Historic England

Stained Glass Windows

Managing Environmental Deterioration

Summary

This Historic England guidance note is aimed at building owners and managers caring for stained glass windows, but it will also be of interest to their professional advisors, and to conservation officers, diocesan advisors and other statutory authorities. It is intended to help readers recognise the symptoms that indicate a decorative window might be suffering from environmental deterioration, and to understand and alleviate the impacts this may be having on the stained glass.

The document is not a complete guide to the deterioration of stained glass (the complexity of which demands the expertise of an experienced accredited stained glass conservator), but instead outlines in general terms the process of making decisions about the conservation of stained glass in danger of environmental deterioration. It explains how internal and external environmental conditions can damage decorative windows, and gives pointers for determining whether a window requires specialist attention.

The benefits of good building maintenance and repair are the first consideration in the preservation of stained glass, and for all historic building conservation. This may still be insufficient to arrest deterioration to a level that accords with the significance of the glass, however, so the document presents a number of specific interventions, most notably Environmental Protective Glazing (EPG). Detailed information is given about the use and detailing of EPG, based on research undertaken by Historic England. It should be read alongside the Historic England Research Report 43/2017, Conserving Stained Glass Using Environmental Protective Glazing.

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Front cover: Exposure to the building environment is the major cause of stained glass deterioration. Here, moisture has led to the flaking and loss of painted decoration. (© Tobit Curteis Associates)

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Introduction

As well as being works of art in their own right, stained glass windows are critical to the appreciation of any building fortunate enough to be decorated with them. Seen as they were intended, from the interior in sunlight, they glow and cast patterns of light and colour onto the walls and floor. Their impact on the exterior is scarcely less important, though. The glitter of a multitude of glass facets ornaments the façade, and when the building is lit at night the colours and patterns of the glass are visible to passers-by.

Stained glass is not just beautiful. For many centuries, it has been a vital way of decorating prestigious public buildings, and historians can learn a great deal about a building's past from it. In medieval churches, cathedrals and palaces, stained glass may be the only significant survivor of elaborate schemes of decoration that once incorporated wall paintings, painted sculpture, woodcarvings and tapestries as well as glass. Windows may record patronage with portraits or inscriptions, and subject matter may be a clue to how the building was once used. This role continues to the present day, with stained glass remaining a favourite choice for patrons wishing to commemorate important events or people.

Because of its nature, however, the survival of stained glass can be precarious. Windows are a critical but sensitive part of the building 'envelope' – the skin that separates the interior from the exterior – and as such are particularly vulnerable to environmental deterioration.

This document is intended to help the custodians of buildings with stained glass windows to understand the nature and causes of environmental deterioration, and to assess options for reducing or preventing damage (including the installation of Environmental Protective Glazing). It should be read alongside the Historic England Research Report 43/2017, Conserving Stained Glass Using Environmental Protective Glazing.

Figures 1–2: King's College Chapel, Cambridge. Decorative glazing is not only beautiful from the interior, but also contributes greatly to the exterior views of the building. During the day, the reflections from the many small panes of glass shimmer and sparkle as the viewer moves (top); at night, when lit from within, the windows glow with colour (bottom).

What is 'stained glass'?

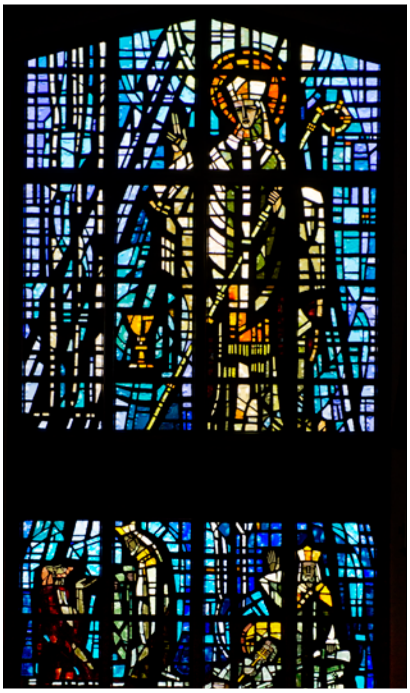
To understand how and why decorative glass might deteriorate, it helps to understand a little about how it was made.

Over many centuries, glaziers have developed an enormous range of techniques and materials for producing decorative windows, but by far the most common is the familiar 'stained glass' system first developed in medieval Europe. Small pieces of thin glass coloured by metallic oxides are decorated with various translucent and opaque coatings and paints, which are either fired onto the glass in a kiln, or (very rarely) applied 'cold'. The decorated pieces are then joined together to make panels by being slotted into 'cames' or 'calmes' (strips of soft metal – usually lead – cast or milled to make an 'H' in cross section). The cames are then soldered together to form a panel. The matrix of lead is not merely functional, but a critical part of the design. Since at least the 16th century, special 'lead-light' cements have been used to stop rainwater penetrating the finished window.

The completed panels are slotted into a 'glazing groove' cut into the window frame and tracery, which are most often stone. They are usually supported and made more resistant to wind by fastening them to metal support bars. The tracery and metal supports are also a critical element of the design.

Stained glass is not the only means of producing a decorative window; others include etching, engraving or 'fritting'. One of the most important alternative methods is *dalle-de-verre*, where thick pieces of glass are set directly into a matrix of resin or concrete. This technique was used to form some of the most dramatic and important stained glass in the periods before and immediately after World War II, but as with all innovative systems, it can sometimes present serious conservation challenges. More tricky still to preserve are windows incorporating fibreglass, or even plastic.

Figures 3–5: A wide range of techniques and materials are used to make decorative windows.
Left: London St Etheldreda (Charles Blakeman).
By far the most common variant is traditional stained glass, where small pieces of coloured and painted glass are held in a lead matrix that is both functional and decorative.
Middle: St Richard's Church, Chichester (Gabriel Loire).
In the period following World War II, *dalle-de-verre* windows became popular, particularly for ecclesiastical buildings.
Right: All Saints Church, Bristol (John Piper).
More rarely, windows have been made from other transparent materials, such as fibreglass.



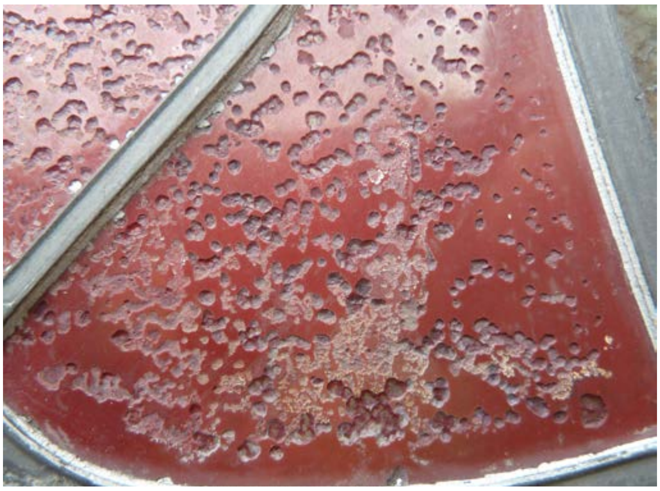
Environmental deterioration

Whatever the technique used to produce them, decorative windows share one critical feature: they are an intrinsic part of the envelope of the building, which protects the interior spaces from the weather, keeping out the rain, wind and sun, modifying the extremes of the external temperature and air humidity, and retaining the interior air that may have been heated or cooled for the building's users.

This functional role places enormous demands on the glazing. Windows are the most fragile and least massive part of the envelope, and as such are particularly sensitive to the weather and changing temperatures. It is little surprise to discover that environmental deterioration is a primary cause of failure for stained glass windows.

Figure 6: Dover Castle. Stained glass windows are a beautiful, yet vulnerable, part of the building envelope.




Figures 7–11: Sources of moisture.
Since glass, metal and glazing cements are all impermeable, rain hitting a stained glass window will run down, collecting into a flow that will then be quickly drawn in through any open joints or fine cracks (top left). Traditional building detailing (such as string courses and hood mouldings) were developed alongside glazing to divert rainwater running down the façade, reducing the amount of water reaching the glass (top right).
Glass and metal both transfer heat very easily, so when glazing is cooled by the wind and outdoor temperatures, it can easily lead to condensation on the interior of the window, especially if the building is damp (middle left). Whatever its source, water is critical to many types of deterioration, including pollutant attack, microbial growth, corrosion of the glass and the lead matrix (bottom left), and corrosion of metal components such as iron ferramenta and unprotected grilles. Rust can severely damage the stone in which the corroding iron is embedded (bottom right).

Much of this deterioration is either caused, or exacerbated, by moisture.

On the exterior, rain will beat on the windows. In itself, this may not be a problem: for glazing in good condition it can even be beneficial, helping to remove dirt and pollutants. If the glass is chemically unstable, though, it can initiate corrosion, and if there are any cracks or poorly sealed joints, the rainwater can be wicked through into the interior.

If rainwater is able to penetrate around the ends of any supporting ironwork set into the window surrounds or mullions, the iron may start to corrode and expand, causing 'rust-jacking', which can easily break apart the stone. Some *dalle-de-verre* windows incorporate embedded iron reinforcing bars, putting them also at risk of corrosion cracking. Any timber components (such as frames) will begin to decay if they remain wet for prolonged periods.

On the interior, water vapour condensing on the cool window surface can initiate glass corrosion, and also damage fragile painted decoration. If the air inside the building is very damp, enough condensate may form that it begins to run down the window and into the wall beneath, causing moisture problems. This is exacerbated by poorly designed space heating systems or regimes. Rapid heating of the air will sharply reduce the relative humidity, drawing moisture out from the walls and furniture; this then condenses onto the windows when the heating is turned off.

Wind will push inwards on glazing on the windward side of the building, and pull outwards on glazing on the lee side. Pressures will fluctuate, and can increase suddenly; the stresses that this produces can permanently distort the lead matrix, or even break the ties attaching the glazing to the ferramenta or saddle bars (allowing the glazing to sag or even collapse).

Wind exposure may change over the lifetime of a building, whenever the surrounding landscape is altered. This can prove especially challenging in urban areas, where the construction of tall buildings can significantly change established wind patterns. Stained glass that has survived for centuries may then begin to fail.

Glass is brittle and very susceptible to being damaged by projectiles (whether these are thrown by the wind, by accident or deliberately). This risk is usually managed by adding protective screens, most commonly metal grilles. Well designed and made of water-resistant materials such as powder-coated stainless steel set into the tracery, grilles will be very effective against larger missiles, and may be quite inconspicuous. If poorly made or designed, however, they can be both ugly and ineffective, trapping debris such as leaves and causing corrosion staining of the stone beneath the window. Wire grilles cannot protect against air-gun pellets or small pebbles, and the pattern of parallel lines can seriously disturb the view of the stained glass from the interior.

Some windows incorporate original opening elements; if these are regularly used for ventilation, though, there is a risk they will be opened when the exterior conditions are unsuitable. This may well increase the relative humidity of the indoor air, exacerbating corrosion.

Sunlight, too, has many impacts on windows. These include local heating of the glass and metal, which causes them both to expand, but to different degrees. For most traditional windows, this does not cause serious problems (the exception being windows set into metal), but it can be a worrying issue for *dalle-de-verre*. Solar heating also accelerates chemical reactions, worsening problems such as glass corrosion. The ultraviolet wavelengths of sunlight can cause the embrittlement and yellowing of components made from plastics, mastics and resins, be they part of the original design or materials added during repair.

One of the most visible environmental problems is the deposition of dirt and pollutants, which decreases the legibility of the window. Dirt also provides a perfect substrate for the growth of mosses and algae, which can trap condensation and rainwater against the glass, further accelerating corrosion.

Windows are often dirtiest on the interior, where the surfaces cannot be cleaned by the rain or wind. Candles, oil lamps and other open-flame light sources (common in churches) produce soot, and early combustion heating systems pumped out pollutants such as carbon dust and sulphates. If these are dissolved in condensation water, they can form aggressive chemical solutions able to attack not only the applied decoration, but also the glass itself. Although the coal-fired stoves that caused the worst problems have now all but disappeared, the damage they caused may endure.

Vulnerability to environmental deterioration depends on the window: well-executed glazing with well-made glass and well-fired paint can survive centuries in almost perfect condition. Other glazing may be much more likely to deteriorate. For example, in some Victorian stained glass, the oxide paints were not correctly made, applied or fired; those windows are, therefore, less able to withstand condensation or careless cleaning. The fashion for experimental glazing techniques in the 20th century – especially those based on plastics and resins – produced windows that can deteriorate in unique ways, presenting serious challenges for skilled conservators.

