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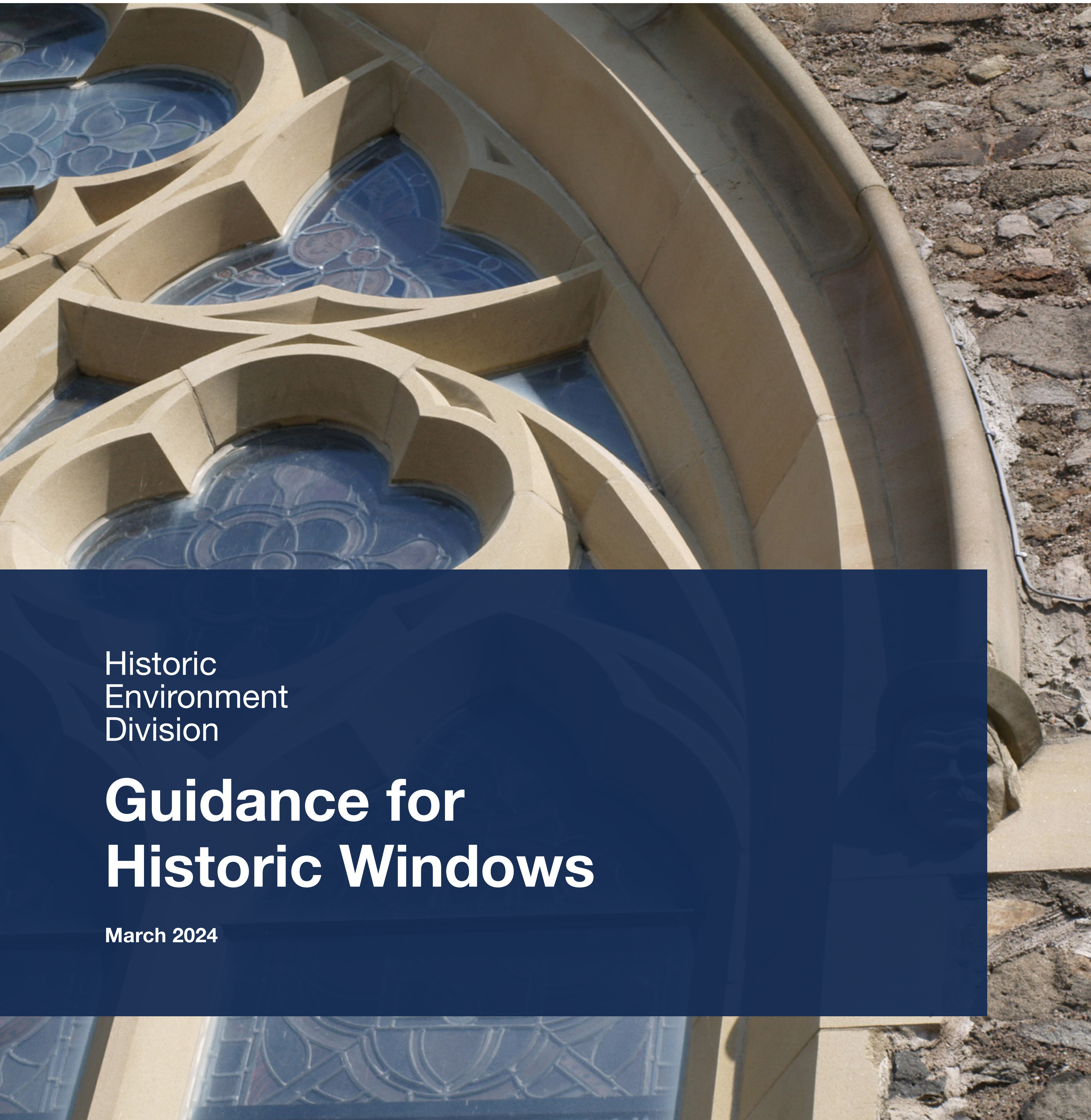

Historic Environment Division

Guidance for Historic Windows

March 2024

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The Department for Communities Historic Environment Division seeks to help communities enjoy and realise the value of our historic environment.

Our historic buildings provide authentic and attractive places that increase our pride, character, and identity, lead to improved well-being and community engagement and generate prosperity through tourism, investment, skills, regeneration, and creativity. Each historic building is a precious and finite resource available to present generations and, with appropriate management, to future generations.

This guidance provides a brief history and background to explain the part played by historic windows, how they are significant, how they can be retained, and, where necessary, how they can be best upgraded to perform and meet our current needs.

Historic Environment Division provides further guidance on understanding what is significant about a heritage asset in their Conservation Principles: Guidance for the sustainable management of the historic environment in Northern Ireland.

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Introduction

Historic buildings make a valuable contribution to the countryside and the towns where we live, forming a unique part of our cultural heritage, and windows form a vital part of the character and significance of historic buildings.

"Of all building elements- windows, doors, their fittings and embellishments can often tell more of the history of a building than any other"[1]

In vernacular buildings, windows can be the most complex element in an otherwise simple 'undesigned' facade.

Ballymacreelly 1780-1799

In formal architecture, such as Georgian architecture, windows are the main compositional element. Their detailed design is fundamental.

Florence Court, 18th Century Georgian House – National Trust

Historic windows were often astonishingly well-crafted objects in durable timber. Early 17th-century windows were made from oak and other hardwoods; however, later in the century and by the early 18th century, these essentially gave way to 'Deal' – a generic term for Scottish or Nordic fir or pine softwood. Deal, however, is not comparable to modern softwood as it often uses the more durable heartwood. In many cases, the craftsmanship and quality materials used have, with basic repairs and regular maintenance, lasted for over two hundred years.

Some windows still retain their historic glass. This glass comes in many types, each with its charm, giving character and variability. It is now a limited resource as many types are no longer manufactured.

Replacement of historic windows

Today, historic windows continue to disappear from our historic buildings' stock. They are often replaced rather than repaired, as a matter of course, and while there are valid reasons that prompt people to want to replace historic windows, there are other solutions that can often be better in terms of overall benefits.

We are coming to appreciate that climate change and sustainability are issues that affect every area of our lives. Buildings and the parts that make them up, such as windows, are essential in this discussion.

Often, answers are more complex than we may like. Take, for example, the thermal performance of windows. It may seem obvious that the overall effect on the environment will be favourable if, for example, a modern performance window with lower heat loss replaces a poorly performing traditional window- reducing energy use in the building. However, if thermal improvement is achieved by replacement, one must also consider the material, time and energy that went into creating the original window and the input of new energy, manufacturing, transport, and raw materials needed to create the new window.

This guide highlights that there are easy and sustainable ways to improve existing windows and match the performance of new windows without needing to replace them.

History

Early windows

Most of our complete historic buildings date from after 1700. Little evidence remains for historic window features prior to 1600. However archaeological investigation and contemporary records tell us that developments in windows were like those in other parts of Ireland and Britain.

Medieval Window with high gothic tracery from Movilla Abbey

Most early buildings did not have any glazing. They had small windows open to the elements. Sometimes they had timber shutters that could close over at night or in extreme weather. These either hinged or were able to slide across.

While no shutters remain from this time, we have archaeological evidence of their existence. Stone cills, such as that at the medieval Abbacy site near Portaferry – a medieval and early post medieval episcopal manor – show the hole for pivoting the shutter and other markings that indicate how the shutter would have fitted.

English example of a medieval Shutter

Medieval church windows had windows comprised of small panes of glass, often they had stained glass, held together with strips of lead. The assembled panels of glass were usually installed directly into the locations for which they were intended, in a groove in the stone window-frame.

Medieval stone cill – the shutter pivoted in the hole on the left - Portaferry Abbacy

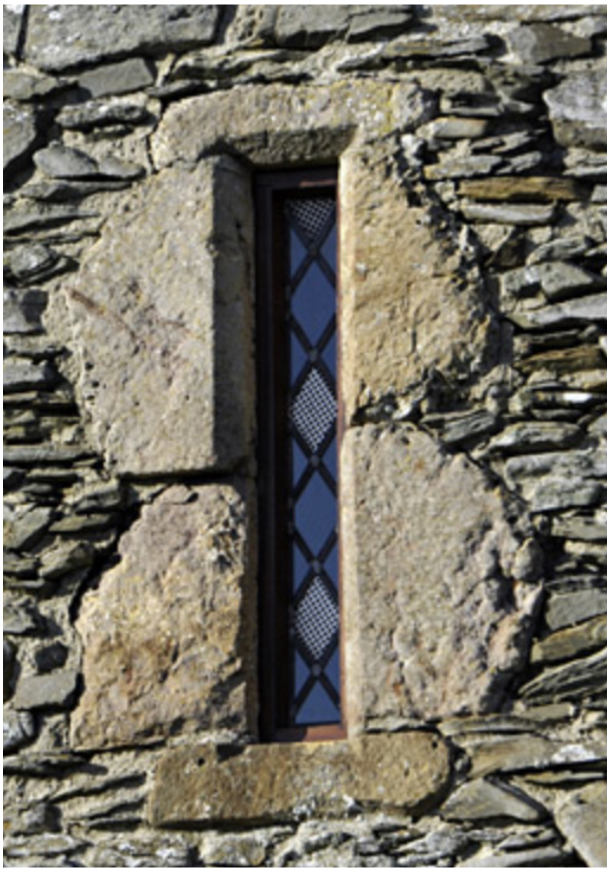
Often, particularly on larger windows, there were ironwork framing systems, consisting of wrought-iron flat bars, which subdivided the stone-framed openings in the window.

Several late 16th and early 17th century churches remain in use. The parish church at Clonfeacle at Benburb, built by Sir Richard Wingfield between 1618 and 1622 retains many of its original leaded windows including the large pointed-arch East window which has fine Jacobean gothic tracery divided into four lights.[2]

Clonfeacle Parish Church, Benburb, 1618-22

Large castles and houses

In some instances, large castles and houses had an adaptation of the church window called 'Quarry glazing' containing small diamond or square shaped panes set in lead 'cames'. These leaded windows were set directly within the frame or, more infrequently, in wrought iron casements.



Audleystown Castle – Recreated Tudor style window

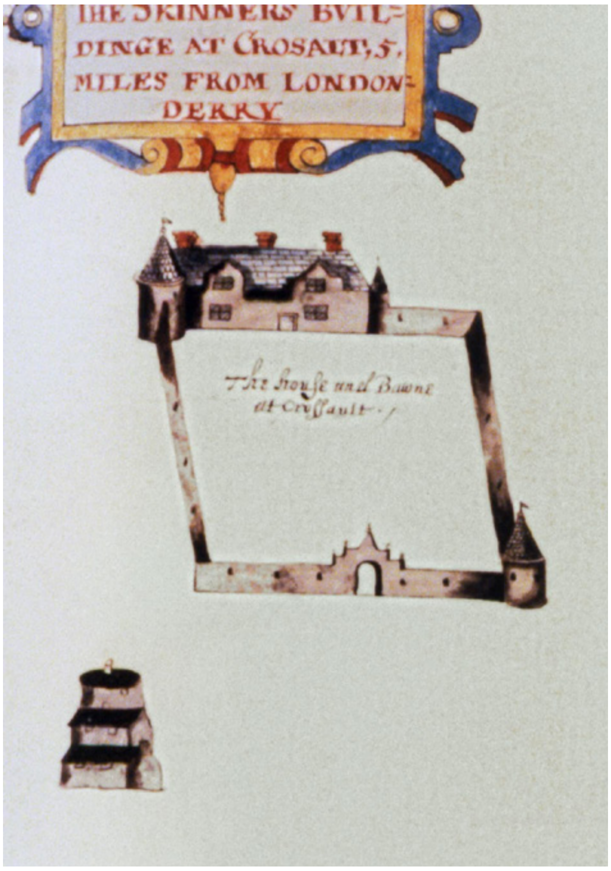
However, the long straight lines generated by the geometric designs were inherently weak, and although the lead joints were often interwoven to help minimise the problem, the windows had limited strength. This meant their overall size of was often small.

To span larger openings, rectangular leaded windows were grouped with stone mullions (vertical) and transoms (horizontal) in between. The windows may also have had a stone or timber drip mould over the top of the opening known as a hoodmould. This became a characteristic of late medieval and early renaissance architecture and is evident in 'Tudor, Elizabethan, and Jacobean styles.

Dunluce Castle-Tall Bay windows in the great Hall

However, displays of glass in large windows several feet long were still something only the rich could afford. Windows, such as these, were employed on the grander early plantation houses such as Dunluce Castle built by the Second Earl of Antrim, perhaps reflecting the tastes of his English wife, the dowager of Buckingham.[3]

Most humbler houses, however, continued to be built of rubble, mud, turf, timber, and thatch. Thomas Raven's early pictorial maps of the 1620s show some of these humble common houses. They are either devoid of windows or have small openings positioned high up close to the eaves. Invariably they were un-glazed but may sometimes have been shuttered. These have long since disappeared.



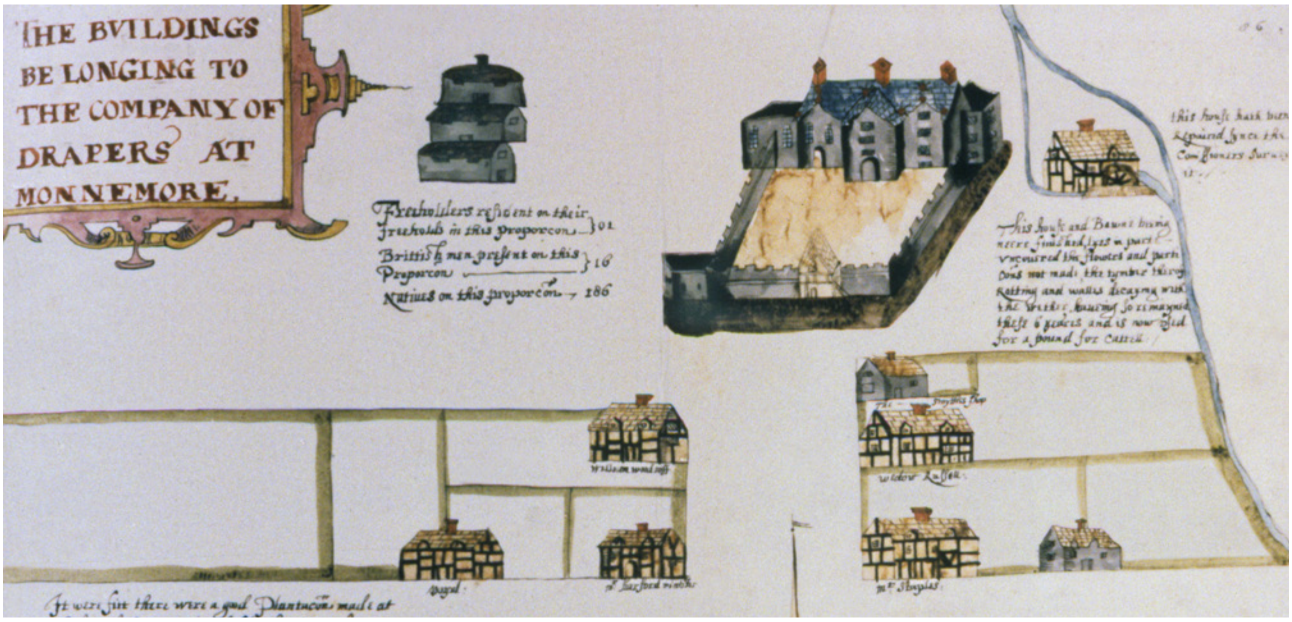
Thomas Raven 1622 Map with drawings showing – bottom left shows three cottages at Crossalt, built with stone or even of turf and thatched or had turf roofs and small window openings.

We know, in the early 17th century, English style timber-framed houses were imported into county Londonderry, such as at the village of Agivey by the Ironmongers Company and at Moneymore by the Drapers Company.[4]

The tendency for smaller rural houses to be windowless, or to have very limited window openings, continued beyond this period and until well into the 19th century. Alan Gailey notes in his Rural houses of the North of Ireland that even as late as the first half of the 19th Century, "the houses of the poor were often windowless or at most had one or two openings, usually unglazed."[5]

Springhill, 17th century, Moneymore – National Trust

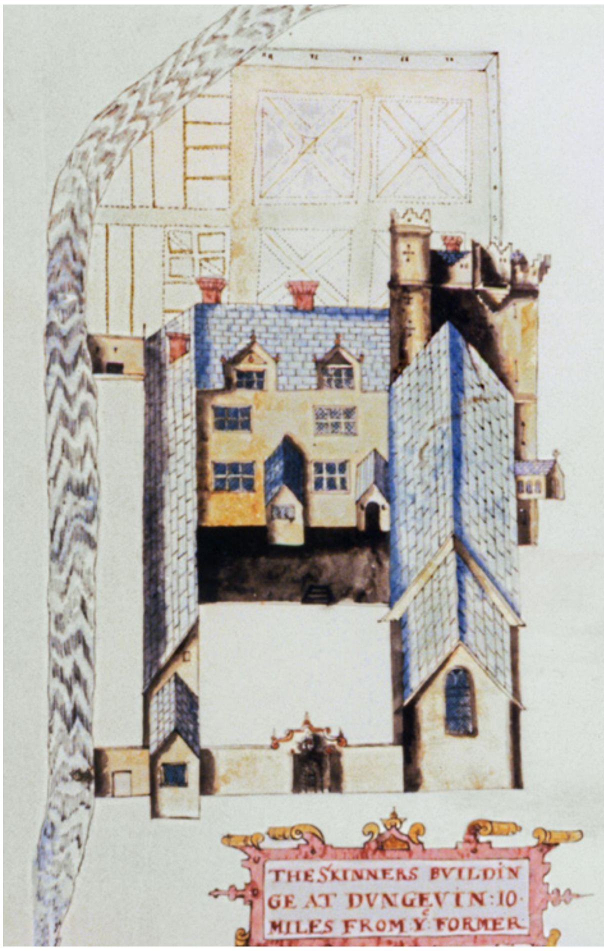
The English planters brought with them the construction methods and the building styles with which they were familiar. Gailey notes, by way of contrast to the local houses, that the "Houses of the English in county Londonderry, on the other hand, had well-proportioned windows lighting ground floor rooms."



Thomas Raven 1622 Map - Timber frame houses at Moneymore

George Canning, the agent of the Ironmongers Company, records in detail in his accounts of 1614,[6] the construction materials and methods employed and even the names of carpenters and other tradesmen that he brought with from Warwickshire. Thomas Raven's 1622 maps show some fifty box frame houses.

These plantation buildings had timber casement windows with quarry glazing. Although none of these houses or their windows survive. One illustration shows Dungiven castle, a courtyard house built by Sir Edward Doddington in the Jacobean style, with glazed casement windows and stone mullions, dividing the windows. According to James Stevens Curl "Doddington therefore introduced a remarkable piece of the new European civilisation to medieval Dungiven: here were symmetrical facades, highly organised gardens, casement windows …"[7]



Grand courtyard house of Sir Edward Doddington at Dungiven with Casement windows and quarry glazing-Thomas Raven 1622 Map

Side-hung casement windows grew in popularity throughout Europe in the seventeenth century. However, early timber sliding sash windows also began to develop during this time. These had a single opening sash. It would most commonly move vertically and be held open with pegs or wedged. Alternatively, it would slide horizontally into a pocket. The horizontal sliding sash in England became known as the 'Yorkshire Sliding Sash.'

Some of our earliest and most interesting sash windows facilitate sliding the sash vertically into a sash pocket. The houses at Vicars Hill in Armagh are an excellent surviving example.

