BNDG04: The technology of energy efficient windows

Version 1.03

This Briefing Note and referenced information is a public consultation document and will be used to inform Government decisions. The information and analysis form part of the Evidence Base created by Defra's Market Transformation Programme.

1 Summary

This Briefing Note provides information on the technology options available to improve the energy efficiency of windows, including the current and possible future technology of:

- Low-e coatings for energy efficient windows.
- Gas filling of insulating glass units for energy efficient windows.
- Edge insulating glass units for energy efficient windows.
- Frame design for energy efficient windows.
- Reducing the air leakage of windows to improve energy efficiency.
- Glass to improve energy efficiency.

2 The technology of energy efficient windows

2.1 Designer windows

Considering windows as a system of components provides designers and specifiers with a range of options for improving the energy efficiency of the system. An outline of the effect of some of these options is presented in Briefing Note BNDG03, Section 7 on Ratings for product improvement. This Briefing Note covers the technology options in more detail and gives guidance on possible future technology developments for improving the energy efficiency of windows.

Energy efficiency is now a key design and specification factor and not something that happens by accident. This means that designers and specifiers need to be aware of the technology options very early in the design stage and certainly at the specification stage. The increasing regulatory requirements also mean that, in many cases, window systems will need to be re-designed to meet future requirements and there is a need for suitable guidance on the commercial availability and practicality of the various options available.

Designer windows will become the future - a future where the window is not simply a 'glass carrier' but an integral part of the energy efficient house.

Note: Costs have not been given in this Briefing Note because a full cost-benefit analysis can only be carried out by an individual company at a specific time. The cost of any technology is market driven and its increasing market uptake will automatically drive the cost down.

Figure 1 The energy flows in a window

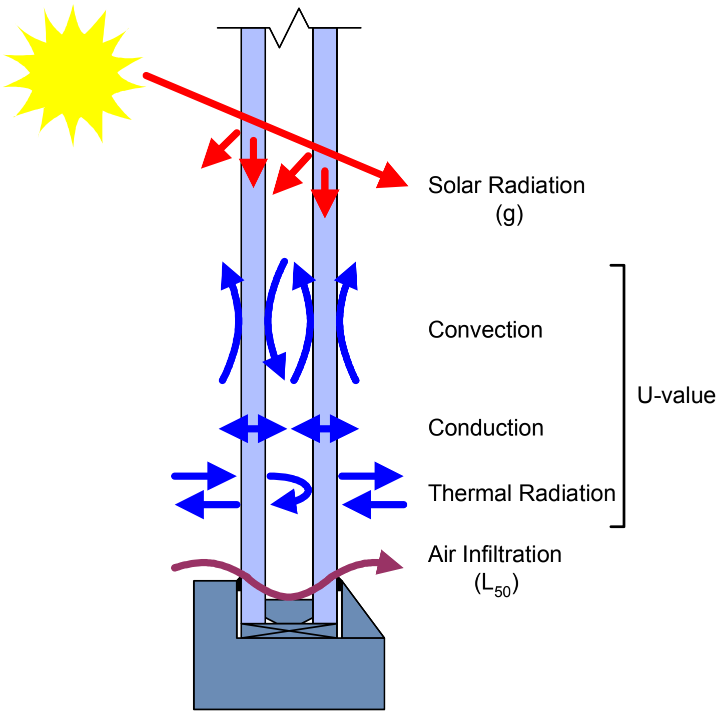
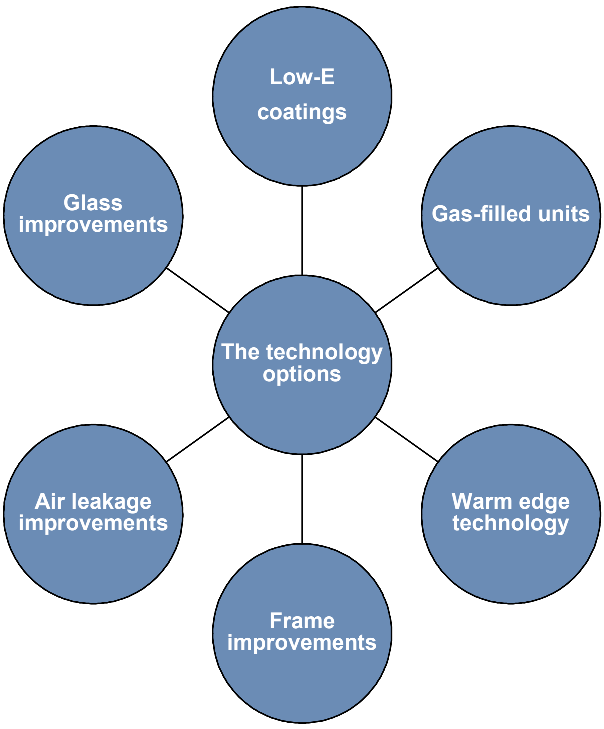