For more information about the manufacture and deterioration of all forms of decorative architectural glass, see the Glass & Glazing volume in Historic England's *Practical Building Conservation* series.

1 Identifying problems

To assess how a decorative window may be affected by environmental deterioration, it is vital to look beyond the window itself: almost all deterioration will have been caused or exacerbated by the environmental conditions. This means developing a working knowledge of the interactions between the building and its environment. Factors that need to be taken into consideration include the nature and condition of the building fabric, the type of surroundings and local weather, and the building's use (including how and when it is being heated or cooled). Assessment may have two stages:

- **Initial evaluation**
  This enables everyone involved to agree in general terms what it is they are dealing with. It incorporates an assessment of significance, and also a basic assessment of condition.

- **Specialist evaluation**
  This stage is required if the initial identification fails to pin down the problem, or discovers that it is complex and hard to resolve.

Where the stained glass is suffering from poor environmental conditions, it is sensible to begin by addressing the major environmental issues with the building, such as maintenance problems, inappropriate heating systems or unsuitable controls on heating systems. Dealing with these may not make direct intervention on fragile stained glass unnecessary, but it will improve the chances of any interventions being able to ameliorate ongoing deterioration. It will also pay benefits in building usability and the conservation of the other parts of the building fabric and contents.

It is important to be aware, however, that even after building repairs, high humidities may take months or occasionally years to stabilise. Therefore, even if environmental improvements are underway, where the stained glass is actively deteriorating it is wise not to put off intervening to conserve it (there is no need to wait until the building stabilises).

It is not difficult to get to the bottom of most building moisture problems: most will be due to simple maintenance issues (such as gutter and downpipe failures, blocked drains or leaking plumbing), often exacerbated by repairs made using unsuitable materials (such as cement-based renders). These issues can be identified and improved easily, and their remediation will immediately reduce the key causes of condensation and corrosion.

If the environmental problems are a little more wide-ranging or complicated, it is wise to ask an experienced conservation architect/surveyor to survey the building (*see* Appendix for information about where to find accredited professionals). For most moisture problems, they will be able to identify the causes and develop remediation plans. They should also be able to project-manage any further assessment and remediation that might be required, including guiding building custodians through the processes of obtaining permissions for remedial works and finding potential sources of funding.

An architect/surveyor should also be able to make a basic assessment of the windows, noting any obvious problems such as damage to the stonework. However, it is worth bearing in mind that only the most simple and cursory assessment of stained glass is possible from ground level. Even serious problems such as severe glass corrosion may be difficult to see without closer access from a scaffold or other raised platform.

To help guide this basic assessment, Historic England has produced a checklist for architect/surveyors. We also strongly recommend that you follow the standard Corpus Vitrearum Medii Aevi (CVMA) numbering system (*see* Appendix), as this avoids confusion when you are describing the locations of particular windows and glazed panes in windows.

The deterioration of stained glass is very complex, so if you and your surveyor agree that there is some cause for concern, the first step will be to bring in an experienced and accredited stained glass conservator. As well as identifying and interpreting deterioration, the conservator should be able to tell you the underlying cause or causes (including any inherent weaknesses in the window), and to suggest approaches to remediation. In some cases, the condition assessment may require input from other accredited and experienced conservation specialists, such as stone and ironwork conservators. You should also consider inviting them if you suspect these features of the window may be of particular interest.

The inspecting conservators will probably begin with a ground-level survey, but to make a detailed assessment they will usually need good access (for example, scaffolding or a raised platform, usually on both sides of the window). Therefore, whenever you erect scaffolding on your building for any reason, and it gives access to a window, it may be well worth scheduling in an inspection of that stained glass.

Together, these specialists will be able to help you better understand not only the nature and causes of any problems, but also the historic significance of the window and its components. This can be very important information for obtaining permission for any works you may wish to undertake. How much additional information you will need to be able to develop a conservation programme depends on the complexity and historic significance of the building and the stained glass, and the complexity of the problems. For a very unusual feature, for example, you may need to call on the services of a building archaeologist or historian.

Information different experts can contribute to understanding the window and its condition	
Who	Information they can contribute
Building owner or custodians	Details about the care and repair of the building, currently and historically Details of the care and repair of the stained glass, including any cleaning Observations about the condition of the stained glass Information about the local significance of the building and the windows, including the glass Information about the day-to-day operation of the building, particularly the times and ways it is used, and details about the heating regime
Conservation architect or surveyor	Details about the aesthetic and historic values of the building and window Basic survey of the condition of the building envelope Basic assessment of the condition of the window components (glass, stonework, timberwork, ferramenta, etc), including identification of possible causes of deterioration Technical details of the heating systems and other services Summary of recent history of the fabric and services, highlighting changes that may contribute to the deterioration of the glazing Options for a repair programme to deal with building-level causes of deterioration Management of project to assess and conserve the stained glass, including identification and coordination of specialist advice
Stained glass conservator or consultant	Detailed assessment of the aesthetic, historic and technical values of the window, including significance Inspection of the glazing, and a detailed assessment of its condition Inspection of the window surrounds and ferramenta etc, and a detailed assessment of their condition Review of outcomes of any building environment improvements on the condition of the stained glass Prioritisation of the works identified as necessary during the inspection Options for conservation of the stained glass, including costings
Stone conservator or consultant	Detailed assessment of the significance and state of conservation of the window surrounds and mullions Options for the conservation of deteriorating stonework, including costings
Metal conservator or consultant	Detailed assessment of the significance and condition of the ferramenta or other metal components of the window Options for the conservation of deteriorating metalwork, including costings
Building performance consultant	Detailed assessment of the building environment, focused on impact on the condition of the window (including condition and operation of the building envelope, and impact of building use and services such as heating) If deterioration is very complex and time-dependent, monitoring of the environment to identify drivers of deterioration Options for improving the environment to reduce stained glass deterioration Review of the outcomes of improvements made to the building environment
Building services engineer	In consultation with the architect and/or the building performance specialist, options for microclimate systems and controls to improve the building environment and reduce the deterioration of the window
Specialist historian	Detailed analysis of the history of the window and its components, including an assessment of historic significance

Finally, if environmental problems prove difficult to understand or to resolve (for example, if there are persistent and damaging episodes of condensation, even after building repairs, with no obvious source), you may need to bring in an experienced building performance expert. They will be able to assess the interactions between all aspects of the 'building performance triangle': fabric, use and services such as heating and plumbing. Again, in most cases, they will be able to quickly identify the source of problems, based on an inspection of the building and the way it is being used. In very large or complex buildings, or buildings with complex uses, though, it may sometimes be necessary to undertake more detailed and long-term investigations, such as environmental monitoring.

For more details about environmental assessment, see Historic England's Building Environment volume in the *Practical Building Conservation* series.

1.1 Initial evaluation

The initial evaluation can usually be completed by the custodian working closely with their conservation architect or surveyor, occasionally in consultation with a building archaeologist, and it has two steps:

1. Assessing the heritage significance of the window and its importance to the building.

2. Identifying the major types of deterioration and understanding the window's condition in the context of the building's construction, condition and use.

Figure 12: Buffs Chapel Regimental Window in Canterbury Cathedral. Stained glass windows are often installed as memorials, especially for shared events such as World War I.

Step 1: Assessment of significance

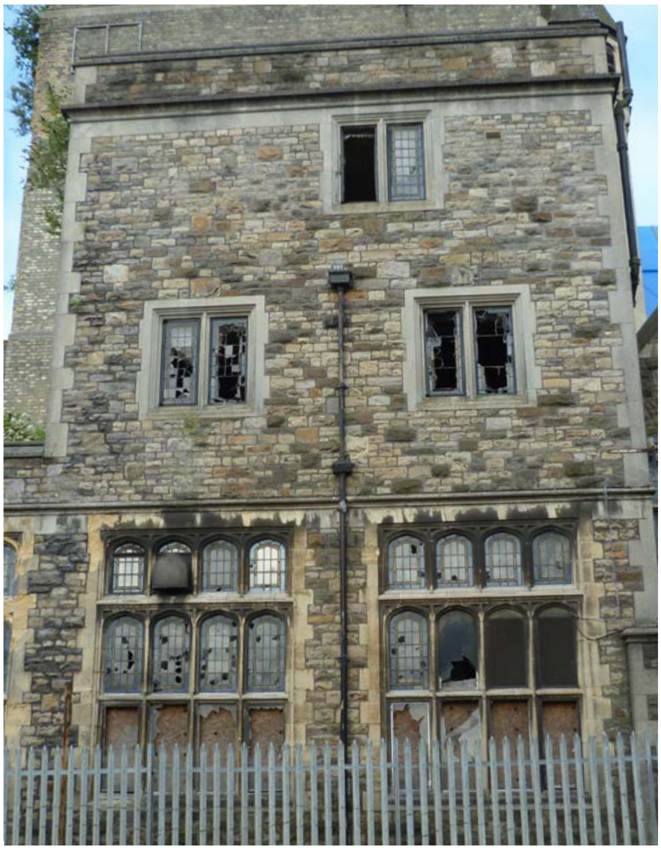
For many historic buildings, this information may already be part of the building record. Questions to address include:

- What is the window's history?
- Does it have any special features? For example, does it incorporate unusual materials or techniques?
- What is its aesthetic importance to the building? For example, from where can it be seen (internally and externally), and how critical is it to those views?
- Are there other factors making the window important? For example, does it commemorate a local event or person, or is it an important example of an artist's work?
- What impact does the community value of the building and/or the window have on their future sustainability?

Step 2: Condition assessment

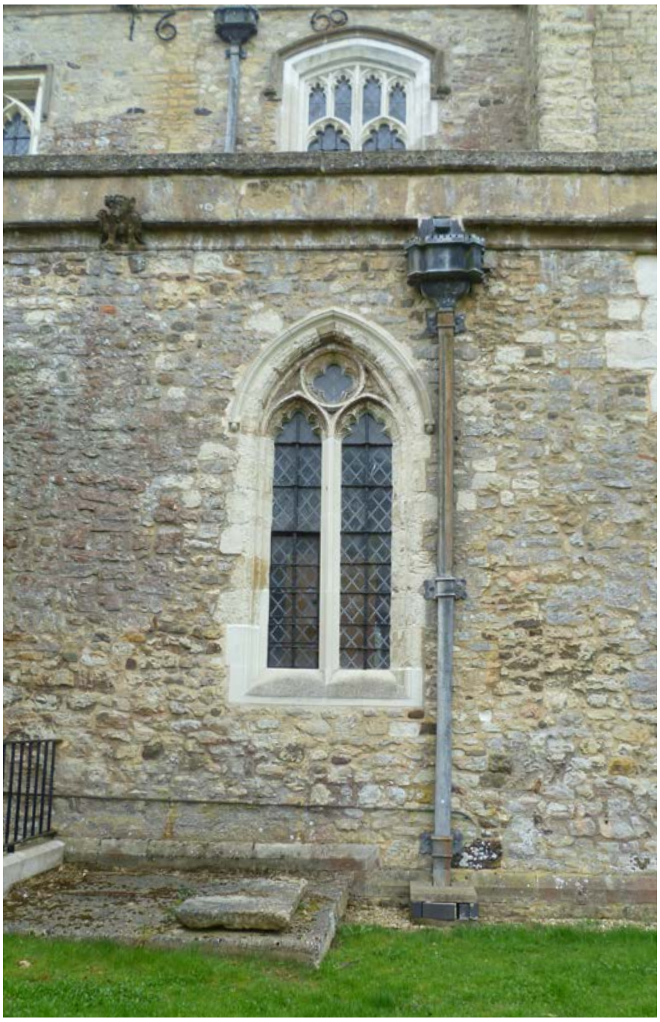
Step 2 begins with a survey of the current condition of both the building and the window. If the building has a recent five-yearly inspection (a 'quinquennial') that explicitly includes a survey of the windows, this would serve this purpose.

Figures 13–14: Risk of physical damage.
The environment around the building may also increase the risk of breakage, which is very serious for glass.
Left: Plants should be kept away from the glass, and nearby trees assessed regularly to ensure there is no risk from branches.
Right: Projectile damage may be the result of mowing or strimming nearby without sufficient care. Deliberate vandalism is a very serious risk in certain locations, and becomes more likely whenever the building does not look sufficiently well cared-for.



