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Double Glazing In Listed Buildings

Project report

Report prepared by Changeworks for The City Of Edinburgh Council, July 2010

This report provides the results and analysis of a research and demonstration project, **Double Glazing In Listed Buildings**, led by Changeworks in partnership with Lister Housing Co-operative and Edinburgh World Heritage at the request of The City Of Edinburgh Council. This project ran from March 2009 to March 2010, and involved retro-fitting a range of bespoke, slim-profile double-glazing units into category 'A' and 'B' listed buildings in Edinburgh's Old and New Towns, both of which are conservation areas and form a UNESCO World Heritage Site.

This report provides full background to the project and the different system specifications, together with analysis of costs, installation and maintenance details, longevity, occupant impact and further recommendations. It also includes the results of technical research into the thermal performance and embodied energy of the installed units, which was carried out with support from Historic Scotland.

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Executive summary

This report provides the results and analysis of a research and demonstration project, **Double Glazing In Listed Buildings**, led by Changeworks in partnership with Lister Housing Co-operative and Edinburgh World Heritage at the request of The City Of Edinburgh Council. This project ran from March 2009 to March 2010, and involved retro-fitting a range of bespoke, slim-profile double-glazing units into category 'A' and 'B' listed buildings in Edinburgh's Old and New Towns, both of which are conservation areas and form a UNESCO World Heritage Site.

The project has demonstrated that appropriate double glazing can be successfully incorporated into listed buildings, improving their thermal performance and lowering their CO_2 emissions without detracting from their historic character or appearance. This report recommends that such systems should be permitted in listed buildings, both in Edinburgh and further afield, where there would not be a significant loss of historic material: this can be carefully regulated by a planning policy update. A breakdown of recommendations is provided below, however the key finding is best summed up in this quote from one of the householders who received double glazing as part of the project:

'Double-glazed windows like mine should definitely be permitted in other listed buildings in Edinburgh, if it cuts fuel bills and makes homes more comfortable for occupants. They don't appear any different from the outside' (Lister tenant).

<u>Recommendations</u>:
The following table provides a list of recommendations arising from this project, for enactment both through policy updates and technical product improvements.

Recommendations for enactment through policy update:
1) **Slim-profile double glazing should be permitted in listed buildings, where the original glazing is no longer in place.** It is recognised that original glazing is deemed important in terms of conservation of historic materials, however in many cases this has been lost, representing an opportunity for thermal improvement without compromising historic fabric. 2) **The types of double glazing permitted should be defined by specification rather than by manufacturer.** An ever-increasing number of systems is emerging onto the market, and new systems should not be excluded by permitting any specific set of manufacturers. 3) **None of the systems installed in this project should be excluded from an updated policy.** It is recognised that the sealing cap on the vacuum glazing units, in particular, could be a source of contention, however in view of its high performance and ease of installation – both important factors in selecting a system – it should be considered as a viable option. It may be that permissions are restricted to windows with up to a set number of glazing panes, which would reduce the number of sealing caps, however this would be at the discretion of the Council. 4) **Use of Crown-effect outer panes should be at the discretion of the property owner**, rather than a planning requirement**.**

Recommendations for enactment by manufacturers

1) **Warranty periods should be made clear on all systems.**

2) **Spacer bars should be made available in white as well as black** (and ideally a number of other colours, in order to minimise their visibility.

3) **Modern 'warm-edge' spacer bars should be used rather than metal** (where it can be demonstrated that this will not compromise the system's performance). This will minimise the risk of cold bridging.

4) **The sealing cap on vacuum glazing units should be reduced in size and moved closer to the corner of the unit, if possible.** This would reduce its visibility, and increase its applicability in listed buildings. (*NB See footnote 18*)

5) **The vacuum glazing units should be manufactured more locally, if possible.** It is recognised that this may not be immediately achievable, however this would not only result in lower embodied energy, but also make installation, planning and repairs considerably easier and faster.

6) **The sealant around the edge of the unit should not extend further into the glazing than is necessary.** It is recognised that a secure and lasting seal is critical, however where this extends into the glazing beyond a further point overpainting becomes necessary in order to conceal the sealant.

The category 'B' listed Georgian corner tenement block that was fully double-glazed as part of this project, with no detrimental impact to the aesthetics of the building

Section 1 Background and project outline

1.1 Introduction & Aims of the project

This report describes a research and demonstration project developed and managed by Changeworks Resources For Life, at the request of The City Of Edinburgh Council. The project involved selection, installation and monitoring of a range of slim-profile double glazing systems into the windows of listed buildings in central Edinburgh, a conservation area and part of the UNESCO World Heritage Site. The project was carried out in partnership with Lister Housing Co-operative and Edinburgh World Heritage, with further support from Historic Scotland.

The aim of the project was to demonstrate that such systems can be successfully installed in listed buildings to reduce their energy consumption, fuel bills and CO_2 emissions, without detracting from their historic appearance. The project was carried out to inform a future Council policy change in relation to windows in listed buildings.

Double glazing is currently not permitted in the majority of listed buildings in Edinburgh, as it has historically been deemed unsuitable. Slim-profile double glazing systems allow either retention of the existing frame or a new frame with the same dimensions as the original. This project aimed to demonstrate that:

- by using slim-profile double glazing in timber frames there is no detrimental effect to historic buildings;
- such products should be permitted in listed buildings across Edinburgh (and elsewhere, although this is outwith he remit of this report).

The installations showed that slim-profile double glazing units can be both retrofitted into existing timber sashes (replacing single glazing), and built into new windows.

1.2 Need for the project

Pre-1919 dwellings account for nearly 20% of Scotland's housing[1]. Far more pre-1919 dwellings are 'Poor' (NHER 0-2) in terms of energy efficiency than more modern dwellings[2]. Only a small proportion of Scottish housing with 'Good' energy efficiency (NHER 7-10) is pre-1919[3].

23% of Edinburgh's population lives in its conservation areas[4]. Edinburgh has more listed buildings than any other UK city apart from London, and accounts for a quarter of all category 'A' listed buildings in Scotland[5]. The entire centre of Edinburgh is also designated as a UNESCO World Heritage Site, where around 75% of the buildings are listed[6].

Householders in conservation areas and listed buildings face particular issues when considering energy efficiency improvements to their homes, as many standard measures are not permitted. Measures relating to windows can be particularly complex, but single glazing is also a particular source of difficulty for householders.

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[1] Scottish House Condition Survey: Key Findings 2008 (Scottish Government, 2009)
[2] *Ibid*
[3] *Ibid*
[4] Single Outcome Agreement 2008-11 (The City of Edinburgh Council, 2008)
[5] *Ibid*
[6] Energy Heritage – A guide to improving energy efficiency in traditional and historic homes (Changeworks, 2008)

Nearly 40% of pre-1919 dwellings have single-glazed windows[7]. 72% of heat lost through a window is lost through the glazing[8]. Single glazing has very poor energy efficiency, with a U-value of around 5.5[9]. Heat loss through a single-glazed window is roughly double the heat loss through a double-glazed window built to Scottish Building Standards[10].

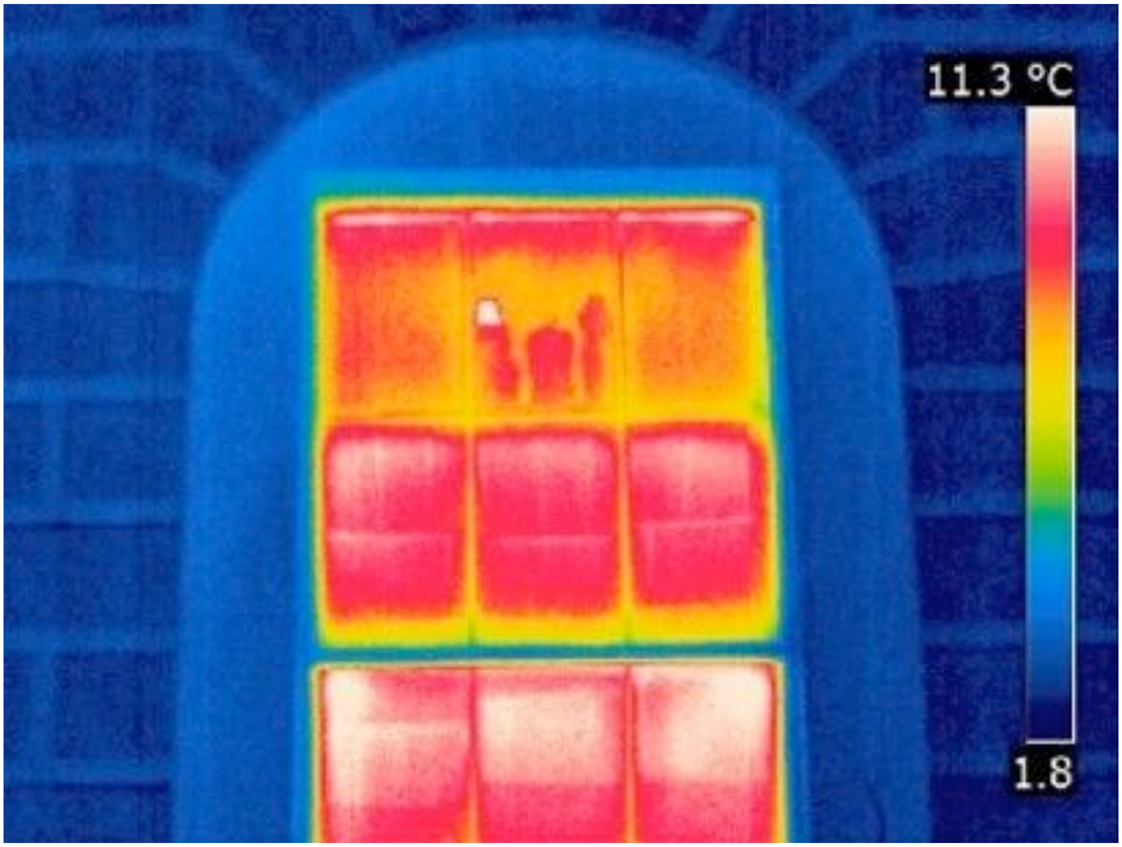

Figure 1 Thermal image showing dramatic heat loss through single glazing

These excessive levels of heat loss mean that households with single-glazed windows have to use more energy than better-insulated homes to heat their properties, resulting in higher CO_2 emissions and higher fuel costs (that can often place people in fuel poverty). Single glazing is also prone to condensation due to its cold surface, and over time this can rot timber frames. This can cause significant and costly damage to windows that in some cases are of historic importance.

Common improvements measures include draughtproofing, secondary glazing, shutters and double glazing. Draughtproofing is effective in reducing heat loss from gaps around the window, and should be considered as part of a range of possible measures; however, it does nothing to remedy the heat loss through the glazing. Secondary glazing can be effective in reducing both draughts and heat loss through glazing; however, it requires a second window, where a single window would be a less intrusive solution. Shutters have been shown to be effective in terms of reducing heat loss, but are only a night-time measure. Further details on these measures can be found in the comprehensive best-practice manual Energy Heritage - A guide to improving energy efficiency in traditional and historic homes (Changeworks, 2008).

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7 Glazing by dwelling age by local authority, 2003-06 (Scottish Government, 2007)
8 Improving the thermal performance of traditional windows (Glasgow Caledonian University, 2008)
9 *Ibid*
10 *Ibid*

Standard double glazing has visual differences to single glazing (particularly older glazing), in terms both of the flatter glass and thicker astragals and transoms. This has historically been deemed unsuitable for listed buildings by some planning authorities, and has led to a misconception that no double glazing is suited to historic buildings.

However, due to increasing pressure to meet carbon emission reduction targets and mitigate the effects of climate change, as well as help combat rising energy costs, planning authorities are increasingly looking to find sensitive and effective double-glazing solutions to improve the energy efficiency of windows in protected buildings.

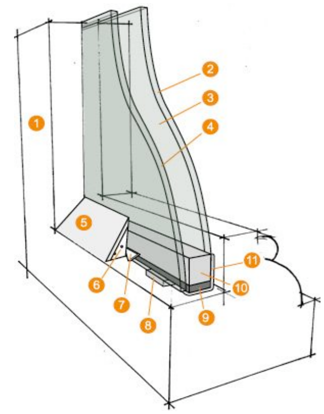


Figure 2 Double glazing section (© Histoglass)

The City of Edinburgh Council currently allows double glazing in timber frames in unlisted buildings in conservation areas, and slim-profile timber-framed double glazing is now permitted in '1-over-1' sash windows in category 'C' listed buildings. However, no form of double glazing is currently permitted in category 'A' and 'B' listed buildings in Edinburgh, which account for the majority of listed buildings.

The City of Edinburgh Council therefore commissioned Changeworks to research, implement and monitor a pilot project, installing a range of specialist slim-profile double glazing systems in listed buildings in central Edinburgh. The results of this project would inform a policy update to allow some such systems to be installed in listed buildings across the city. This would give householders in listed buildings a greater capacity to reduce their fuel bills and CO_2 emissions. Changeworks and Edinburgh World Heritage duly prepared a project brief, which was approved by the Planning Committee in February 2009.

This project built on Changeworks' Energy Heritage project, which included groundbreaking research and formed effective partnerships with key organisations including The City of Edinburgh Council, Edinburgh World Heritage, Historic Scotland and The Cockburn Association.

The project also built on recent research into window efficiencies published by Historic Scotland, which drew on Changeworks' Energy Heritage project. Their research included scientific tests on a range of window improvements, which were carried out in laboratory conditions. This new project would take their research further by allowing them to monitor the *in situ* thermal performance of double glazing. This would allow the windows' aesthetic considerations to be balanced with their thermal performance and CO_2 reduction potential.

1.3 Project outline

The project involved installing a range of slim-profile double glazing options, which were then monitored and the results analysed in order to assess which elements are best suited to listed buildings and conservation areas.

The project comprised:

- Comprehensive research and literature reviews

- Assessment of the pros and cons of various windows options, both in terms of performance and aesthetics (including frame materials, types and widths of double glazing, installation options, thermal efficiency, aesthetics and so on)
- Identification of suitable buildings for trial installations
- Performance assessment of the existing single-glazed windows
- Preparation and negotiation of permissions
- Installation of a range of double glazing systems
- Monitoring of their thermal performance
- Embodied energy assessment for the different systems
- Documenting feedback from building occupants
- Facilitating a focus group of project partners to gauge opinion on the aesthetic merits of the different technologies (taking into account the historic setting of the buildings, planning and building conservation perspectives, householder perspective and environmental aspects)
- Production of report to inform future Council policy updates

The project ran from April 2009 to March 2010. Following the extensive period of background research, permissions were secured in autumn 2009, and the installations and monitoring took place over the winter period. This timescale allowed both installation and monitoring to take place during the peak heating season.

N.B. This project relates to timber-framed windows. uPVC is not generally considered suitable for historic buildings on grounds of appearance, and would not be recommended as an environmental option due to its content and lifespan[11]. Well-maintained timber can often have a considerably longer lifespan, is fully biodegradable and recyclable, and is generally preferred by conservation bodies in terms of appearance for historic buildings.

1.4 Funding

The project was developed and managed by Changeworks, with funding provided by The City Of Edinburgh Council.

The capital costs were funded by Lister Housing Co-operative and Edinburgh World Heritage jointly. Lister's contribution included grant funding from the Scottish Government's Wider Role fund. In some instances, materials and works were provided free of charge or at a reduced rate.

Research and monitoring of the embodied energy and thermal performance of the glazing systems was funded by Historic Scotland.

[11] See embodied energy research report at Appendix 2.

Section 2 Project details

2.1 Locations

Installations were carried out in category 'A' and category 'B' listed buildings in Edinburgh's Old and New Towns, both parts of the UNESCO World Heritage Site.

- All the windows in a Georgian corner tenement building on Lauriston Place (comprising nine flats) were treated. The owner, Lister Housing Co-operative, had identified these flats as having a particular glazing problem: they have large single-glazed '6-over-6' timber sash windows dating from 1992, which are badly affected by condensation and heat loss due to the single glazing. With one exception, most of these flats are relatively small (3-5 windows).

- One window of a Georgian category 'A' listed building in Charlotte Square was treated. This building is owned by the National Trust for Scotland and occupied by Edinburgh World Heritage, a key project partner and funder which strongly supported the project from the outset. The works to this window are temporary only: listed building consent was granted for 1 year, after which the original single-glazed sashes will be reinstated.

Using the Lister properties had an added advantage, in that the different improvement options would be comparable side by side. This single-stair approach has been used very effectively in the recent high-profile Energy Heritage and Renewable Heritage projects, led by Changeworks in partnership with The City of Edinburgh Council, Edinburgh World Heritage and Lister Housing Co-operative.


Figures 3 & 4 The Lauriston Place tenement (left) and Charlotte Square offices (right)

The Lister Housing Co-operative tenement flats in this project suffer from additional limitations in energy efficiency: the majority have electric heating systems, which are relatively inefficient, cost significantly more to run than gas central heating, and have significantly higher associated CO_2 emissions (fossil-fuel-based electricity is far more CO_2-intensive than most other fuels). Due to their configuration, most of these flats are front-facing only (i.e. they have no rear wall), so any gas central heating system would require a flue to project through the front wall. However, this is not permitted on such listed buildings in Edinburgh, meaning that these householders are forced to pay more to run a less efficient system than they might otherwise choose.

The single glazing and relatively poor heating system combine to make it hard for these householders to heat their homes enough to be warm. The cold surface of the single glazing also attracts significant amounts of condensation in these properties, which combined with inadequate ventilation can damage the frames over time as the moisture penetrates and rots the timber. From a conservation perspective, therefore, single glazing can actually cause damage to historic fabric.

Such complexities make it all the more important that these householders are permitted to make energy-efficiency improvements to single-glazed windows.

2.2 Permissions

Listed building consent was the only formal permission required for the project. (However, a considerable amount of informal negotiation was needed to ensure all parties were satisfied with the proposals. Written permission was also secured from the National Trust for Scotland for the works to 5 Charlotte Square).

Listed building consent was granted for all works at Lauriston Place. Listed building consent for the works at Charlotte Square were granted on a temporary basis only; following a 12-month period, the original single-glazed sashes will be reinstated in this window.

In the case of Lister Housing Co-operative, where the existing windows are particularly problematic and contain no historic materials, permanent permissions were the only viable solution. This will ensure that the project remains sustainable, and avoids wasted materials and the need to remove thermally efficient windows and replace them with their inefficient predecessors.

Securing listed building consent was a lengthy process, taking over 3 months to receive formal notification despite the fact that the Planning Committee had requested the project in the first instance. This extended timescale was largely due to the complexity of the project proposal, and the fact it contravened current policy.

2.3 Technologies

Conventional double glazing consists of two layers of glass up to 20mm apart, with dry air or inert gas (e.g. argon) in the cavity. This considerably reduces the heat loss through the glazing, due to the low thermal conductivity of these gases and the additional layer of glass.

For this project, slim-profile systems were installed that have a significantly smaller cavity than conventional double glazing, in order to limit the change in appearance that can occur when single glazing is replaced with double glazing.

The image on the right shows a typical example of how such slim-profile double glazing can be retro-fitted into an existing sash, retaining the original astragal dimensions.

Figure 5 Typical slim-profle double glazing.

It was agreed that a range of systems should be trialled, in order to allow comparison and perspective and achieve a greater understanding of the key issues involved. Changeworks carried out extensive research into the various systems available, and the final selection was subject to agreement from all partners, including The City of Edinburgh Council and Edinburgh World Heritage.

The final selection was as follows:

System	Details
Histoglass	• Based in Leeds • Manufactured in Germany • Supply only
Slimlite	• Based & manufactured in Edinburgh • Supply & installation
Slenderglaze	• Based & manufactured in Bath • Supply (installation available locally)
Supalite	• Based & manufactured in Edinburgh • Manufactured by Peter Noble Glazing & Bonnington's Joinery • Supply & installation
Sashworks	• Based in Lockerbie • Part of Ventrolla Scotland • Supply & installation
Pilkington energiKare Legacy	• Based throughout UK • Manufactured in Japan • Product also called Pilkington Spacia • Supply only

(N.B. Due to product name changes, some of the product names are used interchangeably in the two research reports included at Appendices 1 and 2. These are as follows:

- *Slimlite = Fountainbridge*
- *Supalite = Bonnington's*
- *Sashworks = Ventrolla*
- *Pilkington energiKare Legacy = Spacia)*

Most of these systems are broadly similar in construction and appearance, with the exception of one vacuum-glazing system (see below).