Early sash window, Armagh – sash moves vertically into a pocket.

Sash window development

Typical Double Hung Sash Window

In France, the design of sash windows developed further with larger windows that had two sashes. These had a fixed upper sash and a moveable lower sash that could be pegged or wedged open. From the middle of the 17th century, adopting this French custom became increasingly popular in Britain.

The technology continued to develop, and in Britain at the start of the 18th century, a system of counterweights was introduced that allowed both sashes to move, and this became known as the Double-hung sash. It was the construction choice for windows for the next two hundred years.

In Ireland, it was in the rectories of the established church, and the formally designed farmhouses that sliding sash windows with one or both sashes hung began to appear. By the early nineteenth century, this spread to more modest houses.

The earliest examples often did not have a parting bead (a cross rail between the sashes). They also had many panes of glass and thicker glazing bars. Using lighter glass over time allowed their design to refine, and the timber glazing bars progressively reduced in thickness even to as little as 12mm.

Glass technology improved in the Victorian period, 1837-1901, to allow larger single sheets of glass, and as a result, glazing bars were reduced in number. From the 1870s, most sash windows were free of glazing bars and had a single pane of glass in each sash, but these larger expanses of glass distributed their weight differently than the smaller panes in the earlier windows. Where before the lattice of glazing bars dispersed a portion of the weight to the side rails, now the total weight of the glass was bearing on the bottom rails. This weight puts increased stress on the joints, particularly the joint where the mid-rail meets the side rail.

Curved sash windows with no glazing bars- note horns strengthening the mid rail.

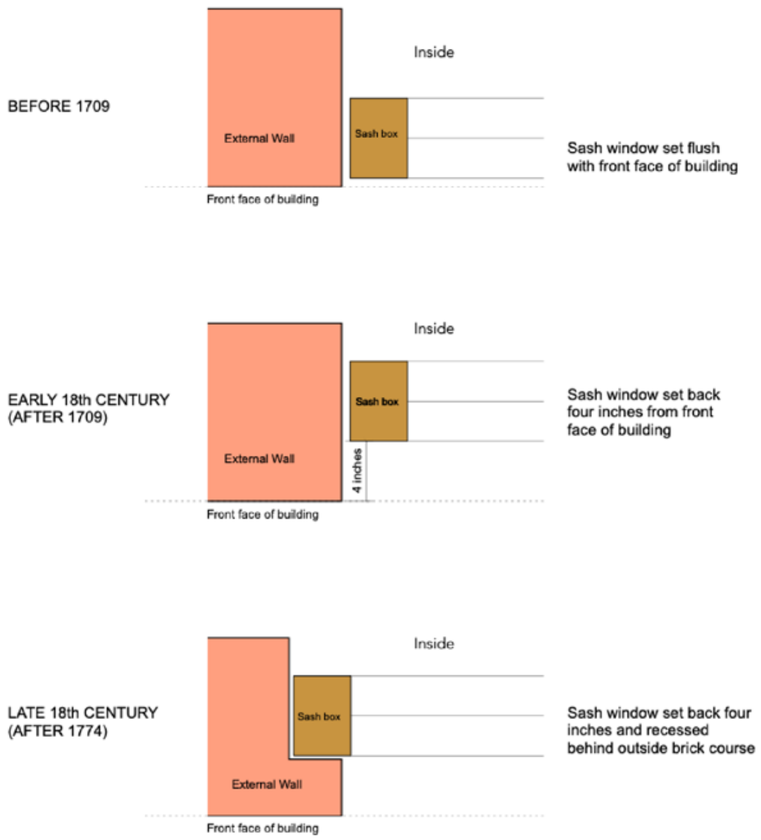
The sash horn evolved to overcome this problem by reinforcing the joint. No window had horns prior to 1850. Sash horns also evolved in their design over time.

Since 1696, a window tax had been operating in England and Wales. It was a tax on houses, scaled according to the number of windows. Houses with less than five windows were exempt, whilst houses with 'larger' windows could be charged more because of their size. Ireland introduced a similar Window Tax in May 1799. The act was repealed in 1822 in Ireland, earlier than the rest of the UK, which did not end the tax until 1851, but for the time it was in operation, the tax had a similar limiting effect on the number and size of windows in houses.

There is a widely held belief that the tax encouraged the blocking of windows, but this may not be true, as the blocking of windows on pre-1799 buildings did not exempt these from the tax.

The end of the Window Tax coincided with changes in technology that allowed the cheaper manufacture of larger pieces of glass with fewer imperfections. These factors combined to ensure that by the middle of the 19th century, the number, size, and variety of windows in domestic properties increased.

The window's position in relation to the outside face of the wall also evolved. In Britain and Ireland, the earliest examples of sash windows have an encased box sash often built flush with the front wall.



The position of the window in relation to the outside face of the wall evolved over time.

In London, the Great Fire of 1666 left a fear of the spread of fire in the city, and Parliament took various measures to reduce the risk of fire spreading. Windows were an area of concern. Lawmakers believed the amount of exposed timber in sash windows posed a fire risk, leading to change. Parliament passed a series of acts; the first in 1709 required sash windows to be recessed four inches from the outer masonry façade. A further act in 1774 required the box frame to be set behind the brickwork on the inside so that only a tiny amount of the sash window box was externally visible. The implementation of these changes spread from London and was adopted to varying degrees, perhaps as often due to fashion or style as necessity.

With Ulster's more exposed weather conditions, recessing the window made common sense beyond reducing the risk of fire spread as it provided a greater degree of shelter to the timber.

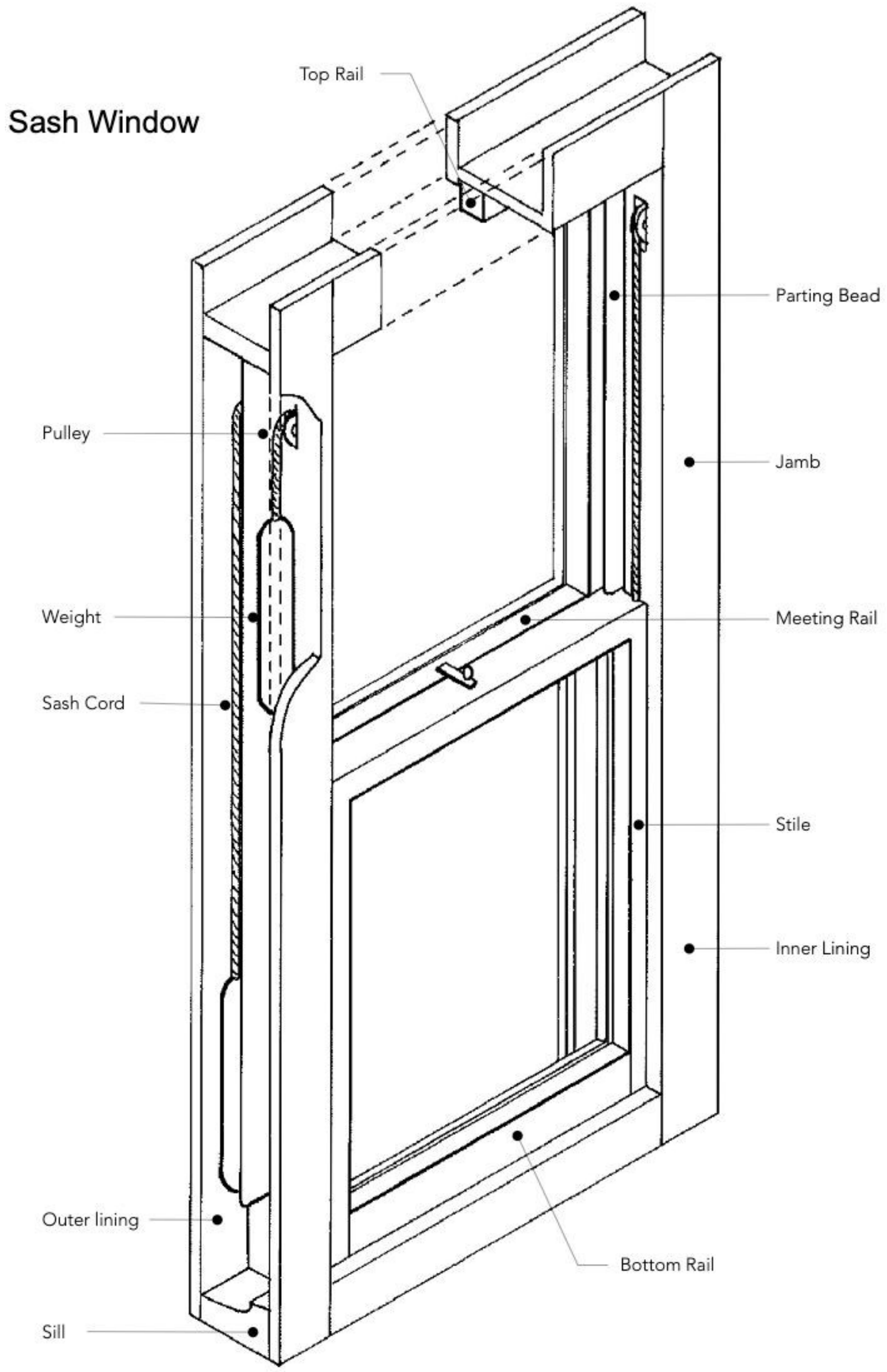
An exposed sash box can indicate an early sash; however, some caution should be exercised as there are many local examples where exposed boxed sash appears in buildings of later date. This ambiguity would suggest the persistence of the custom of using exposed box sash in some places rather than the presence of early windows. The adjacent illustration shows a house near Gracehill Ballymena, which was built as late as 1833 but had exposed box sashes.

In a similar fashion, the positioning of the sash window flush with the exterior wall is not always an indication of an early sash window.

In Armagh, there is a prevalence of flush-mounted sash windows persisting well into the 19th century.

Buildings in College Street, Armagh dating from 1790- 1820 with flush mounted sash windows.

The sash window works on the principle of balance between the windows and weights contained within the boxes on each side. Well-balanced windows should take only the minimum amount of effort to open. The surrounding sash box holds sashes in place, and a central parting bead provides a track for them to move along. A pulley attached to the top of the track supports the sash chord and a lead weight within the box frame.



Illustrating the parts of a Sash Window

Horizontal elements of the window are generally designed to shed water as quickly as possible to avoid decay. The upper sash sits slightly further forward than the lower sash and, by oversailing, throws rainwater outwards. Ideally, the upper and lower meeting rails fit snuggly and minimise the entry of wind-driven rain. Windows glazed from the outside against a backstop reduce the chance of moisture blowing through the construction to the interior.

Sash windows have some distinct advantages over windows that open outwards. The sash is less exposed to the elements when opened than a casement. Unlike a casement, a sash is not at risk of blowing backwards and forward in the wind. A double-hung sash is a window that can be opened by sliding the bottom panel up and the top panel down. These allow excellent ventilation control[8]. They promote air movement when both sashes are open by allowing fresh air to enter through the bottom and, as it warms, rise and exit as stale air through the top. The sliding sash arrangement remains common in the US today, usually in aluminium – it allows ventilation to be easily combined with insect control as insect screens can be fixed to the outer edge of the frame.

Georgian House, Mullaghmore

Vernacular

Windows in vernacular buildings closely followed developments in more formal architecture, though many did without sash cords and weights and instead employed external props or the friction of the box. The glazing bars also tended to be simpler and thicker. It is common to find sash boxes exposed. Many vernacular sash windows dispensed with weights altogether, reducing the need for a deep box.

Casement windows

A casement-style window opens with hinges, usually at the side of the window frame. It can also be hinged at the top or, even more rarely, at the bottom.

The most common arrangement in a historic window is for the casement, or opening part, to be hinged to the side with a system of catches to lock and hold it in place, though top-hung casements were more common in some buildings such as schools. Most casement windows open outwards because it is easier to weatherproof. Those behind stone mullions, however, tend to open inwards.

While the sash window retained its dominance during the 19th Century, the timber casement window would often be used for smaller windows, particularly in rural buildings and small houses. Towards the end of the 19th Century, a renewed interest in historic styles led to an attempt to recreate historic windows and a revival of casement windows for specific buildings.

Churches, alms-houses, and gatehouses began to widely use casement windows in the popular gothic style, often using cast iron and hybrid metals (such as zinc). These buildings recreated the diamond-style quarry glazing pattern of their predecessors. Arts and Crafts style buildings also used timber casement windows in the early twentieth Century. For many industrial buildings, cast iron was often preferable over timber because of the greater fire-resistant properties of cast iron.

Historical timber casement windows often incorporate features to help minimise the decay of the timber. A Projected weather bead at the head throws water clear of the window structure. Sometimes, casement windows would have recesses along the joints to prevent moisture from moving by capillary action and wind pressure to reach the interior. The bottom section of the timber frame often had a slight fall to the outside to shed water away as quickly as possible and reduce the danger of rot.

Internal condensation could also be a problem. If water vapour were allowed to run down the inner face of the glass and pool on the lower rail of the casement or where the cill board meets the frame, it could lead to rot. Sometimes, small diameter holes were drilled through the bottom frame, with a slight fall to the outside, and copper tubes were inserted. The holes allowed condensation to drain to the exterior, though this practice was more common in larger buildings with higher occupancy, such as churches.

Twentieth-century windows

Crittall Window at BBC broadcasting House, Belfast

New buildings, particularly public ones, continued using sash windows until the Second World War. The last British Standard for timber sash windows (BS644-2) was published in 1958.

However, from the 1930s onwards, casements increasingly became the window used for new buildings. Parallel with this was the development of metal windows of increasing sophistication. In Northern Ireland, new school buildings used metal windows, which were also the window of choice for buildings in the Modern Movement style. The Crittall Company made popular steel windows. These windows are often refined and elegant and contribute greatly to the appearance of their buildings.

From the 1950s onwards, metal windows became increasingly sophisticated and replaced timber on most buildings. Timber windows conversely declined as poorer quality timber from 30-year-old trees became the norm. The relative reduction in the cost of aluminium saw its increasing use in commercial and industrial property. Curtain walling commonly uses aluminium. Manufacturers have discontinued many of the early aluminium and steel systems, so it may be necessary to seek specialist advice if repair is necessary.

As with historic buildings, choosing a glazing system for modern buildings is integral to the overall design and appearance.

Curtain walling at Catholic Chaplaincy, QUB

Window surrounds and shutters

The exterior surrounds accompanying the windows are integral to the window composition. They contribute in various ways to the architectural style of the building.

- Hood mouldings for Tudor-style windows.
- Plain surrounds with little embellishment in the Georgian period.
- Classical surrounds or other decorative s urrounds in the Victorian period.

Except for some windows in ecclesiastical buildings, the sills in historic buildings are often of a remarkably consistent depth (around twice the typical modern depth). They are usually stone with a fine vertical tooling discernible along the front edge.

Window surround

Formal houses often have internal shutters as an aid to insulation and security. Most fold back to the reveals on either side, but in some 19th-century houses, the shutters are below the window as an internal sash which slides up behind the window. Due to their complexity, owners have removed most of these windows, or they have become unworkable. Surviving examples are scarce and worthy of retention.

Internal fold back shutter

Glass

A rare example of Crown Glass

Glass technology for use in windows has evolved through several distinct types.

Crown glass was a type of blown glass that developed in France and was quickly adopted in Britain and Ireland in the 1700s. Its introduction coincided with the introduction of the sash window. The manufacturing process involved a skilled operative blowing a giant glass bubble and spinning it out to form a disc of glass, which was then pierced and cooled down on a metal plate before finally being cut into panes. The central hub or bullion was thicker than the rest and usually cut around, prestige buildings seldom used this part. Overall, the process allowed a clarity of glass and a lightness to the section, which made it much sought after.

The process sometimes produces a ripple effect characteristic of the material (though sometimes hard to spot on the finest examples). More obvious imperfections in crown glass tend to be circular and sometimes contain bubbles.

Cylinder glass was a further refinement of the blown glass process, which allowed larger sheets of glass to be produced. The glass was blown into a large cylindrical iron mould, which was then cut down the middle and, after the ends were cut off, placed in an oven where it was unrolled to form a flat sheet. After the 1830s, they could blow longer glass and reduce its thickness. Imperfections had to be ground and polished out, and those that remained were characteristic of a sanded surface with bubbles and other marks tending to be curvilinear.

Plate glass was developed by pouring or laying a cut cylinder onto a polished metal plate and polishing it to produce a glass that was freer from imperfection, though one can sometimes notice swirls from the grinding machine. France first developed the process as early as the 1680s, but the grinding process and other improvements were mechanised in England after 1838. The patent plate glass, as the English product was known, was much more highly polished than its traditional predecessor. It made large, thin sheets of glass much more widely available and led to the removal of glazing bars from windows.

Emile Foucault introduced drawn glass at the beginning of the 20th Century. The process involves drawing sheets of molten glass through a slot in a tank, or die, over water-cooled rollers directly into a cooling chamber. Sometimes, faintly discernible, parallel lines characterise the glass.

In the 1950s, Alastair Pilkington developed the process of Float glass which is still in use. Molten glass is poured onto a bed of molten tin, spreads evenly across the surface, and produces a pane of unvarying thickness. The bed of liquid tin allows a polished sheet on both sides with almost no visible imperfection.

When it comes to the repair of windows, any historic glass should be retained. Modern float glass is very flat, optically perfect glass and has a different character. The imperfections in older forms of glass, especially in hand-made glass, are a part of what makes many older windows so attractive.

Maintenance

All efforts should be made to retain historic windows; the most effective way to do this is to prioritise regular maintenance.

All windows require maintenance. There is a misconception that historic windows equate to maintenance while replacement windows do not. Completely maintenance-free windows do not exist.

There is also longevity to be considered. Replacement windows with modern materials often have a lifespan of at most thirty years (some research suggests 15-25 years[9]), with gaskets needing replacement earlier. Historic windows with regular but minimal maintenance can last over two hundred years.

For both timber and metal windows, maintenance involves typically cleaning and painting regularly. Regular painting has a side benefit: it allows the exterior of the building to be inspected at close range regularly. Often, when windows are replaced with those which may require less maintenance, other items on the facade, such as timber eaves and cast-iron gutters, may be painted less frequently.

Regular inspection of all parts of a historic building is essential, and an early detected problem can be more easily fixed and will substantially reduce costs. The maintenance process starts with regular examination.

Inspection and maintenance of timber windows.

Ideally, owners should inspect timber windows annually. A timber window will often give early warning of problems. We outline some key points below, but for a more comprehensive list to aid the inspection of sash windows, refer to the Sash and Case Window Inspection Checklist[10] developed by Historic Environment Scotland. (Also Reproduced in Appendix 1 at the end of this guidance)

Examine a timber window for signs of water absorption as this could indicate rot. Signs include cracks in paintwork, pitting and swelling on the surface and decay of putty.

Horizontal areas are often most vulnerable.

Examine a timber window for signs of water absorption, as this could indicate rot. Signs include cracks in paintwork, pitting and swelling on the surface and decay of putty.

Check the most vulnerable areas, the horizontal areas where water may linger.

Also, examine the joints for signs of widening.

It is also important to look at where the window timbers meet side walls as this area is likely wet.

The following should form part of an annual maintenance routine:

- Oiling of moving parts such as sash pulleys or between sash and pulley linings in sash windows or hinges on casements.
- Free up jammed sashes or casements
- Check for broken sash chords.
- Replace worn beads.
- Look for signs of overpainting that prevent functionality.
- Check the frame is not distorting due to movement in the surrounding building fabric.
- Replace defective putty.