The primary aim of the survey of the glazing should be to look for any phenomena that might indicate serious deterioration (and that would require checking by a stained glass conservation specialist). These would include:

- The state of the stonework on the exterior and interior
- The loss or breakage of any lead or copper ties connecting the stained glass to the ferramenta
- Distortion and cracking, or other signs of failure of the lead matrix
- Loss or breakage of glass
- Corrosion and pitting of glass, or visible layers of corrosion product (whether on the exterior or the interior)
- Mould or microbial growth
- Damage to or loss of painted detail on the exterior or interior
- Blocked condensation trays




Figures 15–16: Building maintenance is critical to preserving stained glass. Poor maintenance, including leaking rainwater goods, not only increases the risk of water hitting the exterior of the window (left), but even more importantly greatly increases the risk of condensation on the interior (right).

Using the survey for reference, the following questions should then be answered in the best way possible:

- Are there any general issues with the building that may be affecting the stained glass, such as moisture problems that could be leading to condensation?

- In what general state is the window itself? Is there damage to the stone surround or mullions? Does the ferramenta appear to be in good condition, or are there signs of corrosion?

- In what general state is the glazing itself? Are there obvious problems such as cracked or missing panes, damaged leading, condensation or loss of detail?

- Could the way the building is being used (particularly the cleaning and heating regimes) be contributing to deterioration of the window?

To help you, the table on the following page lists some of the environmental factors that might be affecting the window, together with some of their common signs and symptoms.

The aim of all assessment should be to answer, if possible, one fundamental question: how did the window get to be in its current condition? An important clue is whether damage is ongoing, though it should be borne in mind that deterioration may continue for some time after the underlying causes have been dealt with (for example, by repairing a leaking roof or gutter). It is also vital to keep an open mind, because very different underlying problems can result in symptoms that look much the same.

A useful way of bringing the evidence together is to construct a timeline, including everything you know about the window or the building: events such as repairs or refurbishments, or changes in the heating regime, and observations made about condition. Dates do not need to be accurate; it is usually enough to know the broad order in which things occurred.

For observations of condition, old photographs can be helpful, but they need to be interpreted by an experienced stained glass conservator if they are to be used to evaluate the rate of decay over a particular time period.

Following these steps, and thinking through the issues methodically, will put everyone in a good position to decide whether there is enough cause for concern to require an expert evaluation. It will also help you to get maximum benefit from that expertise when it is called in.

If the problems with the building or the window prove difficult to interpret, it is often wise to bring in specialist expertise sooner rather than later. An experienced stained glass conservator, together if necessary with other relevant specialists, will help you work through a challenging assessment.

Possible environmental problems for stained glass

Cause	Signs and symptoms	Comments
Exposure to exterior conditions		
Rain	Corrosion of ferramenta (damage to mullions and surrounds)	Check condition of water-shedding architectural features such as hood moulds
	Exterior decoration damaged or lost	The glass may be decorated on the exterior as well as the interior; how well this survives depends on the durability of the base glass and its resistance to moisture-induced alteration
	Pitting and discoloration of glass and lead	In the worst cases, glass may be perforated
	Breakdown of glazing cements	Leads to rainwater penetration: are there signs of water wicking through on the internal surfaces?
Wind	Distortion of lead matrix	Will be exacerbated in a poorly designed window
	Breakage of ties to ferramenta	Exacerbates distortion
	Breakdown of glazing cements	Leads to rainwater penetration: are there signs of water wicking through on the internal surfaces?
Sunlight	Direct alteration of some materials, temporary or permanent	Look for discoloration, or local changes in tone in exposed areas
	Failure of applied organic materials such as non-original paints or coatings	Check if records of repair are available that specify the material used
	Cracking or distortion of leading	Dimensional change due to temperature and wind pressure
	Cracking, spalling and fracturing of glass pieces, especially around edges	Constrained dimensional change due to temperature; this can be a serious problem for some *dalle-de-verre* windows
	Growth of algae, mosses and lichens	Can disfigure the glass and also trap moisture
Deposition of dirt and pollutants	Decoration disfigured, difficult to read	
	Growth of algae and mosses	
Impact damage	Projectile damage	Accidental or deliberate (vandalism)
Exposure to interior conditions		
Condensation	Loss of applied glass decoration	Can lead to deterioration of stonework and the corrosion of ferramenta Exacerbated if the building has moisture problems May be caused or exacerbated by poorly designed heating systems, which create moisture (such as bottled-gas heaters), or which temporarily reduce ambient relative humidity (drawing moisture out from the building fabric or furniture)
	Glass corrosion	
	Growth of algae, mosses and lichens	
	Water streaks down cill and wall below	
	Moisture problems in wall below window	
Deposition of dirt and pollutants	Growth of algae and mosses	Deposition may be historic (for example, deposited by an old combustion heating system)
	Disfigurement	
	Loss of cold-painted decoration, especially at base of window (within easy reach of dusters)	Inappropriate cleaning: cleaning decorated glass is a job for a professional

1.2 Specialist evaluation

If your initial evaluation confirms that there may be problems with the stained glass that need to be addressed, it is time to consult experienced specialists to help you decide your next steps. For an effective evaluation, any expert consulted will need to be able to work closely with you, your building architect/surveyor and any other specialists that have been engaged.

The key expert for stained glass is an accredited stained glass conservator. If there are problems with the window surrounds or the ferramenta that cannot be answered by them or by your architect/surveyor, you may also wish to consult specialist stone or metal conservators.

The initial evaluation may have made it clear that the building's microclimate is causing problems for the stained glass. Most environmental issues with the building – such as poor maintenance causing high humidities – may be obvious and easily remedied, and whilst remedial action may be unlikely to halt glass deterioration once it has begun, it will have ancillary benefits for the building, its contents and the comfort of its users.

Figure 17: Stained glass is a complicated element, both in itself and in its relationship to the building; its assessment requires specialist expertise.

From time to time, especially in large or complex buildings, environmental problems may be complex, involving air movement and sporadic condensation, or strongly influenced by the way the building is being used (not least the way it is being heated). If you suspect this to be the case, it is sensible to organise a building performance assessment at an early stage. Building performance specialists have the experience and the tools to quickly identify the fundamental issues, giving you and your professional conservation advisors the information needed to plan effective remedial action.

A building performance assessment will include a liquid-moisture survey of the building (looking at how it handles rainwater), coupled with a survey of the building services and the way the building is used (especially the way it is heated and ventilated). This is important, because the causes of environmental deterioration can be multilayered: for example, condensation may well occur in heated buildings, but will be more likely if the building's fabric is damp.

Very occasionally, behaviour may prove so complicated or so dependent on complex factors that change with time (such as seasonal fluctuations in water vapour), or the environmental impacts on the fragile stained glass may be so important, that the building performance specialist may recommend a period of environmental monitoring.

This usually involves computerised recording of a range of environmental factors that are fluctuating over time, to understand how they may be interacting. These usually include both interior and exterior relative humidity and temperature and surface temperature of the glass; they may also include surface wetness, solar gain and air movement (amongst other factors). The recorded data are used to calculate other parameters, such as absolute humidity and dew point temperature, to better understand the underlying causes of events such as condensation.

It is important that any monitoring be designed to answer clear and specific questions, as required by the conservation professionals. It should not be seen as an end in itself.

2 Managing problems

If environmental problems are found to be causing the deterioration of the stained glass, it is important to approach remediation methodically. The first step is to decide, together with your professional advisors, the precise outcome you wish to achieve. Is it to arrest deterioration, or simply to slow it down?

The aim will depend on many things, not least the significance of the window (which may be of great local or sentimental importance, even if its historic or artistic value is not very high). It will need to take account of the type and speed of deterioration, the remedial treatments that would be possible and the resources of time, money and expertise available.

Once everyone involved has agreed the project aims, attention can turn to how they could be achieved. The golden rule, as ever in conservation, is minimum intervention: to do what is necessary to arrest ongoing deterioration that has been clearly identified.

Figure 18: Heaters running on bottled gas are a serious source of indoor moisture, adding to the risk of condensation.

2.1 Addressing building fabric problems

Any pertinent flaws that have been identified in the building envelope should be remedied as far as possible. That might mean repairing any rainwater goods, roofs or drains that are causing high interior ambient humidities, or correcting poor detailing that is exacerbating the impact of rain on the window. For example, faulty drips should be reconfigured, and damaged cornices and hood mouldings and other water-shedding detailing around and above the windows should be repaired, or if necessary replaced.

Putting into action a robust long-term building maintenance programme is also critical, because this will allow you to detect and deal with issues such as leaking gutters before they can cause serious problems that would need extensive repair.

Does your everyday maintenance programme make sufficient provision for the stained glass? For example, a very common cause of damage to fragile painted decoration is amateur cleaning. Your stained glass conservator will be able to guide you on the safest way to care for your windows.

If accidental impact damage is identified as a problem, it may be enough to increase controls over risky activities, such as mowing near the windows, or to ensure that nearby trees are kept pollarded. In many instances, however, window grilles will be required, in which case it is important that these are properly designed and fitted so that they slot correctly into the tracery and cause minimal damage to the stonework. They should be made of a metal resistant to corrosion, such as stainless steel; powder coating in black can make them very unobtrusive from the exterior. It is important to be aware that they may well be very visible on the interior, particularly if the stained glass is very transparent. In such cases, it may be necessary to consider other protective measures, such as laminate glass or high-quality plastic sheeting. Modern polycarbonates and acrylics can have much greater resistance to light damage, so the right material can be an excellent low-cost alternative to grilles. The flat finish of plastic sheeting and ordinary laminates can be problematic, but mouth-blown glass is now available laminated to float glass. Installed with the cylinder glass outwards, this provides a more sympathetic lively reflection.

Allowing for the aesthetic impact of window protection on the building and the stained glass can be challenging, and it is important to involve all stakeholders in the decision-making process from the beginning. You can find more detail about this in the following chapter, which looks closely at Environmental Protective Glazing and discusses how to deal with the aesthetic implications of a protective pane of glass on the exterior.

Not all actions to reduce environmental problems such as condensation will require physical interventions to the building: great improvements can usually be achieved simply by adjusting day-to-day building use (for example, altering heating regimes).

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2.2 Addressing building use problems

What users do inside a building has a critical impact on the building's interior environment, so it is important to manage anything that could lead to potential damage to your windows. In particular, you will need to check whether there are any actions or activities that might increase the humidity of the air, since that could easily lead to condensation on the stained glass. Potential trouble spots to look out for include:

- Heating or other equipment that emits water vapour, such as heaters running on bottled gas, or tea urns.
- Building users entering with wet clothing and umbrellas. It may be necessary to add storage for wet items outside the affected space.
- Opening windows and doors to 'air' the building can have unforeseen impacts. For example, when the exterior air has a high absolute humidity – such as after a spell of rainy weather, or in spring – condensation may increase. After winter, the glass and other surfaces will also often still be cold, making condensation even more likely.
- Heating regimes that cause or exacerbate condensation. For example, if the building has space heating and this is activated irregularly, it will reduce the relative humidity of the air, drawing moisture out from damp fabric and furnishings. When the heating is then switched off, the excess load of water vapour in the air cannot be immediately reabsorbed, and so will condense onto cold surfaces such as the windows. Instead, you could consider equipment that aims to heat the users rather than the air, such as under-pew heaters. This should also improve comfort and decrease energy costs.

A building performance specialist will be able to help with problems such as these. For more information, you can also check the Building Environment volume of Historic England's *Practical Building Conservation* series.

2.3 Assessing the impact of interventions

Once you have undertaken the basic building improvements, you should try to assess their impact, at least as much as is practicable. Have they been sufficient to achieve the aims of your project? Questions to ask include:

- Have the underlying causes of environmental problems been dealt with as completely as possible? Does anything more need to be done to understand or alleviate underlying causes?
- Are any problems proving intractable? If so, how serious are their impacts?

- Are adverse environmental events, such as condensation, still happening? If so, are they less frequent?

- If the stained glass conservator feels that the window is still deteriorating, do they think the rate of deterioration warrants immediate intervention?

It can be useful to compare the results of the pre-intervention surveys of condition with a new condition survey, though it must be borne in mind that deterioration will take some time to manifest itself, so waiting can be risky. Even if things look to have settled, it is vital to keep checking the window and the building at regular intervals to be sure, so that any new deterioration or failure is detected quickly before it causes serious problems.

The records of your assessments and interventions should be carefully stored in an easily accessible place: they will be enormously helpful to the future custodians of the building and its stained glass.