- The Histoglass, Slimlite and Slenderglaze systems all incorporate similar features: a slim-profile double-glazed unit; available in a range of cavity depths to achieve a range of U-values; Low-Emissivity glass used as the inner pane; Crown-effect[12] glass available as an outer pane; and able to be either retrofitted into existing windows or built into new windows.

- The Sashworks and Supalite systems are very similar to the above systems, but are built into new sashes. The Supalite system can be retrofitted into existing windows, but the installer felt that the system is most viable for new-build windows (see section 2.4.2 for details).

- The Pilkington energiKare Legacy system is fundamentally different from the above systems: instead of dry air or inert gases in the cavity, there is a vacuum. This means that the cavity can be extremely small (0.2mm) so the overall unit is slimmer, and the vacuum reduces the heat loss further giving the unit a very low U-value. This system can be retrofitted to existing windows or built into new windows.

Figure 6
Vacuum glazing

2.3.1 Other technologies

Other, similar systems are also available, however due to time and space limitations these were not included in the trial. These include Timbalite (based in Surrey) and Saint-Just SGG Climaplus Colonial (based in France).

Another England-based product also exists, Conservation Glazing, whereby a clear acrylic pane can be fitted directly into a single-glazed window to make an economic form of double glazing, however at the time of the project this product was still at conceptual stage and Lister Housing Co-operative preferred to use established technologies only for this project. However, English Heritage has carried out some tests of this product, which show significant thermal improvement over single glazing. While lifespan and warrantly periods are yet to be confirmed, it should be considered as an acceptable option as it is simple, reversible and economical, and could be an option where windows contain original glass (replacing older, original glass is unlikely to be permitted in most listed buildings). [N.B. Acrylic materials can however have a relatively short lifespan, as long-term exposure to UV light can make it brittle, and it is relatively soft so could be easily scratched (by repeated cleaning, for example).]

[12] It is recognised that there is a range of historic glass types (e.g. Crown, cylinder, hand-drawn). For the sake of consistency, the term 'Crown effect' is used throughout this report to denote original, historic glass: (where imitation of such glass is desired, a glass type in keeping with the original glass of the window in question should be specified).

2.4 Installation

In order to allow for a robust analysis of the glazing performance, each flat had a single system installed throughout.

Lister Housing Co-operative confirmed the importance of selecting a competent and reputable installer (for the supply-only glazing options), as the specialist nature of the units means a sound knowledge both of technical details and conservation principles is needed. For this project, all supply-only systems were installed by Capital Glazing, an Edinburgh-based company.

2.4.1 Installation in existing sashes

The sashes were removed from the windows (which were boarded up) and taken to a factory for installation of the double glazing. The existing glass was removed, and the pre-made double-glazing units were fitted in their place and secured with new putty. Once the works were complete, the sashes were replaced in the frames.

In most instances the glazing manufacturer specified a particular type of putty (generally butyl- or polymer-based), which was recommended to avoid erosion of the seal around the perimeter of the double glazing units. This specification is to combat the suggestion that traditional window putty can in some cases react with the edge seal and cause it to break down, which could lead to eventual loss of performance.

While in the factory, all sashes had draughtproofing applied as an additional energy-saving measure. This is good practice, as it addresses both ventilation and fabric heat loss.

The sash weights were adjusted to cater for the increased weight of the new glazing. Rather than having to add extra weights (which could be problematic due to the space limitations), the existing weights were simply replaced with new weights made of a heavier material.

All the systems installed are available in a range of depths (see image below). Deeper units may be desirable from an energy-saving perspective, as they will generally have a lower (better) U-value than slimmer units. However, this added depth can make installation in existing frames complicated, and add considerably to the cost. The reason for this is that the sash rebates may have to be routed out (i.e. have some of the timber removed) to make them deeper so they can accommodate this extra depth. This could potentially weaken the sashes if done incorrectly, and the considerable extra labour would inevitably add to the cost of the works. The more panes of glass there are in a sash, the more routing out would be required: for example, routing out a '1-over-1' sash would involve considerably less work than routing out a '6-over-6' sash.

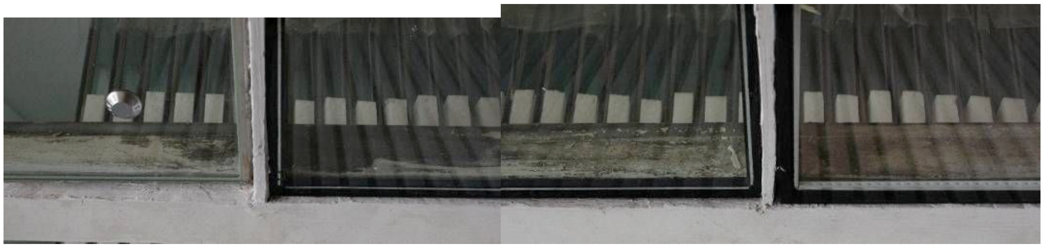


Figure 7 This composite image shows the three lower panes of a 6-pane timber sash. Three different slim-profile systems have been inserted into the sash (without putty) to illustrate their varying depths. The system on the far left is slim enough to leave plenty of space for the putty; the centre system also leaves sufficient space; the far-right system leaves very little space to insert enough putty to hold the glazing securely in place (without having to router out the sash).

2.4.2 Installation as new sashes

As mentioned previously, it was decided to include new sashes in the project to allow further comparison of cost, aesthetics and so on; these are important considerations in terms of replicability. The new sashes matched the profile of the existing sashes.

For the new sashes, the contractors simply built the double glazing units into new sashes. Building these double glazing units directly into new sashes avoids the potential complication of routing out existing rebates, and means that deeper units can be accommodated more easily. However, beyond a certain glazing depth this would result in thicker glazing bars (for sashes with multiple panes of glass), so care is needed to specify dimensions in keeping with those of traditional sashes.

Bonnington's Joinery, the manufacturer and installer of the Supalite product, felt it was preferable (on grounds of cost, workload and replicability) to replace sashes with new double-glazed sashes, rather than retain existing sashes and replace the single glazing with double glazing.

When considering building conservation, retention of historic fabric is an important aspect. Where original, historic timber frames exist, and are in good condition (or easily repairable), it may be preferable to fit double-glazed units into these original frames (as above, see section 2.4.1).

Section 3 Project impact and monitoring

3.1 Visual impact

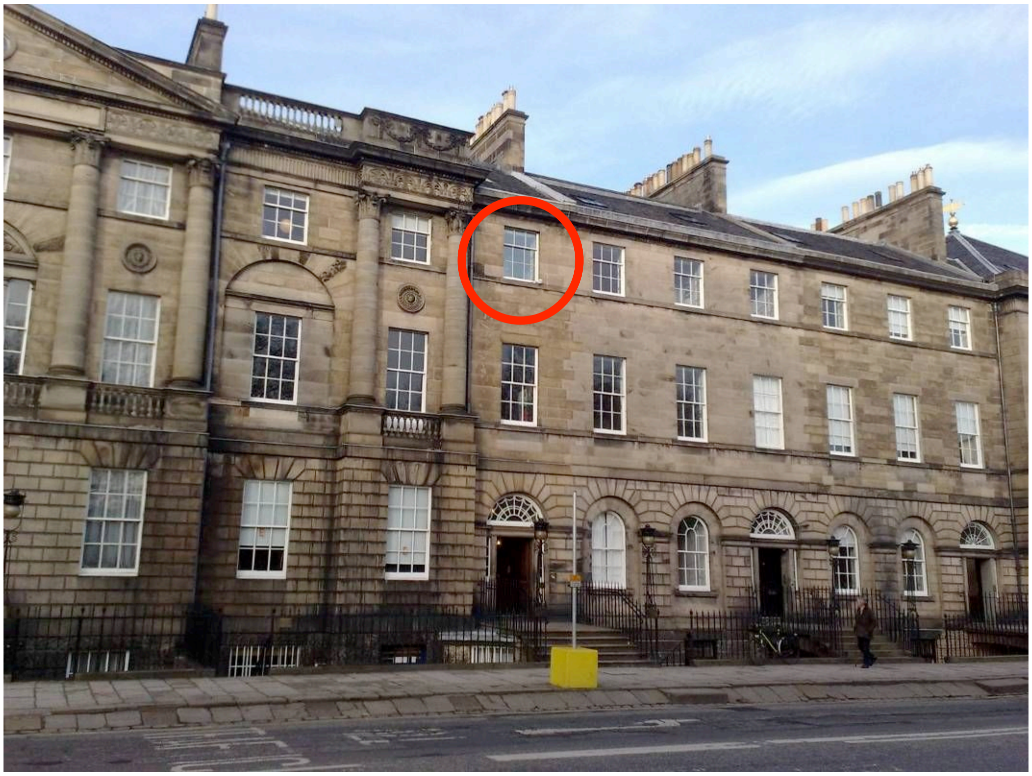


Figure 8 This window at Charlotte Square has new double-glazed sashes. The glazing bar dimensions are identical to the other windows. The new glass' reflective quality is slightly different, however this is minimal and is also dependent on light conditions and glass colour.

Figure 9 A closer view (top left), highlighting the discreetness that double glazing can achieve.

All systems installed have a broadly similar appearance. This can be affected by using Crown-effect glazing in the outer pane of the unit; by the type of glass used in the outer pane (some have more bronzed or blue appearances); by the depth and colour of the spacer bar; and by the sealing cap in the corner of the vacuum glazing units.

The main areas of contention surrounding double glazing in listed buildings are a) the glazing bars and b) the glazing itself. Both these issues are resolved, in large part, by the specialist systems installed under this project.

Issue	Solution
Due to its weight and depth, conventional double glazing requires thicker glazing bars than traditional single-glazed windows.	The slimness of the units means that they can be fitted into existing sashes, and if new sashes are required they an be made to the same dimensions as the original ones (in some cases an extra 1-2mm may be required, however this is negligible), so in either case the thickness of the glazing bars does not need to change.
Modern glass is flatter than old glass and therefore has different reflective qualities; it can also have a different colour tint depending on the glass type. Adding a second layer of glazing also affects the reflective qualities of the window.	The majority of systems can incorporate Crown-effect glass in the outer pane, to mimic the appearance of older glass. However, in many instances traditional and historic buildings no longer have original glass in any case, in which case replacing modern single glazing with modern double glazing should not cause any major change in appearance. Any colour tint should be investigated before selecting a system, to ensure the most appropriate glass type is used.

Figures 10 & 11 All these windows are now double-glazed. However, the bottom row of windows have Crown-effect outer panes (see right for detail)

3.1.1 Appearance of the six different systems

Slimlite (made by Fountainbridge)

Figure 12 External view

Figure 13 Internal view

Histoglass

Figure 14 External view

Figure 15 Internal view

Slenderglaze

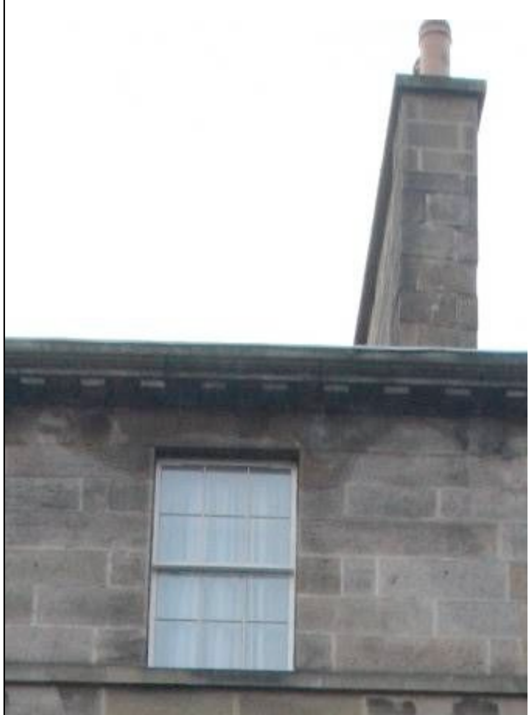


Figure 16 External view

Figure 17 Internal view

Pilkington energiKare Legacy (also known as Pilkington Spacia)

Figure 18 External view

Figure 19 Internal view

Supalite (made by Bonnington's; new sashes)

Figure 20 External view

Figure 21 Internal view (different window)

Sashworks (made by Ventrolla; new sashes)

Figure 22 External view

Figure 23 Internal view (with monitoring kit)

3.1.2 Variations in the six different systems

The **Histoglass**, **Slimlite**, **Slenderglaze** and **Supalite** standard units all have a very similar appearance. To all intents and purposes, they are indistinguishable from the previous single-glazed windows (which had modern glass).

The double-glazed units in the new **Sashworks** sashes have a bigger cavity than the other systems (8mm rather than 3-4mm), which makes the black spacer bar more visible when viewed at an angle. This could be resolved by changing the colour or the spacer bar to match the frame, however in any case this is only visible when viewed close-up.

Figures 24 & 25 The thin spacer bar used in the left-hand image is very discreet. The thicker spacer bar in the right-hand image is more apparent when viewed at an angle

Most of the systems use a black or metal spacer bar in their cavities. The larger the cavity, the more apparent this spacer bar becomes. Changing the colour to white (or whatever colour matches the sashes) would be a simple way to radically reduce any visual impact.

Figure 26 A typical metal spacer bar in a non-traditional timber frame

The **Pilkington energiKare Legacy** units have very small ‘micro-beads’ between the two layers of glass to hold them apart; these are effectively invisible. The sealing cap in the corner of each pane is more visible, but again this is not apparent unless viewed close-up *(NB See footnote 18)*. The effect is compounded by using the product in windows with multiple panes of glass (the sash windows in question are Georgian ‘6-over-6’ style, so each window is divided into 12 panes of glass), and this would be significantly minimised in windows with fewer panes of glass.

In some cases the sealant around the edges of the individual units protrudes some way into the unit, meaning that it could be visible once installed. This can be avoided by overpainting the outer pane 1-2mm when painting the glazing bars, which often occurs in any case as extra layers of paint are added to a window over time.

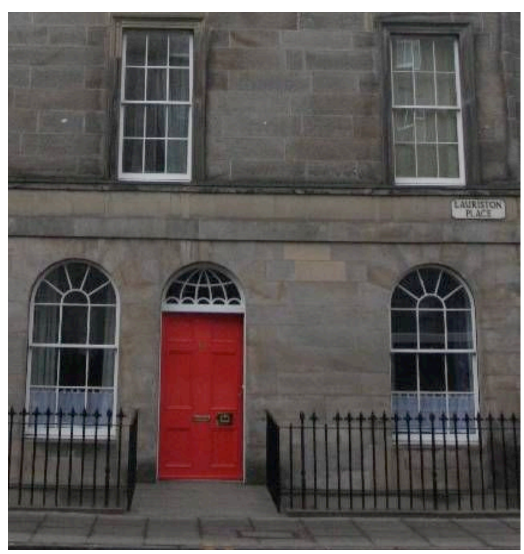
3.1.3 Visual impact summary

In summary, it should be made clear that to all intents and purposes all systems installed had a very negligible impact, if at all, on the appearance of the buildings in question. Indeed, a visual inspection team comprising The City Of Edinburgh Council, Historic Scotland and Edinburgh World Heritage took some time to identify the different systems in each property. However, each group had differing opinions on the relative merits of each system, highlighting the subjective nature of such aesthetic decisions.

Clearly, on close inspection the differences from single glazing may be discernable. However, when balanced against the need for significant CO_2 reductions in all existing housing, these variations should not prevent change. Regarding building conservation as ‘management of change’ allows perspective to be maintained.

Most of the variations in appearance mentioned above are only visible when an individual window is scrutinised close-up. Taking a holistic approach becomes important when considering how to improve the sustainability and energy efficiency of these culturally valuable buildings. This project has demonstrated that slim-profile double glazing can be successfully installed with no *easily apparent* visual impact, and this report recommends that such systems should be permitted in Edinburgh.

Energy-saving measures such as secondary glazing are currently permitted without the need for any permissions (where their installation does not alter any building fabric). As the image below shows, these can have a far greater visual impact than sensitively-installed double glazing. Equality should therefore be awarded to appropriate modern double-glazing technologies, so they can help protect the sustainability and character of Edinburgh’s built heritage.



Figures 27 & 28 Appropriate double glazing (right; all windows are double-glazed) can be considerably more discreet than secondary glazing (left)