Painting

Regular painting should be conducted every three to five years, depending on the window's exposure. Painting over cracks and blisters may not solve a problem as the blisters could expand, causing new cracks. Rub down existing paint with water or a non-alkaline soap before sanding to receive the fresh coat of paint. Fill cracks and indentations with a suitable filler that can stay elastic to cope with the expansion and contraction of the timber and ensure a smooth surface that will not collect water.

If a window needs to be stripped back to reveal the detail of the original timber or for repair work, this could be conducted using an eco-friendly paint stripper. Dipping in a caustic bath, though quicker, will damage glues, cause rapid drying out, and expansion of joints, reducing the strength of the timber windows. Alternating the use of a 'heat box' or 'steam box' to soften putty and paint is a valuable alternative.

Precautions should be taken when sanding or stripping paint on older buildings, as lower layers often contain Lead-based paints. These can be harmful, particularly to children's health. Most often, sash windows can be painted in situ. It is also possible to remove the sash from its' frame if extensive preparation is required. Historic Scotland set out a practical step-by-step order for repainting.

Painting windows in-situ

- ❑ pull the top sash right down, push the bottom sash up past it.
- ❑ paint three sides of the top and bottom meeting rails, the lower half of the stiles and glazing bars, and the parts of the lower sash you can reach.
- ❑ paint the inner cill and the loest 75mm (only of the pulley stiles).
- ❑ let the paint dry.
- ❑ swap the position of the sashes, i.e. bottom sash right down and top sash half way up.
- ❑ paint the remaining parts of both sashes.
- ❑ paint the top half of the pulley stiles.
- ❑ DO NOT paint the parts of the pulley stiles that are hidden by the sashes when they are closed.
- ❑ let the paint dry.
- ❑ paint the surrounding woodwork.

Source: Historic Scotland - Sash & Case Windows A short guide for homeowners

The choice of exterior paint is important as many modern, robust, paints do not have sufficient elasticity. Cracks often occur at the junction of materials, such as between the glass and frame, and allow water ingress. Lead paint was used in the past to maintain historic timber windows. Lead paint use is now limited[11] because of its toxic nature, and more eco-friendly oil-based paints can be used on historic windows as an alternative. Linseed oil-based paint is currently enjoying a revival, and it has advantages in that it acts as a preservative for wood and a repellent for water. Acrylic resin paints can also work well on timber windows.

Older windows, particularly sashes, can be prone to sticking, and care should be taken when repainting to ensure their performance is maintained.

Metal windows - inspection and maintenance

All types of metal windows can face problems arising from frame distortion due to movement in the building, failures of the hinges or fittings, or loss of functionality due to overpainting of moving parts. However, other problems are unique to the material the window is constructed from.

Metal windows are made from either ferrous metal or non-ferrous metal. Ferrous metals contain iron and are magnetic. Some of the most common examples include cast iron, wrought iron and steel. They are prone to rust, except for stainless steel and wrought iron. Wrought iron resists rust due to low carbon levels, and the presence of chromium protects stainless steel. Non-ferrous metals, on the other hand, do not contain iron. Some of the most well-known include aluminium, brass, copper, lead, zinc and tin. Manufacturers use aluminium to construct many aircraft, cars, and windows because it is lightweight and corrosion-resistant.

Since aluminium alloys contain so little iron, they cannot rust in the traditional sense, yet they will nevertheless oxidise over time. Aluminium oxide forms rapidly on the surface of the alloy when it meets water. The hard oxide coating protects the material underneath, making it highly resistant to further corrosion.

An examination of metal windows should check the following:

- What material is the window made from? If the metal is ferrous, particularly if it is mild steel or cast iron, it may be at risk of corrosion.
- Is there evidence of blistering or rust?
- Are there signs of decaying putty which may allow moisture to collect?
- Is there evidence of condensation problems which could give rise to sitting moisture?

Window repairs

Timber window repair

The need for repairs to timber windows can often appear more extensive at first inspection than is in fact the case. For example, cracked paintwork should not be confused for decayed wood. If a penknife does not penetrate 1/3 the depth of the frame into the wood, then the structure is basically sound. Removal of paint and time to dry out before application of a new coat may be sufficient maintenance for the present.

Some of the more common defects are identified below. For a more comprehensive list Historic Environment Scotland provide a table that relates the defects that have been identified in the inspection process to their probable causes and to the suggested repair to remedy them. This can be found in - Sash & Case Windows A short guide for homeowners and is available online at **https://www.historicenvironment.scot/archives-and-research/publications**. (Also Reproduced in Appendix 2 at the end of the guidance)

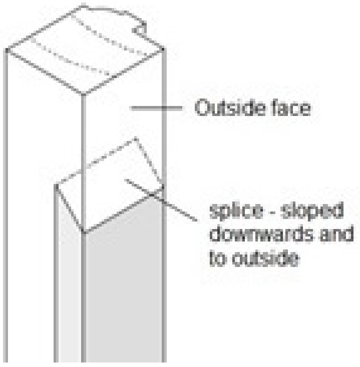
Rot

Historic timber windows will rot if poorly maintained over a long period.

Applying epoxy resin wood filler and preservative may be sufficient for small areas of decay. Try to understand how the rot has occurred. In most cases, this will be due to cracked paint allowing water to enter. If the rot is minor and the rest of the wood sound, scrape out the worst of the damp wood and allow the surrounding area to dry before treating it with a preservative. A wood filler can consolidate the adjacent weakened timber and build up the removed area and sand to a smooth finish for priming and painting. Monitor resin repairs over time in case differential movement between the resin and timber has allowed cracking to occur.

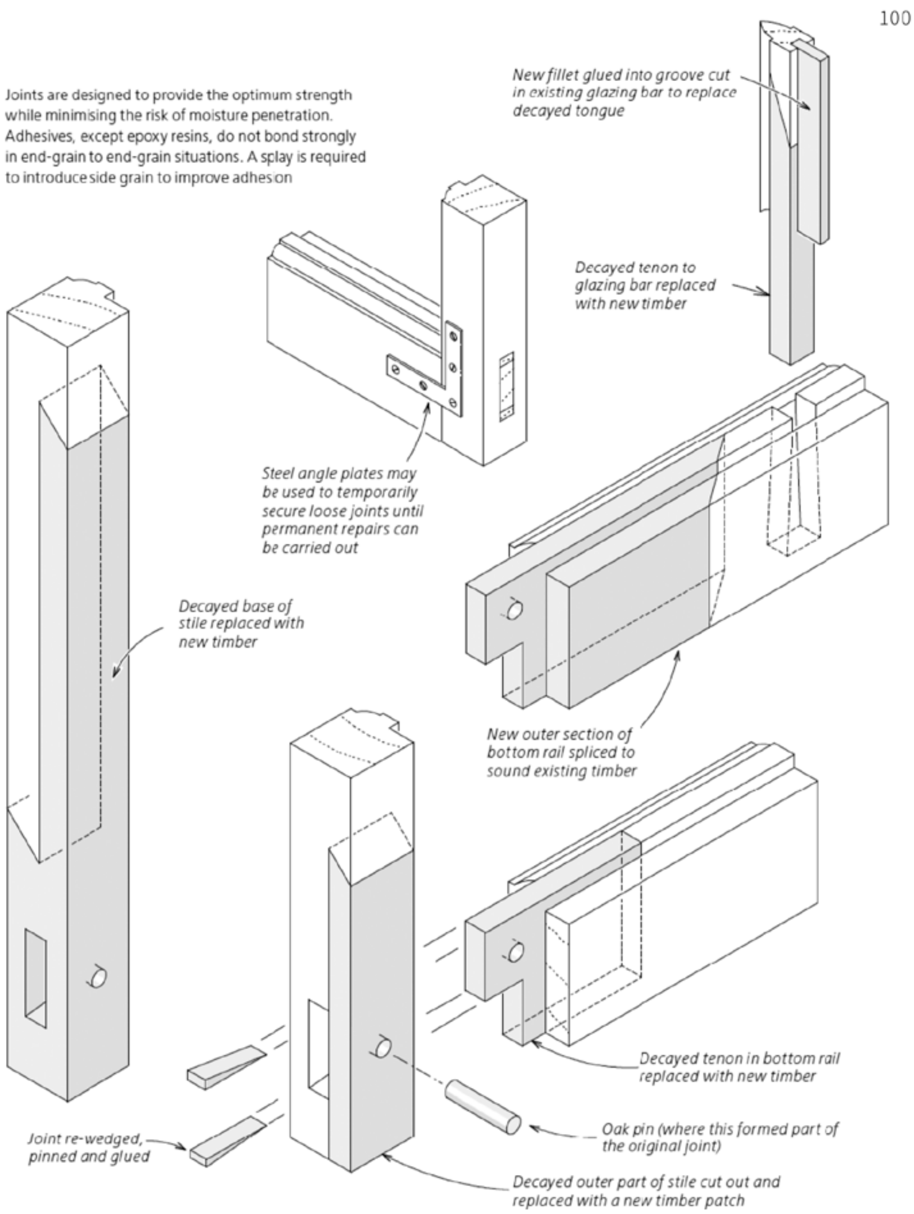
Window not properly maintained and beginning to rot.

If rot is more extensive, decayed portions must be replaced. On older sash windows, it is expected to find a diagonal joint at the bottom of the side boxes, evidence of a spliced repair where the timber has rotted due to splashes from the cill below.



Splicing generally in new timber is a job for a joiner, but the principle is to angle new joints to encourage water to run to the outside of the window and not to lie in the joint and cause future problems. For more detailed information, it is worth referring to the diagrams and guidance on page 37 & 38 of Traditional Windows - Their Care, Repair and Upgrading (**historicengland.org.uk**)

It is preferable to use the same type of timber as the original to ensure similar durability to the existing window and similar movement qualities to prevent differential movement.



Source: Historic England, Traditional Windows:

Their Care, Repair and Upgrading. (2017) HEAG039

Specifying a replacement timber with comparable properties is best where the same species can no longer be sourced. Sash windows were often made from slow-grown pine (deal), and the durable heartwood of European redwood or Douglas Fir are suitable replacements. Ensure that new timber is well-dried to avoid shrinkage and treat the new timber and the adjacent area with preservatives. Any replacement timber should be properly primed and painted.

Cills are particularly vulnerable to decay, so it is common to find oak cills at the bottom of pine windows. Replacement cills should be oak or another suitable, durable hardwood. Replace only the outside half of the cill if the rear is in good condition. The joint should be concealed beneath the bottom rail, and the cill should have a standard drip.

Rot, if found, is most likely to be wet rot. This localised problem occurs only in damp timber and will not spread to dry window parts. There are other forms of rot which affect buildings. Dry rot is one of the most feared, though it is common for other types of fungus to be mistaken for it. Most forms of fungus require damp, humid conditions to survive and though dry rot can be found in the sash boxes of windows and elsewhere, there is usually an external source, such as a leaking downpipe, causing the problem. Check for fungi, dust of spores, rhizomes or cobweb-like strands and contact a specialist surveyor for advice.

A common concern is finding craftspeople who repair rather than replace windows. Some companies, particularly the larger ones, will be better equipped to provide a complete replacement rather than a repair. To counter this, the Department, in conjunction with the Ulster Architectural Heritage, produces the ‘Directory of Traditional Building Skills’ **(Directory of Traditional Building Skills - UAH (ulsterarchitecturalheritage.org.uk)**. Although companies in this publication are not vetted, they are asked to list examples of replacements and window repairs.

Open joints

Over time, the glues of old windows may weaken, and decay and joints will open. Sometimes, wedges will fall out. These can be reglued and reinserted if tackled in time. If left open, moisture will enter through loose joints and cause decay. As a temporary measure, however, a joint can be resin-filled or resecured with a metal angle to prevent further decay. However, long-term, loose joints must be resecured by cramping, glueing, re-wedging, and pinning. Any decayed timber is removed, and the area is preservative-treated before newly treated timber is pieced in.

Cracking and loss of putty

It is important to inspect window putty for signs of cracking. Brittle putty can crack and allow moisture through to the timber behind. Over-painting is sometimes sufficient to prevent further decay if cracks are recent, but if much moisture has penetrated the putty and is trapped, this will hasten decay and need to be replaced. Great care must be taken in removing putty to ensure that historic glass is not damaged. There are appliances on the market to help soften putty before removal to reduce this danger. Putty lamps use infrared heat to soften old paint and putty whilst being gentle on the wood and not causing the glass to crack.

HED recommends using linseed oil putty, the traditional material with preservative qualities that modern counterparts do not possess. New putty must be allowed to dry, and the paint should be taken slightly onto the glass to ensure a good seal.

Sash cords and pulleys

It is common for sash cords and pulleys to stick on sash windows or become damaged if maintained incorrectly. In most windows, the cords were made from cotton or jute, but metal chains can be found on some larger nineteenth-century windows. Overpainting is a common source of problems which will stiffen and reduce the movement of the cord. Nylon cords will stretch much more than traditional materials and are generally not appropriate replacements.

Pulleys should be oiled and inspected to ensure freedom of movement. The original brass or metal pulleys should be maintained in preference to plastic, which will be damaged more easily. The weight balancing the sash window may become less effective if modern heavier glass is installed. The weight may need to be increased to compensate for this. Increasing the weight will require the removal of the sashes and access to the small panels in the side boxes customarily provided for this purpose.

Casement hinges

It is advisable to check casement hinges to ensure they are fully operational and their surface free from rust, dirt or overpainting.

Metal window repairs

Corrosion

Cast iron with surface rust can usually be relatively easily restored.

The main problem with both cast iron and mild steel is corrosion. The problem can vary to differing degrees. If it is superficial, it can be addressed relatively easily by sanding down, priming with a zinc metal primer and repainting. More substantial surface pitting will require infilling the recess with metal filler as part of the process. It is worth noting that significant expansion occurs when metal oxidises, and this can make the problem look much more significant than it is. It may appear beyond repair when it is not. Although cast iron may appear badly rusted, it can often be brushed down and reused.

Some repairs can be done in situ with hand tools such as wire brush, sander, and grinder. Still, for others, it will be necessary to repair at a workshop where the window can undergo processes such as grit blasting or galvanising.

Sometimes, more significant repairs are required. When this is the case, the approach taken will depend on several factors, one of which is the type of metal. Steel and wrought iron can be welded so replacement sections can be inserted but cast iron may crack under heating and requires a process called 'cold stitching.'

For more modern windows made from aluminium or various alloys, it is best to consult the manufacturer for guidance on a repair.

Specialist and modern windows

Lead in windows may have decayed or expanded due to being in strong sunlight or prevailing winds, and these will often need to be reset. This is a job for a specialist to repair or remove the window, remove the lead and replace it with the same pattern.

Repair to a stained glass window by skilled technician

Brass rods are sometimes inserted as a replacement for the iron to avoid rust. Care needs to be taken that such an action does not significantly alter the window's appearance to the interior.

Metal windows in modern listed buildings are usually non-ferrous, or if they are made of steel, they have been galvanised. These windows suffer less from corrosion, though if the protective coating is breached, galvanised steel will rust; similarly, in a marine environment, aluminium will corrode.

Fanlights often have a very detailed form of ironwork with surviving historic glass. It is recommended that a specialist be employed to care for these items.

Detailed Fanlights require a specialist to repair.

Glass repair

Significant repairs will require an assessment of the glass, especially if it is historic glass, to decide whether it can remain during the repair or need to be removed. It is worth highlighting to contractors the importance of retaining historic glass.

Glass repairs

Cost of repair

Repairing the elements of a window is normally cheaper than complete replacement. Most sash windows, even those neglected for some time, are likely to only suffer from rot and damage along their bottom rails. The cost of conducting such repairs depends on the scale of work and the specialism of the company or joiner employed. In most cases, when repairs are performed, the opportunity can be taken to overhaul the window. The sash cords and the putty can be renewed, the windows painted, and draught-proofing installed. These tasks will raise the average price of the work. However, repair is the choice with the longest life expectancy. It will retain the historical and architectural significance of the window and be the best way to maintain the special interest of the building long term.

Sustainability

Repair may be the most sustainable solution when the whole-life environmental costs of replacement are considered. All replacement windows, even timber, have the added carbon footprint of manufacturing the new window.

The common alternative materials used in replacement windows are often less sustainable than timber. Aluminium is formed at extremely hot temperatures and uses much energy.

PVC-u has ethanol as its key constituent, mainly derived from natural gas and a product of the fossil fuel industry. It may be challenging to repair PVC-u while in use; therefore, complete replacement is often the preferred option. This may make it more unsustainable when compared to timber or steel. Wood, by its nature, has always been easy to repair.

Frequently asked questions on improving the performance of existing windows.

Traditional windows often perform very well; however, sometimes, they may be a little more draughty, noisy, or lose more heat than we would prefer. Indeed, many important decisions regarding historic windows revolve around challenges such as these. They are essential to acknowledge, and as we address and deepen our understanding of them, we are better equipped to respond.

How can I improve heat retention?

Often, we perceive windows in an older dwelling as either the primary source of heat loss or one of the main culprits, but the average house loses only 10-20% of its heat through windows. The amount will vary depending on the individual house design and aspects such as the amount of glass relative to the solid wall. While the heat loss through windows is significant, it is crucial to understand that other elements, such as the walls and the roof, account for most of the heat loss.

Replacing historic windows may seem an easy task compared to other thermal improvements, as a single contractor can undertake this in a brief time, and the property can remain occupied. However, it is important to understand the complete picture.

Replacement double glazing is perhaps not the cost-effective option to reduce heat loss one might have hoped. Replacement windows with modern materials often have a lifespan of no greater than 30 years (some research suggests 15-25 years)[12]. English Heritage (before the formation of Historic England) estimated that it would take 60 years to pay in energy savings for the cost of upgrading sash windows with replacement double glazing.[13] While this cost calculation has not been updated recently, a disparity in cost likely remains given that most new windows would have to be replaced well within the timeframe it would take to repay the initial outlay in energy savings.

Other measures can provide considerable benefits at less cost. Draught-proofing, traditional shutters and curtains can substantially reduce heat loss, and other measures can provide equal or better improvements. For example, secondary glazing is less disruptive than total replacement as the original window can remain in situ, and all work happens from inside. A single installer can also undertake it. It can cost less, and, professionally installed, it provides better insulation than replacement double-glazing. These and other alternatives are discussed in more detail later in this guide.

For further information on improving heat retention, see Chapter 5.

How can I reduce draughts?

Research has shown that 90% of the heat loss from traditional windows is due to draught. Along with the legitimate concerns about heat loss, there is also discomfort. For most people, the feeling of a draught is unpleasant, and unfortunately, increased heating in houses often serves only to increase the air entering in and around traditional windows.

Draught-proofing is, therefore, an effective way to improve the thermal performance of historic windows and the comfort levels enjoyed by occupants. Several proprietary draught-proofing systems on the market can effectively reduce draughts. Some of the most effective systems maintain the window's appearance by recessing brushes and seals in the depth of the window.

All buildings, however, need to be ventilated correctly; otherwise, dangerous problems can occur. Without proper ventilation, condensation can lead to severe problems in the fabric, such as rot and fungal growth. These can often be hidden from view until it is too late. Lack of proper ventilation also risks human health; the build-up of airborne contaminants and the presence of black mould have serious implications for the health of occupants. All buildings must address this issue.

Traditional buildings solve the problem by using natural ventilation, including open chimneys and draughts around windows and external doors.