2.4 Intervening on the window

If your improvements of the building's environment are not enough to arrest deterioration of the stained glass (or at least to slow it to a level in keeping with its significance), it will be necessary to consider direct intervention on the window itself. Interventions may range from simple bespoke powder-coated stainless steel grilles to prevent vandalism, to designing an Environmental Protective Glazing (EPG) system to deal with condensation and weathering. EPG is covered in detail in the next chapter.

Since windows are so important to the appearance of the building from both the interior and exterior, and buildings with stained glass are usually of high significance and therefore protected by secular and/or ecclesiastical planning law, the planning authorities will probably require substantial information and justification for any interventions that have a visible impact. Remedial work on windows must be sympathetic to the entire building ensemble, as seen not only from the interior, but also from the exterior. It is usually very helpful to work closely with the planning authorities and statutory consultees from as early as possible in the project. This ensures that the reasoning behind decisions is clear to all those involved.

Your architect/surveyor will be the lead on any programme of intervention, taking on the coordination of tasks, such as developing submissions for permissions and applications for funding. Working together with the stained glass conservator and other specialists, they will be able to ensure that applications take due account of the wider aesthetic and conservation issues.

3 Environmental Protective Glazing

For stained glass suffering from serious and otherwise intractable environmental problems, Environmental Protective Glazing (EPG) is a powerful conservation tool, allowing deterioration to be greatly decreased whilst retaining the window in the building. On the other hand, it can also be one of the most challenging interventions, partly because of its aesthetic impact on the building, and partly because of the skill needed to design a well-functioning EPG system. A poorly functioning EPG system that is aesthetically satisfying is not a good solution.

The aesthetic impacts can be managed, but the myriad options available will need to be considered with care. The optimum approach will vary from window to window, even on the same building.

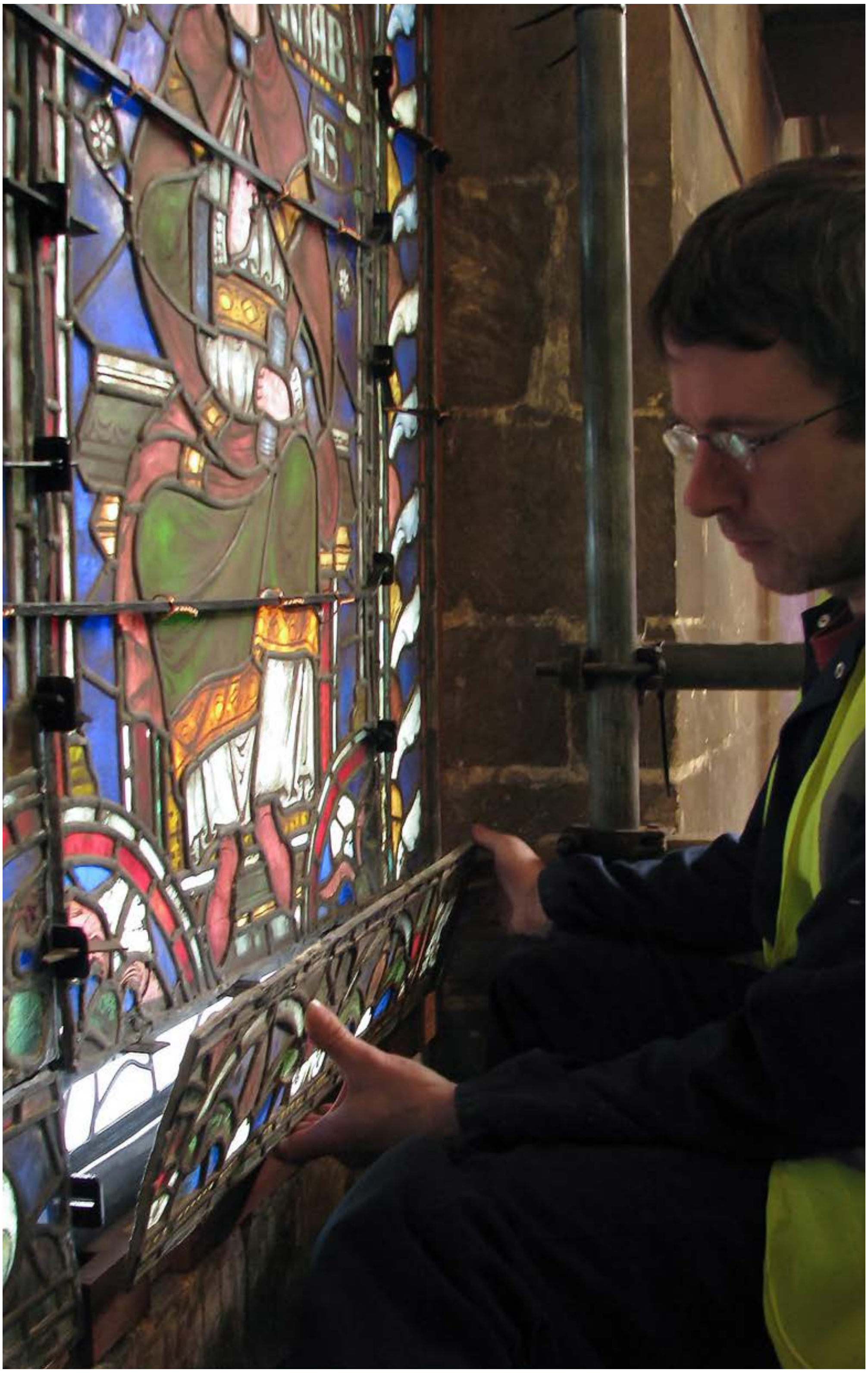
This chapter explains how the design of an EPG system should be approached. It should be read in association with the Historic England Research Report 43/2017, Conserving Stained Glass Using Environmental Protective Glazing, which sets out in detail the technical parameters that an EPG system needs to function effectively.

3.1 What is EPG and how does it work?

EPG is the term used to describe the installation of a second layer of glazing (the 'protective glazing' on the weather side of the glass), with the space in between ventilated to create a thermal buffer for the historic glazing. The precursors to EPG appeared as a conservation method for stained glass as soon as glass became cheap enough to make having a large second window feasible; examples of secondary glazing date back to the very beginning of the 19th century. In the past, EPG was sometimes called 'isothermal glazing', but this is a misleading term that does not reflect how the system operates.

The key to successful EPG is the ventilation of the 'interspace' between the two panes of glass, preferably to the building interior (through the stained glass), or where this cannot be achieved safely, to the exterior (through the protective glazing). This ventilation drives a strong airflow in the interspace that greatly reduces condensation on the stained glass. The driving force is the difference between the buoyancy of the air in the interspace and the buoyancy of the air in the space to which it is being vented. This is mostly due to air temperature, and to a lesser extent humidity: hotter air and more humid air will both rise, and colder air or drier air will fall.

Figure 19: Installing stained glass with Environmental Protective Glazing at Canterbury Cathedral.



The temperature changes that drive the buoyancy, and hence the airflow, are the result of the external weather conditions. EPG is effective because the materials of the glazing – the glass and metal – are such good conductors of heat. This means that when the window is exposed to sunlight or warm air, the interspace air will quickly warm up, and it will cool again quickly at night, when the air temperature drops or when the window is cooled by the wind.

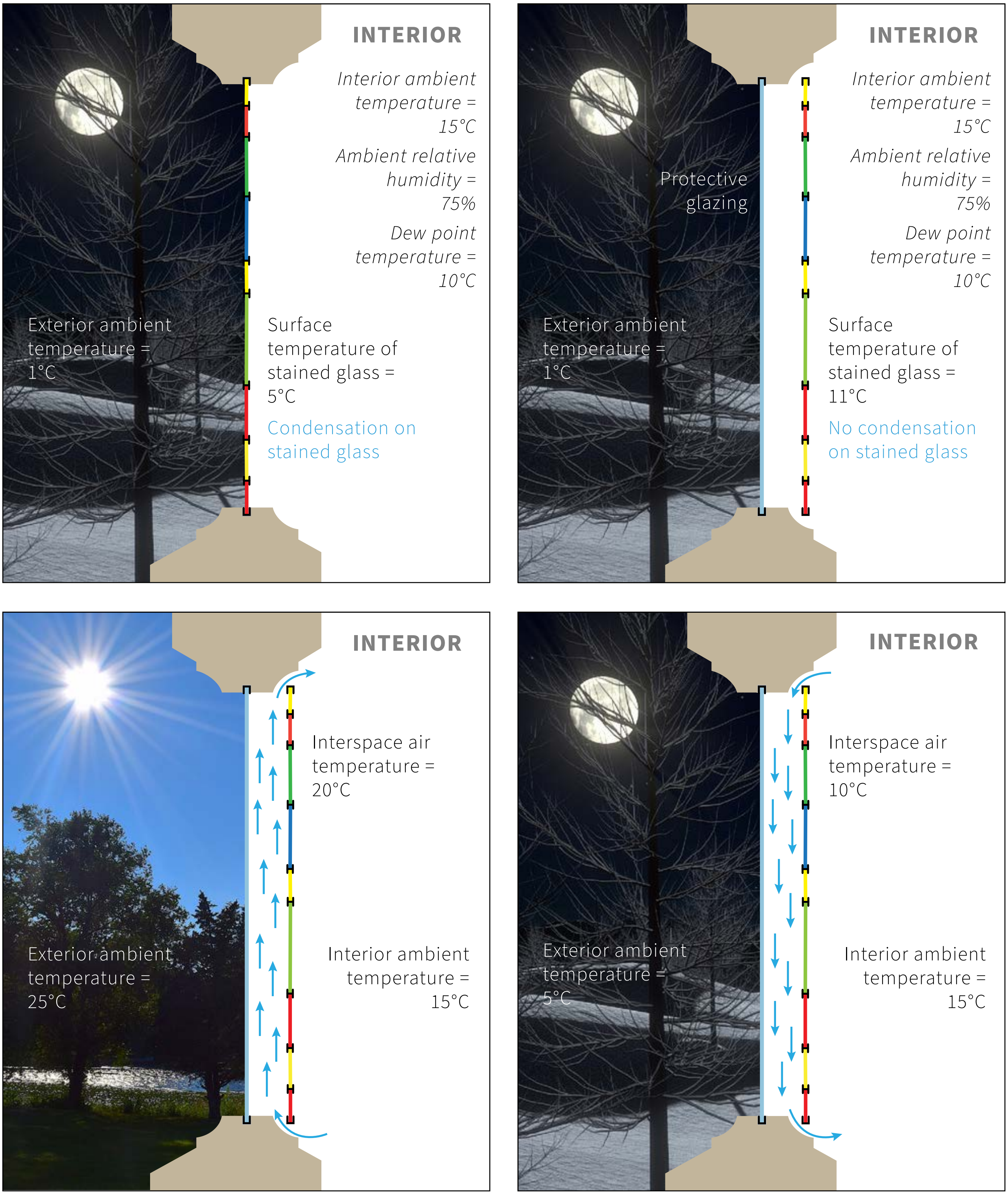


Figure 20: How the exterior conditions drive condensation on stained glass, but also the airflow in an EPG installation.
Top left: Without EPG, low exterior temperatures cause condensation on the interior of the stained glass.
Top right: With EPG, the stained glass is not directly exposed to the exterior air, but rather immersed in the interior air of the building.
Bottom: EPG exploits the ease with which glass and metal change temperature, and the fact that warm air rises. This induces air to flow vertically in the space between the original glass and the protective glazing, which in turn reduces condensation. The direction and speed of flow depend on the relative temperatures.
These are schematic diagrams, with the environmental values simplified to illustrate the principles. Actual values will be dynamic, changing continually throughout the day and night. The resulting airflow is therefore dynamic as well.