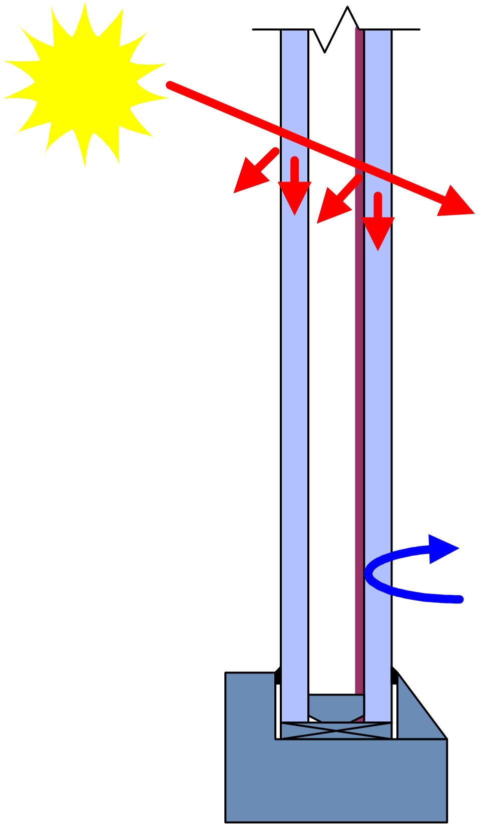
Figure 2 The technology options



3 Low-E coatings in energy efficient windows

The technology for producing energy efficient windows relies heavily on the development of low emissivity (low-E) coatings for glass. These can also be regarded as 'spectrally selective' coatings because their properties vary depending on the wavelength of the incident radiation. A low emissivity (low-E) coating allows the short wave solar radiation to pass through relatively unaffected. The heat radiated from inside the building is long wave thermal radiation and the low-E coating selectively reflects the long wave radiation back into the building.

Figure 3 Low-E coating on surface 3 of a window



The term low-E refers to the emissivity (ε) of the coating and an emissivity of 0.10 means that 90% of the long wave radiation is reflected back into the building - the lower the emissivity the greater the amount of short wave thermal radiation that is retained by the building. Low-E coatings are normally applied to surface 3 of the insulating glass unit. Low-E coatings often have a slight colour tint that varies between suppliers. Glazed units from different sources may therefore look slightly different, especially when viewed at an angle. Records should be kept so that broken units can be replaced with identical products to avoid colour variations in a given installation.

All low-E coatings are thin coatings of metal or metal oxides applied to the glass and, as with any advanced technology, there are several different production methods and the products have different properties. The two basic methods of producing low-E coatings are sputtering and pyrolytic deposition.

3.1 Soft coat – applied by sputtering

Sputtering uses a vacuum chamber to put several layers of coating onto the basic glass and the total thickness of the coatings is around ten thousand times thinner than a human hair. Sputtered coatings are often referred to as ‘soft coats’ and must be protected from humidity and long-term atmospheric contact. The sputtered coatings are very soft but, once inside a sealed unit, they will easily last for the life of the unit.