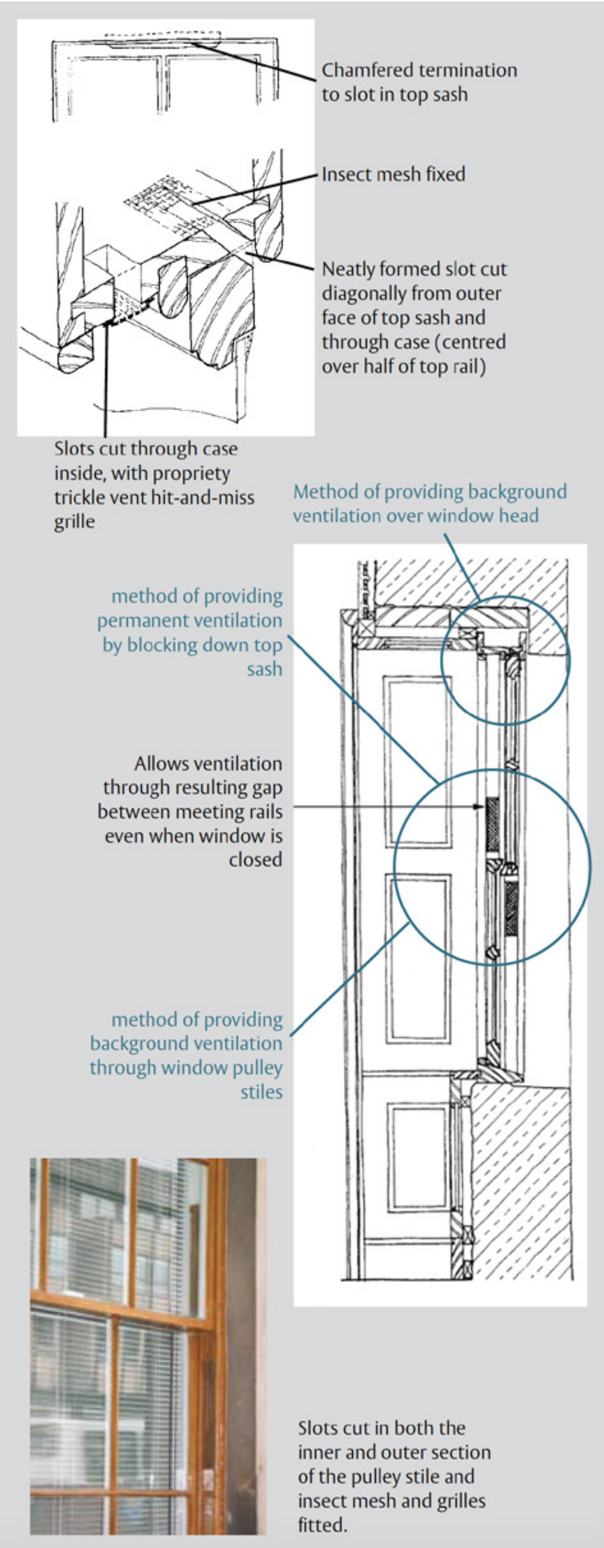
Buildings built to current building regulations are more airtight, but wall vents or trickle vents specifically introduce ventilation.

More recent houses are sometimes built to a higher standard, such as the Passive House standard, which requires almost complete sealing of the building. For the safety of the occupants and the building fabric, ventilation is introduced mechanically, often the Mechanical heat recovery system (MVHR), which expels warm, moist air but utilises a heat exchanger to retain the heat and warm the incoming fresh air.

So, while draughts are a common complaint with historic windows, caution should be exercised when wishing to reduce ventilation, as a critical balance must be achieved. The Sustainable Traditional Buildings Alliance provide practical guidance to owners of traditional buildings to ensure they can minimise the risks and maximise the benefits when they make changes. They have developed a tool called the 'STBA Guidance Wheel'[14] which highlights potential interactions, showing the benefits of a particular measure and the concerns.

A room with an open fire or combustion appliance must not have its natural air supply cut off.

How can I get rid of condensation?



An Illustration showing various sympathetic means of providing trickle ventilation through a sash window. Source: Historic Scotland - Sash & Case Windows A short guide for homeowners

Condensation is an increasing problem in today's centrally heated houses. Washing machines, showers, and electric kettles are all sources of water vapour inside buildings that were not present in the past. Condensation occurs when air containing water vapour cools below the dew point on meeting a cold surface, and water condenses onto that surface.

The two main ways to avoid this problem are insulation and ventilation. Upgrading to double glazing can reduce condensation on windows. Still, if general ventilation is not increased, the problem will simply move, the condensation will occur elsewhere, and hidden damage may be caused. Locating radiators under windows will alleviate the condensation problem on the windows, but again, if the vapour-laden air is not removed, it will cool and condense out elsewhere.

Where windows have serious condensation problems, consideration should first be given to reducing the moisture-creating conditions. The principal way to do this is to remove the water vapour at the source by increasing ventilation. It may be worth reopening a fireplace or introducing vents to provide additional natural ventilation.

Proprietary through-frame trickle vents are not generally acceptable on listed buildings, and more subtle approaches are preferred. Historic Environment Scotland details several sympathetic methods of introducing trickle ventilation through sash windows.[15] Trickle ventilation can be achieved either by chamfering the sash's head to insert a grille or inserting a grille in the pulley box. Permanent ventilation, if required, can easily be achieved by inserting a block on the sash so that it cannot fully close.

Improving ventilation may also mean introducing mechanical extract from kitchens, showers and laundry rooms if they do not exist or an overall mechanical ventilation system such as 'positive ventilation' using proprietary mechanical ventilation or Mechanical Ventilation Heat Recovery (MVHR). Note, however, that the location of vents for mechanical systems requires careful consideration so that they do not detract from the character of the building. It may also be worth considering an alternative whole-house ventilation system, such as a passive Ventilation system, which does not employ mechanical ventilation. Adequate ventilation must be provided for the health of both the building and occupants, no matter which system is chosen. For further information, refer to 5.2 Draught-proofing and 5.5.2 Internal Secondary Glazing.

How can I improve the acoustic properties of windows?

In certain locations, single-paned windows can let in more noise from outside than we would wish. This external noise penetration can be reduced by draught-proofing. Draught-proofing can also reduce window-generated noise if the casement or sash is prone to rattle in the wind. Proper draught proofing will significantly improve sound insulation, even though it may be primarily installed to improve heat insulation.

Curtains and shutters can also significantly contribute to keeping noise out, though this is limited to evenings when they can be closed. For some windows, it is possible to insert double-glazed panes within the existing frame to reduce noise penetration. (Section 5.4 details various types)

The gap between the glass panes reduces the noise passing through the glazing. However, there remains a reliance on other measures, such as draught-proofing, to minimise noise entering around gaps in the frame. Secondary glazing adds a second slim independent unit to the rear of the existing window. This will perform better than inserting individual double-glazed panes into an existing sash window because the new frame is acoustically sealed.

Secondary glazing also provides better noise reduction than a replacement double-glazed sash window. A secondary double-glazed unit will contain a small integral gap between its two panes of glass, like the replacement double-glazing. However, it also has a second, much wider air gap of 60-100mm between the existing window and the secondary unit. This wider gap is highly significant in noise reduction because the effectiveness of noise reduction increases with the size of the air gap. A typical single-glazed window without any draught-proofing may achieve in the region of 18-25 dba noise reduction,[16] secondary glazing can achieve up to and beyond 45 dba noise reduction depending on the size of the air cavity. (Manufacturer's claim 54 dba with 150- 200mm gap.)

Is Replacement not better?

There are limited circumstances where replacement is permitted for protected historic buildings.

Where it is permitted, replacement with modern double glazed replica windows may offer better acoustic performance than inserting double glazing into an existing frame. This is of course provided the frame is well manufactured to a modern high acoustic standard. However, secondary glazing offers a superior performance to either inserting double glazing within the existing frame or complete replacement with new double-glazed windows.

How can I improve security?

Sometimes, we replace older windows because of security concerns. However, historic windows often had traditional solutions to security problems. One option may be to consider reintroducing such measures.

Shutters with a fastening bar were the traditional security improvement for sash windows. These still serve their original purpose well and can even be supplemented by a modern movement detector. Another traditional solution to ensure daytime security was to insert a rod behind the window, thus reducing access even if the glass was broken. Shutters are more flexible in that they can fully retract, and there is no permanent visual impediment. They are also flexible in the event of a fire and can allow safe egress if necessary.

Modern interventions can make historic windows as secure as any other window. Many ironmongery products are on the market specifically designed to counter these problems. Sash limiters, which restrict the movement of the sash, can be obtained. These allow some ventilation but limit the complete opening of the window. Screw locks and mortice bolts can also be fitted, which will keep both sashes firmly locked in place, increasing security.

The downside of this intervention is that it is not appropriate if the window needs to be used to escape in the event of a fire, so it should be restricted to non-escape designated windows.

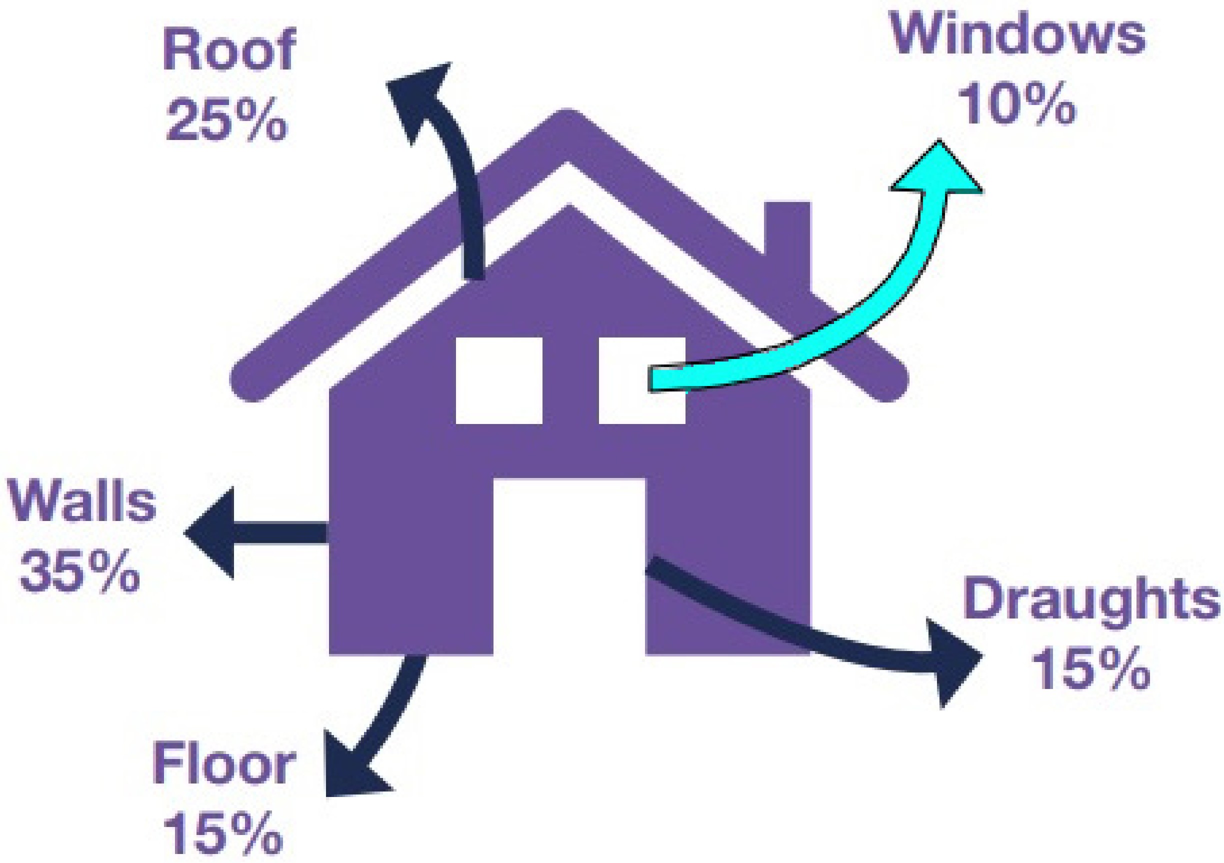
Where a window is highly vulnerable, there is the option of retractable internal grilles. These are preferable to external measures, such as external grilles or roller shutters, which visually impact the building. Sometimes, replacing it with laminated or toughened glass may be appropriate, but this would not be the case where the glass is historic. It would also not be appropriate in, say, a terrace of listed buildings where the significance of the group value must be considered. The reflective quality of laminated and toughened glass differs from standard and can alter the external appearance.

Secondary glazing provides an excellent opportunity to improve security. As secondary glazing cannot be opened from the outside, it adds an extra safety barrier to forced entry. Secondary glazing units can be specified to achieve the full Secured by Design (SBD) standard – the official police security initiative that works to improve the security of buildings. They can also be openable in the event of fire.

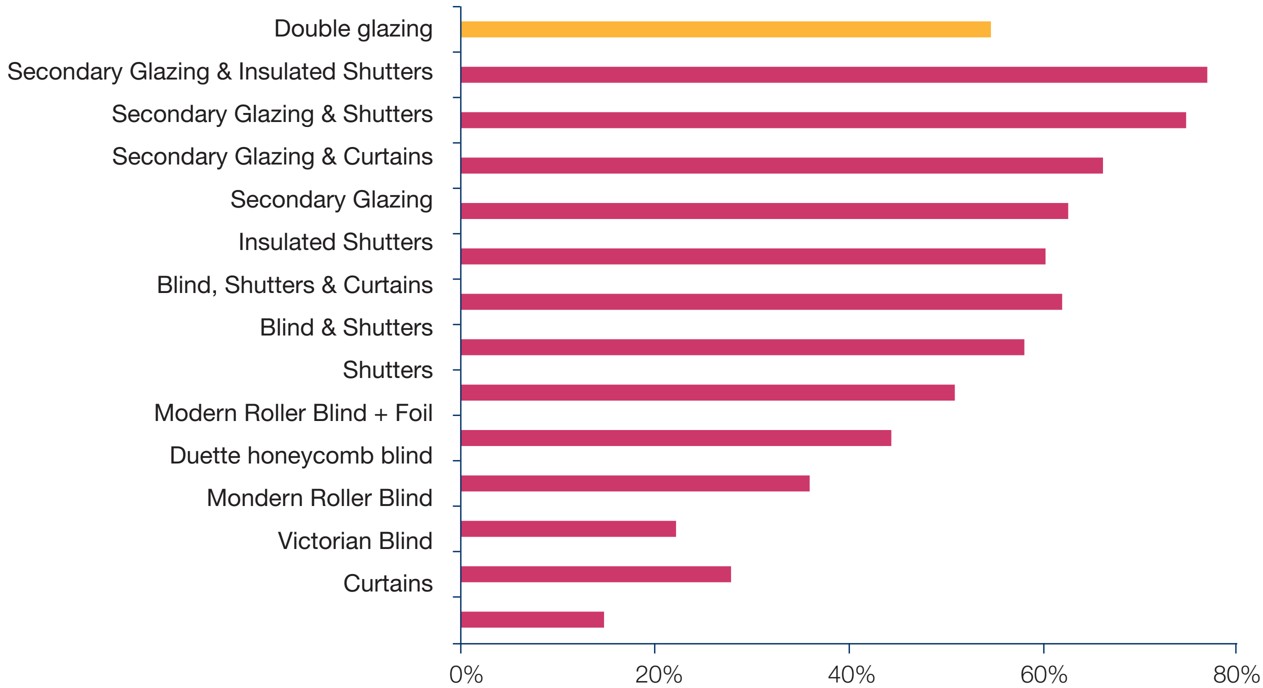
Improving the thermal performance of existing windows.

When considering how best to improve the thermal performance of a historic building, a typical first response is to consider replacing the windows. Inherent in this response are two assumptions. The first is that windows are the element of the building that would be most beneficial to improve, and the second is that the best way to improve the performance of windows is to replace them. Neither of these assumptions are true.

Typically, windows only account for 10% of the heat loss from a dwelling. Therefore, it is best practice to look at windows as part of overall building improvement. In many instances, it is often more beneficial and cost-effective to make other improvements first. Further information on overall improvements to historic buildings is available in the Historic Environment Division's Guidance on the thermal upgrade of Historic Buildings.[17]



Typical heat loss through different elements of a dwelling



Reduction in heat loss through single glazing with option compared to single glazing only

Source: Historic Environment Scotland - Thermal Performance of Traditional Windows. (2008)
Technical Paper – based on standard multi-paned sliding sash window in a tenement building (solid sandstone walls).

When considering how best to improve the thermal performance of historic windows, replacement is neither the only nor always the best solution.

Double glazing is the desired choice for replacement, frequently PVC-u. Although thermal improvement is the prime driver in this decision, other factors, such as the relative ease with which the change can be affected, also come into play. However, even setting aside the permissibility of such change to a historic building, the choice to replace is often made without the full knowledge that alternatives can equal or surpass the performance of replacement double glazing. Research summarised in the table below shows other window-related alternatives reduce heat loss better than replacement double glazing.

Inappropriate PVC-u replacement window detracting from the character of the building.

Traditional methods – Curtains, Blinds and Shutters

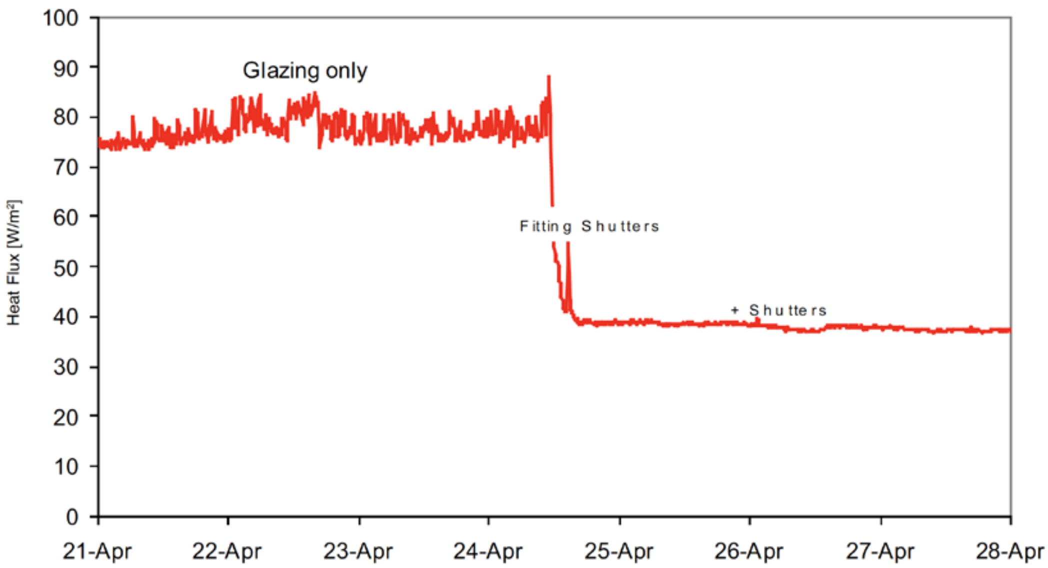
Historic Environment Scotland commissioned research by Glasgow Caledonian University to discover the effect various measures would have on the heat loss through a sash window in poor condition.[18] The research found that both curtains and blinds are effective. Hanging lined curtains will reduce heat loss by 14%.