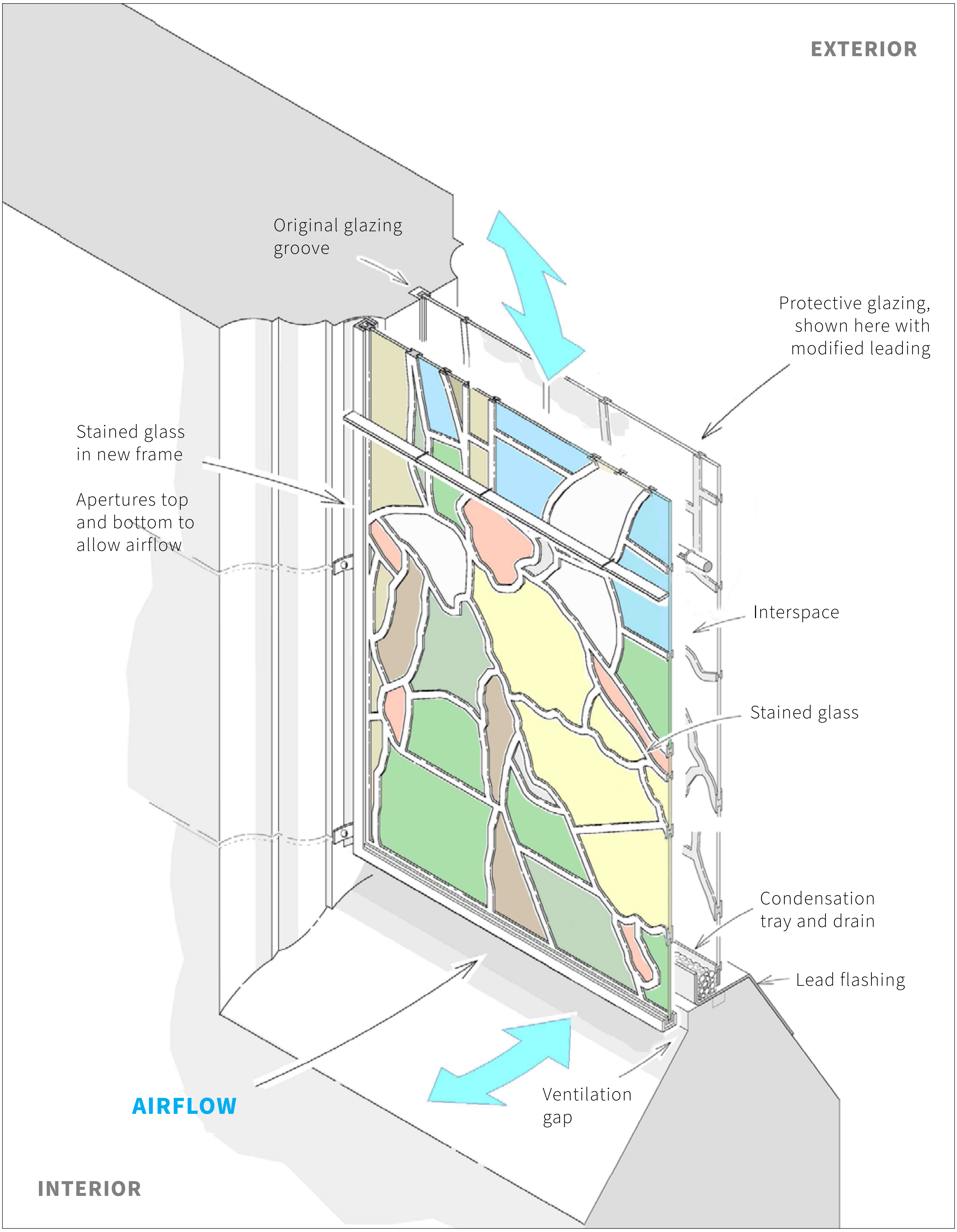


Figure 21: Basic elements of a typical internally ventilated EPG system.
The precise details of every EPG system will depend on the particular building and the configuration of the window being protected.

3.2 The benefits and costs of EPG

Technically, EPG is a very effective intervention against a number of serious environmental problems for stained glass of all types except *dalle-de-verre*. As Historic England's research into the operation of EPG has shown, in a building without significant moisture problems, it can eliminate most condensation on the stained glass; even where the environmental conditions are poor, it can still significantly reduce condensation events. EPG will also protect the stained glass from the weather, allowing stained glass conservators to avoid extensive repair to keep the window weatherproof, and allowing them to use more sensitive and reversible materials. EPG may be the only way to keep *in situ* medieval stained glass suffering serious corrosion, or a window made with highly light- or water-sensitive materials such as fibreglass. In some circumstances, it can help prevent impact damage; it is also largely reversible.

On the other hand, EPG will have a significant effect on the aesthetics of the building and the window: the precise look of the single sheet of stained glass in its original position will have been part of the artistic intentions of the original architects and glaziers. By its nature, it will often have a permanent impact on the fabric (for example, on the stonework and metal supports). It is perfectly possible to minimise these impacts, but the process for doing so can be time-consuming and expensive. Therefore, EPG is not generally an intervention that would be used on a window in good condition 'just in case'.

EPG is sometimes proposed for thermal-efficiency reasons, but the ventilation causes draughts, which may actually increase the discomfort of building users. Also, the area of window in pre-modern buildings – even those that are apparently highly glazed – is very small compared to the area of wall: often the architectural details deliberately emphasise the windows, making them appear larger. In many older buildings, not least churches, the roof is much more significant for heat loss.

EPG may be a good solution:	
✓	If, despite building repairs and adjustments to the climate control systems, environmental problems continue to have serious impacts on the window
✓	If the stained glass is very fragile and/or historically important and will be compromised technically or aesthetically by repair methods that would render it watertight and wind-resistant
✓	If the technique of the stained glass renders it particularly susceptible to condensation damage (underfired Victorian glass is a notable example)
✓	If the stained glass is so significant that no further loss, however slight, is acceptable
✓	If there are good conservation reasons to avoid dismantling the window (such as the risk of damage or the wish to retain early and important leading)
✓	If the window is very inaccessible (and thus unusually difficult to inspect and maintain)

3.3 Assessing the potential of EPG

EPG is a complex intervention. There are multiple options for design, each presenting different cost implications and different benefits and drawbacks. Whether the benefits merit the drawbacks will be case-dependent, and it is therefore important to consider all potential impacts (good and bad) in some detail before you decide whether EPG is the correct intervention for your conservation project.

The impacts of EPG are two-fold: on the window itself and on the building. Stained glass is a highly visible element – from both the exterior and the interior – so poor design can seriously affect how the building as a whole will be seen and appreciated.

For the window, your professional advisors will need to develop an assessment that includes:

- The significance of every component that might be affected by EPG (the glass, the lead matrix, the stonework and the ferramenta)
- The contribution made by each component to the viewer's aesthetic appreciation of the window (from both the interior and the exterior)
- The condition of all those components, and the nature and rate of any deterioration
- The potential positions of the two glazing planes within the depth of the window embrasure. What possibilities are afforded by the profile of the embrasure, and what would be the aesthetic impact of the glazing planes on the window, considered in the context of the building as a whole?

For the building, you will need to assess how the windows (particularly those where it is proposed to use EPG) contribute to its architectural design, historic interest and aesthetic character:

- How prominent is the window, both externally and internally?
- What is its relationship to the other features of the building, particularly any neighbouring windows? Is it part of an architectural ensemble?

If you can, it is very useful to involve all stakeholders – not least the relevant statutory authorities and consultees – in this evaluation process from the very earliest stages. They should be able to help you with many aspects of the assessment. You should aim to achieve consensus on the significance of the window and the contribution it makes to the significance of the building, and also on how this significance might be sustained or even enhanced.

Still collaborating closely with your stakeholders, the next step is to agree the critical issues. Which changes resulting from EPG would be likely to be harmful, and therefore only acceptable if there is clear and convincing justification and the public benefits can be shown to outweigh the harm? This might be the case, for instance, if the stained glass was in immediate danger of being irreparably damaged or lost if not protected by EPG.

This list of the critical issues can then be used as the basis for the guidelines to develop the EPG design.

While aesthetically sensitive design will greatly reduce the impact on the building, it must not compromise the effectiveness of the EPG system, which must take priority. Since EPG should only be used where there is a demonstrable need to protect the stained glass, the principal criterion for its design must be that it can do the job. That basic requirement fulfilled, however, there are many options for making the result sympathetic.

Figure 22: Great Witley Saint Michael and All Angels, Worcestershire.
When designing EPG, it is vital to consider the building holistically and to work closely with all stakeholders to agree the most suitable approach. How best can any negative impacts on, for example, the exterior appearance of the building be mitigated?

3.4 Designing EPG to minimise harm to significance

Although EPG could be argued to be largely reversible in the final analysis, the cost of development and installation (and the likely persistence of the underlying reasons for installing it in the first place) make removal unlikely, except perhaps to replace it with another version of EPG. Nevertheless, if its use would prevent serious ongoing deterioration of important glass, then the harmful impacts it will have on the window embrasure or the aesthetics of the building may be acceptable. It is important, however, to design the EPG so that this harm is reduced as far as possible.

The primary contributor to the design of effective and sympathetic EPG will be your stained glass conservator, who will have experience in adapting EPG to suit many different situations. They will need to work closely with you, your architect and perhaps other conservation specialists (such as stone conservators and metal conservators) to develop the optimum approach for each window.

You, your professional team and any statutory authorities will need to agree a number of basic technical points:

- What is the optimum location of the two glazing planes within the window frame, including the maximum distance between them?
- If the stained glass needs to be moved forwards out of its glazing groove, how the panels will be framed, and how that framing will be fixed into the embrasure?
- How will the interspace is to be ventilated?
- How will water penetrating the interspace be collected and removed?
- How will the secondary glazing will be detailed to minimise its impact on the view of the window from the interior, and on the view of the building from the exterior?

Location of the glazing planes

To ensure sufficient airflow, the interspace between the two glazing planes must be at least 10mm deep at its pinch points, and preferably at least 40mm deep across most of the window. In other words, if the gap includes ferramenta or other obstructions, these must not reduce the depth at any point to under 10mm. Although the necessary depth can sometimes be achieved with the stained glass left in its original groove, in most cases it will have to be moved slightly forwards.

As well as the technical demands of the EPG itself, the positioning of the two glazing planes will need to take account of the way the window appears on the interior and exterior of the building.

Figures 23–24: The impact of EPG on the interior must be weighed with great care.
Here, at Exeter Cathedral, moving the stained glass in the north clerestory forwards out of its glazing groove would have taken it out of alignment with the plain glass in the neighbouring windows. It was judged to be less intrusive to bring the protective glazing outwards, particularly since on the exterior that window is partly hidden from view by a chapel.

Questions to ask when deciding the location of the glazing planes include:

- How does the shape and size of the window, and the profile of the window embrasure, constrain the location of the glazing planes?

- If the stained glass cannot be left in its original glazing groove, what will be the aesthetic impacts of framing it? Even with the lightest and most unobtrusive frames, this can be a real challenge for windows that are small, or that the viewer can get close to. The more complex the tracery, the harder it will be to make framing unobtrusive.

- What will be the aesthetic impact of moving the plane of the stained glass forwards in the embrasure? Does it introduce any additional technical challenges?

- What impact will changing the position of the glazing planes have on neighbouring windows? Would it be necessary to treat a group of windows as an ensemble to maintain aesthetic harmony?

- What impact will the positioning of the protective glazing have on the appearance of the windows from the exterior?

- How do the ferramenta constrain the position of the glazing planes? How important are they to the appearance of the window from the interior and exterior?

Ventilating the interspace

Ventilation is most effective when the gaps at the top and bottom run across the entire width of the glazing, but even smaller or less even vents can produce acceptable flow, especially in tall windows. It is important, though, to minimise any obstructions that create turbulence. For maximum effect, the vent height should be at least one-third of the interspace depth: so, if the interspace depth is 60mm, the vents would need to be at least 20mm high.

To create the ventilation, there is a range of possible options, including:

- Setting the glass into a frame and moving that frame outwards in the window embrasure to create gaps; this works particularly well if the cill is sloped. Potential aesthetic problems include halation (light appearing around the edges of the stained glass), but this can usually be resolved (with lead cloaks, for example: *see* Figure 25).