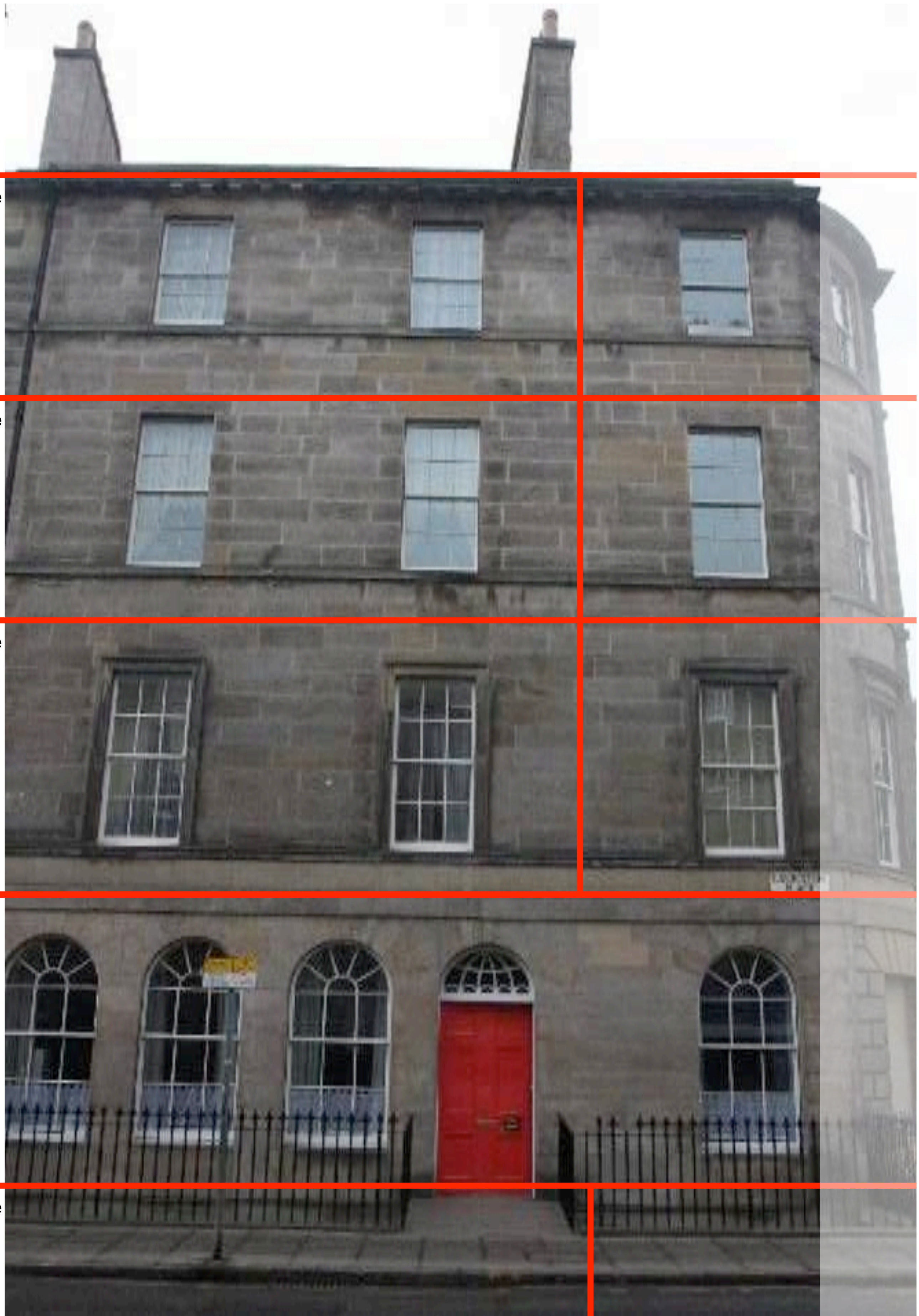
1/7 Archibald Place
Slenderglaze

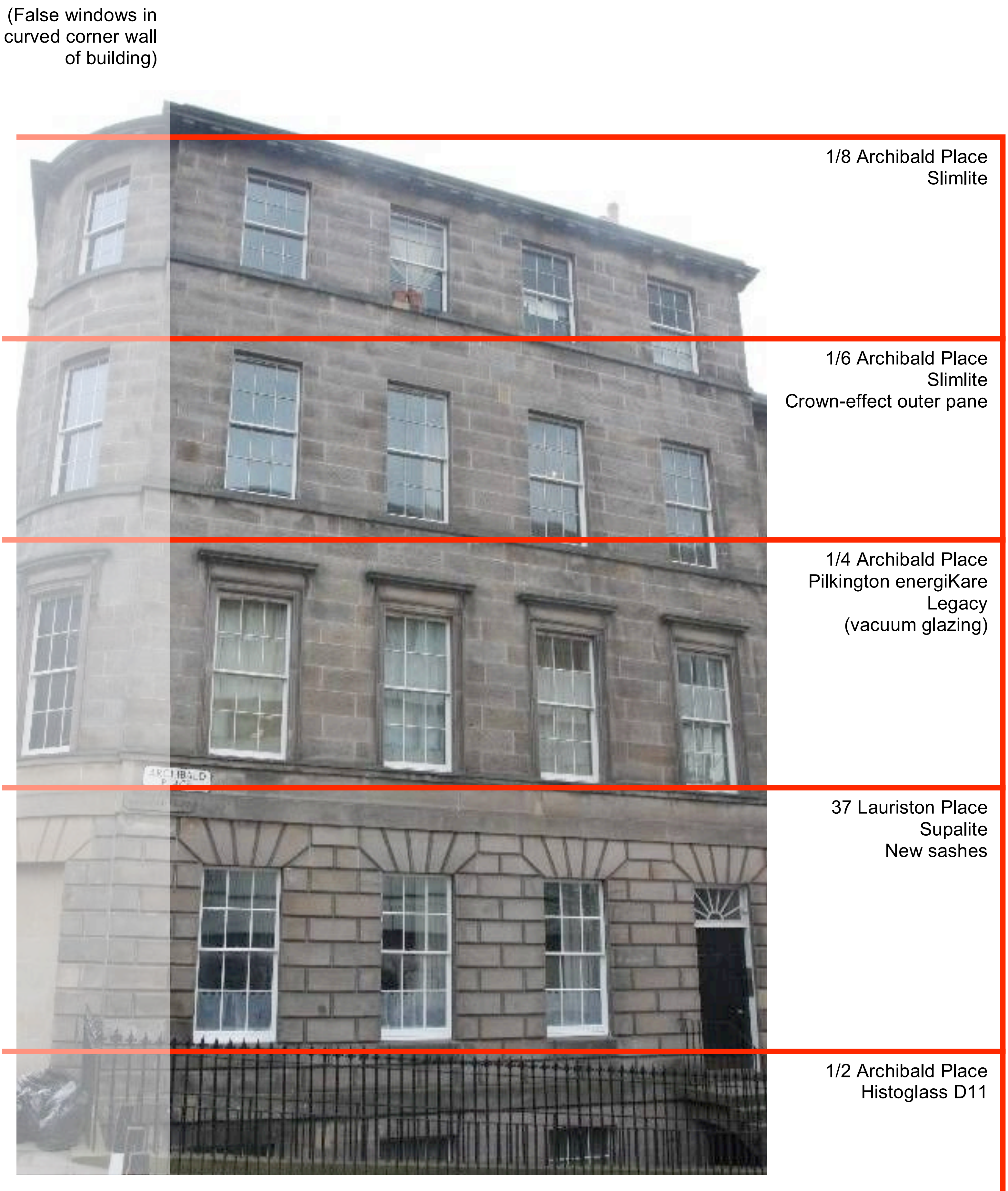
1/5 Archibald Place
Slimlite

1/3 Archibald Place
Histoglass D10
Hand-drawn outer pane

37 Lauriston Place
Supalite
New sashes

1/1 Archibald Place
Sashworks
New sashes




(False windows in curved corner wall of building)
1/8 Archibald Place
Slimlite
1/6 Archibald Place
Slimlite
Crown-effect outer pane
1/4 Archibald Place
Pilkington energiKare
Legacy
(vacuum glazing)
37 Lauriston Place
Supalite
New sashes
1/2 Archibald Place
Histoglass D11

3.2 Thermal performance

Thermal performance is generally the primary reason for installing double glazing. As such, it became important to monitor the efficiency of the units installed in this project.

All manufacturers presented predicted U-values for their products, however Historic Scotland funded *in situ* testing of all the systems installed. Brief commentary and a table of results are included below; the full research report is included at Appendix 1 (and is published independently by Historic Scotland as part of their series of Technical Papers).

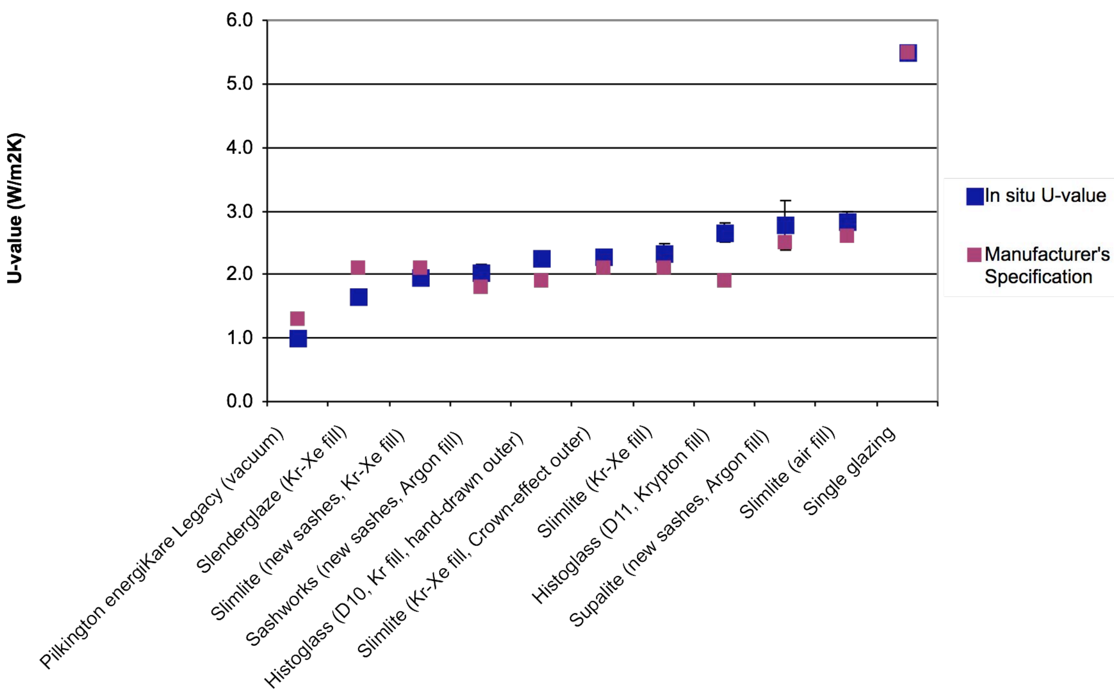


Figure 29 *In situ* U-value test results (centre-pane)

The test result uncertainty is 5-7% on most of the systems. Uncertainty is somewhat higher on the Pilkington energiKare Legacy and Supalite systems, as these were the last systems to be tested and the longer days (March, as opposed to January-February when the other systems were tested) affected the testing methodology (see Appendix 1 for full details).

Many of the results are broadly similar, however some key points arise:

- The U-value of the different systems ranged from 1.0 to 2.8. Most systems achieved a U-value close to 2.0.

- With a small number of exceptions, the *in-situ* U-values tend to be slightly higher than the manufacturers' laboratory-tested U-values. This may be explained by the exposure to the elements that materials face once installed in buildings, rather than in closely controlled laboratory conditions.

- Having only air in the cavity will result in an improved U-value over single glazing alone, however the improvement is smaller than if the cavity contains inert gases or a vacuum.

- Having 100% argon in the cavity does give a lower U-value than air, however the improvement is marginal when the cavity is small. To achieve a significantly lower U-value using argon only, a much wider cavity is needed (as with standard double glazing).

- Xenon- and krypton-filled cavities achieve a lower U-value than air- or argon-filled cavities. This makes these gases better suited to slim-profile double glazing, if thermal performance is the main priority.

- The vacuum glazing achieved the lowest U-value, by a significant margin – despite the fact the cavity is much smaller (0.2mm) than those of the other units. This demostrates the effectiveness of a vacuum as a thermal barrier.

- Using Crown-effect glass in the outer pane has no noticable impact on the U-value.

The inner pane in all cases is Low-Emissivity glass.

In principle it would be possible to install similar double-glazing units with a slightly bigger cavity, which would improve the thermal performance further. However, in many cases this would require significant additional joinery work and costs (see sections 2.4.1 and 3.6 for details).

Some systems use metal spacer bars. This metal could create a cold bridge, increasing the likelihood of heat loss and condensation (although the layer of sealant between the glass and metal could help reduce this effect). Using modern 'warm-edge' spacer bars instead of metal would minimise any potential cold bridging, further improving their performance; however, these should only be recommended where it can be demonstrated that they would not affect the integrity of the unit (anecdotal reports suggest that further research may be beneficial, to ensure warm-edge techology is fully compatible with slim cavities).

3.3 Materials & Embodied Energy

Embodied energy becomes an important consideration where the primary objective is to reduce CO_2 or energy use: if an energy-saving measure (such as double glazing) requires a significant amount of energy in its production, this could offset the energy that the product would save once installed, thus defeating its primary objective. Energy saved in one place is expended elsewhere, so CO_2 emissions are actually just displaced rather than reduced.

Historic Scotland funded the embodied energy study. A summary is included below, and the full research report is included at Appendix 2 (and is published independently by Historic Scotland as part of their series of Technical Papers). As stated previously, this report and recommendations relate only to timber windows. However, a standard uPCV-framed double-glazed window was also included in the embodied energy study, in order to provide a comparison. Different freighting options were also considered, as these become a significant factor for imported materials.

In summary, the study found that the embodied energy is largely dependent upon the gases used in the cavity, the frame material and freighting method. Xenon, uPVC and air-freighting significantly increase the embodied energy.

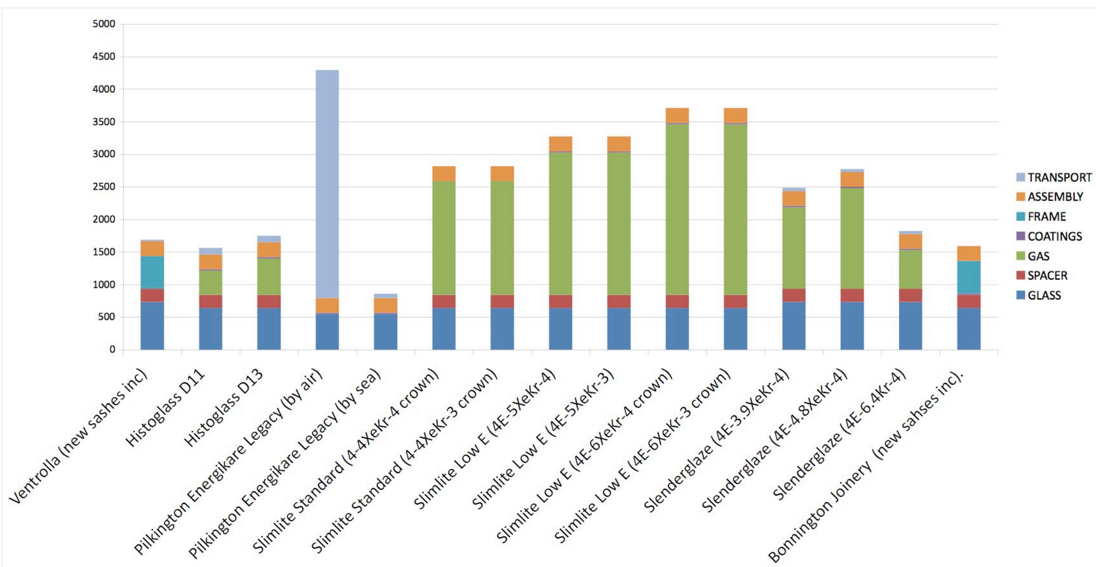


Figure 30 Embodied energy of installed systems (in MJ)

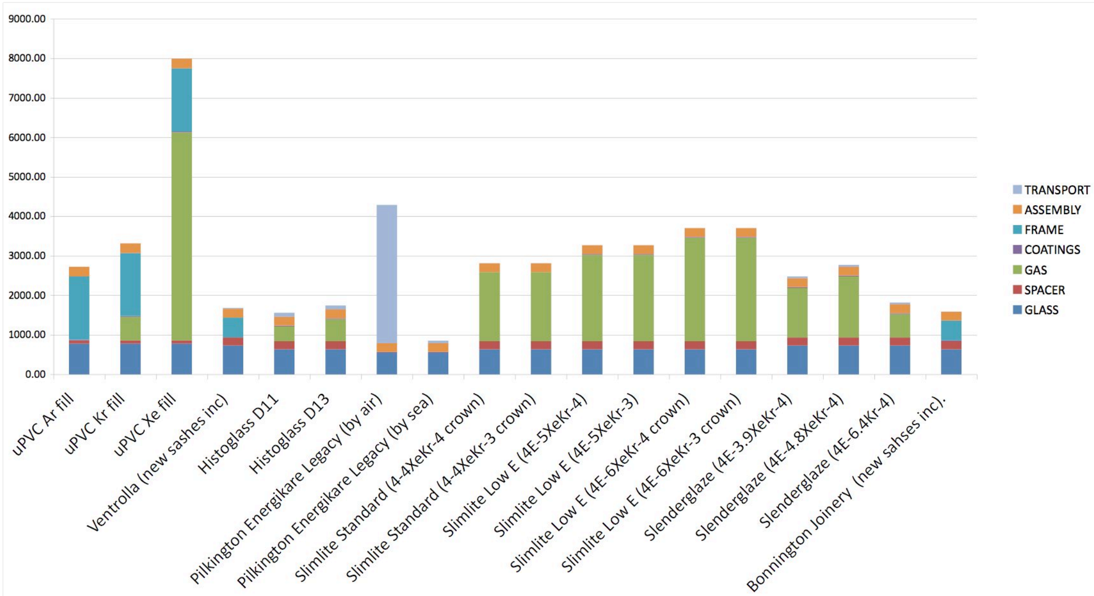


Figure 31 Embodied energy of installed systems, with uPCV and air-freighted options included

Below are some of the key points arising from the embodied energy study:

- Although the Pilkington energiKare Legacy system is manufactured in Japan and has to be freighted to Britain, it has by far the lowest embodied energy when freighted by sea. The reason for this is that it contains a vacuum rather than inert gases (and no frame materials were required as the units were fitted into existing timber frames). However, further research is required to establish the manufacturing energy of vacuum unit designs.

- Inert gases account for a significant proportion of the embodied energy in most double-glazing systems, due to the energy-intense processes needed to extract them from the air. Xenon in particular carries a very high embodied energy (see below).

- The type of gas used can have a considerable impact on the embodied energy. Using a vacuum, air, argon or krypton, the energy embodied within the window could be repaid many times throughout its life. However, using 100% xenon, the reverse could be the case (i.e. the window will never save as much energy as went into its manufacture).

- Using a mix of gases (e.g. krypton & xenon) appears to be increasingly commonplace. This increases the thermal performance of a unit, which to some degree then offsets its embodied energy. However, this is a *cradle to site* study only: a full life cycle energy analysis would confirm this.

- The frames of the new sashes also add to the embodied energy. This makes retrofitting into existing sashes a more sustainable option (as well as the more evident benefits of re-using existing materials).

- Freighting materials by air is not a sustainable option, as the embodied energy spirals once air-freighting is included.

- uPVC frames have a far higher embodied energy than timber-frames. When combined with xenon, a uPVC window would carry by far the highest embodied energy.

3.4 Occupant feedback

'Double-glazed windows like mine should definitely be permitted in other listed buildings in Edinburgh, if it cuts fuel bills and makes homes more comfortable for occupants. They don't appear any different from the outside' (Lister Housing Co-operative tenant).

All buildings, historic or otherwise, were built for a purpose: for people to use. This makes their usability of fundamental importance, and as such surveying the householders in the flats was a key aspect of this project.

The householders were surveyed before and after the works. Prior to the improvements, the following findings were established:

Pre-improvement householder survey results
• All respondents found it hard to make their homes warm enough to be comfortable, and all confirmed that their single-glazed windows contributed to the coldness of their homes. • All were aware that double glazing was not permitted in listed buildings like theirs (one added: *'But this is silly when you think what energy could be saved'*), and they were 'delighted' when they were told they would be able to have double glazing. • All suffered from condensation, which in many cases semed particularly bad. Householders reported being able to hear the condensation dripping off the windows; having to wipe them down frequently; having to tackle a constant build-up of mould and fungus; and swelling of the timbers. Their only solutions were frequent mopping-up of the condensation, and (when the sashes are not too swollen to open) having to leave windows and doors open to ventilate their homes – although they also recognised that this means their heat escapes, making their homes even less efficient.

On completion of the works the householders were asked to complete a second round of surveys. The following findings came out of these surveys:

Post-improvement householder survey results
• **All respondents state that their new double glazed windows look exactly the same as their old single-glazed windows** • All respondents are generally pleased with their new windows and confirm that they are **better in terms of warmth** • All respondents confirm **their homes are more comfortable** as a result of having double glazing • All respondents stressed the benefit in terms of **significantly reduced condensation** on the windows, thus reducing the damage to the timber

frames

- All respondents would recommend their double glazed windows to others
- **All respondents believe that their double glazing system should be permitted in other listed buildings in Edinburgh.**

Some of the comments on the surveys are particularly revealing:

- *'Don't really notice the double glazing, but do notice the improvements they make'*
- *'Massive improvement with lots less condensation in rooms'*
- *Double-glazed windows like mine should definitely be permitted in other listed buildings in Edinburgh, if it cuts fuel bills and makes homes more comfortable for occupants. They don't appear any different from the outside'*

Double glazing was also installed in one window at Edinburgh World Heritage's category 'A' listed offices in Charlotte Square. The Director's window was chosen, as he wished to champion the project and this would enable him to monitor the impact of double glazing first-hand. When asked how he felt about the new double-glazed sashes in his office, Director Adam Wilkinson simply replied: *'Well, I've turned the heating down'*…

3.5 Longevity & maintenance

The warrantly periods vary for the different systems used in this project, ranging from 5 to 10 years. Details are provided in the table below.

System	Warranty period
Slimlite	10 years
Supalite	5 years
Histoglass	7 years
Slenderglaze	5 years
Ventrolla	5 years
Pilkington energiKare Legacy	10 years

As with all double glazing, the key issue is the longevity of the seal. This becomes particularly important when there are inert gases (or a vacuum) in the cavity as these are key to the thermal efficiency of the unit. Once this seal fails, the thermal performance will be reduced, and additional problems such as internal condensation and moisture build-up can occur. Such problems cannot readily be resolved, making total replacement the most viable option. To minimise the likelihood of system failure, individuals should ensure that whatever system they select complies with current legal compliance standards[13].

None of the systems should have any particular maintenance needs, other than the standard timber treatment (e.g. painting) needed to keep the frames in good repair.

[13] BS EN 1279 is the current (6-part) compliance standard for double-glazed sealed units.

Should a unit break at any point, locality of supply for replacement units could become a significant issue. The Pikington energiKare Legacy system, in particular, is manufactured in Japan and the standard lead time is currently 10 weeks, so if a unit breaks (or fails in some other way) it would not be repairable for 2.5 months. There may also be a minimum order for such international materials, making a single-unit replacement more difficult. For this reason it may be beneficial to request spares when placing an order, in case of breakage during transit, installation or post-installation (spares were ordered for the majority of systems used in this project).

3.6 Costs

The overall capital cost for the installations was £37,000 (the addition of VAT increases this amount to £43,500). (This included some spare units for each system, in case of breakage.) The different systems varied in cost, with a significant difference between the least and most expensive options, as shown below.

System	Cost per window *excl. VAT* (capital costs + installation)	Comments
Slimlite	£460	• For standard system; other systems were provided for project free of charge
Sashworks	£950	• Estimate only; actual installations provided for project free of charge • New sashes
Slenderglaze	£1,125	• Materials had to be shipped up from south of England
Histoglass	£1,470	• Average figure for 2 different types (D10 & D11) • Hand-drawn outer panes provided at no extra charge
Supalite	£1,550	• New sashes • Intricate arched sashes added to work and cost (manufacturer stated that standard sashes would be significantly cheaper)
energiKare Legacy	£1,710	• Specialised high-tech system added to cost • Foreign manufacturing location (Japan) added to cost

While broad comparisons can be made, it is hard to compare these figures directly against each other, as they are affected by a number of variables in each instance (e.g. number of windows installed, locality of materials, type of materials used, and so on). The above costs would also be subject to change depending on the specifications chosen, e.g. cavity depths, glazing types and so on.

