Thermal fracture of glass may occur when the glass is heated creating temperature differences across the surface of the glass. Thermal fracture may occur as a result of solar heating or fire. This Technical Note covers the thermal fracture that occurs as a result of solar heating of glass. It explains the principle of thermal fracture, features that predispose glass to thermal fracture and the selection of glass to avoid thermal fracture. Calculations to assess the risk of thermal fracture are outside the scope of this Technical Note. The purpose of this Technical Note is to make readers aware of the phenomenon so that they can recognize the failure and take steps to prevent its occurrence.

This Technical Note is one of eight describing the use and performance of glass. They are:

- TN61 Glass types
- TN62 Specification of insulating glass units
- TN63 Glass breakage
- TN65 Thermal fracture of glass
- TN66 Safety and fragility of glazed roofing: guidance on specification
- TN67 Safety and fragility of glazed roofing: testing and assessment
- TN68 Overhead glazing
- TN69 Selection of glass to prevent falls from height

**Introduction**

If the temperature of part of a glass pane is raised, that area will expand relative to the cooler areas of the pane. The cooler area of glass attempts to restrain the expansion and thermal tensile stresses develop in the cooler area. If the temperature difference is sufficiently great the glass can fracture.

The glass temperature may be raised as a result of:

- Solar radiation
- Space heating devices

The intensity of direct solar radiation incident on an individual pane will depend on its location, slope, orientation and any shading. The pane may also receive reflected solar radiation.

Solar radiation across the UK ranges from 750 - 800 W/m² on a plane orthogonal to the sun’s rays. Solar radiation on sloping surfaces is greater than on vertical surfaces and roof glazing is more prone to thermal fracture.

Space heating devices may cause thermal fracture if they are in very close proximity to the glass. They may also add to the heating effect of solar radiation.

Vertical uncoated clear annealed glass and clear annealed glass with a low absorption coating do not usually suffer from thermal fracture in UK conditions when there is a ventilated space behind the glass. However it may fracture if there are extreme shadow patterns, if the incident solar radiation is increased as a result of reflection from other building surfaces or if the glass is less able to lose heat. Uncoated clear glass may suffer from thermal fracture as a result of:

- Using the glass as part of an opaque spandrel or shadow box
- Internal fit-out behind the glass
- Reflected solar radiation
- The presence of internal heating and cooling sources
- Furniture or goods placed close to the glass
- Use in sliding windows and doors which are left open
- Filming the glass
- Inappropriately selected, detailed or positioned blinds or curtains.

Tinted glasses have greater risk of thermal fracture as the greater absorption of the glass causes it to become hotter.
Coated glasses may also have a greater risk of thermal fracture as the glass may become hotter as a result of solar radiation being reflected back through the glass.

Where there is a risk of thermal fracture it can be overcome by using heat strengthened or toughened glass.

**Failure mode**

Thermal fracture is characterised by a failure pattern where a short straight crack develops at the edge of the pane. This crack runs perpendicular to the pane edge and is perpendicular to the face of the pane. Thereafter the crack tends to propagate across the pane in a meandering pattern. The initial crack is often concealed within the glazing rebate. The stress created in the glass is concentrated at points along the edge by imperfections creating an origin for the cracks. Propagation of the cracks may occur immediately but can occur slowly over a period of days.

![Figure 1 Typical thermal stress fracture pattern](image)

Figure 1 illustrates the meandering nature of a thermal crack.

**Thermal stress**

The unrestrained expansion of heated glass is given by:

\[ \Delta L = \alpha \times L \times \Delta T \]

Where \( \alpha \) is the coefficient of thermal expansion (9 x 10^-6/°C for soda lime silicate glass), \( L \) is the original length and \( \Delta T \) is the increase in temperature. Note that for borosilicate glass the thermal coefficient of expansion lies in the range 3 - 6 x 10^-6/°C. As a result the expansion and induced stresses are only 35 – 70% of those for soda lime silicate glass. However, borosilicate glass is rarely used in architectural applications.