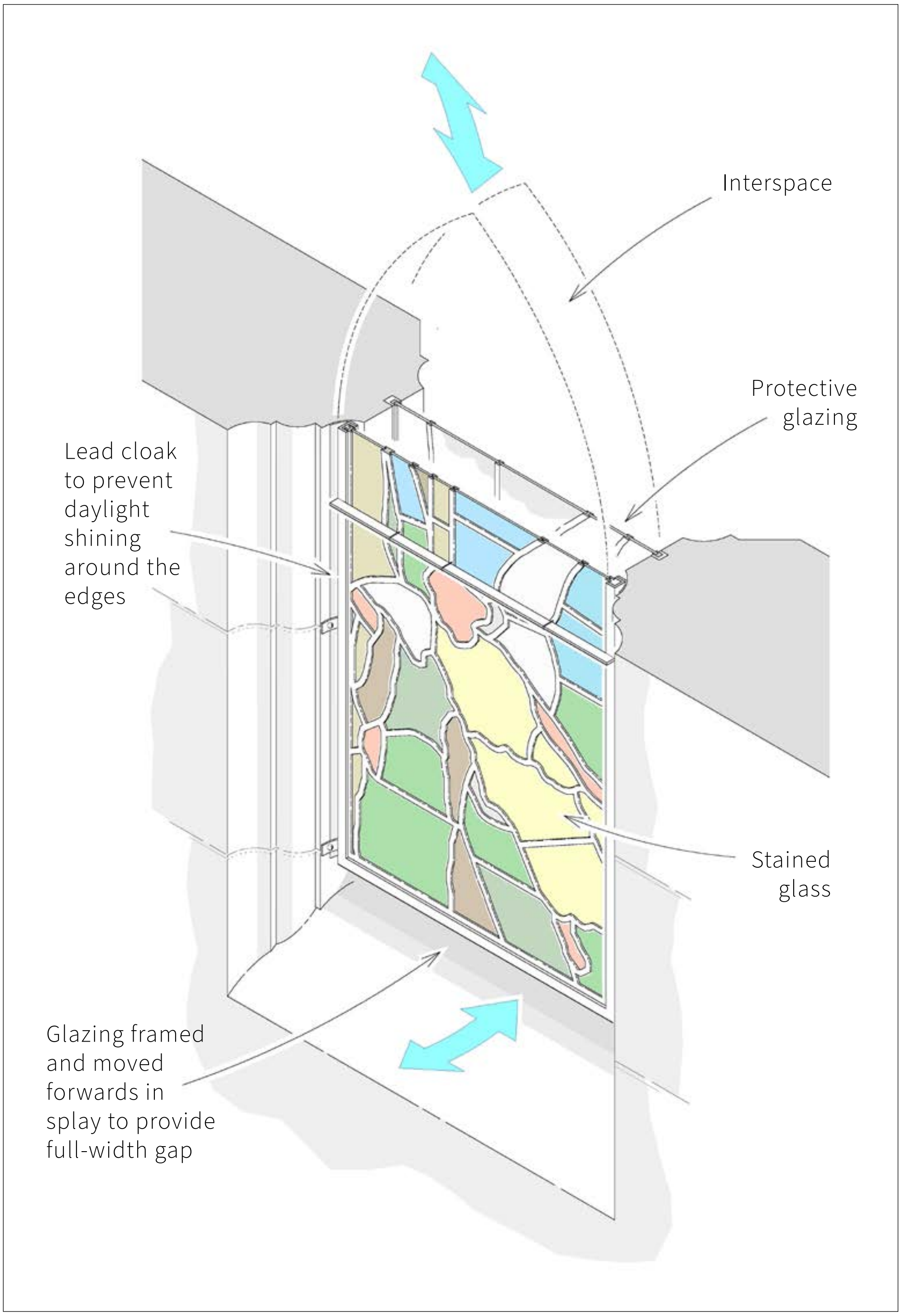
- Tilting complete panels of glazing at the top and bottom of the window outwards.

- Reducing the height of glazing by shaving down the flanges of the exterior leads, or by reducing the thickness of any horizontal framing. In the rare case that panels overlap, the overlap can be increased.

If there is no alternative, it may be possible to create ventilation gaps by tilting individual glass pieces outwards or inwards. This requires great care on the part of the conservator to preserve the visual integrity of the window, and to ensure that there is no risk of damaging or losing the tilted elements.

EPG is most effective if ventilated to the interior (through the stained glass). Occasionally, this may be difficult to achieve without unacceptable disturbance to the glazing, the window surround, the ferramenta or the interior appearance of the window: for example, the stained glass may be so fragile that the conservators would prefer to leave it undisturbed. If that is the case, a system that ventilates to the exterior (through the protective glazing) will still give significant benefits, always provided the design can overcome potential problems such as rainwater penetration.

Figure 25: Options for ventilation.
The aim is to create smooth, laminar airflow through the interspace. This is best achieved by having a full-width opening at the bottom and top of the window.
If the stained glass can be removed from its groove, one option is to set it into a metal frame and move it forwards into the interior, creating gaps around the glass that can be used to provide ventilation.



Since every window is unique, arriving at the optimum design of EPG for that window inevitably demands close consideration of materials and a little fine-tuning: for example, if the stained glass is moved forwards in the splay, the metal frame needs to be as inconspicuous as possible, and halation must be dealt with. The best solution will depend on the configuration and the location of the window: what is perfectly permissible for a large clerestory window may appear very ugly when used on a small window near to the ground. Low windows that can be approached closely by the viewer will usually need more careful consideration.

Well-designed EPG should be all but invisible on the interior, even to a knowledgeable viewer.

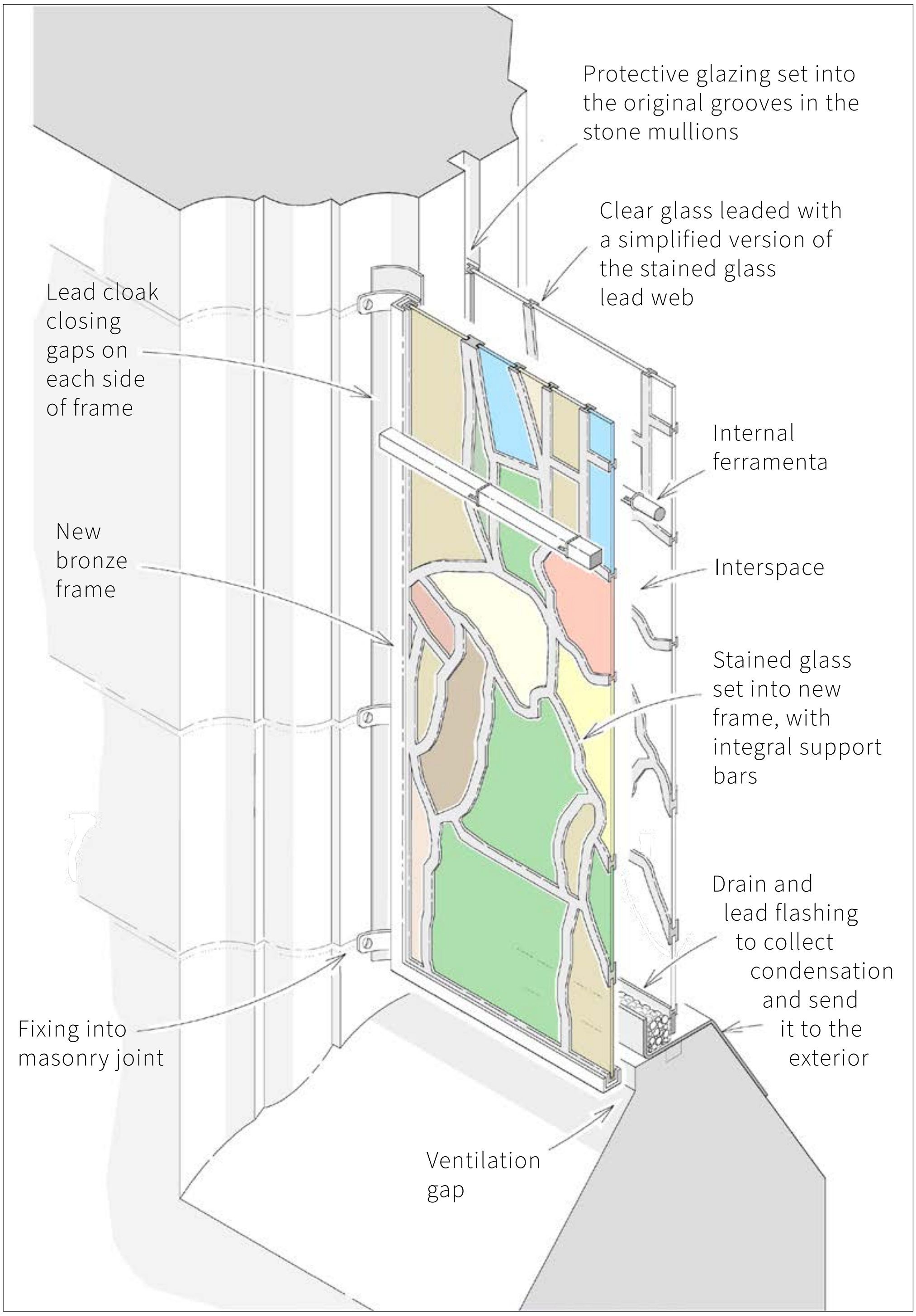


Figure 26: If the glass has been framed, a lead cloak can prevent halation.

Draining the interspace

Because EPG cannot prevent condensation on the protective glazing, and there will always be some risk of rainwater penetration, the interspace must incorporate some means of collecting and ideally directing away any water that might collect.

The most effective way of doing this is to place a lead-lined collection channel at the base of the window, with drainage opening out to the exterior (through the protective glazing). This channel should be filled with graded gravel, which will greatly reduce any evaporation of the collected water back into the interspace. It will also reduce air ingress into the interspace from the exterior. If condensation levels are low, and the collection channel sufficiently deep, a drain may not be needed.

Figure 27: A vital detail is the interspace drainage.

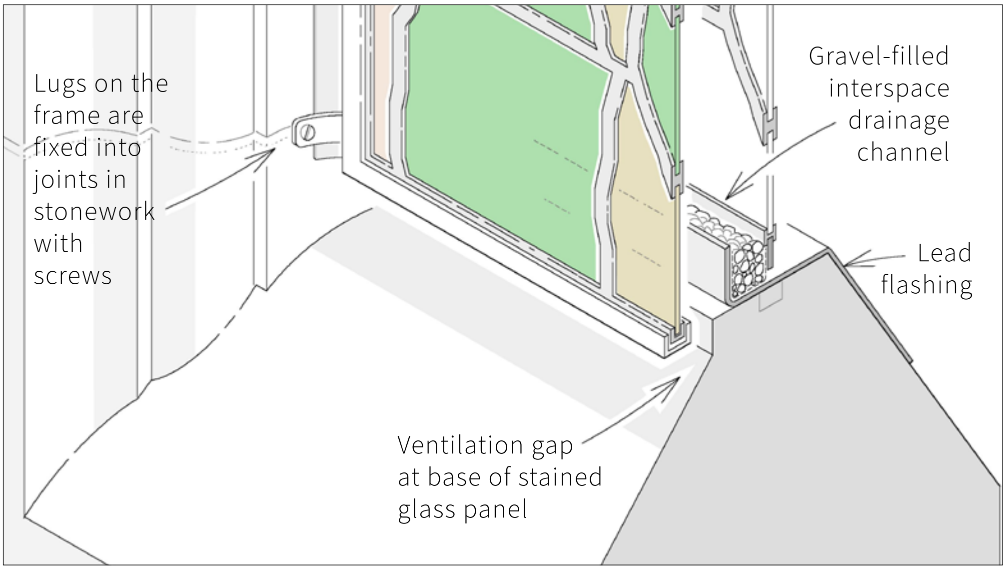


Figure 28: Here, a completed channel on the cill is shown with the protective glazing in place; the stained glass will be inserted into the groove in the window embrasure.

Design of the secondary glazing

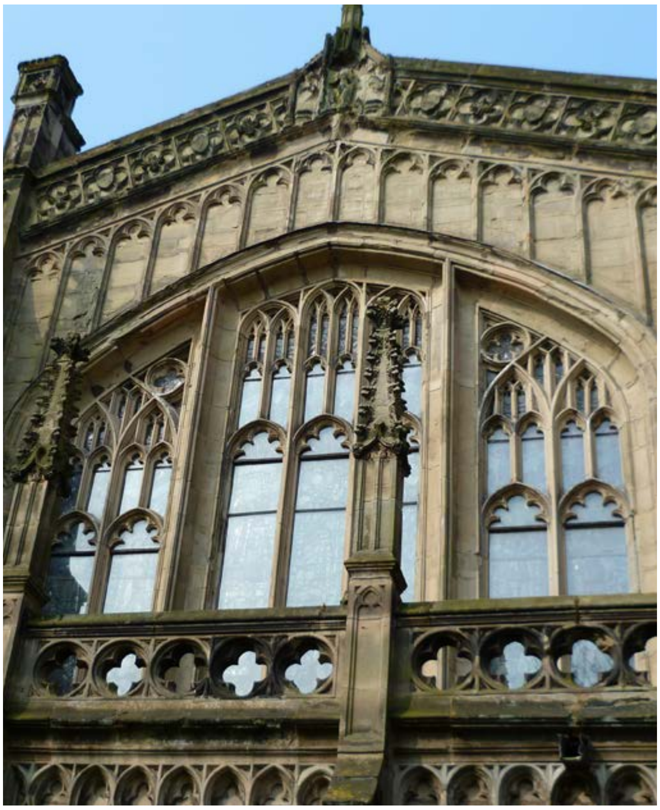
Figures 29–30: Inappropriate materials and approaches for window protection. The impact of window protection on the exterior view of the building can be severe if the wrong materials are used. It is never permissible to cover over tracery, nor to use polycarbonates or any other type of plastic that may discolour or warp with exposure, or increase arson risks (left). Unmodified polished plate glass or float glass are rarely appropriate: they are very flat, producing planar reflections that make the glass stand out prominently against the façade (right).