Sputtered products have very low emissivities and are currently the most effective type of coating for reducing the U_{glass}. These ’soft coat’ products can have an emissivity ranging from 0.05 to 0.10, compared to uncoated glass that has a typical emissivity of 0.89. This means that ‘soft coat’ products will reflect between 95 and 90% of the long wave thermal radiation, whereas uncoated glass will reflect only 11% of the radiant energy received by the surface.

Soft coat low-E coatings require ‘edge-deletion’ to remove the soft coat before they can be processed into insulating glass units. This requires an additional process and additional equipment which can lead to increased process costs and process wastage.

3.2 Hard coat – applied by pyrolytic deposition

Pyrolytic coating deposits the layers of metals or metallic oxides directly onto the glass surface at the end of the production line whilst it is still hot. The low-E coating is effectively ‘baked’ on to the surface and the resulting low-E coating is very hard and durable. The pyrolytic coatings are often referred to as ‘hard coats’. Pyrolytic coatings can be up to 20 times thicker than sputtered coatings (they are still 500 times thinner than a human hair) and the baking process makes them much harder and resistant to wear.

Pyrolytic ‘hard coats’ have a low emissivity but this is higher than those achieved for soft coats. Hard coat products have emissivities ranging from 0.15 to 0.20 and are thus between two to four times less effective than soft coats.

The ability to apply ’hard coats’ whilst the glass is still hot means that hard coated products are cheaper than soft coated products, but this is reflected in the energy performance.

3.3 Future technologies

Very low emissivity glass (ε = 0.02 - 0.04) is a soft coat glass and will have a major impact on the manufacture of insulating glass units. The material generally has a limited shelf-life before assembly into an insulating glass unit and it is currently uncertain that all products can be satisfactorily toughened.

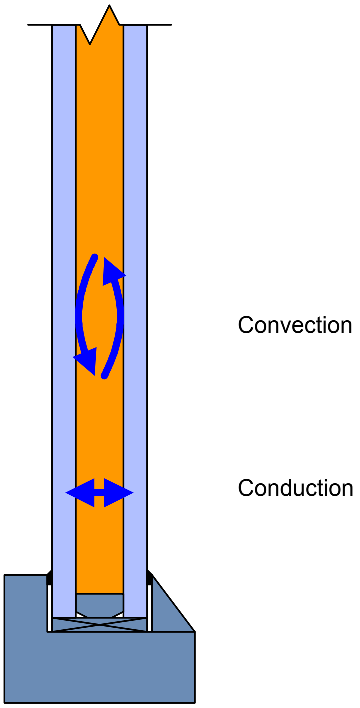
3.4 Total window performance

Low-E coatings reduce the amount of light passing through the glass (transmittance), which in turn reduces solar gain. This does not affect U_{glass} or $U_{window,}$ but does affect the energy efficiency and the BFRC Rating (see Briefing Note BNDG03 Section 8 Changing an industry).

4 Gas-filled units in energy efficient windows

One of the major areas of heat transfer in an insulating glass unit is by convection and conduction between the panes of glass. Conventional units are either filled with dry air or flushed with dry nitrogen before assembly and both gases are susceptible to convection (where the warm air rises to the top of the unit and the cold air falls to the bottom of the unit) and conduction through the gas in the space between the panes of glass (see Figure 4).

Figure 4 Gas filling in windows



Gas filling replaces the air or nitrogen with an inert gas such as argon or krypton. These gases are more viscous and slower moving than air or nitrogen and minimise both the convection currents and the conduction of heat through the glazing gap.

The gas fill is inserted into the glazing gap through an inlet port and vent in the spacer bar, or by using special corner pieces. Gas filling is not possible through some warm edge spacer bars due to their design. Gas filling is relatively easy to carry out, although it is necessary for the unit manufacturer to buy and install filling equipment.

4.1 General factors with gas filling

Gas filling is particularly effective when combined with the use of a low-E coating because the combination reduces all three of the main energy transfer mechanisms through the insulating glass unit.