It should be noted that all the windows in question are relatively large (1.12m x 2.3m), which naturally affects the cost per window. Additionally, the 6-over-6 design means that 12 individual panes were needed for each window: this also added considerably to the cost. Similar installations in a smaller window with only one or two panes of glass would cost significantly less.

Routing out the window rebates to accommodate deeper units requires considerable additional work, and as such would add a substantial amount to the installation costs. In some cases this could render the total cost not viable.

The relatively high cost of most of these technologies makes it unlikely that there will be a mass change from single to double glazing in listed buildings following any planning policy update. (The important point is that listed property owners should at least be given the option to install such systems.)

Other aspects should also be factored into cost considerations for double glazing. The excessive condensation that can be caused by single glazing can eventually cause timber frames to rot. Apart from being damaging from a building conservation perspective, this further reduces thermal efficiency leading to higher heating bills, and eventually requires window replacement with its high associated costs.

3.7 Cost and carbon savings

The Energy Saving Trust estimates that, for a typical property, replacing single-glazed windows with double-glazed windows can save around **£135 per year** on heating bills[14]. While such predictions are by necessity generic, and dependent on a number of variables (including behaviour, property type and size, fuel tariff, current fuel cost and so on), this still provides a good indicator of the potential impact that an updated policy could have on fuel poverty. In the longer term, as fossil fuel prices continue to rise these potential savings will increase further.

In terms of environmental impact, the Energy Saving Trust also estimates and annual saving of around **720kg CO_2** when replacing single glazing with double glazing in a typical property[15]. Again bearing in mind the generic nature of these predictions, the potential environmental impact that a policy update could make is nonetheless significant: if every listed property in Edinburgh were able to make CO_2 savings of nearly three-quarters of a tonne annually, this would allow these valuable buildings to help play their part in meeting the drastic CO_2 reduction targets in place in the UK.

Changeworks is carrying out SAP-based energy assessments of the Lauriston Place properties in July 2010, which will be compared against pre-improvement SAP ratings to identify energy, CO_2 and cost savings predicted by this national energy rating software.

3.8 Social impact

Fuel poverty is a recognised problem in Edinburgh and its World Heritage Site, where most buildings are pre-1919 and around three-quarters are listed[16]. The Fuel Poverty Map Of Edinburgh, produced by Changeworks and The City Of Edinbrugh Council in 2005, highlighted householders in the World Heritage Site as being at particular risk, due partly to the age and listing of the buildings.

Scotland has a target to eradicate fuel poverty by 2016. Older and listed properties will make this a difficult target to meet; around a third of householders in pre-1919 buildings across Scotland are currently living in fuel poverty[17], and listing restricts the improvement options available to such householders.

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[14] Energy Saving Trust, at May 2010 (http://www.energysavingtrust.org.uk/Home-improvements-and-products/Home-insulation-glazing/Glazing)
[15] *Ibid*
[16] Energy Heritage – A guide to improving energy efficiency in traditional and historic homes (Changeworks, 2008)
[17] Scottish House Condition Survey

These restrictions can also pose comfort and health risks to householders. It is important that listing does not bring with it a negative perception of buildings as creating potentially cold and uncomfortable homes; rather, it should protect the special significance while allowing them flexibility to make appropriate changes. Listing should manage rather than prevent change: this is a fundamental requirment to ensure they stay viable as needs change over time.

As such, it is important that further steps are taken to allow such householders to make their homes more energy efficient. A policy update on double glazing would facilitate this, without compromising the appearance of these culturally valuable buildings.

Section 4 Conclusions and recommendations

The project has demonstrated that appropriate double glazing can be successfully incorporated into listed buildings, improving their thermal performance and lowering their CO_2 emissions without detracting from their historic character or appearance.

The project has also demonstrated the ongoing durability, practicality and adaptability of traditional Scottish timber sash-and-case windows, and shown how existing window patterns can be maintained without significant visual change.

This report recommends that such slim-profile double glazing systems should be permitted in listed buildings, both in Edinburgh and further afield, where there would not be a significant loss of historic material. The choice of system should be made by the property owner, however acceptable system specifications should be made clear by the Council in any updated policy, in order to ensure quality control for future installations.

A breakdown of recommendations is provided below, however the key finding is best summed up in this quote from one of the householders who received double glazing as part of the project:

'Double-glazed windows like mine should definitely be permitted in other listed buildings in Edinburgh, if it cuts fuel bills and makes homes more comfortable for occupants. They don't appear any different from the outside' (Lister tenant).

Recommendations:

This report makes the following recommendations, for enactment through a **policy update**:

1. **Slim-profile double glazing should be permitted in listed buildings.**

2. **The type of double glazing permitted should be defined by specification rather than by manufacturer.** An ever-increasing number of systems is emerging onto the market, and new systems should not be excluded by permitting any specific set of manufacturers.

3. **None of the systems installed in this project should be excluded from an updated policy.** It is recognised that the sealing cap on the vacuum glazing units, in particular, could be a source of contention, however in view of its high performance and ease of installation – both important factors in selecting a system – it should be considered as a viable option. It may be that permissions are restricted to windows with up to a set number of glazing panes, which would reduce the number of sealing caps, however this would be at the discretion of the Council.

4. **Use of Crown-effect outer panes should be at the discretion of the property owner**, rather than a planning requirement**.**

This report makes the following further recommendations, for enactment by **manufacturers** of such products:

1. **Warrantly periods should be made clear on all systems.**

2. **Spacer bars should be made available in white as well as black** (and ideally a number of other colours, in order to minimise their visibility.

3. **Modern 'warm-edge' spacer bars should be used rather than metal** (where it can be demonstrated that this will not compromise the system's performance). This will minimise the risk of cold bridging.

4. **The sealing cap on vacuum glazing units should be reduced in size**[18] **and moved closer to the corner of the unit, if possible.** This would reduce its visibility, and increase its applicability in listed buildings.

5. **The vacuum glazing units should be manufactured more locally, if possible.** It is recognised that this may not be immediately achievable, however this would not only result in lower embodied energy, but also make installation, planning and repairs considerably easier and faster.

6. **The sealant around the edge of the unit should not extend further into the glazing than is necessary.** It is recognised that a secure and lasting seal is critical, however where this extends into the glazing beyond a further point overpainting becomes necessary in order to conceal the sealant.

[18] At the time of writing this report, Pilkington confirmed that **a new, smaller black sealing cap has been developed, tested and released for the European market**. They state that the colour is less eye-catching than the current silver colour, and the diameter has been reduced from 15mm to 12mm. This change is effective from **1 July 2010**, although the silver cap will still be available and will continue to be used in other markets.

Section 5 Further information

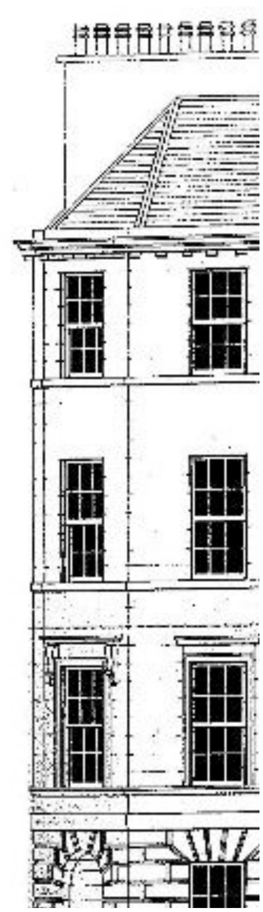
As part of this project two Research Reports were prepared for Historic Scotland, investigating the thermal performance and embodied energy of the double glazing systems installed. Both documents are enclosed as Appendices with this report, however they are also published independently by Historic Scotland and are available as Technical Papers on their website.

Other window guidance is available in the following publications. (A degree of caution is suggested if older data is used (for payback periods, technical options, U-values, etc.), as such figures can be subject to change and can quickly become out of date.)

- Energy Heritage: A guide to improving energy efficiency in traditional and historic homes (Changeworks, 2008)
- Technical Paper 1 – Thermal Performance of traditional windows (Historic Scotland, 2008)
- *In situ* U-value measurements in traditional buildings: preliminary results (Historic Scotland, 2008)

Technologies mentioned in this report:

System	Website
Conservation Glazing	www.conservationglazing.co.uk
Histoglass	www.histoglass.co.uk
Pilkington energiKare Legacy	www.pilkington.com/europe/uk+and+ireland/english/energikareconsumer/energikare-range/legacy.htm# www.nsg-spacia.co.jp/index.html
Sashworks	www.sashworks.co.uk
SGG Climaplus Colonial	www.saint-gobain-glass.com/saint-just/download_all/datasheets_gb/SGG_CLIMAPLUS_COLONIAL_GB.pdf
Slenderglaze	www.sashconsultancy.co.uk/index.cfm?page=51
Slimlite	www.slimliteglass.co.uk
Supalite	Glazing manufactured by Peter Noble Glazing: www.peternobleglazing.com
Timbalite	www.timbalite.com



Appendix 1

Research report 1: Thermal performance

CHANGEWORKS
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Double Glazing In Listed Buildings

Research report 1: Thermal performance

Report commissioned by Changeworks on behalf of Historic Scotland, March 2010

This report provides the results and analysis of a thermal performance study, carried out as part of a Changeworks project, **Double Glazing In Listed Buildings**. This project ran from March 2009 to March 2010, and involved retro-fitting a range of bespoke, slim-profile double-glazing units into category 'A' and 'B' listed buildings in Edinburgh's Old and New Towns, both of which are conservation areas and form a UNESCO World Heritage Site.

A full project report has been prepared for The City of Edinburgh Council by Changeworks, and is available on request. This report provides full background to the project and the different system specifications, together with analysis of costs, installation and maintenance details, longevity, occupant impact and further recommendations.

This report should be read in conjunction with the full *Double Glazing In Listed Buildings project report* (see above) by Changeworks, and with *Research report 2: Embodied energy*, prepared for Changeworks by Heriot Watt University.

In situ measurements of the U-values of double glazed replacement units in Georgian sash and casement windows

Prepared for Changeworks by Dr Paul Baker

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School of Built & Natural Environment

Glasgow Caledonian University

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March 2010

Introduction

This report summarises an investigation carried out by the Centre for Research on Indoor Climate & Health, School of the Built & Natural Environment, Glasgow Caledonian University (GCU) on behalf of Changeworks to evaluate the thermal performance of various "slimline" double-glazed replacement units in Georgian sash and casement windows. These units were installed as part of Changeworks' *Double Glazing In Listed Buildings* project at the 'A' listed offices of Edinburgh World Heritage (5 Charlotte Square) and in nine 'B' listed tenement flats owned by Lister Housing Co-operative (Lauriston Place and Archibald Place) in Edinburgh. The measurements were carried out over the winter season 2009-2010. Table 1 gives the locations and specifications of the glazings.

The test method using heat flow meters has been used previously to evaluate methods for reducing heat loss through traditional windows for Historic Scotland [1]. As part of the Historic Scotland project *in situ* measurements were carried out in a tenement flat and the offices of Lister at Lauriston Place in Edinburgh, following the installation of insulation measures under Changeworks' previous *Energy Heritage* project [2]. The results on refurbished shutters and a high specification secondary glazing system showed good agreement with laboratory tests on similar systems.

Test Method

The test objective is to measure the centre-of-glazing U-value of the double-glazed replacement units. The test method uses Hukesflux Type HFP01 heat flux sensors, which are affixed to the room-side surface of the glass with double sided adhesive tape. The sensors have a quoted manufacturer's thermal resistance of less than 6.25×10^{-3} m^2K/W. Type-T thermocouples are used to measure the surface temperature of the glazing internally and externally and also of the heat flux sensor. The thermocouples are affixed with transparent tape. Two sensors are used on each window typically, as shown in Figure 1. Campbell Scientific dataloggers are used, which record at 5-second intervals and store data as 10-minute averages.

Experience has shown that generally about two weeks' data are required to give a satisfactory result with dynamically changing indoor and outdoor conditions. A U-value (Equation 1) can be calculated from the average heat flux sensor reading and the surface temperature difference between the outer glazing surface and the surface of the heat flux sensor, as follows:

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

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

Alternatively, a dynamic analysis software tool, LORD [3] can be used to determine the U-value.

The heat flux sensors were generally applied to North facing windows to excluded the effect of direct solar radiation, except at Charlotte Square (South; the only elevation with replacement glazing), Flat 1/4 Archibald Place (West; only accessible elevation) and 37 Lauriston Place (West; only accessible elevation).

Figure 1: Typical test arrangement on glazing in Georgian sash

Table 1: Location and specification of the replacement glazing. The glazing configuration gives the inner pane, gap and outer pane thicknesses

Address	System / manufacturer	Glazing configuration - inner pane / cavity / outer pane (mm)	Inner pane glazing type	Gap fill	Comments	Manufacturer's Centre of Pane U-value - upper limit [W/m^{2}K]
1/1 Archibald Place	Sashworks	4-8-4	Low-E	argon	New sashes	1.8
1/2 Archibald Place	Histoglass	3-4-4	Low-E	krypton		1.9
1/3 Archibald Place	Histoglass	3-4-4	Low-E	krypton	Crown-effect outer pane	1.9
1/4 Archibald Place	Pilkington energiKare Legacy	4-0.2-3	Low-E	vacuum		1.3
1/5 Archibald Place	Slimlite	3-3-3	Low-E	air		2.6
1/6 Archibald Place	Slimlite	3-3-3	Low-E	xenon & krypton	Crown-effect outer pane	2.1
1/7 Archibald Place	Slenderglaze	4-3.9-4	Low-E	xenon & krypton		2.1
1/8 Archibald Place	Slimlite	3-3-3	Low-E	xenon & krypton		2.1
37 Lauriston Place	Supalite	4-4.8-3	Low-E	argon	New sashes	2.5
5 Charlotte Square	Slimlite	3-3-3	Low-E	xenon & krypton	New sashes	2.1

Table 2: Test results

Glazing Type	Location	Test start	Test end	U-values, W/m2K	Uncertainty
Sashworks (new sashes, argon fill)	1/1 Archibald Place	22/02/2010	08/03/2010	2.0	7%
Histoglass (D11, krypton fill)	1/2 Archibald Place	08/03/2010	22/03/2010	2.7	5%
Histoglass (D10, krypton fill, hand drawn outer)	1/3 Archibald Place	08/03/2010	22/03/2010	2.3	5%
Pilkington energiKare Legacy (vacuum)	1/4 Archibald Place	08/03/2010	22/03/2010	1.0	11%
Slimlite (air fill)	1/5 Archibald Place	05/02/2010	22/02/2010	2.8	5%
Slimlite (xenon & kryton fill, Crown-effect outer)	1/6 Archibald Place	22/02/2010	08/03/2010	2.3	5%
Slenderglaze (xenon & krypton fill)	1/7 Archibald Place	22/02/2010	08/03/2010	1.7	6%
Slimlite (xenon & krypton fill)	1/8 Archibald Place	05/02/2010	22/02/2010	2.3	7%
Supalite (argon fill, new sashes)	37 Lauriston Place	08/03/2010	22/03/2010	2.8	14%
Slimlite (xenon & krypton, new sashes)	5 Charlotte Sq.	22/12/2009	13/01/2010	2.0	7%

Results

The South- and West-facing windows were affected by solar radiation, therefore analysis of the data from Charlotte Square, Flat 1/4 Archibald Place and 37 Lauriston Place was carried out using night-time data only with the LORD software [3].

The centre-of-pane U-value estimates are given Table 2. Figure 2 compares the measured values with the manufacturers' specification. The results show that the glazing units exhibit a range of values, from 1.0 W/m^{2}K for the vacuum glazing to 2.8 W/m^{2}K for one of the Slimlite glazing units and the Supalite glazing. Note that the U-value of single glazing is about 5.5 W/m^{2}K.

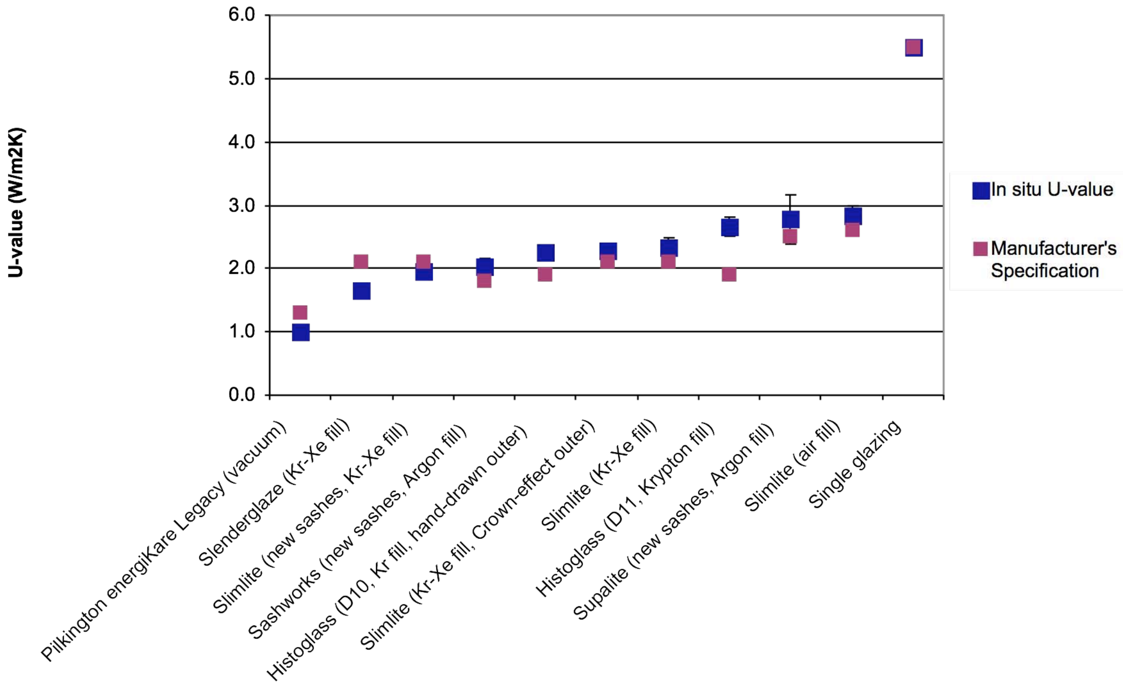

Figure 2: Measured centre of pane (COP) U-values compared with manufacturers' specifications

There is higher uncertainty on the U-values measured on the West-facing glazings during March 2010, particularly the Supalite glazing used in 37 Lauriston Place, since there were less data available, which excluded the influence of solar radiation, due to increasing day length. The uncertainty on the other measured values is 5-7%.

Generally the manufacturer's specification tends to overestimate the performance of the glazing unit, except for the Pilkington energiKare Legacy vacuum glazing and the Slenderglaze unit.

The vacuum glazing is effective as the evacuated gap prevents convective heat transfer between the two panes. However, heat is transferred through the small support pillars separating the panes and the edge seal. The performance of the gas filled units, whilst not as effective as vacuum glazing, is generally better than the unit filled with air. The performance of the individual glazing type depends on the following:

- The emissivity of the low-e coating – the lower the emissivity the lower the U-value (note that no information was available on the type of low-e glazing used in the double glazed units).

- The gas type – Argon, Krypton and Xenon have superior properties to air, however the *gap width* should be optimised for the gas type. For air the optimum gap width is 16mm, Argon 15mm, Krypton 11mm and Xenon 8mm.

- The benefits of using gases other than air are most significant using low-e glass with lower emissivities and the optimum gap width.

A useful reference is BS EN ISO 10077-1:2006 Appendix C [4], which gives the thermal transmittance of double glazing filled with different gases.

The gas-filled replacement panes tested are not optimised for thermal performance. This is sacrificed in order to produce slimmer units suitable for conservation-grade buildings.

A simple area weighting method has been applied to estimate the influence of the centre-of-pane U-value of the slimline replacement panes on the whole window U-value, based on the whole window U-value of a similar window design measured for the Performance of Traditional Windows project [1]. The U-value of the single-glazed window was 4.4 W/m^2K with a glazed area of about 55% of the total window area. The results are given in Table 3.