The success of EPG as an intervention into the building depends not least on the aesthetic sensitivity of the protective glazing itself. This is usually made of glass: sheet plastics have a higher thermal inertia, and most will deteriorate and discolour when exposed to sunlight. Modern acrylics and polycarbonates have improved stability, and their lightness can occasionally be an advantage, but the flatness of their finish can be an issue. Polished plate glass and plain float glass have the same problem of highly directional reflections, and should be avoided except in very rare cases.

Generally, decision makers and consultees will prefer the use of traditional materials, or materials that are sympathetic to those found in the building and are aesthetically appropriate.

There are many ways of making the protective glazing less visible, including using hand-made glass or kiln-slumped glass, adding paint or modified leading, or positioning the glazing behind a protective grille (in many cases, grilles will already be in place, minimising the change in appearance).

Although any of these options will greatly improve the impact of the EPG system on the exterior views of the building, you must be equally sure that it does not significantly affect the appreciation of the windows from the interior. For instance, if there is too much leading on the secondary glazing, shadowing may make the stained glass difficult to read. The impact of this shadowing will depend on the distance between the glass planes, and on the height of the viewer and the window; it will become more obtrusive as the angle at which you are viewing the windows becomes more acute.








Figures 31–36: Modifying the exterior impact of EPG.
There are many materials and configurations that can be used to reduce the impact of EPG on the exterior views. The best choice will always depend on the particular location and window, and it is important to consider the impact on the interior view as well as the exterior. A great deal depends on how the protective glazing has been detailed.
Top left: For the protective glazing, this window at Patrixbourne uses float glass that has been laminated to resist impact, but the result is strong linear reflections.
Top right: Also at Patrixbourne, another EPG installation uses mouth-blown glass for the protective glazing, and this is further softened by the introduction of a wire guard.
Middle left: Low-reflection float glass is available. Here, at Cologne Cathedral, it has been used in a single sheet; in England, it is more common to break up large areas of glass with ferramenta or modified leading.
Middle right: At Chartres Cathedral, the ferramenta is positioned on the exterior of the protective glazing, which has also been 'kiln-formed' (heated in a kiln over a mould) to echo the texture of the stained glass.
Bottom left: At Long Melford, kiln-distorted glass has been cut into smaller panels to coincide with the ferramenta.
Bottom right: At Canterbury Cathedral, kiln-formed glass has been used with leading, and further modified by a thin coating of glass paint to reduce reflections.

There may be other demands on the protective glazing. For example, impact or vandalism may be a significant risk, but if the stained glass is very transparent, protective grilles can be intrusive from the interior. In such cases, laminated glass can be a useful option. The linear reflections from float glass can make it very obtrusive, but fortunately mouth-blown laminated glass is available. This has cylinder glass laminated to float glass, and should be installed so that the mouth-blown surface faces outwards.

There are other options that may be suggested by your stained glass expert for conservation reasons. For example, if the window includes light-sensitive components, including the epoxy resins used to invisibly glue broken glass, it may be desirable to choose protective glazing that can block ultraviolet (UV) wavelengths of sunlight. Similarly, if the window tends to suffer from overheating, it may be beneficial to filter out infrared (IR) components.

In the past, filtering would have required either specialist float glass or the glass to be covered with a short-lived plastic film, but today, mouth-blown glasses are available that incorporate minerals able to attenuate either the UV or the IR components of sunlight.

Stained glass conservators will take great care when selecting these filtering glasses, to ensure that they do not reduce the incoming light too greatly, since this could have a negative impact on the appearance of the stained glass from the interior (making it hard to read or distorting the colour balance).

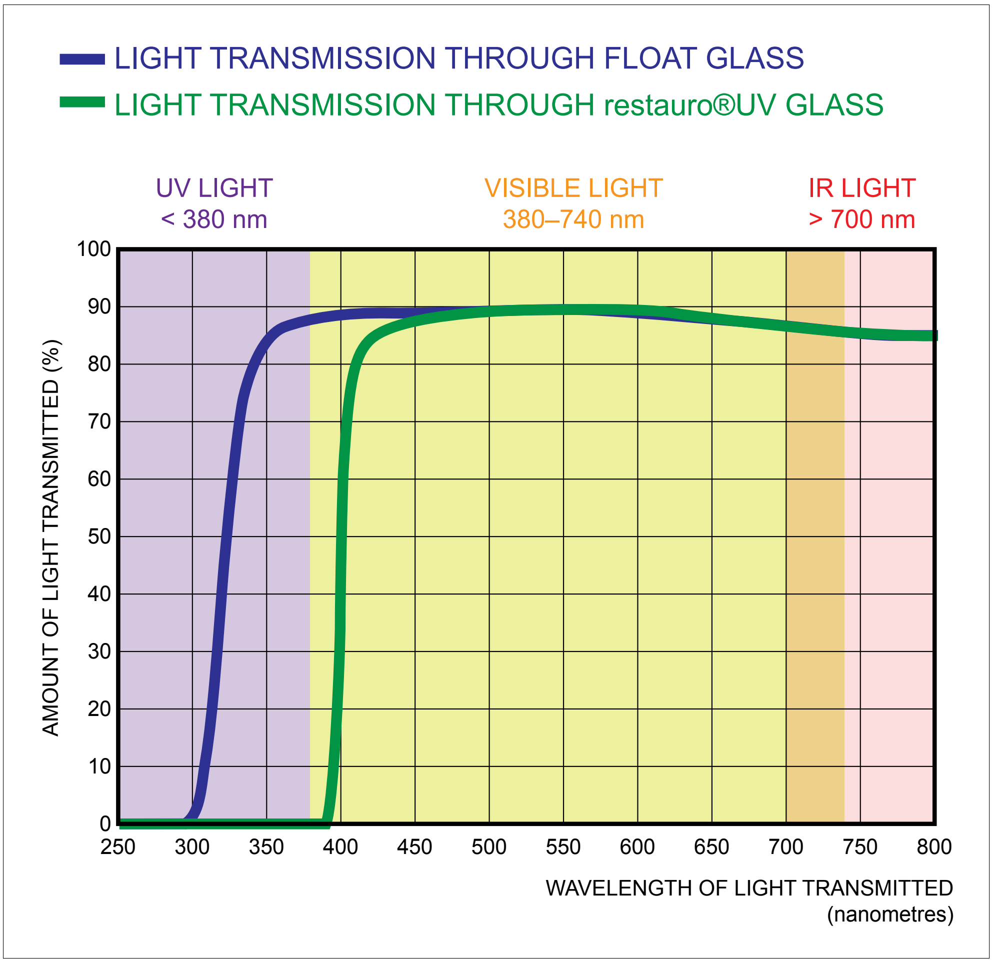


Figure 37: This graph compares the transmission of sunlight through float glass with its transmission through a specialist mouth-blown glass, which is able to filter out the UV component of sunlight reaching the original window. It is important to design filters so that they do not reduce too much of the incoming visible light, since this can affect the colours and intensity of the glass as seen from the interior.

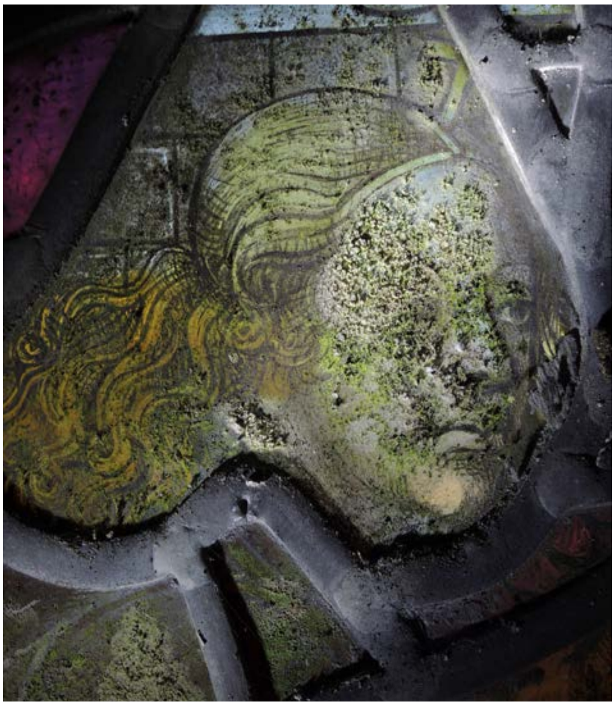
The treatment of the ferramenta, which are almost always affected by the installation of EPG, is often critical to success. They may need to be moved into a new position, or adapted to allow sufficient space for the secondary glazing, but it is important to remember that they may be significant in their own right. In some difficult cases, ferramenta have been cut out and moved outside the secondary glazing, taking on a purely decorative role (the function of window support being transferred to new framework inside the interspace), but this would be a last resort.

On the other hand, the ferramenta can also provide the key to visually breaking up the secondary glazing and making it less obtrusive. Grilles can also be useful in this regard. Grilles and protective glazing should be fitted inside the mullions and tracery, so that all the stonework remains visible (rather than covering the entire surface of the window).

With so many factors to take into account, and so many design options available, there is no 'best option' for EPG design: what works very well on one site may prove completely unsuccessful on another. It is not uncommon to find the approach needs to be different on different elevations, or for different periods of stained glass.

Although specialist stained glass conservators can help to cut down the multitude of potential options to a sensible level, for significant buildings there is rarely any alternative to composing mock-up panels, so that different approaches may be judged *in situ*. It is always helpful to invite the relevant authorities and other stakeholders to view and comment on these trials.

Figure 38: To agree the many details of EPG, including the treatment of the protective glazing itself, the most effective approach is to organise an on-site meeting with all stakeholders. This is particularly effective if it is possible to discuss *in situ* mock-ups of the proposed designs.



Figures 39–43: The optimum design of the protective glazing is case-dependent.
EPG design is so sensitive that, even on a small building, different elevations and even different windows may require different treatments. Here, at St Leonard’s Church, Marston Bigot, Somerset (top left), the condition of the 1845 glass by Thomas Willement on the south side of the building – which had fewer and briefer periods of condensation due to solar exposure – was good apart from broken ties, and the windows could be left unprotected. The Willement glass on the north elevation, by contrast, was staying wet for long periods, and showed paint loss and severe algal growth (middle left). These windows and also the east window, which contains important glass collected from Flanders and the Rhineland (top right), urgently required the protection of EPG.
The decision was made to divert the greater part of the church’s limited budget to the very visible east window, where great care was taken to make the protective glazing as inconspicuous as possible: the glass used was mouth-blown and leaded, with individual glass pieces tinted by hand (bottom right). On the south elevation, which is invisible from any public space, plain float glass was used instead (bottom left). When funds permit, this can easily be replaced with a more sensitive alternative; in the meantime, the stained glass is protected from further damage.

Designing for the future

EPG should be designed to allow for easy access to the interspace, whether that is by demounting the protective glazing, or by taking out the framed stained glass. Any fixings must, therefore, be robust enough to withstand periodic removal and re-installation. Special attention should be given to the specifications of any system that includes fixings and fittings of different types of metal, to avoid the risk of galvanic corrosion.

Serious thought must be given to the long-term ability of the support system to carry the weight of the historic glazing. Ideally, loads should be transferred vertically into the masonry cill, rather than relying solely on the horizontal attachments.

Figure 44: Insects such as wasps and spiders have been observed to nest in unventilated spaces between stained glass and protective sheeting (the cause of the staining shown here), but there may be some evidence that flying insects are discouraged by the airflow in the EPG interspace. This remains highly uncertain, however.

For important stained glass, the ability to demount the glazing quickly in an emergency can be one crucial advantage of a framed EPG system, but care does need to be taken with the design in certain sites, to ensure the risk of theft is not increased. Theft risk can be further reduced by using security screws and fixings.