In practice some parts of the glass may be heated to a lesser extent. Replacing \( \Delta T \) with the temperature difference between the warmest and coolest parts of the pane gives the relative free expansion of the warmed part.

If this expansion is restrained, the induced stress is given by:

\[ \sigma = (\Delta L/L) \times E \]

where \( E \) is the Young’s modulus (70,000 N/mm² for glass).

The maximum stress induced by a temperature difference of one degree is therefore \( \alpha \times E \) and a temperature difference of one degree results in a maximum theoretical stress of approximately 0.63 N/mm². In practice the stress will be lower and will depend on the relative size of the warmer and cooler areas.

The risk of thermal breakage in basic (annealed) glass becomes significant when stress levels exceed about 20 N/mm². A temperature difference of some 30°C can, therefore, be sufficient to cause thermal fracture. If the glass has been poorly cut, damaged during handling or improperly glazed, breakage could occur at lower temperature differentials.

This is a simplistic and conservative approach to calculating the risk of fracture. A fuller calculation taking into consideration heat flow and movement of the glass can be undertaken by the glass manufacturer or supplier.

A European Standard for determining the risk of thermal fracture due to solar radiation is being drafted by CEN/TC129.

**Acceptable temperature difference**

The safe temperature difference below which thermal fracture does not occur depends on the tensile strength of the glass. Approximate safe temperature differences for different types of glass are given in Table 1. The precise value will depend on the method used to calculate the
temperature difference. These values assume that the glass has a clean cut edge and is glazed appropriately. The condition of the edge of the glass pane is considered in more detail later.

The safe temperature differences given for heat treated glasses may be relied on for glasses produced to comply with European Standards. Other heat treated glasses may have different characteristics.

<table>
<thead>
<tr>
<th>Glass type</th>
<th>Temperature difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermally toughened borosilicate glass¹</td>
<td>300°C</td>
</tr>
<tr>
<td>Thermally toughened glass²</td>
<td>200°C</td>
</tr>
<tr>
<td>Heat strengthened glass³</td>
<td>100°C</td>
</tr>
<tr>
<td>Basic borosilicate glass⁴</td>
<td>80°C</td>
</tr>
<tr>
<td>Basic (annealed) float glass⁵</td>
<td>40°C</td>
</tr>
<tr>
<td>Basic (annealed) patterned glass⁶</td>
<td>30°C</td>
</tr>
<tr>
<td>Basic (annealed) wired glass, (patterned or polished)⁷</td>
<td>25°C</td>
</tr>
</tbody>
</table>

¹ BS EN 13024-1, ² BS EN 12150-1, ³ BS EN 1863-1, ⁴ BS EN 1748-1, ⁵ Pilkington (1980)

Table 1 Safe temperature differences

The resistance to thermal stress of any glass type varies as a result of its dimensions, surface and edge conditions and different panes may therefore have different resistances to thermal stress. When investigating incidences of suspected thermal fracture it should be borne in mind that some panes may be more susceptible than others and not all panes are destined to fail.

Heat strengthened and thermally toughened glass will withstand high temperature differences and will not normally suffer thermal fracture as a result of solar radiative heating.

Glass temperatures

The temperature difference due to solar radiation can be calculated as the difference between the temperature of the unshaded pane area and that of the shaded area. Shading may be caused by the glazing frame, deep reveals, fins, brises soleil, other buildings etc.

**Un-shaded temperature**

The temperature of the un-shaded area of glass will depend on the solar absorptance and reflection characteristics of the glass and coatings, the make up of an insulating glass unit, applied films, internal features and reflection of solar radiation on to the glass. It is comparatively easy to calculate.

**Solar control glasses,** both body-tinted and coated, will heat up more than clear uncoated glass when exposed to solar radiation, increasing the risk of thermal breakage. Body tinted glass may absorb up to 75 per cent of the incident solar radiation compared with 15 – 27% for clear glass. A reflective coating on the inner face of the glass reflects a proportion of the incident solar radiation so that it passes through the glass for a second time further heating the glass.