Table 3: Whole window U-value estimates

Glazing Type	**Location**	**Whole window U-value, W/m^2K**
Single glazing	-	4.4
Sashworks (new sashes, argon fill)	1/1 Archibald Place	2.5
Histoglass (D11, krypton fill)	1/2 Archibald Place	2.8
Histoglass (D10, krypton fill, hand drawn outer)	1/3 Archibald Place	2.6
Pilkington energiKare Legacy (vacuum)	1/4 Archibald Place	1.9
Slimlite (air fill)	1/5 Archibald Place	2.9
Slimlite (xenon & kryton fill, Crown-effect outer)	1/6 Archibald Place	2.6
Slenderglaze (xenon & kryton fill)	1/7 Archibald Place	2.3
Slimlite (xenon & krypton)	1/8 Archibald Place	2.7
Supalite (new sashes, argon fill)	37 Lauriston Place	2.9
Slimlite (new sashes, xenon & krypton fill)	5 Charlotte Sq.	2.5

The Pikington energiKare Legacy vacuum glazing is the most effective option, reducing the whole window U-value by 56% compared with the single glazed window.

Conclusions

The *in situ* U-values of various "slimline" double glazed replacement units in Georgian sash and casement windows has been measured.

The Pilkington energiKare Legacy vacuum glazing is the most effective option, offering both good thermal performance with a narrow profile. The other double glazed options, whilst giving a significant improvement, are not optimised for thermal performance. This is sacrificed in order to produce slimmer units suitable for conservation-grade properties.

Improving the design of the gas-filled units may be a challenge: using Xenon with lower emissivity glazing could result in U-values in the range 1.1-1.5 W/m^2K for cavity widths of 6-8mm.

References

[1] Baker P.H. Thermal Performance of Traditional Windows, Technical Paper 1, Technical Conservation Group, Historic Scotland, November 2008 (http://www.historic-scotland.gov.uk/gcu-technical-_thermal-efficiency-traditional-windows.pdf)

[2] The project is fully described in the comprehensive guide *Energy Heritage: A guide to improving energy efficiency in traditional and historic buildings*, Changeworks, 2008 (http://www.changeworks.org.uk/uploads/83096-EnergyHeritage_online1.pdf)

[3] Gutschker O. LORD 3.2, Modelling and identification software for thermal systems, Manual, BTU Cottbus / Angewandte Physik, 2003

[4] BS EN ISO 10077-1:2006 Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 1: General. BSI, London, ISBN 0 580 49527 2

Appendix 2

Research report 2: Embodied energy

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Double Glazing In Listed Buildings

Research report 2: Embodied energy

Report commissioned by Changeworks on behalf of Historic Scotland, July 2010

This report provides the results and analysis of an embodied energy study, carried out as part of a Changeworks project, **Double Glazing In Listed Buildings**. This project ran from March 2009 to March 2010, and involved retro-fitting a range of bespoke, slim-profile double-glazing units into category ‘A’ and ‘B’ listed buildings in Edinburgh’s Old and New Towns, both of which are conservation areas and form a UNESCO World Heritage Site.

A full project report has been prepared for The City of Edinburgh Council by Changeworks, and is available on request. This report provides full background to the project and the different system specifications, together with analysis of costs, installation and maintenance details, longevity, occupant impact and further recommendations.

This report should be read in conjunction with the full *Double Glazing In Listed Buildings project report* (see above) by Changeworks, and with *Research report 1: Thermal performance*, prepared for Changeworks by Glasgow Caledonian University.

Embodied Energy Analysis of retrofit glazing options for listed buildings

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July 2010

Executive Summary

The embodied energy has been calculated for a number of retrofit window and glazing unit options for use in traditional buildings, specifically category 'B' listed Georgian tenement buildings in the UNESCO World Heritage Site, Edinburgh, as part of Changeworks' *Double Glazing In Listed Buildings* project. This Cradle-to-Site analysis incorporates data relating to raw material extraction and processing, manufacturing and transportation.

This report finds that Krypton gas filled units demonstrate lower embodied energy values than units with a mix of heavier gases. The omission of inert gases in Pilkington Energikare units significantly reduces their embodied energy, but further research is required to establish the manufacturing energy of vacuum unit designs. It also finds that transportation energy can be significant in *Cradle to Site* analyses and demostrates the increased environmental impact of air freight over more sustainable means of transport.

It is recommended that these embodied energy figures be used in combination with operational energy consumption analysis, based on the individual U-values achieved by various unit options. This type of analysis is likely to expose greater differences in options when evaluated over a 40-year operational lifecycle.

1 Introduction

This report accompanies the spreadsheet, *LCI Data 2010*. The products of seven various window and glazing manufacturers have been investigated, with 18 options presented. Three base-case options have been presented, although it is recognised that these will not actually be installed: one each of uPVC replacement windows of comparable size and efficiency with Argon, Krypton and Xenon infill gas options. These are for comparative purposes only. Two further options are presented which also illustrate the embodied energy of replacement timber sashes.

2 Data sources

Due to time and resource restrictions this report uses embodied energy findings from third parties:

1. Hammond, G.P. and Jones, C.I., 2008. *Embodied energy and carbon in construction materials*, Energy, 161 (2): 87-98. Sourced at http://www.bath.ac.uk/mech-eng/sert/embodied/

2. Weir, *Life Cycle Assessment of Muti-Glazed Windows*, PhD Thesis, Napier University, Edinburgh, 1998

3. Asif, Davidson and Muneer, *Life Cycle of Window Materials – A Comparative Assessment*, Napier University, Edinburgh. Sourced at http://www.cibse.org/pdfs/Masif.pdf

4. Fernie and Muneer, 1996 *Monetary, energy and environmental cost of infill gases for double glazings*, Building Services Engineering Research & Technology, 17 (1) 43-46

5. Department for Environment, Food and Rural Affairs (Defra), 2009, *Greenhouse Gas Conversion Factors for Company Reporting*. Sourced at http://www.defra.gov.uk/environment/business/reporting/conversion-factors.htm

6. Sustainable Energy Authority of Ireland (SEAI), conversion factors sourced at www.sustainableenergyireland.com/Publications/Statistics_Publications/Emission_Factors

3 Assumptions

A number of assumptions have been necessary throughout the study. These are explained below:

- Work by Weir (1998) shows life cycle inventory data based on four main activities from cradle to gate: material extraction, manufacture, packing and transportation. Where possible this methodology has been followed. No specific allocation has been given in this study for ironmmongery (n/a unless entire window replaced) or butyl sealants (information available is very limited; Weir (1998) makes no allocation for this material). An estimation for the energy consumed during assembly of the glazing units has been given: this includes the energy associated with assembling glazing units and cutting and forming spacers, and an allocation for factory heating, lighting and administation.

- No specific data relating to the manufacture energy associated with the creation of a vacuum for the Pilkington energiKare Legacy product was found. Literature searches on the topic revealed that the technology and associated analyses are in their infancy.

- Embodied energy data for aluminium assumes a UK recycling rate of 33% (Hammond and Jones, 2008)

- Embodied energy data for glass assumes a UK recycling rate of 38% (Hammond and Jones, 2008)

- Transport data makes no allowance for warehouse storage/handling requirements, and relates purely to the energy embodied in various transport means – the functional unit is MJ/km/kg transported. Data from Defra is included within *LCI data 2010.xls* spreadsheet *Freight Transport*. The UK average for all HGVs has been used for road transport since no specific data is available on lorry type and size, with an average of 7.23 tonnes of goods per vehicle (56% weight laden). For long-haul international flights a 9% uplift factor has been used, in accordance with the IPCC's *Aviation and the Global Atmosphere* which states that 9-10% should be added to take into account non-direct routes (i.e. not along the straight line, great circle distances between destinations) and delays/circling. Airline industry representatives have indicated that the percentage uplift will be higher for short-haul flights and lower for long-haul flights; however specific data is not currently available to provide separate factors.

4 Embodied Energy (EE) Results

(The main body of results is contained in spreadsheet *LCI data 2010*. The following text and figures present a brief overview of this detailed analysis.)

The Life Cycle Inventory data presented in spreadsheet *LCI data 2010* includes the extraction of materials required for the various windows or glazing units, namley: glass, infill gases, spacers, low emissivity coating(s), and (where appropriate) frame/sash materials, based on work by Weir (1998). EE values for glass and aluminium were taken from Hammond and Jones (2008), while EE values for Argon, Krypton and Xenon gases were taken from Fernie and Muneer (1996), and EE values for low emissvity coatings and assembly functions from Weir (1998). Information relating to frame and sash materials were derived from Asif *et al*.

Figure 1 (below) shows the summary of EE data for all options, while Figure 2 (below) shows the same information excluding uPVC options, and Pilkington energiKare Legacy products arriving by air. **The source of EE difference between various options is limited in the main to two factors: transportation and infill gas.**

Tranport by air is energy-intensive due to the load capabilities of jet transport. Container ship over the same distance is less energy-intensive when based on a kg-km basis.

It is seen that Xenon gas leads to extremely high EE values. Weir (1998) fround that it would take many times the design life intended to justify the use of Xenon gas filled constructions. Using a mix of inert gases now appears to be more commonplace, and may offer good energy accounting. What is presented in this report is a *Cradle to Site* analysis. A full Life Cycle Energy Analsysis of window options is required in order to select the optimum window design. Despite their higher emboded energy It is possible that a window/unit design which contains a mix of inert gases may offer lower lifecycle energy consumption via reduced U-values. i.e. less heat is lost through the window during its operational phase, thus off-setting the raised embodied energy value.

5 Sensitivity Analysis

The ICE database (Hammond and Jones, 1998) publishes low and high estimates of EE for raw materials. For extruded aluminium this is +/- 20%, while for glass is +/- 30%. No sensitivity data is available for the EE of gases, low-E coatings, assembly, transport or frame information.

Figure 3 (below) shows the resulting maximum and minimum EE data for all options. “Estimated EE Data” refers to the calculated embodied energy values presented in Figure 1.

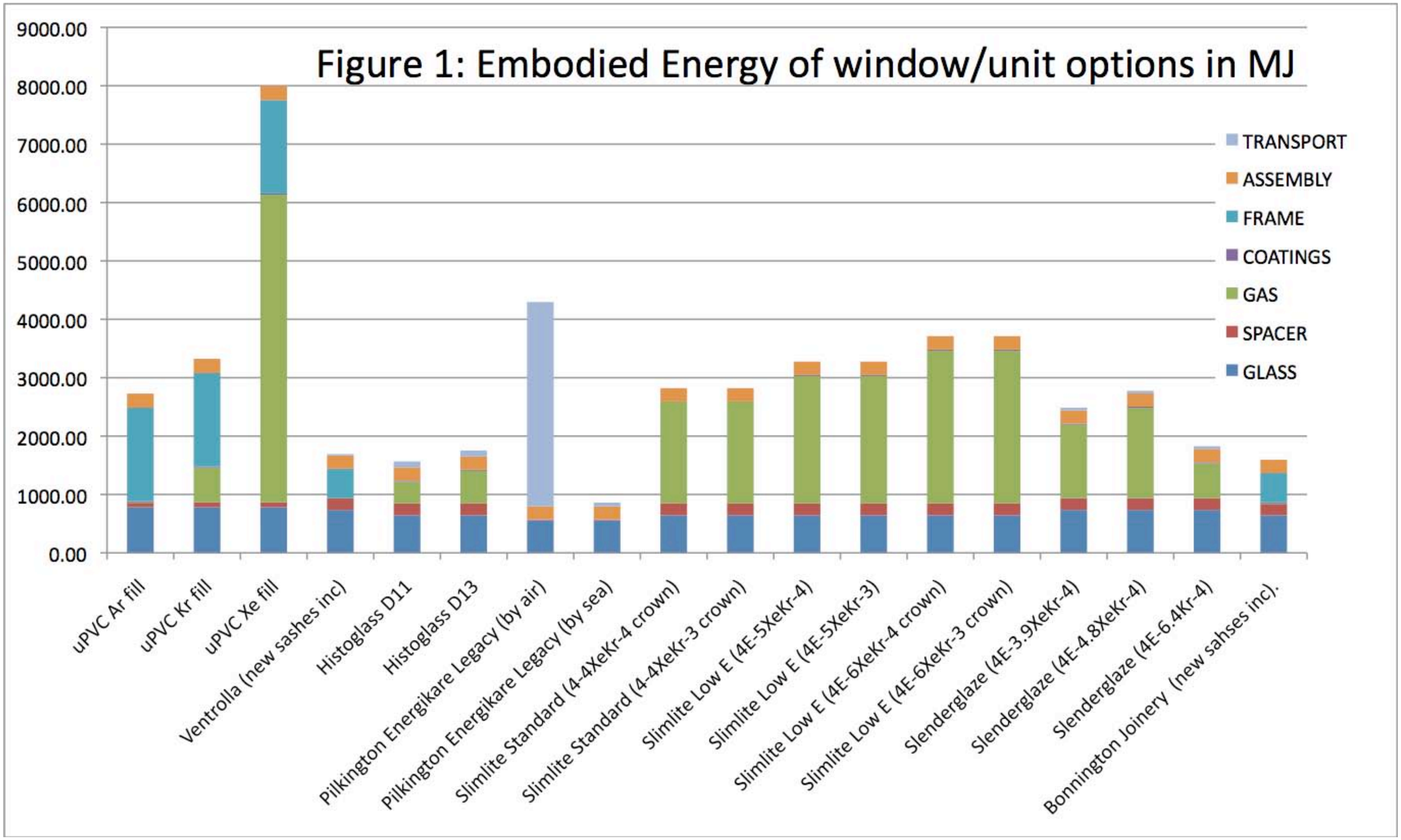
Figure 1: Embodied Energy of window/unit options in MJ
9000.00
8000.00
7000.00
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
TRANSPORT
ASSEMBLY
FRAME
COATINGS
GAS
SPACER
GLASS
uPVC Ar fill
uPVC Kr fill
uPVC Xe fill
Ventrolla (new sashes inc)
Histoglass D11
Histoglass D13
Pilkington Energikare Legacy (by air)
Pilkington Energikare Legacy (by sea)
Slimlite Standard (4-4XeKr-4 crown)
Slimlite Standard (4-4XeKr-3 crown)
Slimlite Low E (4E-5XeKr-4)
Slimlite Low E (4E-5XeKr-3)
Slimlite Low E (4E-6XeKr-4 crown)
Slimlite Low E (4E-6XeKr-3 crown)
Slenderglaze (4E-3.9XeKr-4)
Slenderglaze (4E-4.8XeKr-4)
Slenderglaze (4E-6.4Kr-4)
Bonnington Joinery (new sahses inc).

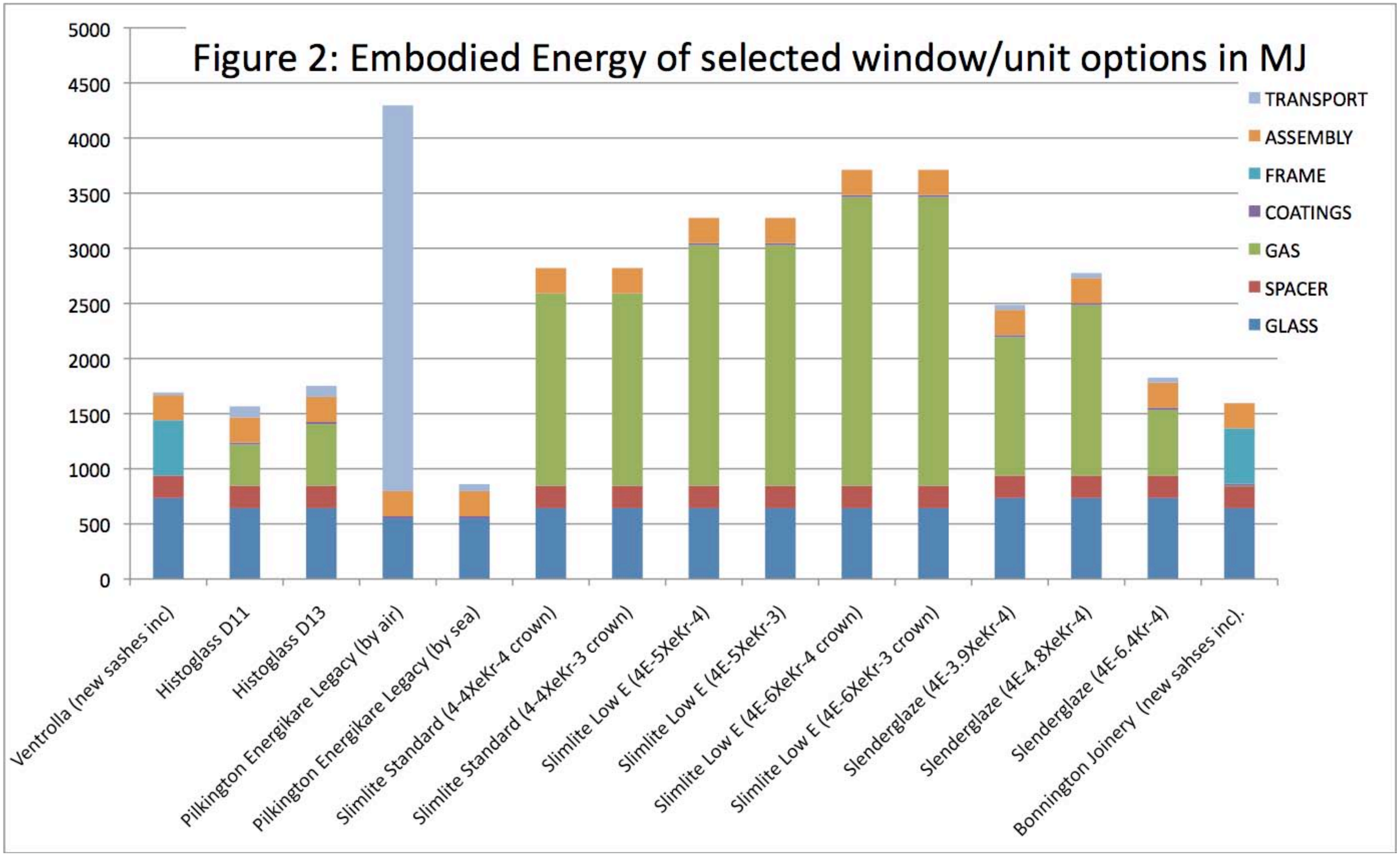

Figure 2: Embodied Energy of selected window/unit options in MJ
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
TRANSPORT
ASSEMBLY
FRAME
COATINGS
GAS
SPACER
GLASS
Ventrolla (new sashes inc)
Histoglass D11
Histoglass D13
Pilkington Energikare Legacy (by air)
Pilkington Energikare Legacy (by sea)
Slimlite Standard (4-4XeKr-4 crown)
Slimlite Standard (4-4XeKr-3 crown)
Slimlite Low E (4E-5XeKr-4)
Slimlite Low E (4E-5XeKr-3)
Slimlite Low E (4E-6XeKr-4 crown)
Slimlite Low E (4E-6XeKr-3 crown)
Slenderglaze (4E-3.9XeKr-4)
Slenderglaze (4E-4.8XeKr-4)
Slenderglaze (4E-6.4Kr-4)
Bonnington Joinery (new sahses inc).