3.5 Care and maintenance of EPG

As with all other elements of windows and glazing, EPG needs to be effectively maintained. Positioning flower arrangements and other ornaments on the window cill will need to be discouraged, as these can block the ventilation vents and impede airflow.

It is currently unclear whether the interspaces of EPG are more or less likely to attract dirt or insects; there seems to be little consistency in case studies and observations. It may well depend on many factors, some quite subtle, such as the orientation of the window. Nesting insects are unlikely to appreciate strong airflows, but this would not deter spiders, for example. More research is being undertaken to examine this issue, but in the interim it is best to assume that periodic cleaning of the interspace will be necessary, and this must be planned for in the design of the EPG.

Cleaning and other maintenance of EPG must always be undertaken by a specialist stained glass conservator, who can take the opportunity to check the state of the stained glass and the EPG system. In many cases, this maintenance work will be possible from a mobile elevated working platform, although it may require scaffolding.

Everyday maintenance should include frequent quick checks to ensure that:

- the vents are not blocked by dust deposits or other accretions
- collected water is draining freely out from the condensation trays, and that these are not overflowing during periods of intense condensation.

The EPG system should be explicitly included in any regular inspection regime. Visual inspection of the interspace can easily be carried out from the exterior, looking through the secondary glazing.

4 Appendix

Corpus Vitrearum Medii Aevi (CVMA) numbering system

This is the standard system for recording stained glass in ecclesiastical buildings and should be used by preference in all surveys and conservation programmes. It is published in the CVMA Guidelines 2001: www.cvma.ac.uk/about/guidelines.html

Numbering windows

Each window is identified according to its position on plan and in elevation. A line is drawn on the plan from liturgical east to west: the windows north of this centre line are denoted with ‘n’, and those south with ‘s’. Lower case letters are used to denote the ground-level windows, and upper case letters the clerestory windows. Triforium windows are indicated with Nt and St. The east window on the centre line is 1, and the west window w1. Each window opening is then numbered from east to west (whether or not the window contains significant glass), using Roman numerals.

If the plan is complex, it can also be divided into sections horizontally. Similarly, if it has an annex, such as a chapter house, that may need to be given its own separate window notation.

Numbering of panels in windows

The panels of a window are numbered according to their registers, or horizontal rows, starting from the base of the window. Numbering always follows the same sequence from bottom to top, and from left to right. Each of the registers is given an Arabic numeral. The lights are then named from left to right using lower case letters; they should include the panels in the heads of the lights.

The panels in the tracery at the head of the window are identified by a system of capital letters and Arabic numerals adapted to the architectural forms of that window.

Rose windows or window elements can follow a radial numbering, counting clockwise (independent rose windows should always follow this radial system of numbering).

If the composition is very complex, it can be illustrated with a diagram as a key, but the underlying logic should be simple and easy to reconstruct even if that key is lost.

5

Glossary and useful terms

Absolute moisture content

The amount of water held in vapour form by the air, usually expressed as weight per volume.

Black paint

Fired monochrome decoration, mostly in shades of grey, using paints consisting of finely ground low-melting glass, powdered metal-oxide pigments, and a medium or binder.

Broad glass

See Cylinder glass

Came (sometimes 'calme')

A strip of malleable metal (usually lead or industrial lead alloys, but sometimes copper, brass or zinc), H-shaped in cross section, which is used to fix together small pieces of glass to make a larger area of glazing. The flanges of the strip are wrapped around the edges of the glass pieces, the 'heart' separating each piece from its neighbour. Cames are jointed with molten lead, or by soldering, and the gaps between the flanges and the glass are filled with glaziers' cement. Medieval cames were cast, and then cut and shaved to the desired width and length. Later cames were milled or, more recently, extruded to give longer lengths.

Cold paint

Colouring of glass by cold application of oil paint, as opposed to enamelling or firing (flashing), in which powdered glasses and coloured pigments are fused to the surface by heating. Often used historically for retouching.

Crown glass

Method of producing sheet glass by hand. A bubble of molten glass is transferred onto a solid metal 'punty rod', or 'pontil rod', which can be spun between the hands of the glass blower. The blowing pipe is then cut away, and the molten glass spun using the punty rod until it suddenly opens out into a disc, or 'table'. The earliest known crown glass in England dates from the 1440s; it was widely used for windows until the mid-19th century, when taxation by weight ceased and cylinder glass became cheaper. Also known as 'spun glass'.

Cylinder glass

The principal method of making sheet glass by hand, developed in the early Middle Ages, and still in use. The glass maker swings a bubble of molten glass back and forth whilst blowing, producing an elongated balloon. The end of the balloon is opened out using a hot iron tool, and it is then cut from the blowing rod to produce a cylinder of glass. This is scored down its length and returned to a kiln, where the heat causes the cylinder to open out along the scored line and flatten into a sheet.

Dalle-de-verre

Thick slabs of cast glass, moulded or chipped into shape with facets to refract the light, and set in concrete or resin; popular for 20th-century architecture. Also known as prismatic glass.

Dew point

The temperature below which condensation will begin to form. It depends on the absolute moisture content of the air as well as the temperature of the condensing surface.

Drawn glass

Industrial method of producing sheet glass, in which the molten glass is drawn vertically through a die, in a continuous sheet, and then cut and cooled; in early days, this often gave sheets imperfections such as waves, bubbles or inclusions. Produced in England from 1919, but eventually superseded by new methods (particularly float glass).

Embrasure

A window opening in a wall, typically bevelled or splayed on the inside.

Enamelling

Colouring of glass using heat to fuse powdered glasses, mixed with flux and a binder, to the surface.

Ferramenta

An interlocking system of metal bars that supports the glazing.

Float glass

Most common modern method of producing sheet glass, developed around 1959 by Pilkington Brothers. Molten glass is floated over a bath of molten tin to give a uniform and extremely flat sheet that does not require polishing.

Frit, fritting

1. In glass painting, a paste of metal-oxide pigments and granules of finely ground glass, fired onto white glass to produce coloured glass. The result is more durable than back enamelling.
2. In glass making, the partial fusing of granular raw material as a first stage in the production of glass: crushed silica, fluxes and colourants are combined and heated to temperatures too low for full vitrification, but high enough to remove gases and impurities. This is then cooled, ground and re-melted to make glass.
3. In modern solar glass, ceramic paint screen-printed onto modern float glass and then heated to produce a durable light-diffusing coating.

Galvanic corrosion

Metal corrosion resulting from the current flow between two dissimilar metals in the presence of a fluid able to conduct the current (for example, water containing dissolved salts). The type and the relative surface area of the two metals determine which of the metals corrodes, and the degree of that corrosion.

Gel layer

Silica-rich hydrated layer, structurally and chemically different from the original glass, caused when glass is covered with a film of water that leaches out sodium and potassium ions. It represents the first stage in glass corrosion.

Glass blowing

Glass-forming technique, probably developed in Babylonia and the Middle East by the 1st century BC. Molten glass is gathered into a ball on the end of a hollow pipe, and rolled on an iron former to roughly shape it and to slightly cool the surface. Then the pipe is used to blow air into the glass and form it into a bubble. By repeated blowing, shaping and reheating, the glass can be formed in many ways.

Heart (of lead came)

See Came

Horticultural glass

Usually refers to low-grade drawn sheet glass, used in the greenhouse trade, and often specified as an inferior substitute for early cylinder glass or crown glass.

Interspace

The space between the planes of glass in an insulating glass unit or a secondary glazed system such as EPG.

'Isothermal glazing'

A misleading term that in the past has been used in the UK to refer to EPG.

Kiln-distorted glass

Modern sheet glass that has been slightly deformed in a kiln to imitate the irregular reflections of traditional cylinder glass.

Kiln-formed glass

Modern sheet glass that has been heated in a kiln over a mould to echo the texture of stained glass.

Laminated glass

Glass panel composed of one or more sheets of polyvinyl (or some other resin) sandwiched between sheets of glass. If the glass breaks, the plastic prevents the shards from falling.

Lead-light cement

Glazier's term for a jointing and sealing compound brushed into the gap between the flanges of lead came and the glass units in a leaded window.

Leading

Assembly of a window panel using a framework of lead cames to join together small pieces of glass, which may be regularly or irregularly shaped.
See also Came

Monitoring

The systematic observation, recording and evaluation of dynamic processes, in a selective fashion, either continuously or on a periodic basis, for as long as is necessary to capture all the important cycles, trends or permutations. Used, for example, to track structural behaviour, characterise the building environment, identify risks or record rates of decay.

Mullion

In traditional windows, a vertical member dividing a window into two or more lights.

Saddle bars

Individual thin metal bars (usually horizontal) that support the window. They can be positioned internally or externally.

Stanchion

Vertical metal bar set between the mullions of a leaded window; part of the system that supports the panel. Can be set on the inside or outside of the window.
See also Ferramenta

Tie bar

A horizontal metal bar supporting the window structure, spanning the entire width of the window, usually at springing level. It pierces and passes through any mullions.

6 Further reading

6.1 Historic England publications

Curteis, T and Seliger, L 2019 Conserving Stained Glass Using Environmental Protective Glazing. London: Historic England

English Heritage 2012 Glass & Glazing. *Practical Building Conservation* series. London: Routledge

English Heritage 2014 Building Environment. *Practical Building Conservation* series. London: Routledge

6.2 Other publications

Barley, K 2010 'A history of protective glazing' in Pilosi, L, Shepard, M B, Strobl, S (eds) *The Art of Collaboration: Stained-Glass Conservation in the 21st Century.* London/Turnhout: Harvey Miller, 111–118

Bernardi, A et al 2013 'Conservation of stained glass windows with protective glazing: main results from the European VIDRIO research programme', *Journal of Cultural Heritage*, **14**, 527–536

Bettembourg, J M 1994 'Preventive conservation of stained glass windows' in *Preventive Conservation: Practice, Theory and Research, Preprints of the contributions to the Ottawa Congress, 12–16 September.* London: IIC, 110–115

ICOMOS/CVMA 2004 Guidelines for the Conservation and Restoration of Stained Glass, available on the CVMA website:
www.cvma.ac.uk

Trümpler, S 1988 'Experience with protective glazings in Switzerland' in Newsletter of the Technical Committee Corpus Vitrearum International 41/42,available on the CVI website:
cvi.cvma-freiburg.de

The Building Conservation Directory has many free online publications on the conservation of stained glass available on its website:
www.buildingconservation.com

7 Where to get advice

7.1 Useful organisations

General information

The Churchcare pages of the Church of England's Church and Cathedrals Building Division have links to conservation information, grant aid and surveying:
www.churchcare.co.uk/churches/art-artefacts-conservation/caring-for-conservation-of-artworks-historic-furnishings/stained-glass-historic-glazing

The Corpus Vitrearum is dedicated to the recording and study of stained glass from medieval to modern times; the Corpus Vitrearum Medii Aevi (CVMA) is an international research project dedicated to recording medieval stained glass. Its British pages contain a wealth of historical and technical information:
www.cvma.ac.uk

Grants for surveying and conservation work are also available from the National Churches Trust and the Heritage Lottery Fund:
www.nationalchurchestrust.org/our-grants
www.hlf.org.uk/looking-funding

The Stained Glass Museum in Ely Cathedral holds extensive stocks of stained glass and information about manufacture:
stainedglassmuseum.com/about

The website of the Corning Museum of Glass, in the US, also has extensive information about historic glass making, including videos showing production processes:
www.cmog.org

7.2 Finding a conservation professional

Historic England recommends the use of accredited conservation professionals with the appropriate experience. You will need to develop a close working relationship, and so should not hesitate to ask to see examples of their work, or to contact their previous clients.

Conservation architects and surveyors

Registers of accredited conservation architects and surveyors are maintained by a number of organisations:

Register of Architects Accredited in Building Conservation (AABC)
www.aabc-register.co.uk

The Royal Institute of British Architects (RIBA)
www.architecture.com

Royal Institution of Chartered Surveyors (RICS)
www.rics.org/uk

Stained glass conservators

The Professional Accreditation of Conservator-Restorers (PACR) scheme is operated through the Institute of Conservation (Icon). You can find accredited stained glass conservators, stone conservators and metal conservators (amongst others) by contacting Icon directly, or by looking on the Conservation Register (please note that not all registered conservators choose to pay for inclusion on the Register):
www.conservationregister.com

The British Society of Master Glass Painters lists accredited conservators who are also members of the BSMGP:
www.bsmgp.org.uk/about-us/the-society/bsmgp-accredited-members

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8 Acknowledgements

Text

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