A modern roller blind will perform slightly better, reducing heat loss by 22%. A thermal honeycomb blind will give a 32% reduction in heat loss. Therefore, both curtains and blinds can provide savings at little cost, are easy to fit, and have little impact on the fabric of the building.

Curtains & Blinds	Reduction in heat loss	U-Value (w/m2k
Single Glazed sash window	0	5.5
Fitting lined curtains	14%	3.2
Fitting modern roller blind	22%	3
Fitting thermal honeycomb blind	32%	2.4

Source: HES: Thermal performance of traditional windows. 2008

Timber shutters are another traditional method of improving the thermal performance of timber sash windows. They are more effective than curtains. The same research for Historic Environment Scotland found that simply closing shutters reduced heat loss by 51%. However, it is important to acknowledge that shutters and curtains only provide a viable improvement at night.



Effect of Closing Shutters

Source: HES: Thermal performance of traditional windows. 2008

Inserting insulation into the shutters further improved this performance, and fitting a 10mm aerogel blanket to cover the entire shutter's rear achieved a remarkable 82% reduction. It is usually straightforward and low-cost to restore existing shutters if they have fallen out of use.

The thermal improvements suggested above are also low-cost and easy to affect. It would, therefore, be cost-effective to restore existing shutters to use and thermally improve them.

Shutters	Reduction in heat loss	U-Value (w/m2k
No shutters - Single Glazed sash window	0	5.5
Closing timber shutters	51%	2.2
Insulation set into Shutter panels	60%	1.6
10mm aerogel blanket fit to shutters	82%	0.4

Source: HES: Thermal performance of traditional windows. 2008

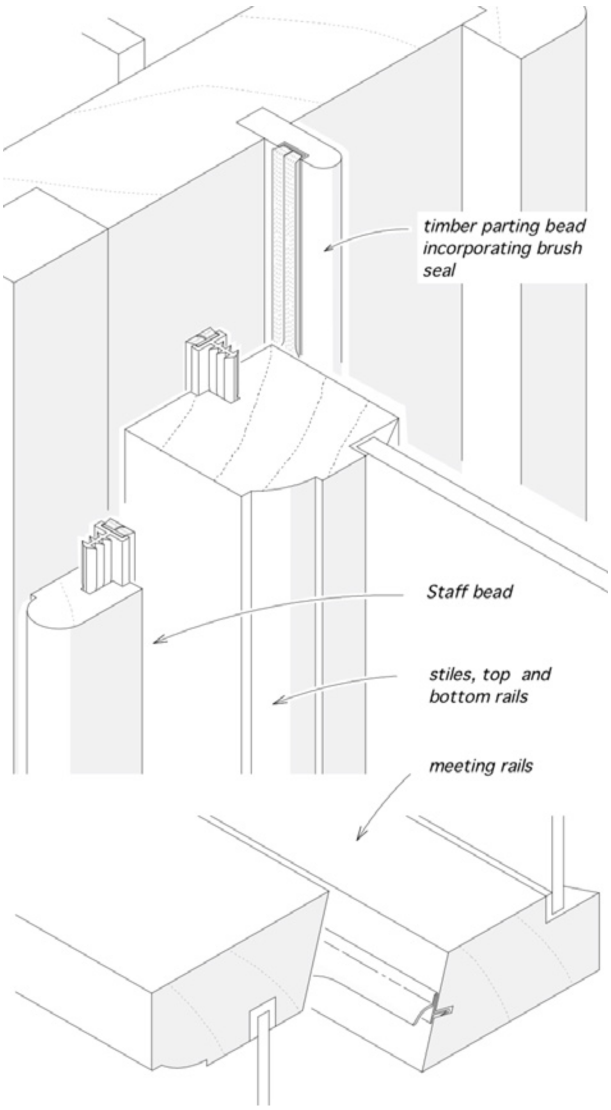
Illustration showing that even internal shutters can have an impact on the appearance of a listed building.

Internal shutters can alter the external appearance of a building. Although they are likely screwed to the inside face of the frame, and so are reversible, they can have an impact and the overall significance of an individual building or terrace and should be considered carefully.

Internal timber shutters, blinds and curtains all share a disadvantage as a means of reducing heat loss. They stop light coming in, so their practical use is limited to evenings. However, this disadvantage is less as evenings are a time of peak occupancy for dwellings and when temperatures drop.

Draught-proofing

Historic windows can be draughty. Over time, the original snug fit of a sash window against its parting beads may reduce, leading to a gap. A metal or timber casement may distort and similarly permit draughts. These draughts are often more noticeable in modern, heated buildings.



Source: Historic England, 2017, 'Traditional Windows: Their Care, Repair and Upgrading'. HEAG039

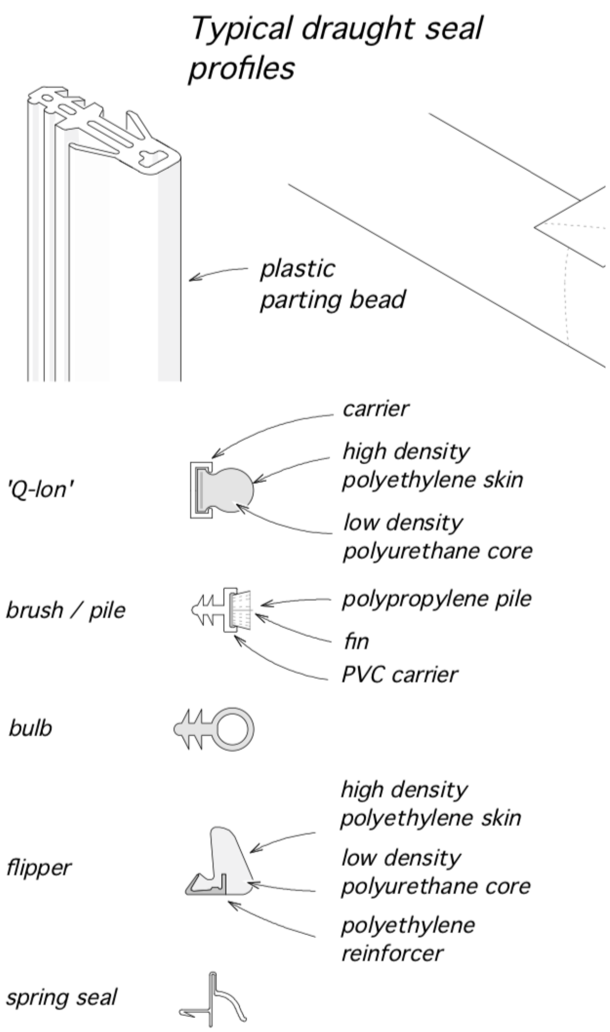
Essential maintenance will go a long way to reducing the draughts caused by gaps in timber windows. The parting beads can be replaced in sash windows, and cracks can be repaired. Historic England commissioned research assessing the thermal performance of a traditional two-over-two double-hung vertical sliding sash window in poor condition.[19] Historic Environment Scotland commissioned similar research of a six-over-six sash window in good condition[20]. Both found that even simple maintenance to mend cracks and eliminate gaps reduced the amount of air infiltration or draughts by more than 33%.

Draught-proofing can be installed where the air ingress is excessive, and can be highly effective. The same research showed that Draught-proofing can reduce the amount of air entering through sash windows by over 80%.

Draught-proofing has many benefits. It is a cost-effective way to reduce energy costs and improve the thermal comfort of a traditional building. It can also reduce noise coming from outside, stop the rattling of loose-fitting windows, and be achieved in ways that have minimal visual impact on the windows' appearance.

Historic England's guidance Energy Efficiency and Historic Buildings: Draught-proofing windows and Doors. (2016) provides valuable details on how best to approach draught-proofing. Many options are currently available for draught-proofing windows, and it is essential to complete any work correctly.

Brush strips



Source: Historic England, 2017, 'Traditional Windows: Their Care, Repair and Upgrading'. HEAG039

Brush strips are an effective system for draught-proofing the sliding parts of a sash window. Some methods involve replacing the central parting bead, often replaced anyway, with a specialist parting bead that incorporates a brush seal. Other methods involve routing out part of the timber of the window and inserting flexible brush seals. The sash can be routed on the sides and top and bottom rails, or the parts of the window the sash meets, the staff bead and the meeting rail, can be routed.

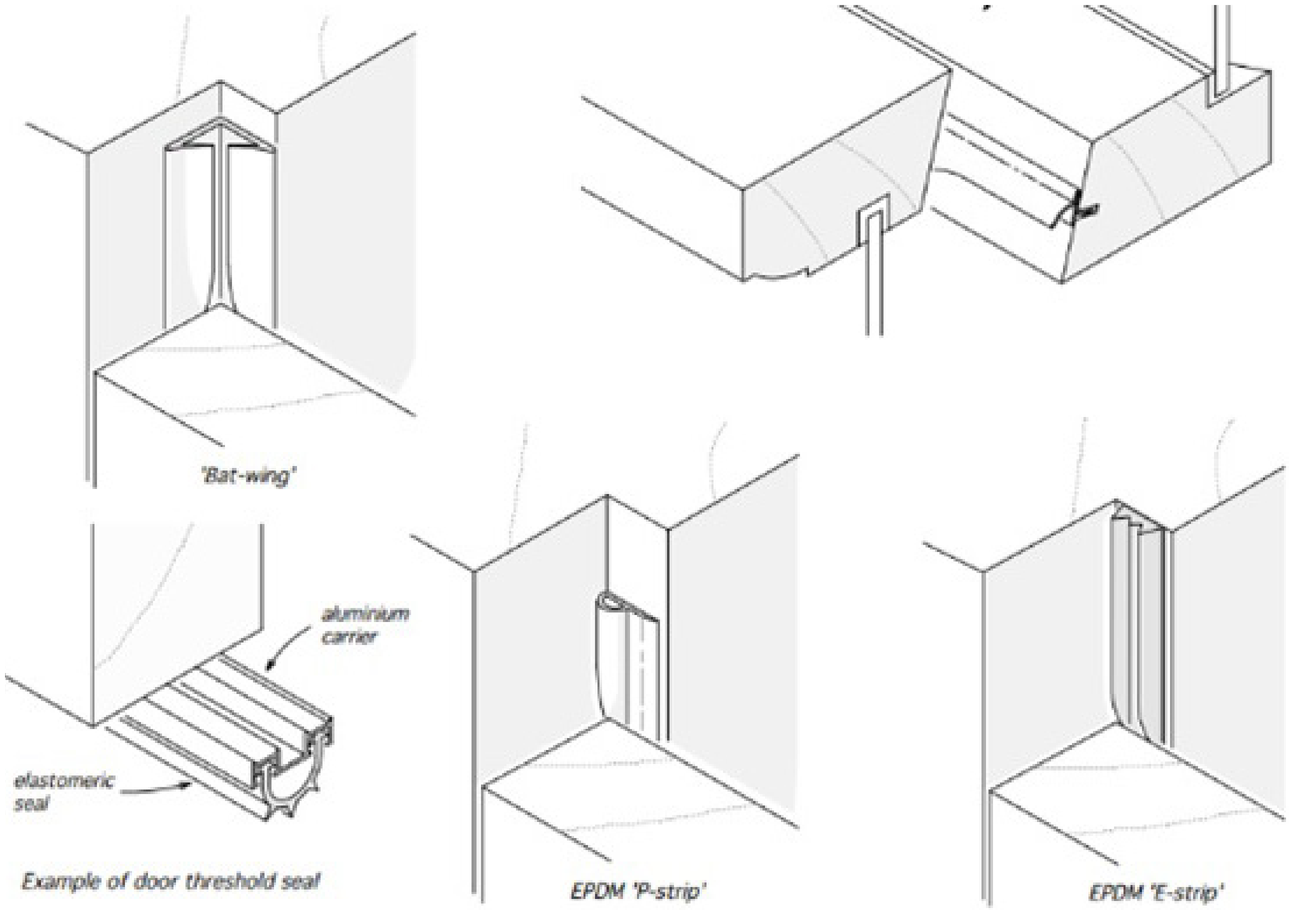
HED recommend systems recessed into the windows as they are concealed from view when the window is closed. Brush seals on the sash's sides are better as they are permanently hidden from view, whereas those in other areas are visible when the window is open.

Flexible strips

Some systems use flexible strips, often polyethylene, to achieve the same results as brush strips. These come in various profiles.

Compression seals

Compression seals are used in a sash window along the top and bottom rails where the sash compresses against the head and sill and where they meet in the middle at the meeting rail. They can also be used in casement windows, applied to the rebate of the frame where the opening light can press against it when closed. Relatively cheap and easy to install, they are available in various materials, including strips of rubber (EDPM) foam and silicone. V-shaped profiles in silicone and rubber are more suitable for larger gaps.



Source: Historic England, 2017, 'Traditional Windows: Their Care, Repair and Upgrading'. HEAG039

Gel Seals

It can be more difficult to fit a strip or profiled compression seal to a significantly warped window due to the variation in the gap size. Where a timber or metal window has warped, a gel seal can be applied to account for the variability. The seal, most often silicone, is applied only to the frame, while the face of the opening light is greased to prevent it from sticking. Care should be taken to ensure silicone is applied correctly, as too much will adversely affect the window's appearance. The seal takes up the variable shape of the gap when the window is closed.

Other draughts

Physical gaps are not the only cause of draughts. Historic windows are mainly single-glazed, and single-pane glass is not a good insulator with a U-value of around 5.5w/m2k, making the inner surface of the glass much cooler than a heated room. Much of the draught is caused by convection downdrafts from air in contact with the cooler glass.

Positioning radiators beneath windows will go a long way to combat this draught. In the evening, tight-fitting blinds or shutters will minimise the problem. During the day, to allow daylight in, a glazing solution such as secondary glazing or double glazing will be required.

Ventilation

Any intervention which reduces ventilation in a historic building must be considered in the round. Draught-proofing that is overzealous may lead to increased internal humidity and a potential build-up of condensation on cooler areas such as glass. The installation of trickle vents may be necessary to restore the balance. However, they will require Listed Building Consent as they can have a detrimental impact on the significance of the listed building.

A timber sash or a casement window in good condition should not normally need draught-proofing. It will have a small amount of air leakage, but research has shown this to be no more than the equivalent air infiltration through a trickle vent and therefore may be the minimum ventilation required to keep the building healthy.

Thermal improvement by replacing existing glass with a better performing single glass.

Historic windows are single-glazed, but the thermal performance of a single pane of plain glass is poor (5.3w/m2k)[v]. There are different approaches to improving this aspect of the window: some seek to replace the glass with an alternative which performs better thermally, and others, as we will discuss later, seek to retain and improve the thermal performance of the existing glass.

However, before replacing any glass, it is first important to establish if there is any historic glass as modern float glass has a much more uniform surface than historic glass, and the external appearance of the building can differ markedly as modern glass is much more reflective. This can impact the significance of a building, and more so where it is part of a group.

If historic glass is present in a listed building, it is unlikely replacement would be acceptable. There are alternative options, which we will discuss later in this section.

Replacement single glazing - low emissivity glass

Where replacement has been permitted, it may be possible to replace existing single-pane glass with modern single-pane glass that performs better thermally. The replacement glass will have a low emissivity coating. These coatings allow the longwave radiation from the sun to pass through the glass from the outside while restricting the shortwave radiation from surfaces within a building radiating back to the outside.

Low emissivity glass can replace existing glass without additional weight where the glass is not thicker. A single pane replaces a single pane, and as there is no need to alter the frame or how it operates, the visual and physical impact of this intervention is reduced.

Replacement single glazing - laminated glass with an interlayer

Single glass can also be replaced by two thin layers of glass laminated together with an insulating film between them. These are only slightly thicker than a standard pane. The Historic Environment Scotland Guide to Energy Retrofit of Traditional Buildings 2021 cites a 50% improvement in thermal performance. There are also security benefits, as the interlayer makes it difficult to break the glass. The overall weight is slightly heavier than a standard pane, and the sash weight may require some modification to accommodate it. Still, both the visual impact and necessary modification to the existing window frame are less than would be needed for most double-glazed units as these have a gap of 7 to 16mm between panes, vacuum glazed units being an exception.

Provided there is no loss of historic glass, neither of these changes is likely to require Listed Building Consent, as there is no change to the external form and character of the building. It is always advisable to check with HED.

Thermal improvement achieved by inserting new double glazing into existing frames.

Standard double glazing

Inserting panes of replacement double-glazing into a frame is never appropriate if it means the removal of historic glass. Still, where this is not the case, replacing existing glass with double-glazed units is sometimes possible.

It is only sometimes feasible to use standard-thickness double-glazed units. The average thickness of standard double-glazed units is 24mm. Using thick units often necessitates deep glazing rebates, to accommodate the increase in thickness and robust framing members capable of taking the weight increase. These factors limit the appropriateness of such units to larger areas of glazing.

Six-over-six
Sash window

One-over-one
Sash window

Multi-pane sash windows are unlikely to be suitable for replacement with standard-width double-glazed units however it may be possible with a one--over- one sash. Where a building is listed, Replacement double glazing will require Listed Building Consent

Large, non-opening windows or casement windows often provide such an opportunity.

Sash windows with multiple panes are generally inappropriate for standard thickness double-glazed units, particularly 18th and mid-19th century multi-pane glazing with thin profile glazing bars and shallow reveals. The existing sash needs to be replaced to accommodate the thicker unit, and this is not acceptable in a listed building where it results in a loss of sound historic fabric and is detrimental to the overall character and appearance.

Sash windows that are not multi-paned, such as one-over-one sash windows, can sometimes be appropriate. However, they need to have robust frames to take the weight and sufficiently deep reveals that can accommodate the thickness of the unit. Weights may also need to be rebalanced to accommodate the heavier weight of glass. It is not always possible, or acceptable, to alter the rebates to accommodate thick units. Sometimes, modifying the rebates to accommodate thicker glazing units is possible, where no change is required to the edge profile, thickness, or fixing method.

The Edge seal in a double-glazed unit becomes more visible as the overall thickness of the double-glazed unit increases. A slim profile option is preferable as it minimises this loss of visual integrity. Colour can also be important – an edge seal coloured white set in a white timber sash will be less visually prominent than a black or silver.

The continuing functionality of most double glazing depends on the seals that prevent air and moisture from entering the gap. When these fail, the units become much less thermally effective and are likely to fog because of internal condensation. The lifespan of current double glazing is estimated to be between 15 and 25 years. An exception to this may be vacuum-sealed units, which do not rely on a separate seal. It is always advisable to check the warranty carefully to establish what is covered and for how long.

Where a building is listed, replacement double glazing will require Listed Building Consent, and the local Council Planning Authority must consult with HED on any proposals. The Department will consider each application on a case-by-case basis.

Slim-profile double glazing

Replacing single-glazing panes with slim-profile double-glazing panes is a lower-impact solution than replacing them with standard double-glazing. This form of double-glazing has a thinner cavity between the two glass panes than the usual 24mm cavity in conventional double-glazing units. Due to the reduction in overall thickness, it is often possible to fit slim profile glazing into windows designed for single glazing.

The thickness of the unit is determined primarily by what is inside the cavity. Units can be filled with an inert gas or air or have a vacuum. Slim double-glazing units with air in between have an optimum gap of 16mm. Inert gases such as – Argon, Krypton and Xenon have superior properties to air; however, each has a different optimum gap: Argon 15mm, Krypton 11mm and Xenon 8mm.

A research project in Edinburgh[21], replaced the single-glazed sash windows in ten historic properties with various slim-profile double-glazing products. It showed that the thermal performance of historic timber windows improved significantly. Glasgow Caledonian University measured their thermal performance and showed the U-values of the different systems, which ranged from 1.0 to 2.8. Most systems achieved a U-value close to 2.0.