The retention of the inert gas in the insulating glass unit is essential for continued energy efficiency. Research work has shown that for a well manufactured gas filled insulating glass unit, the gas loss rate is likely to be approximately 0.5% per year and in the order of 10% over a 20-year lifetime of a unit. The current European Standard (BS EN 1279: Part 3) requires a type test performance of no more than 1% gas leakage per year. These leakage rates will have no significant effect on the energy efficiency of the unit within the normal life of the unit. Correct specification of the sealed units is important in order to reduce the risk of failure (and subsequent gas loss), and to maintain energy efficient performance.

The optimum performance of insulating glass units varies with the thickness of the gap between the panes of glass and increasing the gap beyond this can lead to small decreases in glazing energy efficiency:

- Air or argon filled units reach a minimum U-value for a glazing gap of approximately 12 mm.
- Krypton filled units reach a minimum U-value for a glazing gap of approximately 8 mm.

Visible light transmittance and other factors, such as solar heat gain, are unaffected by the presence of inert gases.

There are no Health and Safety issues associated with the use of gas filling. The gases are inert, non-toxic and do not pose any risk in the event of breakage.

4.2 Argon

Argon is the most common gas fill used in the UK and is relatively inexpensive, easily obtainable and easy to use. Achieving a BFRC Rating of ‘C’ or above will almost certainly require the use of argon filled insulating glass units.

4.3 Krypton

Krypton gas fill offers much better energy performance than argon but its use has previously been relatively rare in the UK. The current drive for greater energy efficiency is leading to a rise in the use of krypton filling (see Briefing Note BNDG03, Section 8 Changing an industry). Krypton requires 100% gas fill for full performance. Krypton filling uses the same technology as argon filling, but it is expensive and there are long supply lead times in some cases. It is possible to use an argon/krypton blend to reduce costs but this also reduces the effectiveness of the gas fill. Achieving a BFRC Rating of ‘A’ will almost certainly require the use of krypton filled insulating glass units.

4.4 Vacuum sealed units

The optimum gas filling to use is no gas at all and the vacuum sealed unit represents the optimum that could be achieved for insulating glass units. Research is being carried out around the world to develop a commercially viable vacuum sealed unit but there are two major problems to overcome:

- The vacuum between the glass panes draws the panes of glass inward and the resulting reduction in structural strength and visible distortion make the units unsuitable for commercial use.

- The vacuum provides a strong force for air ingress to the glazing gap and retaining a seal for the lifetime of the unit is difficult to achieve. Any small loss in vacuum greatly reduces the effectiveness of the unit and maintaining an effective seal is essential for continued performance of the unit.

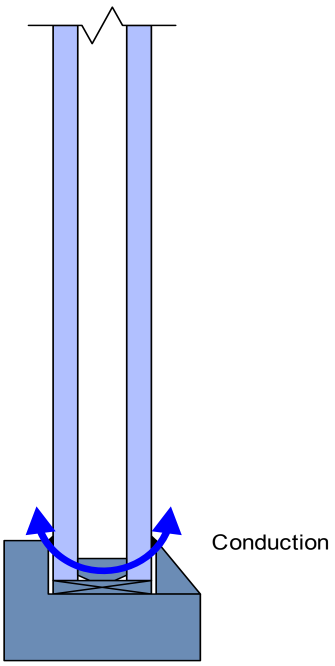
Despite this, the technology of the vacuum sealed unit is being actively investigated and it represents a potentially significant improvement in insulating glass unit performance.

5 Warm-edge technology in energy efficient windows

5.1 Insulating spacer bars

The panes of glass in a sealed unit are separated by a spacer bar, which has traditionally been made of aluminium. However, the high thermal conductivity of the metal creates a thermal bridge around the edge of the unit. This results in greater heat loss, the ‘edge effect’ and also makes the area more prone to condensation, which can encourage mould growth (see Figure 5). Stainless steel spacer bars have a lower conductivity than aluminium (17 W/mK as opposed to 230 W/mK), but while this is an improvement, the term ‘insulating spacer bar’ should only be used to refer to spacers that have reduced (or even zero) metal content. These are sometimes referred to as ‘warm-edge’ spacers.