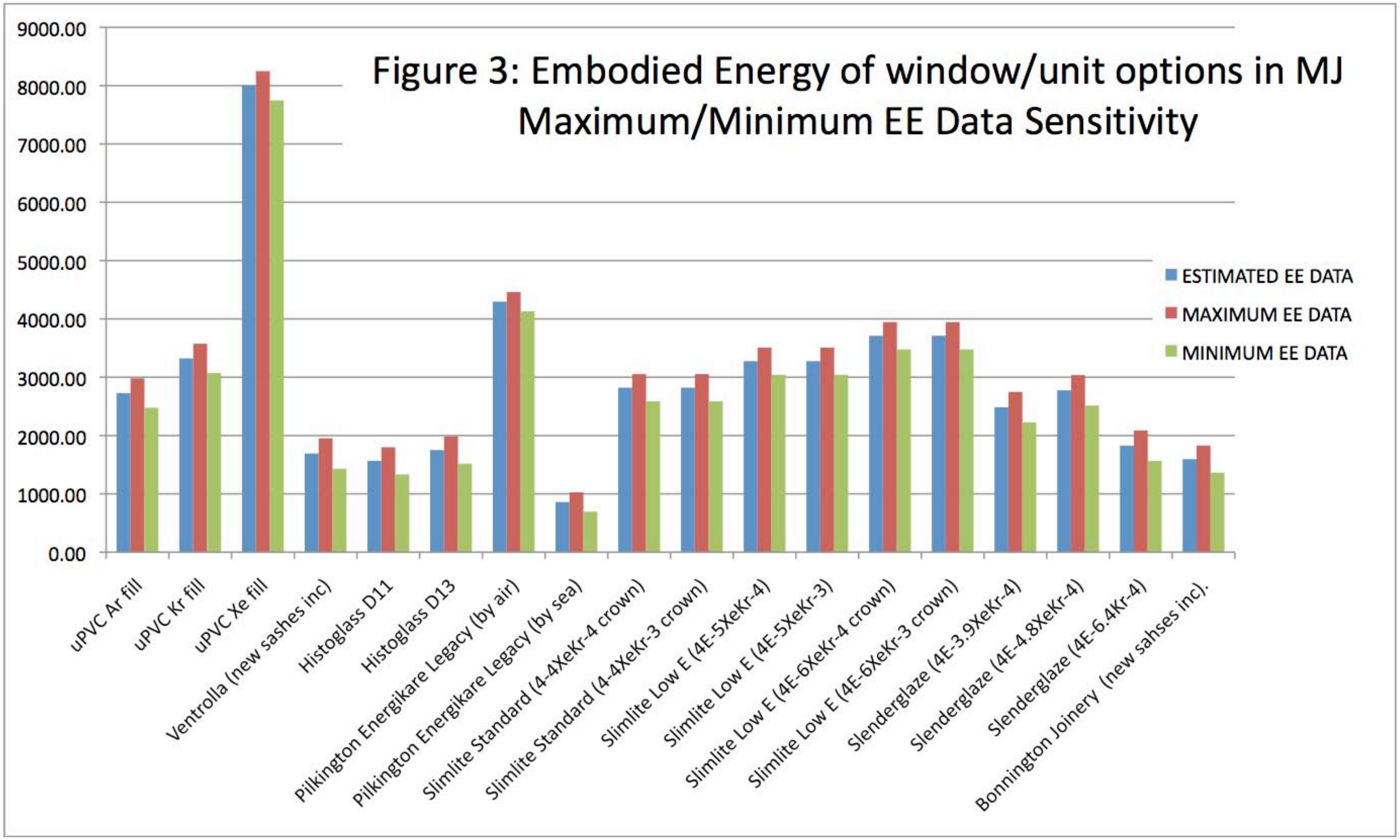
Figure 3: Embodied Energy of window/unit options in MJ
Maximum/Minimum EE Data Sensitivity
9000.00
8000.00
7000.00
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
ESTIMATED EE DATA
MAXIMUM EE DATA
MINIMUM EE DATA
uPVC Ar fill
uPVC Kr fill
uPVC Xe fill
Ventrolla (new sashes inc)
Histoglass D11
Histoglass D13
Pilkington Energikare Legacy (by air)
Pilkington Energikare Legacy (by sea)
Slimlite Standard (4-4XeKr-4 crown)
Slimlite Standard (4-4XeKr-3 crown)
Slimlite Low E (4E-5XeKr-4)
Slimlite Low E (4E-5XeKr-3)
Slimlite Low E (4E-6XeKr-4 crown)
Slimlite Low E (4E-6XeKr-3 crown)
Slenderglaze (4E-3.9XeKr-4)
Slenderglaze (4E-4.8XeKr-4)
Slenderglaze (4E-6.4Kr-4)
Bonnington Joinery (new sahses inc).

6 Conclusions

The *Cradle to Site* analysis performed in this report demonstrates that Krypton-filled units demonstrate lower embodied energy values. The omission of inert gases in Pilkington Energikare units significantly reduces their embodied energy, but further research is required to establish the manufacturing energy of vacuum unit design.

It is clear to see from Figure 1 that Krypton- and Xenon-filled window cavities lead to higher EE values. Argon-filled windows offer marginally increased thermal resistance compared to air-filled cavities, and have significantly lower EE values than Krypton- and Xenon-filled windows. Weir (1998) showed that both Argon- and Krypton-filled windows demonstrated positive life cycle energy analyses – i.e. the energy embodied within the window could be repaid many times throughout the life of the window – whereas Xenon-filled windows showed this analysis to be negative. Weir's analysis was based on cavities of 16, 12 and 8mm for Argon, Krypton and Xenon respectively.

With slim-profile glazing units the cavities are much smaller, and therefore the gas quantities are significantly reduced. This has an obvious knock-on effect on the EE of the glazing unit, but also on the increased centre-pane U-value of the the unit. The use of various Xenon/Krypton gas concentrations in window units needs further investigation to include the operational use phase of the building. Only once a full energy analysis has been performed can this question be fully answered – see recommendation below.

The embodied energy of air transport (Pilkington energiKare Legacy option) is significant, showing that despite a product with lower EE of materials and manufacture, the means of transport cannot be ignored. Container ship transport embodies considerably less energy and carbon per kg-km than air transport.

With more accurate data on the manufacturing process of Pilkington energiKare Legacy the LCI daya for this product could be made more complete. In this case it is likely that the further pursuit of reliable data would show positively in a sensitivity analysis.

7 Recommendation

The EE data presented in this report should be used in combination with U-value analysis and resulting operational energy of the windows/units/properties concerned. A holistic evaluation of this nature would present the optimum choice in terms of full life cycle energy analysis.

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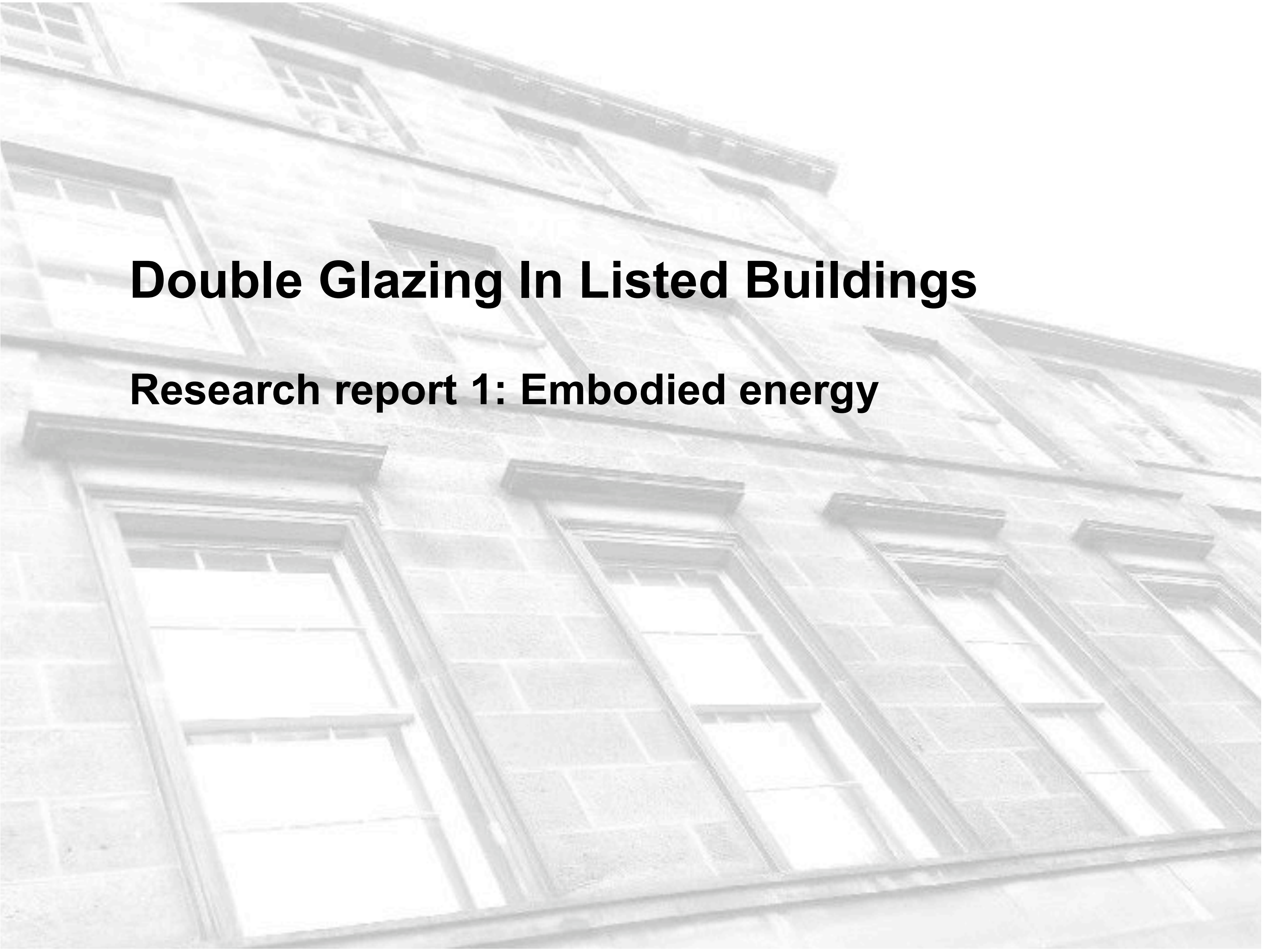

Double Glazing In Listed Buildings

Research report 1: Embodied energy

Appendix 1: LCI Data 2010

Embodied energy analysis of retrofit glazing options for listed buildings

APPENDIX 1
LCI Data 2010
spreadsheet

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July
2010

LCI DATA 1

LIFE CYCLE INVENTORY - DOUBLE GLAZED WINDOW OPTIONS

WINDOW OPTION	WIDTH	HEIGHT	NO.PANES	Cavity	PROFILE DEPTH	MANUFACTURE LOCATON	Centre Pane U-Value	GLASS	SPACER	GAS TYPE	VACUUM	TOTAL GAS VOLUME (m3)	COATINGS	FRAME	TOTAL SPACER LENGTH	TRANSPORT DATA
uPVC Ar fill	1.12	1.15	2.00	0.02	0.02	Edinburgh	1.33	4mm low-E float inner / 4mm float glass outer	Al	Ar	-	0.02	Low-E inner	Upvc	9.08	-
uPVC Kr fill	1.12	1.15	2.00	0.01	0.02	Edinburgh	1.14	4mm low-E float inner / 4mm float glass outer	Al	Kr	-	0.02	Low-E inner	Upvc	9.08	-
uPVC Xe fill	1.12	1.15	2.00	0.01	0.02	Edinburgh	1.00	4mm low-E float inner / 4mm float glass outer	Al	Xe	-	0.01	Low-E inner	Upvc	9.08	-
Ventrolla (new sashes inc)	0.36	0.56	12.00	0.01	0.01	Harrogate	1.80	4mm float inner/4mm float outer	Al	Ar	-	0.00	none	timber	22.08	151 miles/243 km by road
Histoglass D11	0.36	0.56	12.00	0.00	0.01	Germany (471 miles to London by road)	1.90	3mm low-E float inner / 4mm float outer	Al	Kr	-	0.01	Low-E inner	n/a	22.08	534km London to Edinburgh plus 758 km to Germany, plus 34 km freight ferry (negligible)
Histoglass D13	0.36	0.56	12.00	0.01	0.01	Germany (471 miles to London by road)	1.50	3mm low-E float inner / 4mm float outer	Al	Kr	-	0.01	Low-E inner	n/a	22.08	534km London to Edinburgh plus 758 km to Germany, plus 34 km freight ferry (negligible)
Pilkington Energikare Legacy (by air)	0.36	0.56	12.00	0.00	0.07	Japan by air	1.40	Optiwhite inner / K glass outer	micro-spacers	-	yes	-	Low-E outer	n/a	-	9585 km by air plus 534 km London to Edinburgh
Pilkington Energikare Legacy (by sea)	0.36	0.56	12.00	0.00	0.07	Japan by container ship	1.40	Optiwhite inner / K glass outer	micro-spacers	-	yes	-	Low-E outer	n/a	-	9585 km by ship plus 534 km London to Edinburgh
Slimlite Standard (4-4XeKr-4 crown)	0.36	0.56	12.00	0.00	0.01	Edinburgh	1.90	4mm float inner /4mm crown sheet outer	Al	30% Xe / 70% Kr	-	0.01	none	n/a	22.08	-
Slimlite Standard (4-4XeKr-3 crown)	0.36	0.56	12.00	0.00	0.01	Edinburgh	1.90	4mm float inner / 3mm crown sheet outer	Al	30% Xe / 70% Kr	-	0.01	none	n/a	22.08	-
Slimlite Low E (4E-5XeKr-4)	0.36	0.56	12.00	0.01	0.01	Edinburgh	1.80	4mm K glass inner /4mm float outer	Al	30% Xe / 70% Kr	-	0.01	Low-E inner	n/a	22.08	-
Slimlite Low E (4E-5XeKr-3)	0.36	0.56	12.00	0.01	0.01	Edinburgh	1.80	4mm K glass inner /3mm float outer	Al	30% Xe / 70% Kr	-	0.01	Low-E inner	n/a	22.08	-
Slimlite Low E (4E-6XeKr-4 crown)	0.36	0.56	12.00	0.01	0.01	Edinburgh	1.60	4mm K glass inner / 4mm crown sheet outer	Al	30% Xe / 70% Kr	-	0.01	Low-E inner	n/a	22.08	-
Slimlite Low E (4E-6XeKr-3 crown)	0.36	0.56	12.00	0.01	0.01	Edinburgh	1.60	4mm K glass inner / 3mm crown sheet outer	Al	30% Xe / 70% Kr	-	0.01	Low-E inner	n/a	22.08	-
Slenderglaze (4E-3.9XeKr-4)	0.36	0.56	12.00	0.00	0.01	Bath	1.90	4mm low-E float inner / 4mm float glass outer	Al	20% Xe / 80% Kr	-	0.01	Low-E inner	n/a	22.08	317 miles / 510 km Bath to Edinburgh by road
Slenderglaze (4E-4.8XeKr-4)	0.36	0.56	12.00	0.00	0.01	Bath	1.80	4mm low-E float inner / 4mm float glass outer	Al	20% Xe / 80% Kr	-	0.01	Low-E inner	n/a	22.08	317 miles / 510 km Bath to Edinburgh by road
Slenderglaze (4E-6.4Kr-4)	0.36	0.56	12.00	0.01	0.01	Bath	1.60	4mm low-E float inner / 4mm float glass outer	Al	Kr	-	0.02	Low-E inner	n/a	22.08	317 miles / 510 km Bath to Edinburgh by road
Bonnington Joinery (new sahses inc).	0.36	0.56	12.00	0.00	0.01	Edinburgh	2.1 ?	3mm float outer/4mm low-E inner	Al	Ar	-	0.01	low-E inner	timber	22.08	-

WINDOW OPTION	AIR/SHIP TRANSPORT tonnes km	SHIP TRANSPORT diesel litres	ROAD TRANSPORT tonnes km	ROAD TRANSPORT diesel litres	GLASS VOLUME (m3)	GLASS DENSITY (kg/m3)	MASS (kg)	EMBODIED ENERGY (MJ) GLASS	SPACER	GAS	COATINGS	FRAME	ASSEMBLY	TRANSPORT	TOTAL	Comments	
uPVC Ar fill	0.00	0.00	0.00	0.00	0.02	2530.00	52.14	782.07	83.90	0.01	19.71	1599.27	243.31	0.00	2484.96	e.g. http://www.eurocell.co.uk/70mm.html	
uPVC Kr fill	0.00	0.00	0.00	0.00	0.02	2530.00	52.14	782.07	83.90	595.06	19.71	1599.27	243.31	0.00	3080.00		
uPVC Xe fill	0.00	0.00	0.00	0.00	0.02	2530.00	52.14	782.07	83.90	5269.47	19.71	1599.27	243.31	0.00	7754.41		
Ventrolla (new sashes inc)	0.00	0.00	11.90	0.58	0.02	2530.00	48.96	734.47	204.02	0.00	0.00	501.48	228.50	23.22	1439.97	http://www.ventrolla.co.uk/services/?gclid=CPPm9seJn58CFZ1h4wodzDTMJA limited information on website - relates to renovation rather than glass replacement.	
Histoglass D11	0.00	0.00	55.35	2.49	0.02	2530.00	42.84	642.66	204.02	372.56	18.51	0.00	228.50	99.67	1237.74	contact Michiel Brouns michiel@histoglass.co.uk - to sne spacer bar details (25.1.10)	Acoustic performance window
Histoglass D13	0.00	0.00	55.35	2.49	0.02	2530.00	42.84	642.66	204.02	558.84	18.51	0.00	228.50	99.67	1424.02	 15kg/ 	
Pilkington Energikare Legacy (by air)	351.99	86.50	19.61	0.89	0.01	2530.00	36.72	550.85	0.00	0.00	18.51	0.00	228.50	3498.15	569.36	17.5kg/	Nippon glazing/ spacia
Pilkington Energikare Legacy (by sea)	351.99	0.67	19.61	0.89	0.01	2530.00	36.72	550.85	0.00	0.00	18.51	0.00	228.50	62.45	569.36	17.5kg/	
Slimlite Standard (4-4XeKr-4 crown)	0.00	0.00	0.00	0.00	0.02	2530.00	42.84	642.66	204.02	1745.40	0.00	0.00	228.50	0.00	2592.08		
Slimlite Standard (4-4XeKr-3 crown)	0.00	0.00	0.00	0.00	0.02	2530.00	42.84	642.66	204.02	1745.40	0.00	0.00	228.50	0.00	2592.08	cavity for Slimlite varies between 4, 5 and 6 mm. Various options available.	
Slimlite Low E (4E-5XeKr-4)	0.00	0.00	0.00	0.00	0.02	2530.00	42.84	642.66	204.02	2181.76	18.51	0.00	228.50	0.00	3046.94	glazing options vary also between 3mm and 4mm.	
Slimlite Low E (4E-5XeKr-3)	0.00	0.00	0.00	0.00	0.02	2530.00	42.84	642.66	204.02	2181.76	18.51	0.00	228.50	0.00	3046.94		
Slimlite Low E (4E-6XeKr-4 crown)	0.00	0.00	0.00	0.00	0.02	2530.00	42.84	642.66	204.02	2618.11	18.51	0.00	228.50	0.00	3483.29		
Slimlite Low E (4E-6XeKr-3 crown)	0.00	0.00	0.00	0.00	0.02	2530.00	42.84	642.66	204.02	2618.11	18.51	0.00	228.50	0.00	3483.29		
Slenderglaze (4E-3.9XeKr-4)	0.00	0.00	24.97	1.12	0.02	2530.00	48.96	734.47	204.02	1255.59	18.51	0.00	228.50	44.83	2212.59		
Slenderglaze (4E-4.8XeKr-4)	0.00	0.00	24.97	1.12	0.02	2530.00	48.96	734.47	204.02	1545.35	18.51	0.00	228.50	44.83	2502.34		
Slenderglaze (4E-6.4Kr-4)	0.00	0.00	24.97	1.12	0.02	2530.00	48.96	734.47	204.02	596.09	18.51	0.00	228.50	44.83	1553.09		
Bonnington Joinery (new sahses inc).	0.00	0.00	0.00	0.00	0.02	2530.00	42.84	642.66	204.02	0.01	18.51	501.48	228.50	0.00	1366.67	IS THIS MANUFACTURED IN 2 PANES WITH FALSE BARS? ANALYSIS ASSUMES 12 INDIVIDUAL PANES AT PRESENT.	