The University repeated the research two years later[22] to see if there would be a drop off in performance, and the replacement double-glazed units still demonstrated a significant performance improvement, as shown in the table below.

CAVITY FILL	U-VALUE (w/m2k)	Overall width
Air	2.9	9mm
Krypton	2.5 - 2.7	11mm - 12mm
Xenon & Krypton	2.0 – 2.6	9mm - 11.9mm
Argon	2.1	16mm
Vacuum	0.9	7.2mm

Extracted from Historic Scotland Technical Paper 20, 'Slim profile double-glazing in listed buildings' 2013.

The wide edge seal is visible.

The research showed an inverse relationship between the overall width of the unit and the performance of all gas and air-filled units. The air-filled unit had a slim profile at 9mm, but the thermal performance was not as good as the gas-filled units.

Of the inert gas-filled units, argon performed well but was the thickest overall at 16mm. Krypton and Xenon generally fell between these extremes in terms of thermal performance versus overall depth.

In general, slim-profile double-glazing performs better thermally than single-glazing but will not act as well as conventional double-glazing with its larger cavity size. There is, however, a notable exception. Vacuum glazing allows the slimmest gap of all. Such units have an exceedingly small gap, 0.2mm, but their performance far exceeds gas-filled units despite this small gap. In the research above, the vacuum glazing achieved the lowest U-value by a significant margin (0.9 w/m2k) – despite having a much smaller cavity width (0.2 mm) than the other units. This demonstrates the effectiveness of a vacuum as a thermal barrier. The vacuum unit is as thin as 7.2mm overall (4mm glass -0.2mm cavity- 3mm glass). There is minimal impact on the fabric of the sash or frame to fit it and minimal visual impact when fitted.

The edge seal of inert gas-filled units can break down over time. Care should be taken when fixing the units in the sashes, as traditional putty may cause some deterioration of the units' edge seals. However, vacuum-glazed units do not have edge seals, as the two glass panes are welded together at their edges. In the research cited above, they showed no deterioration over time. The lack of degradation over time is an important factor in terms of cost. When longevity is factored into the overall cost, it may well offset the more lavish initial outlay for vacuum-sealed units.

When viewing a window from outside, the width of the edge seal can have a significant visual impact, especially if the view is not head-on. Therefore, the slimmer the profile of the units, the less detrimental the visual impact. Vacuum-filled units (at 7.2mm) or some air and xenon-filled units at not much more (9mm) will significantly reduce impact.

HED will generally consider acceptable slim profile units with an overall thickness of less than 10mm. However, Listed Building Consent will be required for all forms of replacement double glazing. Please note this does not apply to windows with historic glass as these should be retained in their original profile.

Thermal improvements that allow both glass and frame to be retained.

New timber windows may also add to the embodied energy of a building, which often makes retrofitting into existing sashes a more sustainable option than replacement.

The inert gases in many double-glazing systems need energy-intense processes to extract them from the air. This process often accounts for a considerable proportion of the embodied energy in the window. Xenon has a high embodied energy.

Conservation glazing – (acrylic double glazing)

Acrylic double glazing, sometimes called ‘Conservation Glazing,’ is a system designed to improve the thermal performance of traditional single-glazed windows with minimal impact on the window’s appearance or the historic fabric. This system consists of scratch-resistant acrylic panes cut by laser and fitted between the glazing bars approximately 20mm behind the existing glass.

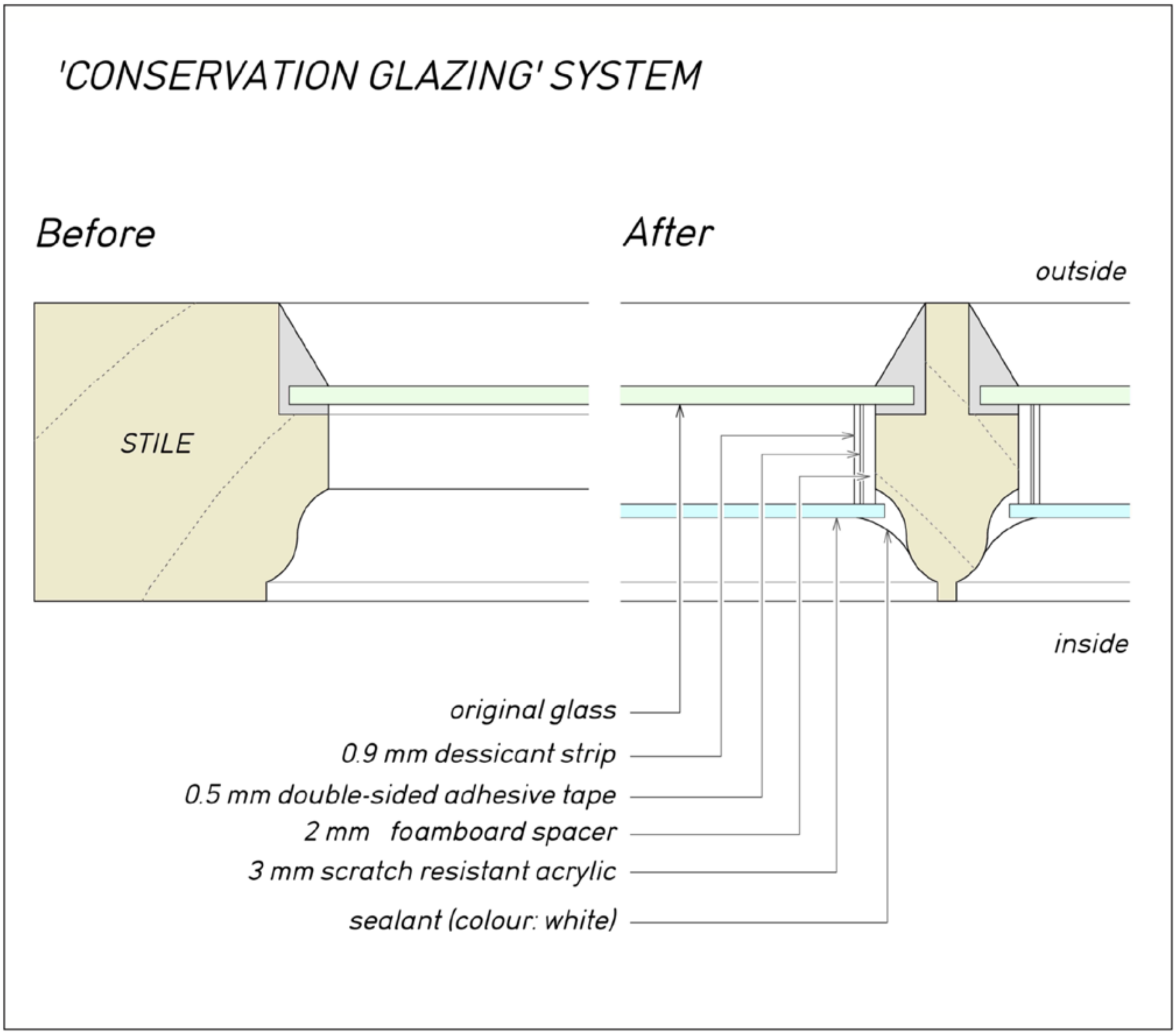


Illustration from Historic England Report: - The Engine House Swindon. Thermal performance of energy efficiency improvements to timber windows (2017) Research Report Series no. 2/2017. - Figure 5: Diagram of retrofit double glazing system for small pane windows

The windowpane labelled 6A has been altered while the lower windowpane has yet to be altered. This close-up view shows how less of the internal moulding profile of the glazing bar is visible after installation. Source: The Engine House Swindon. Thermal performance of energy efficiency improvements to timber windows (2017) Research Report Series no. 2/2017

Conservation glazing retains both the historic timber and glass. It is a low-impact solution that can be reversed if necessary. Acrylic is lightweight, so the glazing bars do not need to be incredibly thick or strong to take on additional weight. When added to a sash window, it is also not necessary to alter the rebates of the original sash or glazing bars to accommodate the extra lightweight pane, nor is it necessary to rebalance the sash.

Acrylic double glazing is particularly worth considering for multi-paned sash windows, such as 18th-century and early 19th-century windows, which often have delicately profiled glazing bars. The system is less visually intrusive than other alternatives, and there is no conspicuous double reflection when viewed from the outside.

Historic England conducted research that assessed the effectiveness of a system of Acrylic double glazing in situ at one of their main national offices - home of the Historic England Archive – The Engine House, Swindon.[23] In 2014, they upgraded the existing single-glazed timber sash windows. The improvements were intended to enhance the occupants' comfort levels, improve the windows' energy performance, and reduce noise penetration without harming the heritage significance of the building. The results found a 56% reduction in heat loss. The centre pane U-value dropped from 5.2 W/ m2 K to 2.3 W/m2 K. While other alternatives, such as secondary glazing and replacement double-glazed units, are more effective thermally, there are situations where acrylic double glazing can prove an appropriate solution.

Suitable scratch-resistant acrylic can be as thin as 3mm. However, the gap between it and the existing glass pane is relatively large (20mm). As a result, the moulding profiles of glazing bars are rendered less legible due to the overall increase in depth.There is also some risk of condensation forming in the gap between the panes; however, good detailing that includes a desiccant strip can minimise this. The long-term satisfactory performance will also depend on the condition and adequate maintenance of external putties and paintwork to prevent moisture ingress.

Low-grade acrylic can scratch and discolour in sunlight, but high-grade, scratch-resistant acrylic will reduce this, though care should still be taken during cleaning to avoid surface abrasion of the acrylic panes. Conservation glazing is reversible and will have a minimal impact on the significance of a listed building and, therefore, may not require Listed Building Consent. Contact HED for further guidance.

Internal secondary glazing

Secondary glazing is the installation of a second window within the reveal of the original window. It is one of the most effective methods for improving the thermal performance of a window. Secondary glazing will increase energy performance to a greater degree than alternatives that involve replacing or supplementing existing glazing because it reduces heat losses through the mullions, frame, and glass. It also lessens uncontrolled draughts. A low emissivity coating improves thermal efficiency, but vacuum glazing further enhances performance.

Glasgow Caledonian University conducted research for Historic Scotland using a 6 x 6 sash window in good condition. Their findings showed that when a timber frame double-glazed unit was added behind an existing sash window in poor condition, the heat loss was reduced by 85% (an improvement in U-value from 5.5 to 0.8 Wm^2K).[24]

Even secondary glazing with a single pane of glass achieved a remarkable reduction of 71%.

Secondary Glazing

SECONDARY GLAZING	Reduction in heat loss	U-Value (w/m2k
Single Glazed timber sash window	0	5.5
Secondary Glazing - single pane, timber frame	71%	1..5
Secondary Glazing -Double glazed, Aluminium frame.	85%	0.8
Secondary Glazing - Single sheet polycarbonate held with magnetic strips	56%	2.4

Source: HES: Guide to Energy Retrofit of Traditional Buildings. 2021

Historic England cites the achievability of a remarkable U-value of 0.6Wm²K if using insulated frames and vacuum-glazed units.[25] This equates to a reduction of over 90% in heat loss.

Double-glazed secondary glazing units can avail of all the benefits of modern replacement double glazing. The units can similarly have low emissivity glass coatings, be filled with gas such as Krypton or Argon or, best of all, be vacuum sealed. Secondary glazing also reduces draughts. As we have discussed previously, most of the heat loss from a typical traditional window is through gaps around the window. Only with exceptionally large windows is the greater proportion of heat lost by conduction through the glass. With efficient perimeter sealing, secondary windows can form an effective seal over the whole of the frame of the original window and significantly reduce excessive draughts.

Secondary glazing has other benefits in addition to its significant thermal performance. One of the most important of these is that existing historic windows and their historic glass, if they have any, can remain unharmed by secondary glazing, and there is no loss of existing fabric in the installation process. However, the remaining existing windows will still need to be maintained and, if necessary, repaired. Secondary glazing is also likely to have minimal effect on the external appearance of the window. There may be some additional reflectivity, but as the glass is mounted internally behind the original glass, it is not significant enough to be considered adverse. However, if the window is large, ensure mullions for support align with the existing window to minimise their visibility.

It may also be cheaper to install secondary glazing than to replace the existing windows with double glazing. A replacement external window has many roles: to keep out the rain and draughts, keep in the heat and deal with the wind loading. A secondary unit does not have to keep out the rain nor deal with the wind load, and with fewer demands on the design, the unit can be simpler and cheaper.

Secondary glazing can be designed to the highest security standard - just the same as any double-glazed unit and, as it provides a second line of defence, it offers an even greater deterrent to unauthorised entry.

The benefits of Secondary Glazing may exceed those of replacement double-glazing.

- Better thermal performance
- Lower cost
- Less Noise
- No draughts
- Better Security
- Easier to install.
- Reversible

Secondary glazing successfully reduces noise penetration from outside. It will perform even better than replacement double glazing. The extent to which a double-glazed window or secondary glazing unit reduces noise penetration depends on the size of the gap between the two panes of glass - as the size increases, so too does the noise reduction. Having an additional separation distance between the secondary unit and the existing window, a large gap of 50 -100mm makes secondary glazing even more successful than double glazing on its own, with a gap of 14 to 24mm.

Secondary glazing is reversible, and HED considers it to have minimum impact on the heritage significance of a building. HED may not require Listed Building Consent for this thermal improvement; however, you should consult the local council or HED for advice and guidance.

Installation of secondary double glazing

Making the arrangements for secondary glazing is a relatively easy undertaking for an owner. It can be a 'one-stop-shop,' like standard replacement double-glazing, where one window company can fit an entire house in a few days. Secondary glazed units fit from the inside, making installation easier on buildings with more than one floor, as there is no need for external scaffolding.

A 50-60mm gap from the face of the existing window is recommended when installing secondary glazing. If the gap is larger, a convection current can be set up, which allows some heat to transfer. The available space to fit the secondary unit may be less where a window has shutters, but it still will be effective.

Although secondary glazing can be fixed, openable or demountable systems allow access to cleaning and ventilation in the summer months.

There are lightweight alternatives which use polycarbonate instead of glass. These attach with a magnetic strip that allows the entire unit to be removed in warmer months. They require no permanent alteration to the existing window frame. They can be less visually intrusive than standard secondary glazing because they do not need a separate frame to support them. The Historic Scotland research cited above shows even a lower-cost alternative such as this will achieve a 56% reduction in heat loss.

How secondary glazing compares to inserting double glazed units into the existing frame.

With all forms of glass replacement, thermal bridging will continue to occur through the sash or casement frame as the timber or metal offers a poorer insulant than the double glazing. It will happen with replacement standard-width double glazing or slimline double glazing and conservation glazing where, although glass is not replaced, the acrylic secondary panes are inserted within the existing glazing bars. The extent to which thermal bridging occurs will vary according to the material of the frame; for example, metal will transfer heat much more than timber as it is more conductive. It will also depend on the proportion of frame relative to glazing. A multi-pane sash window will remain less thermally efficient than a one-over-one sash window because the additional glazing bars between the individual panes of glass provide more thermal breaks. The frame of a secondary double-glazing system can be designed to present a smaller ratio of frame/glazing than the existing historic frame or sash, mainly because it does not have to withstand the external wind load.

It is also likely to be more cost-effective to install secondary glazing than insert replacement double glazing as there is less labour involved, and a single double-glazed secondary window costs less than multiple double-glazed inserts.

Replacement

Replacement of windows in a listed building

Replacement of historic windows should only be permitted where the existing windows are verifiably decayed beyond repair following inspection by HED.

Any permitted replacement window should match in all respects the material, form, detailing and operation of the original window. It should also sit within the reveal and on the cill in the same way.

It is best to copy an example of the original window design if it still exists. If none survive, use window patterns obtained from surviving examples in the same terrace or adjacent buildings of the same period to inform the design. HED can also help advise on an appropriate design.

Reuse of aspects of the original, such as the careful reuse of historic glass, may also be possible. HED requires owners to keep historic glass as it is now increasingly rare. It may be hard to remove and install in the new windows, and an experienced professional should conduct this work to ensure maximum retention of the glass. In some instances, it may be possible to integrate undamaged aspects of the original sash or casement. Glazing bars are often remarkably intricately detailed. If practicable, the overhaul and reuse of ironmongery should also be considered.

Unlike this example, it is preferable to replace a window that is unsympathetic and out of keeping with the age and character of the building with a window that replicates both the original style and material.

It is not in keeping with the special interest of a listed building to replace a historic window with a window of inappropriate pattern or material. A PVC-u window or a standardised timber window that is out of keeping with the special interest of a building will result in a loss of authenticity. In some instances, a window may have been replaced historically, which may or may not be in character with the building or building group. Any further change to a previously replaced window will still require a listed building consent. HED will assess such proposals on a case-by-case basis.

Replacement of non-historic windows in a listed building

Sometimes, HED will list a building that includes windows which are not historic, for example, PVC-u windows. However, such windows will typically be noted in the report as an 'inappropriate alteration' and highlighted as a negative criterion in the listing evaluation by applying the criterion H-. Historic Environment Division set out the criterion for listing in the Criteria for the Scheduling of Historic Monuments and the Listing of Buildings of Special Architectural or Historic Interest, with associated procedures.

As it is a negative listing criterion, HED would strongly encourage future works to rectify the windows to be more in keeping with the building's original design and special interest.

Replacement PVC-u windows (sash and dormer on the right) can alter the appearance of a terrace.

Incorporating thermal improvements

A replacement window can also incorporate appropriate thermal and performance improvements to ensure optimum performance. Many of these are detailed earlier. For example, the glass can be double-glazed with Low-E glass with a gas infill or a vacuum between panes. The window should be manufactured to closely match the original design and not harm the character of a group of listed buildings. Existing windows can incorporate draught-proofing and other traditional improvement methods, such as shutters, curtains, and blinds.

Relative cost of replacement

It is often perceived to be cheaper to replace a window rather than repair. However, in most cases, repair should be more affordable and, in almost all cases, cheaper in the long term as the expected life of a well-repaired and maintained historic window far exceeds a replacement in any material.

It will usually cost more to replace historic windows to improve a building's energy efficiency than it will cost to implement simple thermal upgrading options such as draught-proofing or even to install secondary glazing.

If it is necessary to replace windows, there is a cost consideration. However, an owner may wish to balance the initial cost against the lifetime cost. Replacing historic windows with windows manufactured to a matching historic design may initially appear costly. While there may be greater initial outlay, the result, with improved energy efficiency and manufacturing techniques, is a high-quality product that can last more than one hundred years.

Will replacement improve the value of a property?

Removing historic windows can hurt the value of a property; a survey of UK estate agents conducted by English Heritage in 2009[26] found that when the historic windows of a dwelling were replaced with PVC-u, the value of the property fell when compared to the resale price of comparable dwellings in the same street or Conservation Area. This may be different from what one may expect. However, 82% of estate agents surveyed agreed that original features added financial value to homes, and 78% believed they helped houses sell more quickly.[27]

Environmental protective glazing (EPG)

Stained glass windows form part of the building envelope of many historic buildings. Often more fragile than they appear, they are especially vulnerable to environmental deterioration. On the outside, rain, wind and pollution can cause structural and chemical deterioration to the glass and lead. On the inside, condensation can cause irreversible loss of paint and decoration.