Figure 5 Edge effects in windows



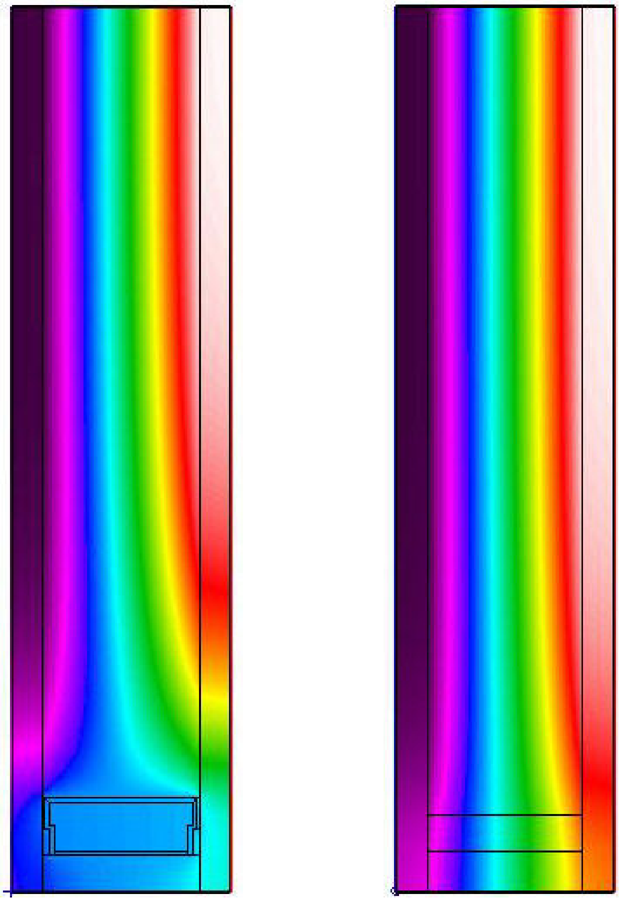
The effort of getting the U_{frame} down to the legislative requirements of the Building Regulations is often concentrated on the frame and the low-E coating. This can result in the use of expensive coating technology when a similar result can be more easily achieved at a lower cost by using new ‘warm-edge’ technology in sealed unit construction. The benefit of using warm-edge spacers is dramatically shown in

Figure 6. This shows THERM simulations of a standard metal spacer (left) and a warm-edge spacer (right).

For the standard spacer, the almost uniform blue colour shows that the temperature is nearly constant across the edge of the sealed unit in the area of the spacer. This shows that heat is freely moving across the unit in the area of the spacer. This can greatly reduce the U_{window} value.

For the warm-edge spacer, the pattern of colours shows that the temperature changes dramatically at the centre of the spacer - heat is no longer flowing freely across the unit in the spacer area but is being stopped by the 'warm-edge' technology of the spacer.

Figure 6 Heat flows related to standard and warm-edge spacers



Standard spacer **Warm-edge spacer**

(Graphic courtesy of Thermbridge Ltd)

The use of traditional metal spacers at the edge of the unit results in a much higher heat flow at the edges than at the centre of the glass and increased heat loss along the outer edge of the glass. It is not enough to rely on the decreased heat flow through the glass area: heat flow will always follow the easiest path and the relative impact of the edge effect actually becomes more important as the U-value of the rest of the unit decreases through the use of low-E coatings and gas filling (see section 4). Therefore, warm-edge spacers are more important for high performance sealed units than for older conventional sealed units and, as other technology options are used, the edge effect becomes even more important.