FIGURE 1

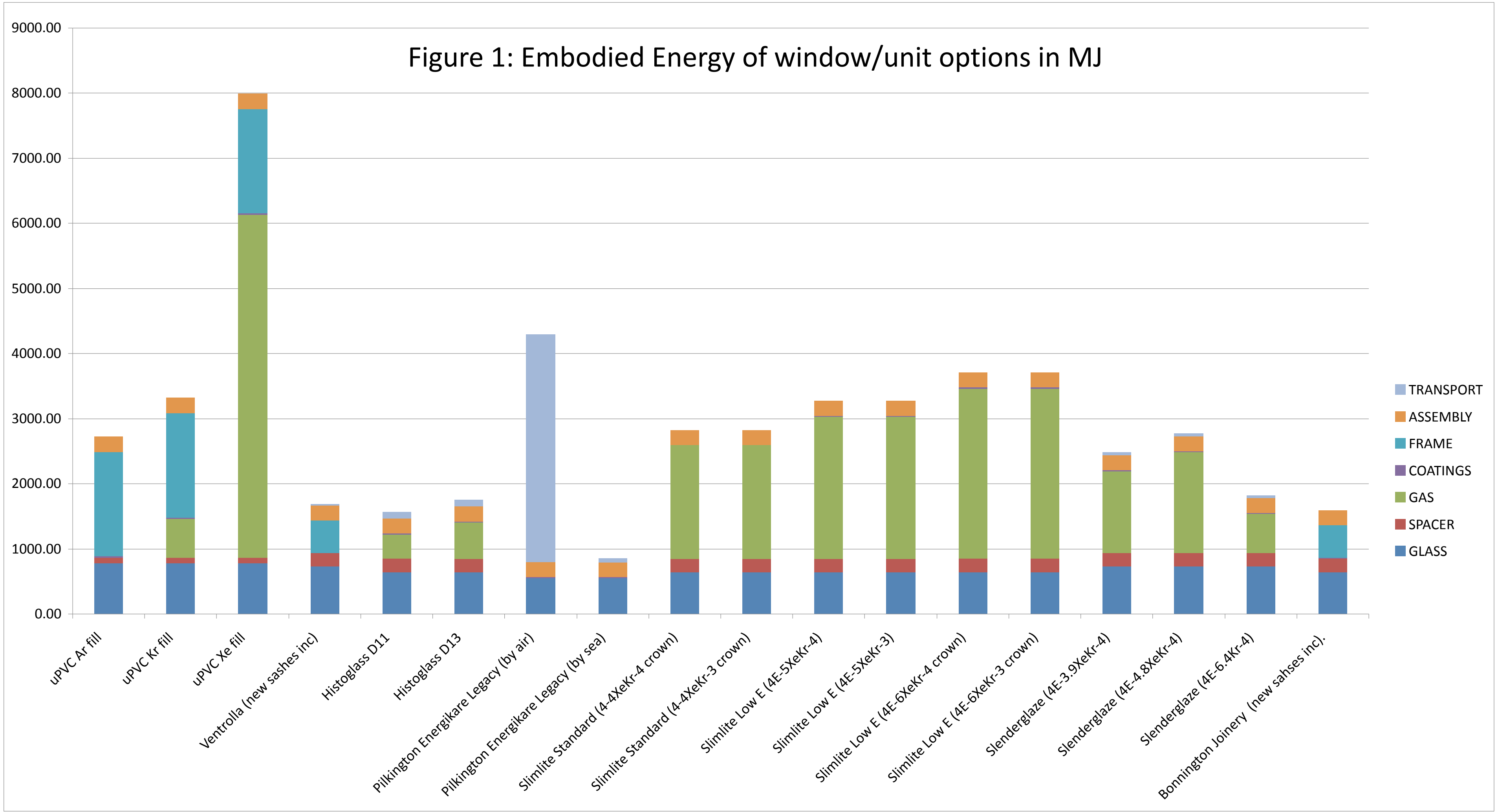


Figure 1: Embodied Energy of window/unit options in MJ
9000.00
8000.00
7000.00
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
uPVC Ar fill
uPVC Kr fill
uPVC Xe fill
Ventrolla (new sashes inc)
Histoglass D11
Histoglass D13
Pilkington Energikare Legacy (by air)
Pilkington Energikare Legacy (by sea)
Slimlite Standard (4-4XeKr-4 crown)
Slimlite Standard (4-4XeKr-3 crown)
Slimlite Low E (4E-5XeKr-4)
Slimlite Low E (4E-5XeKr-3)
Slimlite Low E (4E-6XeKr-4 crown)
Slimlite Low E (4E-6XeKr-3 crown)
Slenderglaze (4E-3.9XeKr-4)
Slenderglaze (4E-4.8XeKr-4)
Slenderglaze (4E-6.4Kr-4)
Bonnington Joinery (new sahses inc).
TRANSPORT
ASSEMBLY
FRAME
COATINGS
GAS
SPACER
GLASS

LCI DATA 2

LIFE CYCLE INVENTORY - DOUBLE GLAZED WINDOW OPTIONS

WINDOW OPTION	WIDTH	HEIGHT	NO.PANES	Cavity	PROFILE DEPTH	MANUFACTURE LOCATON	Centre Pane U-Value	GLASS	SPACER	GAS TYPE	VACUUM	TOTAL GAS VOLUME (m3)	COATINGS	FRAME	TOTAL SPACER LENGTH	TRANSPORT DATA
Ventrolla (new sashes inc)	0.36	0.56	12	0.008	0.014	Harrogate	1.8	4mm float inner/4mm float outer	Al	Ar	-	0.0016128	none	timber	22.08	151 miles/243 km by road
Histoglass D11	0.36	0.56	12	0.004	0.011	Germany (471 miles to London by road)	1.9	3mm low-E float inner / 4mm float outer	Al	Kr	-	0.0096768	Low-E inner	n/a	22.08	534km London to Edinburgh plus 758 km to Germany, plus 34 km freight ferry (negligible)
Histoglass D13	0.36	0.56	12	0.006	0.013	Germany (471 miles to London by road)	1.5	3mm low-E float inner / 4mm float outer	Al	Kr	-	0.0145152	Low-E inner	n/a	22.08	534km London to Edinburgh plus 758 km to Germany, plus 34 km freight ferry (negligible)
Pilkington Energikare Legacy (by air)	0.36	0.56	12.00	0.00	0.07	Japan by air	1.40	Optiwhite inner / K glass outer	micro-spacers	-	yes	-	Low-E outer	n/a	-	9585 km by air plus 534 km London to Edinburgh
Pilkington Energikare Legacy (by sea)	0.36	0.56	12	0.002	0.065	Japan by container ship	1.4	Optiwhite inner / K glass outer	micro-spacers	-	yes	-	Low-E outer	n/a	-	9585 km by ship plus 534 km London to Edinburgh
Slimlite Standard (4-4XeKr-4 crown)	0.36	0.56	12	0.004	0.012	Edinburgh	1.9	4mm float inner /4mm crown sheet outer	Al	30% Xe / 70% Kr	-	0.0096768	none	n/a	22.08	-
Slimlite Standard (4-4XeKr-3 crown)	0.36	0.56	12	0.004	0.011	Edinburgh	1.9	4mm float inner / 3mm crown sheet outer	Al	30% Xe / 70% Kr	-	0.0096768	none	n/a	22.08	-
Slimlite Low E (4E-5XeKr-4)	0.36	0.56	12	0.005	0.013	Edinburgh	1.8	4mm K glass inner /4mm float outer	Al	30% Xe / 70% Kr	-	0.012096	Low-E inner	n/a	22.08	-
Slimlite Low E (4E-5XeKr-3)	0.36	0.56	12	0.005	0.012	Edinburgh	1.8	4mm K glass inner /3mm float outer	Al	30% Xe / 70% Kr	-	0.012096	Low-E inner	n/a	22.08	-
Slimlite Low E (4E-6XeKr-4 crown)	0.36	0.56	12	0.006	0.014	Edinburgh	1.6	4mm K glass inner / 4mm crown sheet outer	Al	30% Xe / 70% Kr	-	0.0145152	Low-E inner	n/a	22.08	-
Slimlite Low E (4E-6XeKr-3 crown)	0.36	0.56	12	0.006	0.013	Edinburgh	1.6	4mm K glass inner / 3mm crown sheet outer	Al	30% Xe / 70% Kr	-	0.0145152	Low-E inner	n/a	22.08	-
Slenderglaze (4E-3.9XeKr-4)	0.36	0.56	12	0.0039	0.0119	Bath	1.9	4mm low-E float inner / 4mm float glass outer	Al	20% Xe / 80% Kr	-	0.0094349	Low-E inner	n/a	22.08	317 miles / 510 km Bath to Edinburgh by road
Slenderglaze (4E-4.8XeKr-4)	0.36	0.56	12	0.0048	0.0128	Bath	1.8	4mm low-E float inner / 4mm float glass outer	Al	20% Xe / 80% Kr	-	0.0116122	Low-E inner	n/a	22.08	317 miles / 510 km Bath to Edinburgh by road
Slenderglaze (4E-6.4Kr-4)	0.36	0.56	12	0.0064	0.0144	Bath	1.6	4mm low-E float inner / 4mm float glass outer	Al	Kr	-	0.0154829	Low-E inner	n/a	22.08	317 miles / 510 km Bath to Edinburgh by road
Bonnington Joinery (new sahses inc).	0.36	0.56	12	0.0048	0.0118	Edinburgh	2.1 ?	3mm float outer/4mm low-E inner	Al	Ar	-	0.0116122	low-E inner	timber	22.08	-

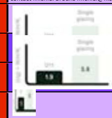
WINDOW OPTION	AIR/SHIP TRANSPORT tonnes km	SHIP TRANSPORT diesel litres	ROAD TRANSPORT tonnes km	ROAD TRANSPORT diesel litres	GLASS VOLUME (m3)	GLASS DENSITY (kg/m3)	MASS (kg)	EMBODIED ENERGY (MJ) GLASS	SPACER	GAS	COATINGS	FRAME	ASSEMBLY	TRANSPORT	TOTAL	Comments	
Ventrolla (new sashes inc)	0.00	0.00	11.90	0.58	0.0193536	2530	48.9646	734.46912	204.0192	0.0010838	0	501.48	228.50	23.22	1439.97	http://www.ventrolla.co.uk/services/?gclid=CPPm9seJn58CFZ1h4wodzDTMJA limited information on website - relates to renovation rather than glass replacement.	
Histoglass D11	0.00	0.00	55.35	2.49	0.0169344	2530	42.844	642.66048	204.0192	372.5568	18.50688	0.00	228.50	99.67	1237.74	contact Michiel Brouns michiel@histoglass.co.uk - to sne spacer bar details (25.1.10)	Acoustic performance window
Histoglass D13	0.00	0.00	55.35	2.49	0.0169344	2530	42.844	642.66048	204.0192	558.8352	18.50688	0.00	228.50	99.67	1424.02	 15kg/ 	
Pilkington Energikare Legacy (by air)	351.99	86.50	19.61	0.89	0.01	2530.00	36.72	550.85	0.00	0.00	18.51	0.00	228.50	3498.15	569.36	17.5kg	Nippon glazing/ spacia
Pilkington Energikare Legacy (by sea)	351.99	0.67	19.61	0.89	0.0145152	2530	36.7235	550.85184	0	0	18.50688	0.00	228.50	62.45	569.36	17.5kg	
Slimlite Standard (4-4XeKr-4 crown)	0.00	0.00	0.00	0.00	0.0169344	2530	42.844	642.66048	204.0192	1745.4044	0	0.00	228.50	0.00	2592.08		
Slimlite Standard (4-4XeKr-3 crown)	0.00	0.00	0.00	0.00	0.0169344	2530	42.844	642.66048	204.0192	1745.4044	0	0.00	228.50	0.00	2592.08	cavity for Slimlite varies between 4, 5 and 6 mm. Various options available.	
Slimlite Low E (4E-5XeKr-4)	0.00	0.00	0.00	0.00	0.0169344	2530	42.844	642.66048	204.0192	2181.7555	18.50688	0.00	228.50	0.00	3046.94	glazing options vary also between 3mm and 4mm.	
Slimlite Low E (4E-5XeKr-3)	0.00	0.00	0.00	0.00	0.0169344	2530	42.844	642.66048	204.0192	2181.7555	18.50688	0.00	228.50	0.00	3046.94		
Slimlite Low E (4E-6XeKr-4 crown)	0.00	0.00	0.00	0.00	0.0169344	2530	42.844	642.66048	204.0192	2618.1066	18.50688	0.00	228.50	0.00	3483.29		
Slimlite Low E (4E-6XeKr-3 crown)	0.00	0.00	0.00	0.00	0.0169344	2530	42.844	642.66048	204.0192	2618.1066	18.50688	0.00	228.50	0.00	3483.29		
Slenderglaze (4E-3.9XeKr-4)	0.00	0.00	24.97	1.12	0.0193536	2530	48.9646	734.46912	204.0192	1255.5938	18.50688	0.00	228.50	44.83	2212.59		
Slenderglaze (4E-4.8XeKr-4)	0.00	0.00	24.97	1.12	0.0193536	2530	48.9646	734.46912	204.0192	1545.3463	18.50688	0.00	228.50	44.83	2502.34		
Slenderglaze (4E-6.4Kr-4)	0.00	0.00	24.97	1.12	0.0193536	2530	48.9646	734.46912	204.0192	596.09088	18.50688	0.00	228.50	44.83	1553.09		
Bonnington Joinery (new sahses inc).	0.00	0.00	0.00	0.00	0.0169344	2530	42.844	642.66048	204.0192	0.0078034	18.50688	501.48	228.50	0.00	1366.67	IS THIS MANUFACTURED IN 2 PANES WITH FALSE BARS? ANALYSIS ASSUMES 12 INDIVIDUAL PANES AT PRESENT.	

FIGURE 2

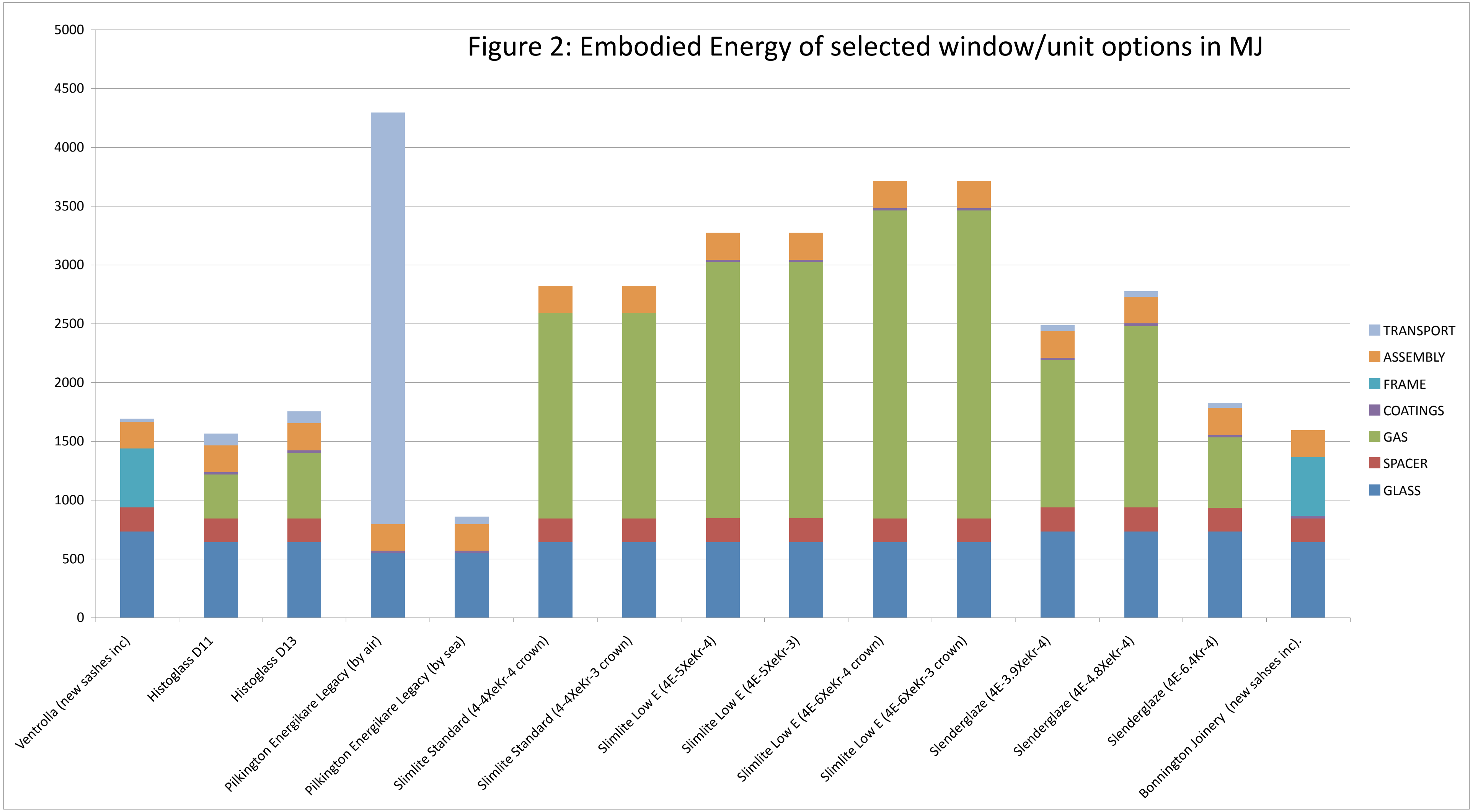


Figure 2: Embodied Energy of selected window/unit options in MJ
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
TRANSPORT
ASSEMBLY
FRAME
COATINGS
GAS
SPACER
GLASS
Ventrolla (new sashes inc)
Histoglass D11
Histoglass D13
Pilkington Energikare Legacy (by air)
Pilkington Energikare Legacy (by sea)
Slimlite Standard (4-4XeKr-4 crown)
Slimlite Standard (4-4XeKr-3 crown)
Slimlite Low E (4E-5XeKr-4)
Slimlite Low E (4E-5XeKr-3)
Slimlite Low E (4E-6XeKr-4 crown)
Slimlite Low E (4E-6XeKr-3 crown)
Slenderglaze (4E-3.9XeKr-4)
Slenderglaze (4E-4.8XeKr-4)
Slenderglaze (4E-6.4Kr-4)
Bonnington Joinery (new sahses inc).