One of the most effective ways to protect stained glass from deterioration is to use a secondary glazing system to shield it. Two main types of protective glazing systems exist: internally ventilated and externally ventilated. Externally ventilated systems are still used today by local churches and cathedrals. However, more recently, as the understanding of the science behind how Environmental Protective glazing systems work has increased, the choice has tended toward internally ventilated systems[28]. In the past, other systems such as Mixed internal/external vented systems and sealed systems have also been used, as well as designs employing heating, but these are rare.

Types of environmental protective glazing

There are two main types of Environmental Protective Glazing: internal and external.

Internally ventilated environmental protective glazing

Internally ventilated systems commonly have the historic glass set into a new frame positioned further back within the window reveal and ventilated with gaps at the top and bottom. The protective glazing is placed in the grooves that housed the original glazing. This system allows internal air to circulate between the two layers. Sometimes, it is referred to as isothermal glazing.

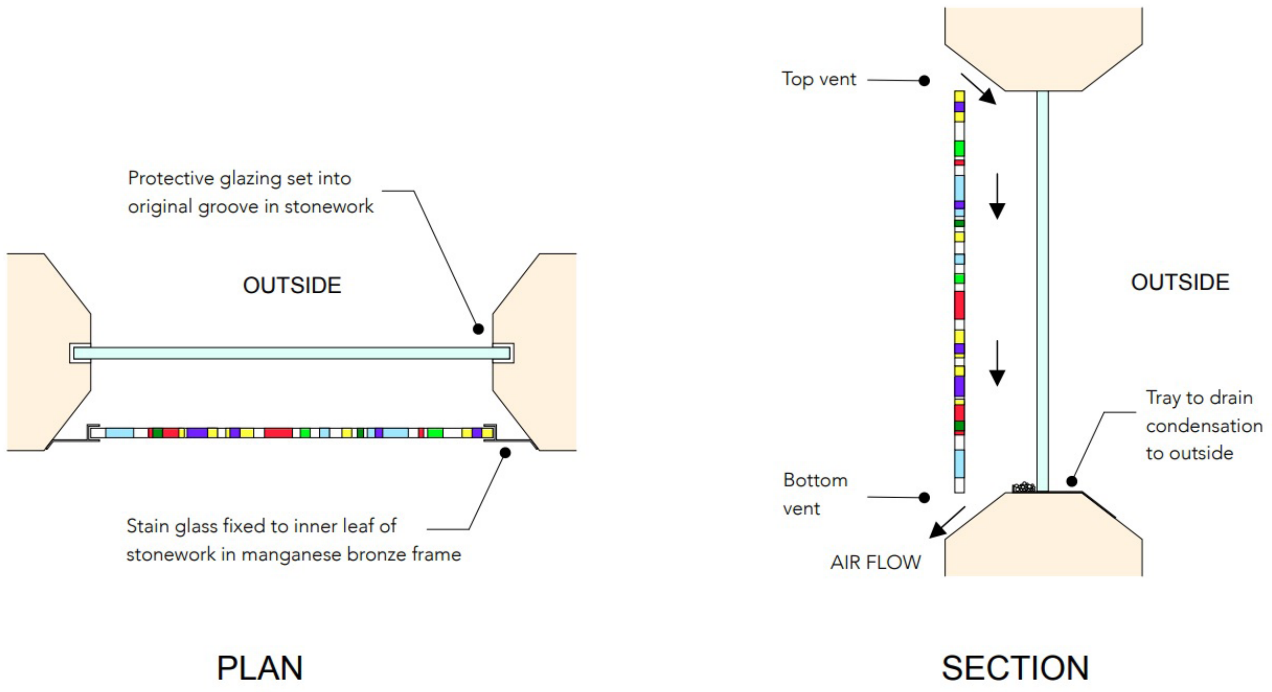


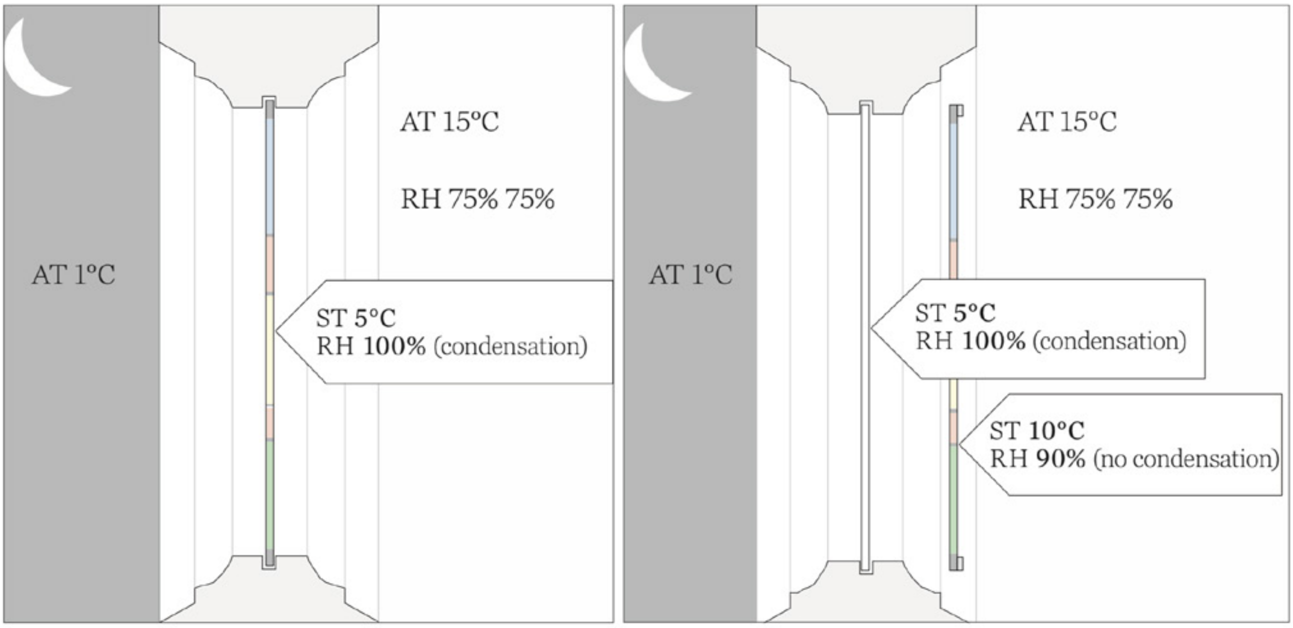
Illustration showing Internally ventilated Environmental Protective Glazing (EPG)

There are other examples in the UK and mainland Europe where the historic glass remains in the original glazing grooves, the external protective glazing is placed outside, and the historic glass is altered with individual sections set forward to create ventilation gaps that allow the circulation of internal air. This alternative method of internally ventilated EPG changes the appearance of the stained glass from the inside and, with some of the glass sections set forward from the rest, can detract from the completeness of the overall composition. Besides maintaining a minimum cavity between the glazing panels, the put forward pieces of glass must provide a sufficiently large total gap at the top and bottom of the window.

Achieving this is not always easy, and it is more straightforward when the original glass is set back in a new frame. This method of internally ventilating is not commonly used in Northern Ireland.

The most critical concern with any system of EPG is condensation forming in the face of stained glass. Condensation is most likely when the outside temperature is much lower than the internal temperature. Therefore, it is crucial at this most critical period to raise the minimum temperature of the historic glass to reduce the risk of condensation forming on it. The problem will happen most often on a cold night.

Simplified Example showing relative humidity lowered next to the stained glass.



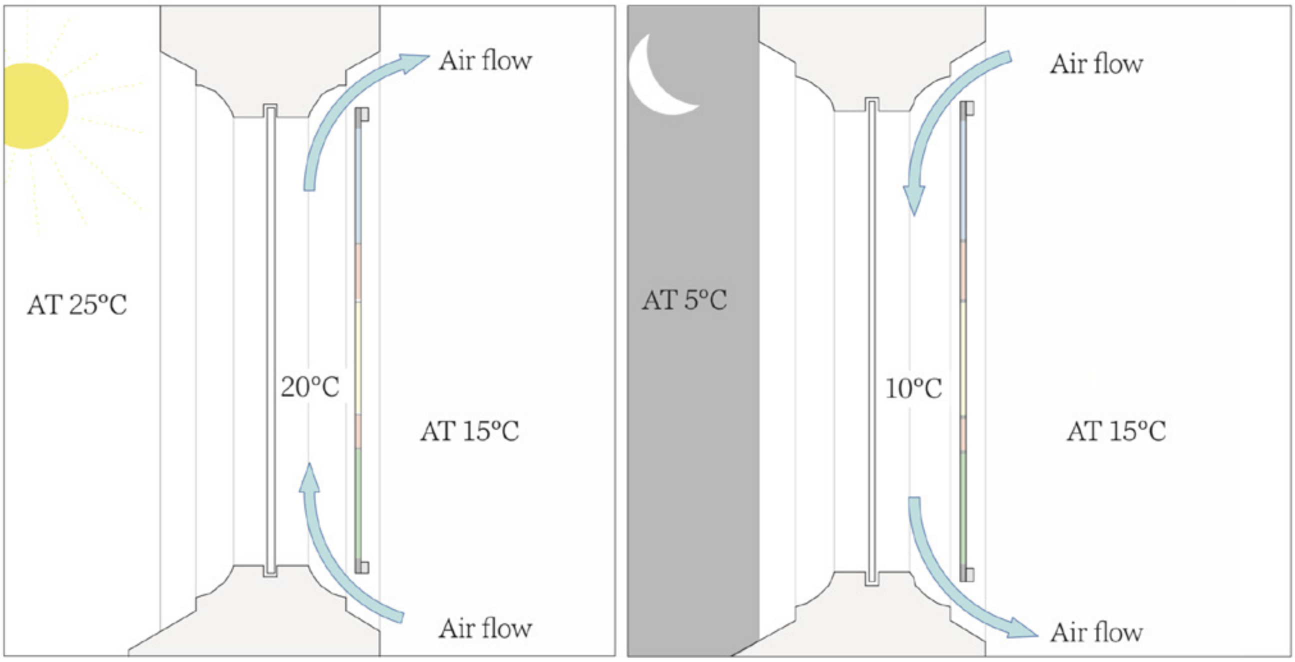
Source - Historic England Report: Conserving Stained Glass using Environmental Protective Glazing. (2019) Research Report 43/2017

An internally ventilated environmental protection system works by ventilating the air gap between the new glazing panel and the historic glass with internal air. By creating an intermediate zone it buffers the temperature between inside and outside. When cold outside, the stained glass is kept warmer, reducing the likelihood of condensation forming. If condensation is going to develop at all, it is more likely to form on the inside face of the external protective glazing, where it can be safely drained away. A lead tray containing gravel allows any condensation forming on the protective glazing to drain through to the exterior while also resisting air ingress from the exterior.

The direction of the flow of air in the gap will change depending on the time of day and the climate conditions. In the evening, warmer air from inside the building is drawn down the air gap as the external temperature drops relative to the internal temperature. Mediating the gap-temperature to be warmer than the outside air keeps the temperature around stained glass higher than outside.

During the daytime, when the external temperature is warmer than the internal temperature, the direction of airflow reverses and draws air up through the gap. The high airflow rate has a cooling effect, moderating the temperature of the stained glass. The cooling effect moderates the temperature of the stained glass in peak summer temperatures.

Simplified Example illustrates the principles of Internally ventilated EPG.



When the air in the interspace is warmer and more buoyant than the air in the building (which will occur when the external conditions are significantly warmer than the interior) the air will flow upwards drawing air in through the bottom vent and expelling air through the top vent. When the air in the interspace is cooler and less buoyant (as when external conditions are colder than internal) the opposite flow pattern will occur. Source - Historic England Report: Conserving Stained Glass using Environmental Protective Glazing. (2019) Research Report 43/2017

Externally ventilated environmental protective glazing

An externally ventilated system works on the same fundamental principles as an internally ventilated system. Still, instead of circulating air from inside the building in a cavity, it circulates the air from outside. Many churches in Northern Ireland have followed this approach.

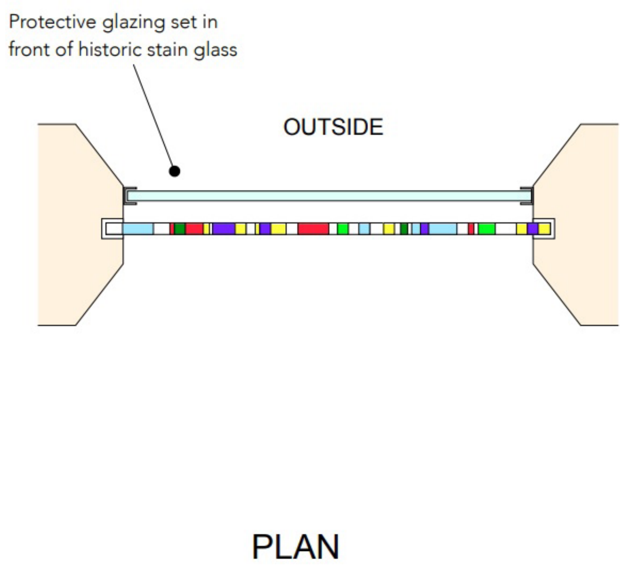
External ventilation systems allow the historic glass to remain in its original position without any alteration. The importance of this is not be understated; however, research has shown there are other factors to consider if proposing an externally ventilated system, such as:

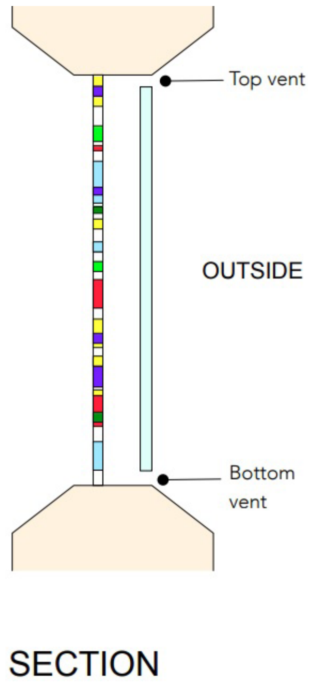
Temperature of the glass

The fluctuations in the temperature of the stained glass tend to be more extreme with an externally ventilated system than with an internally ventilated system. For example, both types were measured at Holy Cross Church at Keyenburg, Germany.[29] The temperature for the external system was found to range from -5°C to 30°C. The temperature range of the internal system was not only found to be less; it ranged from +5°C to 30°C, but, more importantly, it did not fall as low. The internally ventilated system kept the temperature of the glass 10 degrees warmer when the outside temperature was at its coldest.

Condensation

Condensation will sometimes still form on the historic glass with an externally ventilated system. It is the assessment of an international research project dedicated to recording medieval stained glass (Corpus Vitrearum Medii Aevi) that: "All the externally ventilated systems could be classified as inferior to the internally ventilated ones from the data collected in situ, using the frequency with which condensation formed as the criterion."[30] However, the research also showed that the occasions where condensation formed were far fewer and for much briefer amounts of time than would have been the case if the glass was unprotected altogether.[31]





Externally ventilated environmental protective glazing

Weather Protection

No matter which EPG system is used, placing protective glazing as an external barrier in front of the stained glass will prevent direct rainfall and wind loading from damaging or further corroding the external surface of the stained glass. However, if the EPG is ventilated to the outside, there is still a risk of some wind and some wind-driven rain entering via the vents. An internally ventilated system, therefore, offers more complete protection from the weather.

Pollution

Outside air is generally more polluted than the internal air, so external ventilation may not reduce the effect of pollutants on the outer historic glass surface to the same extent as an internally vented system. A European research project, VIDRIO, found that while NO_2 levels were similar with both systems, SO_2 and O_3 levels were lower with an internally ventilated system.[32]

Factors which reduce the performance of EPG.

Whether it is an internally ventilated or an externally ventilated system, it is essential to ventilate the interspace between the two layers of glazing sufficiently to minimise the occurrence of moisture. The buffering of the temperature in the interspace depth will not work correctly if either the interspace is not wide enough or it the ventilation slits top and bottom are not large enough. This was demonstrated at Cologne Cathedral, where the effectiveness of the EPG system was measured after various increases in the size of the ventilation slits. The tendency for condensation to form overall fell from 12% to 4% as the ventilation slits were enlarged; however, there was an optimum (2cm) beyond which there was no further benefit.[33] The VIDRIO research project comparing Saint Urbain Basilica in Troyes with Paris and Cologne found an interspace gap of 7 to 8cm performed better than a smaller 3cm gap.

The gap ventilation will also not work properly if stone tracery, historic ferramenta and modern metalwork support or deformation of the historic glass panels restrict the airflow. It will also only work properly if the vents are well designed and sized.

The effectiveness of EPG is affected by the environmental conditions within the building itself. These can include water ingress or a poor heating system.

The building environment must be in reasonable condition for EPG to prevent condensation damage to stained glass completely. European research showed that EPG was less effective in churches with a high relative humidity.[34] It, therefore, cannot be seen as a way of avoiding the need to deal with problems of the building use or envelope that result in a high background humidity.

There is a concern that direct solar radiation may create high summer temperatures that give rise to a 'greenhouse effect' within the cavity of the protective glazing. However, studies by Bernardi et al.[35] suggest that protective glazing reduces glass deterioration due to thermal shocks and heating events. Their results also showed that the unprotected glass was subjected to more rapid temperature changes than the protected glass. These temperature changes were both more frequent and more intense. Studies on the 12th-century South Oculus at Canterbury Cathedral[36] (a south-facing window set high on the southwest transept) similarly suggest that internally ventilated protective glazing did not increase temperature over the unprotected control glass. The authors of this research suggest this is due to the interrelationship between temperature and the speed of airflow, namely, "as the temperature increased, so did the buoyancy of the air, increasing airflow and speed, thus cooling the historic glass and countering cumulative heating."

Ways to mitigate the detrimental appearance of protective glazing systems.

The installation of external protective glazing is a major intervention in a building. On the outside, with any of the systems, the flatness of the new protective glass can significantly alter the view of the window. If it is necessary to reposition the historical stained glass inwards, this will obscure the profiles of the stone framework on the interior.

There have been different approaches to mitigate the problem of the exterior view. In Germany, many historical windows are fitted with protective glazing consisting of hand-blown window glass (known as 'Goethe glass'). These slight irregularities break up the flatness of the glass.

Another German approach has been to fit protective glazing panels that have rectilinear patterned leadwork, which subdivide the protective glazing. However, leadwork casts shadows on the original stained glass.

Some protective glass has been given a matt finish, but the success of this is variable dependent on the angle of view. From some viewpoints, it can appear opaque.

A French approach, such as that used at Tours Cathedral, was to make a mould of the external surface of the original leaded glazing and create the protective glass from this mould with all the irregularities of the original medieval panel. The exterior surface of the protective panel was then painted with various colours of the original stained glass. The painted-on colours, however, slightly reduced the amount of light coming through and so altered the appearance of the original stained glass.

A Woven-wire grille will disguise the flat protective glazing behind it. It can be a possible solution where this has been used historically to protect from vandalism.

Cheaper window glass is a good solution.
It has the advantage of naturally occurring irregularities and allows the maximum possible transmission of light at a low cost.

Some consider the intervention of modern float glass to be more appropriate as it allows clear differentiation of old from new. However, if this approach is taken, it is better that the glass is fitted within stone tracery rather than in front of it, where it will obscure the historic stonework to a much lesser degree. None of these approaches are perfect, and the impact on the building must be weighed against the importance of preserving historical stained and painted glass.

Deeply in set the protective Glazing –
St Columb's cathedral Derry/Londonderry

St Columb's cathedral Derry/Londonderry - The protective glazing is inset deeply;
this results in considerably less impact on the overall aesthetic of the building.