The edge effect is relatively independent of the size of the sealed unit and it extends at least 70 mm into the bulk of the sealed unit. The importance of the edge effect on U_{window} depends on the size of the window and the relative amount of glass edge to the total glass area. For standard test samples, such as the BFRC and Building Regulations samples (AD L1 2002 Edition), the impact of the edge effect is reduced but in real windows the edge effect can be very significant. This is particularly true for small windows that have a large ‘frame fraction’ (and therefore ‘glass edge’ fraction) in comparison to the ‘glass fraction’. Test samples may not actually represent the improvements in perceived benefits felt by the consumer.

An even more significant benefit for the consumer may be the effect of warm-edges on the interior glass surface temperature at the bottom edge of the window. This is the area of the window that is most subject to condensation. In this area, warm-edge spacers can increase the internal surface temperature by 3-4^{o}C at the sightline position and 2-4^{o}C at a position 30mm above the sightline, these may appear small increases but they can have a significant effect in terms of reduced condensation.

5.2 Industry developments

The general concept of warm-edge technology has led to the development of a wide variety of potential solutions using technologies as diverse as:

- Thin stainless steel webs combining primary and secondary sealants.
- Butyl tapes combined with thin metal strips and a backing sealant.
- Silicone foam combined with metallised foil and a backing sealant.
- Dual aluminium spacers joined by a polyurethane thermal break and a backing sealant.

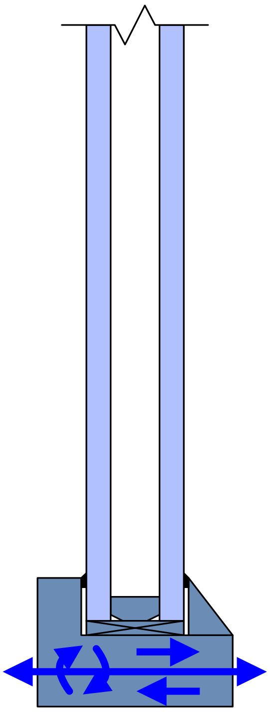
The majority of warm-edge technologies are easily integrated by insulating glass unit manufacturers into existing production lines and uptake of the general technology is well advanced in the UK.

The application of warm-edge technology is an inexpensive method of increasing the energy efficiency of the window system and achieving a BFRC Rating of ‘C’ or above will almost certainly require the use of warm edge technology of some description.

6 Frame improvements in energy efficient windows

Treating the window as a system means using the U-value of the complete window (U_{window}) and not simply the U-value of the glass (U_{glass}). The frame contributes to U_{window} because it also transmits heat through the conventional mechanisms of radiation, convection and conduction. The U-value of the frame is calculated using finite element or finite difference analysis tools such as THERM or BISCO (see Figure 7).

Figure 7 Frame effects in windows



Minimising the U_{frame} is a key objective for profile designers in any material. There is potential for improvements in all current frame systems and materials but Building Regulations and current standards for safety, durability, security and wind loading make it unlikely that these improvements will be greater than 0.1 to 0.2 of U_{frame}. This will therefore have a proportionately less impact on the whole-window U value (U_{window}).

6.1 PVC-U

PVC-U designers can increase U_{frame} by providing more internal chambers in the profile. Most current systems use a 3-chamber design and using more internal chambers can decrease U_{frame}. Using a 5-chamber design will improve U_{frame} but designers must be aware that the size of the chamber needs to be carefully considered. Very small or inappropriately located chambers may not provide any significant improvement in U_{frame}. PVC-U windows use internal reinforcement profiles of steel or aluminium and both the location and treatment of these reinforcing profiles can have a significant effect on U_{frame}.

6.2 Timber

Timber has an excellent inherent U_{frame} but the monolithic nature of timber profiles makes it difficult to designers to change U_{frame} significantly. Designers can modify the shape of the profile but there are few other opportunities to improve U_{frame}.

