy modelling for traditionally constructed dwellings
19 Monitoring of thermal upgrades of ten traditional properties
20 Slim-profile double-glazing in listed buildings – *Re-measuring the thermal performance*