Maintenance of EPG systems

Inspection is recommended every five years. It should include a visual inspection of the interspace from the outside and an internal check to ensure that the air vents are not blocked and that the drainage of the condensation trays is flowing freely. The design of the EPG should allow for easy access, with the fixings robust enough to withstand periodic removal and re-installation. Qualified conservators should undertake the temporary removal of glazing and the cleaning of historic stained glass.

Where to find more information on EPG

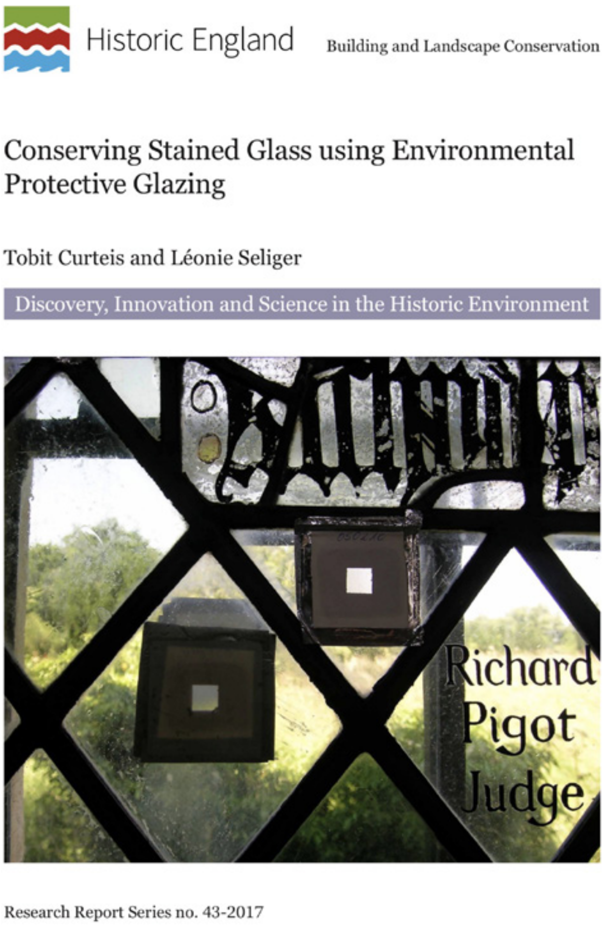
Prominent sources for more detailed information on stained glass and its preservation include Corpus Vitrearum Medii Aevi and Historic England.

Corpus Vitrearum Medii Aevi is an international body focused on stained glass. Considerable research has been conducted in Europe in the later part of the 20th Century. CVMA has translated key research documents, originally published in German, into English and made these available on their website. This includes research conducted on many cathedrals such as Erfurt, Augsburg, Cologne, and Altenburg, as well as many churches, Holy Cross Keyenburg, Kloster Neuendorf, and Kloster Weinhausen, to name just a few.

Historic England is regularly consulted regarding EPG systems. It has had to balance the merits and justifications of environmental protective glazing systems against the aesthetic impact that such a system will inevitably have on the building. To this end, they set up the EPG Research Programme in 2011 to understand the critical features of EPG systems—an important research report by Tobit Curteis and Léonie Seliger, published in 2019[37] summarises much of this work. The aim of the study was to draw together the current understanding of the effect of environmental protective glazing through an extensive literature review and consultation with practitioners, to understand the implications of different designs and arrive at a set of protocols by which judgements could be made as to the advantages and disadvantages of a particular protective glazing installation.

The study contains not only an extensive literature review of previous European research but also English case studies - Canterbury Cathedral, Long Melford, Lincoln Cathedral, The Vyne, Mary and St Barlok's Church, and King's College Chapel.

It is worth noting that: "The research confirmed that both internally and externally ventilated EPG systems do indeed afford stained glass considerable protection from wind, rainfall, and pollution. Almost all systems examined also significantly improved thermal buffering, reducing the risk of condensation on the internal surfaces. Internal ventilation was the most effective option, but externally ventilated systems still gave useful benefits."


Historic England Building and Landscape Conservation

Conserving Stained Glass using Environmental Protective Glazing

Tobit Curteis and Léonie Seliger

Discovery, Innovation and Science in the Historic Environment

Research Report Series no. 43-2017

A summary of the pros and cons of environmental protective glazing

There are advantages and disadvantages to all types of EPG systems, including both kinds of internally ventilated systems. These are usefully summarised in a table by Tobit Curteis and Léonie Seliger in their Historic England Report[38]. The table is partly reproduced in Appendix 3. Therefore, the precise details of every installation will depend on the building and the configuration of the protected window.

While an EPG system can have many benefits, it can also harm the appreciation of stained glass from both inside and outside the building and even more strongly the appearance of the building itself. The persistence of this tension demands that an owner consider individually the heritage significance of the glass, the window, the building, and the setting. There may be some instances where glass is especially rare, so its heritage value outweighs the significance of the building itself.

If, after a holistic assessment, a decision is taken to use an EPG system, the appropriateness of the design must be considered on a case-by-case basis. The solution may even vary for different windows in the same building. By devoting enough time and care to the design, it is possible to resolve technical and aesthetic problems and arrive at the most suitable solution. However, it is worth bearing in mind the conclusion of Historic England's extensive research report maintains that it is always necessary to strike a balance between conservation need and aesthetic impact and 'If an EPG system cannot be made aesthetically acceptable without undermining its ability to protect the stained glass, then it should not be installed.'[39]

Listed Building Consent is required for any EPG system and HED assesses each application on a case-by-case basis.

Other types of protective glazing

Sealed systems

Sealed systems have no ventilation between the protective glazing and the original glass; the protective glazing is sealed to the window reveal. While this effectively decreases heat transfer through windows, there is a serious risk of condensation. Such systems have been used locally in the past but are not recommended.

Stained glass sandwiched in between modern glass.

Some window manufacturers offer a service to encapsulate stained glass inside a double-glazed unit. However, this technique does not provide ventilation and is not advisable for historic glass or use on a listed building.

Storm glazing

Storm glazing is a term used to describe an externally mounted secondary glazing system intended primarily to protect historic glass from impact. Impact can be from high winds or vandalism. The system is not intended to provide environmental protection beyond protection from wind. However, any externally mounted, secondary glazing system ventilated to the outside may inadvertently provide environmental protection in the same way as an externally ventilated Environmental Protection System.

On a listed Building, Consent is required for storm glazing, and the Historic Environment Division will need to consider each situation on a case-by-case basis. Sometimes, it may be permitted as a reversible holding operation for windows in poor condition.

Like EPG, storm glazing can be visually intrusive externally. Stained glass windows are non-reflective and generally appear dark in the overall architectural composition of a building as viewed from the outside, whereas storm glass is often highly reflective. For windows with tracery, as with EPG, better results can be achieved by fitting the glass within the individual openings so that all the stonework elements remain visible rather than covering the entire window opening.

However, if laminate glass has been used, it is challenging to cut laminate glass to fit into complicated-shaped heads or tracery. Laminate glass is often used where the primary purpose is to prevent vandalism.

Where storm glazing is permitted, it is essential to allow a gap between the secondary glazing and the historic window with ventilation in the form of a continuous gap around the perimeter edge to avoid decay or erosion of fabric.

It is essential to ensure insects and plants do not colonise the space. Therefore, the system should be easy to remove for cleaning and maintenance; some systems hinge and others unscrew.

In the past, storm glazing used polycarbonate, but as this can be prone to scrapes and discolouration, true glass is a more sensitive and effective solution in the long term. The sensitive choice of paint colour for the frame to minimise visual impact is advised.

Regulations

Listed buildings

Works of alteration that will affect the character of a listed building as a building of special architectural or historic interest will require Listed Building Consent. This application will be made to the local council, and HED must be consulted.

Section 85 of The Planning Act (NI) 2011 provides the legislative requirement for Listed Building Consent when changes to a listed building are proposed. Owners can refer to Guidance on making changes to Listed Building: Making a better application for listed building consent and other HED guidance for advice.

Scheduled monuments

Under the Historic Monuments and Archaeological Objects Order 1995, Scheduled monument consent is required from HED for works in a scheduled area, regardless of whether planning permission or other permissions have been sought or obtained. Further information can be found in the document Historic Environment Division Scheduled Monument Consent, which can be found at **Historic Environment Division Scheduled Monument Consent | Department for Communities (communities-ni.gov.uk)**

Building control

Building Control regulations may require the replacement of a building element, such as a window, to comply with Building Regulation requirements. However, article 3A of the NI Building Regulations provides that 'special consideration must be given by local authorities where changes would unacceptably alter the essential character of a protected building'.[40] It is therefore important to discuss any proposed changes with both HED and Building Control to ensure the special interest of the building is protected.

Appendix 1

Historic Environment Scotland – Window Condition Checklist

Sash and Case Window Inspection Checklist

Window No. Date Your name

Condition of window

Defect	Tick if present	Notes – *add any extra information eg precise location, severity of defect*
Visible defects:		
Visible gap at cill		
Gaps leading to draughts		
Meeting rails not level		
Joints in sashes opening up		
Broken sash cords		
Broken or cracked glass		
Flaking or missing paint		
Timber missing or damaged		
Worn sides to sashes		
Evidence of previous repairs, including metal strengthening angles		
Missing or defective glazing putty		
Missing or defective external mastic at junctions between window and wall		
Missing or defective cill bedding mortar		
Hidden defects:		
Sash(es) drop or rise of their own accord when left unfastened or 'drift' out of position when open.		
Timber decay in cill		
Timber decay in parting beads		
Timber decay in sash frame		
Timber decay in hidden parts of case joinery		
Debris in weight pockets		
Other defects:		
Shutters will not open		
Shutters open with difficulty		
Split panels to shutters or lining		
Timber decay to shutters or lining		
Damp plaster in window recess or behind shutters		
Structural opening defects or distortion		

General Comments
Note any extra information you consider relevant eg timber profiles, type of ironmongery, type of glass, type of sash cord etc.

Appendix 2

Historic Scotland – Guide table to specifying repairs.

Guide to specifying repairs

The following table relates the defects that you may have identified during inspection to their probable causes and to the suggested repair to remedy them.

Defect	Probable cause	Suggested repair
Visible defects:		
Visible gap at cill	Twisted outer case or weights being prevented from performing full travel in weight box	Check and free snagged weights. Remove lower sash and piece in additional timber to bottom rail
Gaps leading to draughts		Consider installation of draughtstripping (see upgrading section that follows)
Meeting rails not level	Twisted, warped or excessively worn sashes	Check and replace sash cords. Remove both sashes and piece in new timbers to each side to square up sashes
Joints in sashes opening up, showing through paint finish	Mortices snapped or being eased apart, due to excessive force in use	Glue, wedge and clamp the joint. Or strengthen sash by adding non ferrous metal angle plates across corners. Or take out glass from sash; take apart the sash frame members (identify any wedges or dowels and remove these before carefully easing apart the sash rails and stiles by gentle tapping with a hammer against a wood block placed inside the frame near to the joints; any glued joints can be released by the application of steam) and piece in new timbers at ends with new mortices and/or tenons. Old loose dowels should be carefully driven out and new dowels glued into place
Broken sash cords	Wear and tear in old cords. If new cords broken may be due to under-sizing of cord for heavy sashes, or cord snagging on pulley wheel	Take out sashes and weigh them to ensure correct weights. Replace weights or amend as necessary. Renew sash cord. Check sash pulleys free from defects
Broken or cracked glass	External accidental damage or vandalism. Small diagonal cracks in corners often indicate distortion in sash frame	Small corner cracks in original valuable glass will probably be acceptable. For more serious breaks, remove broken glass without damaging timbers and re-glaze as necessary
Flaking or missing paint	Deterioration of old paint system, or may indicate excess moisture levels in under-lying timber	Check moisture levels in timber and correct associated defects. Remove loose paint layers back to a sound base, prepare and re-paint windows using an appropriate paint system
Badly worn and grooved sash stile timber allowing sash to move too freely	Wear and tear erosion of surface as sash is slid up and down – aggravated by projecting lumps and bumps on running surfaces and often by contact with projecting simplex hinges knuckles	Scrape and sand back any projecting timber or paint build up on the surfaces of the pulley stiles, parting beads and batten rods to ensure running surfaces are smooth. Adjust simplex hinge positions knuckles so that they do not project. Move baton rods closer to sash to reduce lateral movement. Make good grooves in sash with a proprietary filler. Where wear is very severe, sashes may require to be re-edged
Timber missing or damaged from any member	May be due to localised decay (e.g. in cills), but elsewhere is likely to be as a result of physical impact damage (e.g. external part of glazing bars split due to careless removal of old putty from the glazing bar check)	Piece in new timber. Decayed timber should be cut out (first removing glass if necessary), and replaced with matching sections. For glazing bar repairs, piecing in missing part is unlikely to be successful over anything other than a short length. In which case, full bar should be replaced
Evidence of previous repairs, including metal strengthening angles	Often metal angles are used to secure broken mortice joints in sashes	No work may be necessary. Metal angles may continue to perform their function. If necessary replace by re-making mortices as described above as the final suggested repair for 'Joints in sashes opening up'

Guide to specifying repairs

The following table relates the defects that you may have identified during inspection to their probable causes and to the suggested repair to remedy them.

Defect	Probable cause	Suggested repair
Visible defects:		
Visible gap at cill	Twisted outer case or weights being prevented from performing full travel in weight box	Check and free snagged weights. Remove lower sash and piece in additional timber to bottom rail
Gaps leading to draughts		Consider installation of draughtstripping (see upgrading section that follows)
Meeting rails not level	Twisted, warped or excessively worn sashes	Check and replace sash cords. Remove both sashes and piece in new timbers to each side to square up sashes
Joints in sashes opening up, showing through paint finish	Mortices snapped or being eased apart, due to excessive force in use	Glue, wedge and clamp the joint. Or strengthen sash by adding non ferrous metal angle plates across corners. Or take out glass from sash; take apart the sash frame members (identify any wedges or dowels and remove these before carefully easing apart the sash rails and stiles by gentle tapping with a hammer against a wood block placed inside the frame near to the joints; any glued joints can be released by the application of steam) and piece in new timbers at ends with new mortices and/or tenons. Old loose dowels should be carefully driven out and new dowels glued into place
Broken sash cords	Wear and tear in old cords. If new cords broken may be due to under-sizing of cord for heavy sashes, or cord snagging on pulley wheel	Take out sashes and weigh them to ensure correct weights. Replace weights or amend as necessary. Renew sash cord. Check sash pulleys free from defects
Broken or cracked glass	External accidental damage or vandalism. Small diagonal cracks in corners often indicate distortion in sash frame	Small corner cracks in original valuable glass will probably be acceptable. For more serious breaks, remove broken glass without damaging timbers and re-glaze as necessary
Flaking or missing paint	Deterioration of old paint system, or may indicate excess moisture levels in under-lying timber	Check moisture levels in timber and correct associated defects. Remove loose paint layers back to a sound base, prepare and re-paint windows using an appropriate paint system
Badly worn and grooved sash stile timber allowing sash to move too freely	Wear and tear erosion of surface as sash is slid up and down – aggravated by projecting lumps and bumps on running surfaces and often by contact with projecting simplex hinges knuckles	Scrape and sand back any projecting timber or paint build up on the surfaces of the pulley stiles, parting beads and batten rods to ensure running surfaces are smooth. Adjust simplex hinge positions knuckles so that they do not project. Move baton rods closer to sash to reduce lateral movement. Make good grooves in sash with a proprietary filler. Where wear is very severe, sashes may require to be re-edged
Timber missing or damaged from any member	May be due to localised decay (e.g. in cills), but elsewhere is likely to be as a result of physical impact damage (e.g. external part of glazing bars split due to careless removal of old putty from the glazing bar check)	Piece in new timber. Decayed timber should be cut out (first removing glass if necessary), and replaced with matching sections. For glazing bar repairs, piecing in missing part is unlikely to be successful over anything other than a short length. In which case, full bar should be replaced
Evidence of previous repairs, including metal strengthening angles	Often metal angles are used to secure broken mortice joints in sashes	No work may be necessary. Metal angles may continue to perform their function. If necessary replace by re-making mortices as described above as the final suggested repair for 'Joints in sashes opening up'

Defect	Probable cause	Suggested repair
Other defects:		
Shutters will not open	Shutters may simply be stuck with layers of paint, or nailed shut	Carefully prise open shutters, removing any fixings. Remove excess paint
Shutters open with difficulty	Hinges on shutters may be damaged or require overhauling. Frequently shutters with back flaps suffer from distortion, causing parts to catch on the surrounding joinery during operation. This could also be caused by distortion of the structural opening, de-pressing the soffit linings and causing the shutter to snag (see 'Structural opening defects' below)	Take off and set aside shutters, check dimensions. Rectify external causes of deflection where possible. Reinstate shutters, 'easing' as required
Split panels to shutters or panelled lining	May be due to changes in moisture levels in timber	Fill very wide cracks with slivers of timber and sand smooth. Normal cracks should be filled with filler prior to redecoration
Timber decay to shutters or panelled lining	Likely to be the result of some external building defect, or of a change of internal environmental conditions	Remedy external sources of moisture. Carefully dismantle and set aside decayed components. Check window case joinery is sound before repairing and reinstating linings
Damp plaster in window recess or behind shutters	Lack of ventilation can cause minor efflorescence on plaster, but more significant moisture is likely to be the result of some external building defect, or of a change of internal environmental conditions	Remedy external sources of moisture. Remove defective plaster. Ensure adjacent timbers are dry, and fixings securing window are sound before replacing plaster
Structural opening defects or distortion	There may be evidence of historic movement, due to settlement or changes in ground or support conditions, but recent movement may be due to ongoing problems, such as decaying timber safe lintels	Employ an engineer to investigate causes of deflection, using non-destructive techniques where possible. Once any structural defect is remedied, window case joinery should be set plumb, level and square in openings to ensure that sashes can operate correctly

Appendix 3

Advantages and Disadvantages of main EPG systems.

Table 14-1. Considerations when choosing protective glazing			
ARCHITECTURAL CONSIDERATIONS	New external mounting of protecting glazing (internally ventilated system)	Stained glass can remain in original glazing grooves No internal fixings required, hence no changes to the internal window reveals	External reveal depth around windows reduced. External fixings can be visible Vents must be created on internal stained glass (can be less effective due to smaller size and uneven distribution). Creating a reliable weather tight setting for the external glazing is difficult without a glazing groove Air and water leaks into the interspace are possible
	New external mounting of protective glazing (externally ventilated system)	Stained glass can remain in original glazing grooves No internal fixings required, hence no changes to the internal window reveals No changes to the historic glazing to accommodate ventilation slots	External reveal depth around windows reduced External fixings can be visible Vents in the external glazing provide access for wind-driven rain which can cause new corrosion damages Thermal buffering is not as efficient as internally ventilated systems Creating a reliable weather tight setting for the external glazing is difficult without a glazing groove Air and water leaks into the interspace are likely
	Protective glazing mounted in original grooves and historic stained glass moved forward internally (internally ventilated, isothermal system)	Original architectural reveal depth at window is preserved externally Ensures ornate tracery is visible externally Easier to create good vent sizes and locate them at the top and bottom of the stained glass panel	Changes internal aspect of window rebate Can lead to halo effect around historic glass unless skirts (or wider frames) are provided Mounting frame visible on low windows Where historic window furniture such as ferramenta remain in position, the historic glazing and the historic ferramenta will be divorced

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Available in alternative formats.

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