6.3 Aluminium

All aluminium profiles need a thermal break (a low thermal transmittance material) between the inner and outer aluminium sections of the profile. Traditional thermal breaks of the ‘fill and mill’ variety are unlikely to provide sufficient resistance to energy flow to meet the current and proposed Building Regulations or to achieve good BFRC Ratings. Designers now have available both new materials (polyamide or polyurethane) and significantly wider thermal breaks that will enable compliance with the Building Regulations and improve the BFRC Rating, a typical technology is the ‘clip and pour’ technology which allows thermal breaks of 24 mm and greater.

The precise location of the thermal break in the frame relative to the glazing will also have a large effect on the overall U_{frame}. Designers need to consider not only the shape and size of the thermal break but also the location.

6.4 Steel

Steel window systems are primarily used in replica refurbishment and whilst the high thermal conductivity of steel gives a high U_{frame}, the overall energy efficiency of steel framed windows can be improved by the slim sight-lines and high solar gain of the overall window.

6.5 New materials

The window industry is currently actively examining new materials that combine the benefits of both high structural strength (to eliminate metal reinforcement) and also low thermal transmittance (to minimise U_{frame}). Potential materials are pultrusions (glass fibre in a thermosetting resin matrix) and PUR (solid polyurethane foam with or without metal reinforcement). The drive towards increased energy efficiency is changing the industry (see Briefing Note BNDG03 Section 8 Changing an industry).

6.6 General design

One general method of minimising U_{window} is to make the contribution of U_{frame} as small as possible by reducing the visible sight lines (projected area) of the window frame. This maximises the amount of glass (U_{glass} is generally better than U_{frame}) and therefore lowers the U_{window} value. This method also maximises the beneficial effects of solar heat gain and therefore improves the overall energy efficiency from two directions. An entirely separate result of this approach is that the window frames are both less obtrusive and admit more daylight into the building.

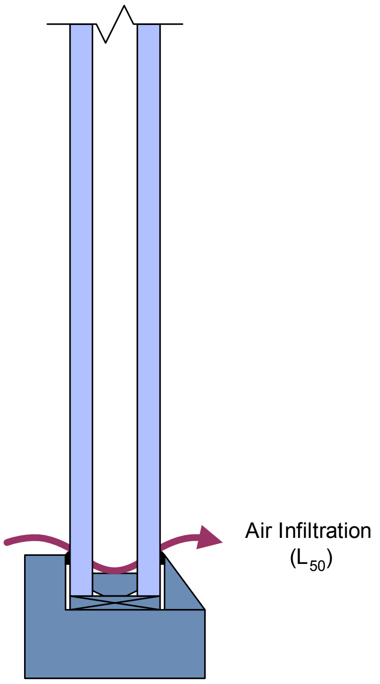
The design of energy efficient frames is not always intuitive and some of the possible improvements are not always obvious. Designers need to test potential improvements by thermal simulation to find the best design for energy efficiency before commissioning tooling.

7 Air leakage improvements in energy efficient windows

Air leakage is the unwanted movement of air through the window system. Air leakage must be differentiated from planned air movement though user controlled ventilation. Controlled ventilation is necessary for the prevention of condensation, the removal of odours and general air quality inside the building. Window energy rating does not include any consideration of controlled ventilation.

Air leakage into the building is termed ‘air infiltration’ (see figure 8) and air leakage out of the building is termed ‘air exfiltration’. Air infiltration allows cold air to move into the building and energy is required to heat the air to the room temperature. Air exfiltration allows warm air to move out of the building and energy is required to heat the replacement air. In either case the air movement causes more energy to be used as a result of the window properties.

Figure 8 Air leakage in windows



Air leakage occurs primarily through joints in the window frame, poorly sealed gaps between opening lights and outer frames and to a much lesser extent through gaps between the glass and the surrounding frame.

Improvements in frame design, manufacturing tolerances and sealing have resulted in the reduction or elimination of gaps at the frame joints.

The availability and widespread use of flexible and compressible weatherseals (modern windows often use both an inner and an outer weatherseal) has resulted in improved sealing between the opening lights and the outer frame. Current materials are both flexible enough to seal any gaps but also resilient enough to avoid taking up significant compression set when left closed for a long time.