SENSITIVITY ANALYSIS

WINDOW OPTION	EXISTING EMBODIED ENERGY (MJ) GLASS	GLASS + 30%	GLASS - 30%	SPACER	SPACER + 20%	SPACER - 20%	GAS	COATINGS	FRAME	ASSEMBLY	TRANSPORT	EXISTING TOTAL	MAXIMUM TOTAL	MINIMUM TOTAL
uPVC Ar fill	782.07	1016.70	547.45	83.90	100.68	67.12	0.01	19.71	1599.27	243.31	0.00	2728.27	2979.68	2476.87
uPVC Kr fill	782.07	1016.70	547.45	83.90	100.68	67.12	595.06	19.71	1599.27	243.31	0.00	3323.32	3574.72	3071.91
uPVC Xe fill	782.07	1016.70	547.45	83.90	100.68	67.12	5269.47	19.71	1599.27	243.31	0.00	7997.73	8249.13	7746.32
Ventrolla (new sashes inc)	734.47	954.81	514.13	204.02	244.82	163.22	0.00	0.00	501.48	228.50	23.22	1691.69	1952.84	1430.55
Histoglass D11	642.66	835.46	449.86	204.02	244.82	163.22	372.56	18.51	0.00	228.50	99.67	1565.92	1799.52	1332.32
Histoglass D13	642.66	835.46	449.86	204.02	244.82	163.22	558.84	18.51	0.00	228.50	99.67	1752.20	1985.80	1518.60
Pilkington Energikare Legacy (by air)	550.85	716.11	385.60	0.00	0.00	0.00	0.00	18.51	0.00	228.50	3498.15	4296.01	4461.27	4130.76
Pilkington Energikare Legacy (by sea)	550.85	716.11	385.60	0.00	0.00	0.00	0.00	18.51	0.00	228.50	62.45	860.31	1025.56	695.05
Slimlite Standard (4-4XeKr-4 crown)	642.66	835.46	449.86	204.02	244.82	163.22	1745.40	0.00	0.00	228.50	0.00	2820.59	3054.19	2586.99
Slimlite Standard (4-4XeKr-3 crown)	642.66	835.46	449.86	204.02	244.82	163.22	1745.40	0.00	0.00	228.50	0.00	2820.59	3054.19	2586.99
Slimlite Low E (4E-5XeKr-4)	642.66	835.46	449.86	204.02	244.82	163.22	2181.76	18.51	0.00	228.50	0.00	3275.45	3509.05	3041.84
Slimlite Low E (4E-5XeKr-3)	642.66	835.46	449.86	204.02	244.82	163.22	2181.76	18.51	0.00	228.50	0.00	3275.45	3509.05	3041.84
Slimlite Low E (4E-6XeKr-4 crown)	642.66	835.46	449.86	204.02	244.82	163.22	2618.11	18.51	0.00	228.50	0.00	3711.80	3945.40	3478.20
Slimlite Low E (4E-6XeKr-3 crown)	642.66	835.46	449.86	204.02	244.82	163.22	2618.11	18.51	0.00	228.50	0.00	3711.80	3945.40	3478.20
Slenderglaze (4E-3.9XeKr-4)	734.47	954.81	514.13	204.02	244.82	163.22	1255.59	18.51	0.00	228.50	44.83	2485.93	2747.07	2224.78
Slenderglaze (4E-4.8XeKr-4)	734.47	954.81	514.13	204.02	244.82	163.22	1545.35	18.51	0.00	228.50	44.83	2775.68	3036.82	2514.53
Slenderglaze (4E-6.4Kr-4)	734.47	954.81	514.13	204.02	244.82	163.22	596.09	18.51	0.00	228.50	44.83	1826.42	2087.57	1565.28
Bonnington Joinery (new sahses inc).	642.66	835.46	449.86	204.02	244.82	163.22	0.01	18.51	501.48	228.50	0.00	1595.18	1828.78	1361.58

FIGURE 3

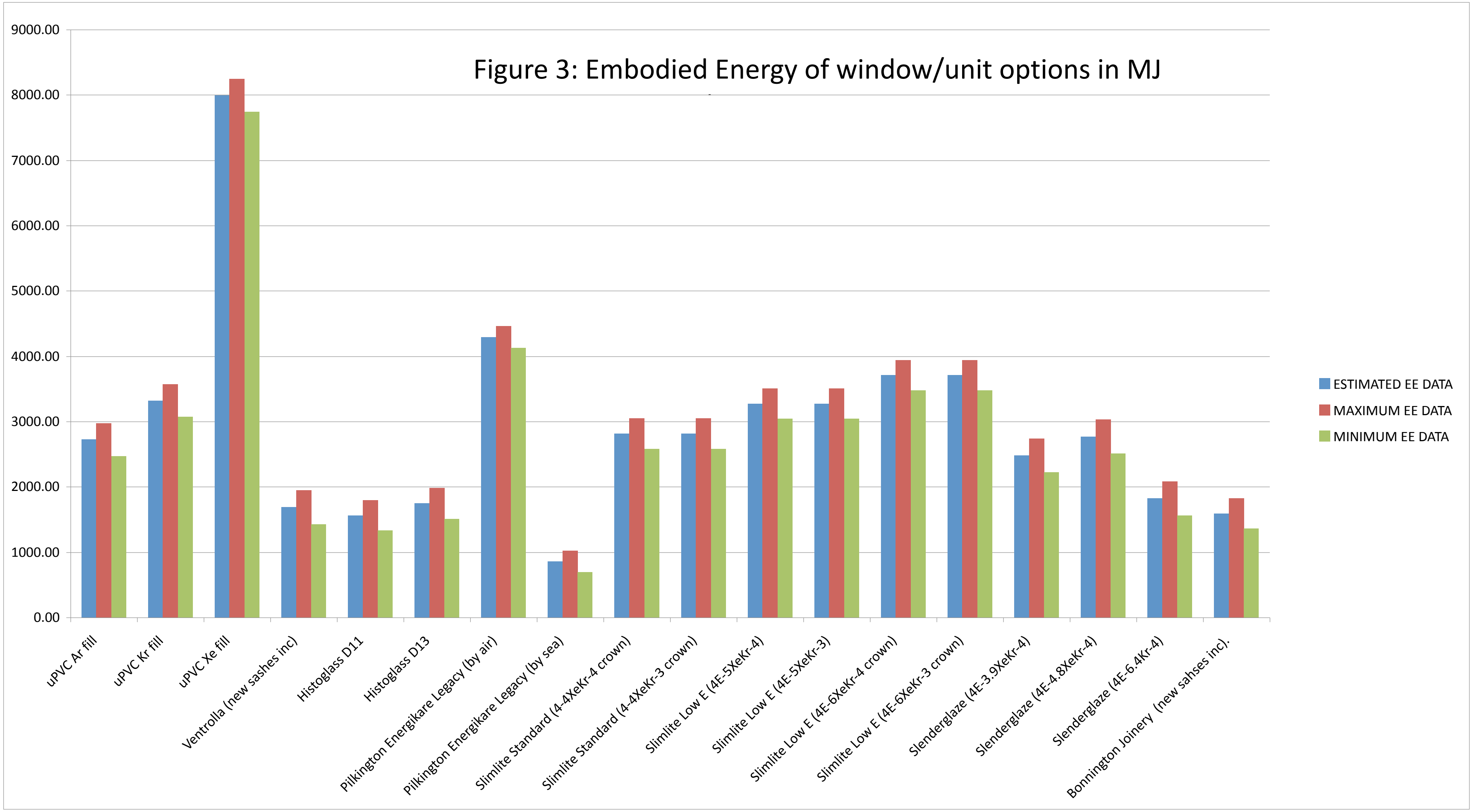


Figure 3: Embodied Energy of window/unit options in MJ
9000.00
8000.00
7000.00
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
uPVC Ar fill
uPVC Kr fill
uPVC Xe fill
Ventrolla (new sashes inc)
Histoglass D11
Histoglass D13
Pilkington Energikare Legacy (by air)
Pilkington Energikare Legacy (by sea)
Slimlite Standard (4-4XeKr-4 crown)
Slimlite Standard (4-4XeKr-3 crown)
Slimlite Low E (4E-5XeKr-4)
Slimlite Low E (4E-5XeKr-3)
Slimlite Low E (4E-6XeKr-4 crown)
Slimlite Low E (4E-6XeKr-3 crown)
Slenderglaze (4E-3.9XeKr-4)
Slenderglaze (4E-4.8XeKr-4)
Slenderglaze (4E-6.4Kr-4)
Bonnington Joinery (new sahses inc).
ESTIMATED EE DATA
MAXIMUM EE DATA
MINIMUM EE DATA

Data Info

Density of float glass	2530 kg/m3	Source	http://en.wikipedia.org/wiki/Soda-lime_glass	
EE Float Glass	15 MJ/kg		38% recycing rate (British Glass)	
	source	ICE database version 1.6, Bath, accessed 19/3/10		sensitivity +/- 30%
		includes typicl UK rate of 38% recycled glass		
low-E coating	7.65 MJ/m2	Source	Weir, 1998	
Gas EE				
Xe	511.4 MJ/litre	Source	Fernie & Muneer, 1996	
Kr	38.5 MJ/litre	Source	Fernie & Muneer, 1996	
Ar	0.672 kJ/litre	Source	Fernie & Muneer, 1996	
Aluminium				
typical UK extruded Al	154 MJ/kg	source	ICE database version 1.6, Bath, accessed 19/3/10	sensitivity +/- 20%
			includes typicl UK rate of 33% recycled Al	

FRAME INFO

A standard window (1.2m × 1.2m) has been evaluated for its embodied energy with aluminium, PVC, Al-clad timber and timber manufacture. It has been found that the aluminium windows consume the highest amount of energy equal to 6GJ. PVC, Alclad timber and timber windows have their respective embodied energy equal to 2980 MJ, 1460MJ and 995MJ as shown in Fig.7.

Fig. 7 Embodied energy of frames**

source LIFE CYCLE OF WINDOW MATERIALS - A COMPARATIVE ASSESSMENT
M. Asif BSc MSc, A. Davidson BSc and T.Muneer PhD DSc CEng MlmechE
FICBSE Millennium Fellow
School of Engineering , Napier University, 10 Colinton Road, Edinburgh EH10 5DT, U.K.
found at http://www.cibse.org/pdfs/Masif.pdf on 19/3/10

EE per linear length of frame material =	620.8333	MJ/m length	uPVC
EE per linear length of frame material =	207.2917	MJ/m length	timber

Annex 7 - Freight Transport Conversion Tables source Defra, http://www.defra.gov.uk/environment/business/reporting/conversion-factors.htm

Last updated: Sep-09

DIESEL DENSITY	870.2 kg/m3	SOURCE UNFCCC	
DIESEL CALORIFIC VALUE	46 MJ/kg	SOURCE http://www.kayelaby.npl.co.uk/chemistry/3_11/3_11_4.html	
KEROSENE	71.4 t CO2 / TJ	SOURCE sustainable energy authority of ireland	http://www.sustainableenergyireland.com/Publications/Statistics_Publications/Emission_Factors/
DIESEL	73.3 t CO2 / TJ	SOURCE sustainable energy authority of ireland	http://www.sustainableenergyireland.com/Publications/Statistics_Publications/Emission_Factors/

How to use this Annex

If you know how much of a particular fuel type is consumed, emissions can be calculated using **Table 7a**. This is the most accurate way to calculate emissions.

Table 7b gives emissions for distance travelled for vans and small trucks.

Table 7c gives emissions *per tonne freight carried* for vans and small trucks. Emission factors for vans in tonne km were calculated from the emission factors per vehicle km provided in Table 6i (Annex 6) and an average load factor of 40%. The average cargo capacity was taken to be 0.5 tonnes for vans up to 1.25 tonnes gross vehicle weight, and 2 tonnes for vans up to 3.5 tonnes gross vehicle weight.

Table 7d gives emissions *per vehicle kilometre travelled* for a range of HGV sizes with a range of different loads. Use this table if you know the distance the *vehicle* has travelled. If you do not know the load capacity of your vehicle, apply the *UK average load* which is given for a range of vehicle classes.

Table 7e gives emissions *per tonne kilometre travelled* for a range of HGV sizes with a range of different loads. Use this table if you know the distance the *freight* has travelled and what the mass (in tonnes) of the freight was.

Table 7f gives emissions factors for *tonne kilometres* of freight for *shipping, rail,* and *air freight*.

How do I determine UK rail travel distances (in miles) where start and destination stations are known?

1. Click on web link: http://www.networkrail.co.uk/aspx/3828.aspx
2. Select the Route Index under Train Timetables
3. Use your mouse cursor to click on the appropriate train route in the 'Table' column that matches your starting and destination stations. This should open a
4. In the timetable, refer to the 'Miles' columns on the left to determine mileage between your starting and destination stations

How were these factors calculated?

For further explanation on how these emission factors have been derived, please refer to the GHG conversion factor methodology paper available here:
http://www.defra.gov.uk/environment/business/reporting/conversion-factors.htm

Table 7a

Standard Road Transport Fuel Conversion: Fuel used	Total units used	Units	x	CO_2: kg CO_2 per unit	CO_2: Total kg CO_2	CH_4: kg CO_2eq per unit	CH_4: Total kg CO_2eq	N_2O: kg CO_2eq per unit	N_2O: Total kg CO_2eq	Total GHG: kg CO_2eq per unit	Total GHG: Total kg CO_2eq
Petrol		litres	x	2.303		0.0047		0.0226		2.3307	
Diesel	86.5	litres	x	2.639	228.2	0.0019	0	0.0283	2	2.6694	231
Compressed Natural Gas (CNG)		kg	x	2.727		0.0041		0.0016		2.7335	
Liquid Petroleum Gas (LPG)		litres	x	1.495		0.0006		0.0011		1.4968	
Total					228		0		2		231

Sources UK Greenhouse Gas Inventory for 2007 (AEA)
Digest of UK Energy Statistics 2008 (BERR), available at: http://www.berr.gov.uk/whatwedo/energy/statistics/publications/dukes/page45537.html
Carbon factors for fuels (UKPIA, 2004)

Notes 1 imperial gallon (UK) = 4.546 litres

Table 7b

Van/Light Commercial Vehicle Road Freight Conversion Factors: Type of van	Gross Vehicle Weight (tonnes)	Total vehicle km travelled	x	CO_2: kg CO_2 per vehicle km	CO_2: Total kg CO_2	CH_4: kg CO_2eq per vehicle km	CH_4: Total kg CO_2eq	N_2O: kg CO_2eq per vehicle km	N_2O: Total kg CO_2eq	Total GHG: kg CO_2eq per vehicle km	Total GHG: Total kg CO_2eq
Petrol	up to 1.25t		x	0.2243		0.0003		0.0035		0.2282	
Diesel (Class I)	up to 1.305t		x	0.1608		0.0000		0.0010		0.1619	
Diesel (Class II)	1.305t to 1.74t		x	0.2249		0.0000		0.0014		0.2264	
Diesel (Class III)	1.74t to 3.5t		x	0.2993		0.0000		0.0019		0.3013	
Diesel (average)	up to 3.5t		x	0.2716		0.0000		0.0018		0.2734	
LPG or CNG	up to 3.5t		x	0.2718		0.0003		0.0035		0.2757	
Average	up to 3.5t		x	0.2666		0.0000		0.0019		0.2686	
Total					0		0		0		0

Table 7c

Factors (UK Average Vehicle Loads): Tonne.km Basis	Gross Vehicle Weight (tonnes)	Total tonne km travelled	x	CO_2: kg CO_2 per tonne.km	CO_2: Total kg CO_2	CH_4: kg CO_2eq per tonne.km	CH_4: Total kg CO_2eq	N_2O: kg CO_2eq per tonne.km	N_2O: Total kg CO_2eq	Total GHG: kg CO_2eq per tonne.km	Total GHG: Total kg CO_2eq
Petrol	up to 1.25t		x	[illegible]		[illegible]		[illegible]		[illegible]	
Diesel (Class I)	up to 1.305t		x	[illegible]		[illegible]		[illegible]		[illegible]	
Diesel (Class II)	1.305t to 1.74t		x	[illegible]		[illegible]		[illegible]		[illegible]	
Diesel (Class III)	1.74t to 3.5t		x	[illegible]		[illegible]		[illegible]		[illegible]	
Diesel (average)	up to 3.5t		x	[illegible]		[illegible]		[illegible]		[illegible]	
LPG or CNG	up to 3.5t		x	[illegible]		[illegible]		[illegible]		[illegible]	
Average	up to 3.5t		x	[illegible]		[illegible]		[illegible]		[illegible]	
Total					0		0		0		0

Sources Factors developed by AEA and agreed with Department for Transport (2009)

Notes Emission factors for vans in tonne km were calculated from the emission factors per vehicle km provided in Table [illegible]
New emission factors for CH_4 and N_2O are based on UK Greenhouse Gas Inventory default values for 2007

Table 7d

Diesel HGV Road Freight Conversion Factors: Vehicle km Basis

[illegible]

Sources Revised factors developed by AEA and agreed with Department for Transport (2009)

Notes [illegible]

Table 7e

Vehicle Loads): Tonne.km Basis

[illegible]

Sources Revised factors developed by AEA and agreed with Department for Transport (2009)

Notes [illegible]

Table 7f

Other Freight Mileage Conversion Factors: Tonne.km Basis: Mode	Detail	Total tonne km travelled		x	CO_2: kg CO_2 per tonne.km	CO_2: Total kg CO_2	CH_4: kg CO_2eq per tonne.km	CH_4: Total kg CO_2eq	N_2O: kg CO_2eq per tonne.km	N_2O: Total kg CO_2eq	Total GHG: kg CO_2eq per tonne.km	Total GHG: Total kg CO_2eq
Rail	Diesel			x	[illegible]		[illegible]		0.0033		0.0319	
Shipping	Type	Vessel deadweight tonnes										
	Large RoPax Ferry	[illegible]		x	[illegible]	[illegible]	[illegible]	0	0.0029	0	0.3874	0
	Small tanker	[illegible]		x	[illegible]		[illegible]		0.0001		0.0201	
	Large tanker	[illegible]	[illegible]	x	[illegible]	[illegible]	[illegible]	0	0.0000	0	0.0050	2
	Very large tanker	[illegible]		x	[illegible]		[illegible]		0.0000		0.0040	
	Small bulk carrier	[illegible]		x	[illegible]		[illegible]		0.0000		0.0110	
	Large bulk carrier	[illegible]		x	[illegible]		[illegible]		0.0000		0.0070	
	Very large bulk carrier	[illegible]		x	[illegible]		[illegible]		0.0000		0.0060	
	Small container vessel	[illegible]		x	[illegible]		[illegible]		0.0001		0.0151	
	Large container vessel	[illegible]		x	[illegible]		[illegible]		0.0001		0.0131	
Mode	Detail	Total tonne km travelled	km uplift factor	x	kg CO_2 per tonne.km	Total kg CO_2	kg CO_2eq per tonne.km	Total kg CO_2	kg CO_2eq per tonne.km	Total kg CO_2	kg CO_2eq per tonne.km	Total kg CO_2
Air	Domestic		109%	x	[illegible]		[illegible]		0.0188		1.9362	
	Short-haul international		109%	x	[illegible]		[illegible]		0.0138		1.4183	
	Long-haul international	[illegible]	109%	x	[illegible]	[illegible]	[illegible]	0	0.0058	2	0.6007	230
Total						[illegible]		0		2		232

Sources Revised factors developed by AEA and agreed with Department for Transport (2009)

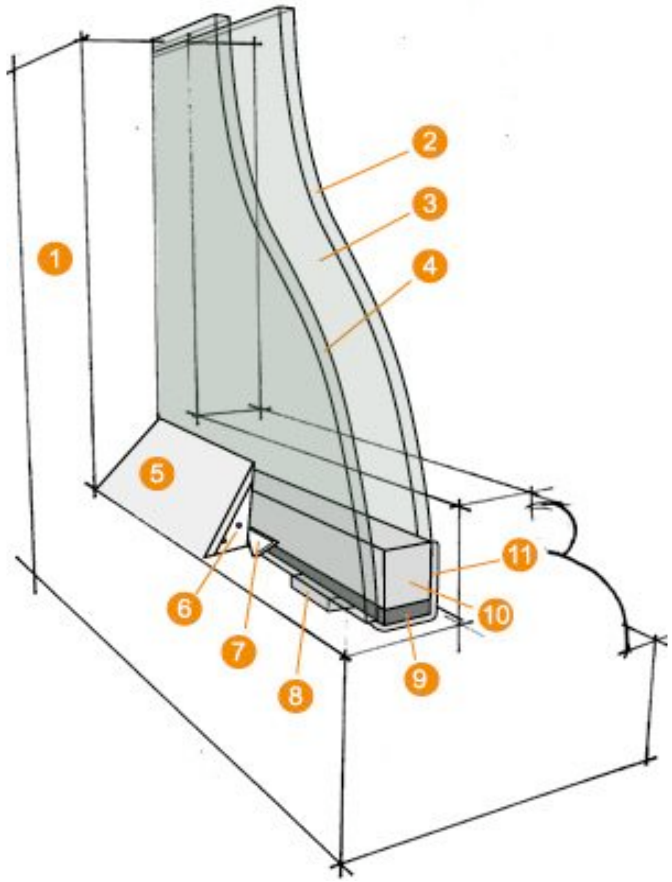
Notes **Rail:**
[illegible]

Shipping:
[illegible]

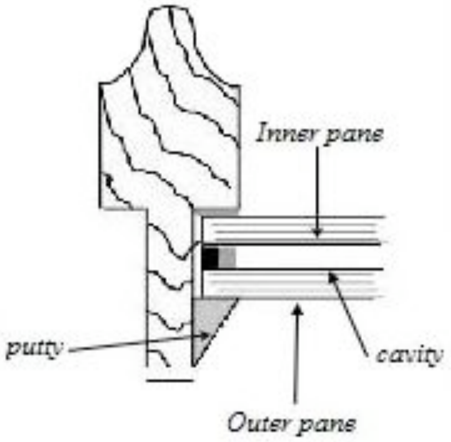
Air:
[illegible]

HISTOGLASS

1. Window frame
2. 3mm Low-E float glass inner pane
3. Gas filled cavity
4. Outer Pane
5. Paint overlapping onto the glass by 1-2mm
6. Modified putty
7. Sprig
8. Hardwood spacer
9. Perimeter Seal
10. Aluminium profile
11. Sealant



SLENDERGLAZE



Glazing options

Inner pane
4mm Low Emissivity glass that reflects heat back into the room (can be supplied toughened)

Outer pane
4mm float glass
(can be supplied toughened)
6.4 laminated
6.8 sound reducing laminated glass

Antique glass
One of the most aesthetically pleasing aspects of old windows is the reflection given off by imperfect crown or cylinder glass. To replicate this we offer the option of reproduction cylinder glass in the outer pane. Patterned or Acid etched glass can also be specified.

Putty
Slenderglaze is glazed with a special Polymer rich glazing putty that will keep out water, remain flexible and can be over-painted. This ensures the sealed unit will not breakdown due to water ingress or brittleness - problems associated with normal putty.

Cavity
Slenderglaze can be supplied with the following centre pane U values:

3.9mm U value 1.9
4.8mm U value 1.8
6.4mm U value 1.6
7.9mm U value 1.5
9.5mm U value 1.4
1.1mm U value 1.3

All units are gas filled