Similarly, the availability and widespread use of flexible glazing gaskets has further improved sealing of the insulating glass unit.

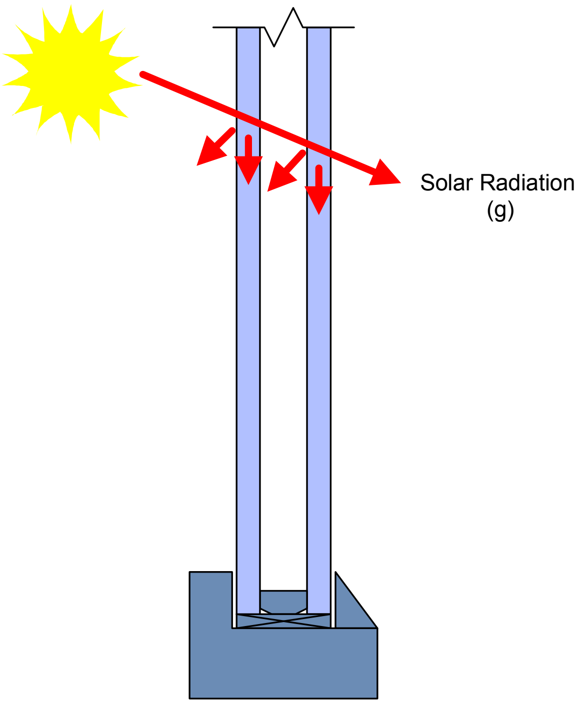
Modern windows can often achieve an effective air leakage rate of zero in normal use.

8 Glass improvements in energy efficient windows

8.1 Low-iron glass

It is possible to improve the overall energy efficiency of a window by improving the solar heat gain through the glass (see Figure 9). Conventional float glass, as used for most glazing purposes contains iron as an impurity and this gives the glass a slight green tint. This is particularly noticeable with thicker sheets of glass or when the glass is viewed along the edge. This iron impurity blocks solar radiation and can significantly reduce solar heat gain. Reducing the iron content produces an exceptionally clear and transparent glass (low-iron glass) and increases the transmission of solar radiation by approximately 5% from around 85% to 90%. Solar radiation is also not totally dependent on the amount of visible light available. Visible light is only a part of the complete solar spectrum and contains around half of the energy of the solar spectrum - the rest is in the infrared or UV areas of the solar spectrum. What you see is not what you get!

Figure 9 Glass improvements in windows



Low-iron glass is commercially available, but not currently manufactured, in the UK. Current UK glass plants require modifications, which can only be done at the time of a major tank rebuild to produce low-iron glass. Low-iron glass also has a longer cycle time for toughening when this is required.

This benefit of low-iron glass is more marked with multiple paned units (eg triple glazing) where it is used in the outer panes.

Achieving a BFRC Rating of ‘C’ or above will almost certainly require the use of low-iron glass in some of the glass panes.

8.2 Triple glazing

Triple glazing offers obvious benefits in reducing the thermal transmittance of the sealed unit but this is not always the most energy efficient option. The introduction of another pane of glass into the insulating glass unit can dramatically reduce the solar transmittance and lead to an overall decrease in the energy efficiency of the window system.

Triple glazing also increases the weight of the insulating glass unit by 50% and can result in window size limitations, the need for more substantial window hardware and Health & Safety implications when lifting.

Related MTP information

- BNDG01: Explanatory notes and assumptions for policy brief on domestic glazing
- BNDG02: BRFC ratings of known window types
- BNDG03: Background to energy efficient windows
- Policy Brief: Domestic Glazing Sector: Windows

Changes from version 1.02

Hyperlinks to related documents inserted.

Consultation and further information

Stakeholders are encouraged to review this document and provide suggestions that may improve the quality of information provided, email **info@mtprog.com** quoting the document reference, or call the MTP enquiry line on +44 (0) 845 600 8951.

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