**Insulating glass units** have a greater risk of thermal fracture as the glass will heat up faster and become hotter than single glazing. This occurs because of the insulation provided by the second pane of glass and the cavity.

This effect is increased by the use of low-E coatings on the inner pane of insulating glass units with solar control glass as the outer pane as the rate of heat transfer across the cavity is further reduced.

**Applied films** may be used to control transmittance of solar radiation. They may be reflective and reflect solar radiation so that it passes through the glass a second time further heating the glass. Alternatively they may absorb solar energy and heat up transferring heat to the glass.

Films may be applied to glass for other reasons than solar control, for instance security or safety. However, these films may also modify the solar transmission characteristics of the glass and lead to thermal fracture. CWCT TN43 gives further guidance on filmed glass.

**Internal features** and thermal conditions on the room side of the glass affect the amount of heat absorbed and lost by the glass.

Internal blinds and light coloured drapes may reflect radiation that further heats the glass.
Blinds and shutters may also reduce heat loss by restricting air convection currents that would otherwise carry heat away from the glazing.

As a result, at glass selection stage, it is essential to specify the proposed blind details, including colour, perforations, distance from glass, and width of gaps between the blinds and adjacent mullions and transoms.

**Reflection of solar radiation** on to the glass will add to the heating effect of solar radiation directly incident on the glass.

Solar radiation may be reflected from a framing member on to the glass. Other causes of reflected radiation include signage and glass canopies. Solar radiation may also be reflected by an adjacent orthogonal wall.

**Edge temperature**

The edge temperature of the glass will depend on the low overnight temperature, frame construction and external shading. It is more difficult to estimate than the un-shaded temperature.

**Low overnight temperature** will cool the glass and frame. The edge of the glass will subsequently warm at a slower rate than the exposed glass as a result of shading by the frame, insulation of the frame and the thermal mass of the frame and its surroundings. The difference between night-time and daytime air temperatures is therefore a factor in assessing the edge temperature relative to the un-shaded temperature.

**Frame construction** determines heat loss from the frame to the surrounding structure and the response of the frame to solar radiation.

The risk of thermal breakage will be increased if the frame is in good thermal contact with a substantial heat sink thus keeping the edge of the glass cool. The most severe example is where the glass is glazed directly into concrete or brickwork.

Frame material, colour and design will affect the temperature rise of the frame and hence the edge of the glass in response to solar radiation. The risk reduces as the frame is changed from wood to metal and then plastic and dark frames give a lower risk than light ones.

The edge spacer will also have an effect. Glass units typically contain a metal edge spacer to separate the panes of glass. The spacer acts as a thermal bridge and in cold winter conditions will conduct heat to the edge of the outer pane, so reducing the centre-to-edge temperature difference when the sun is shining. ‘Warm edge’ spacers are increasingly being specified and, although they enhance the overall insulating properties of the unit and reduce the risk of condensation, they will increase the risk of thermal breakage.

**Temperature difference**

The temperature difference will also be affected by lateral heat flow in the glass and shading of the glass.

Shading of the edge 100mm of the glass has no effect on thermal fracture. Static shading that exists for a period of 4 hours or more has the greatest effect.

Shadows may be created from overhanging balconies or walkways or nearby buildings. The shadow from a cleaning cradle parked in front of a glass panel can induce thermal fracture.

**Edge condition**

Thermal cracks start at the edge of the glass pane and resistance to thermal cracking therefore depends on the condition of the edge of the pane.

A clean wheel cut edge gives the greatest edge strength. Edge damage, which is usually caused by poor handling, can impair the strength of a pane of glass by creating stress concentrations. Edge damage can also occur when cutting glass (difficulty increases with thickness) although this is likely to be less severe than damage due to poor handling and hence much less likely to lead to breakage.

Edge working may be used to remove imperfections due to cutting; a polished edge is almost as good as a clean cut edge but a ground edge will be weaker due to the minute imperfections that make up a ground surface. This will be more significant if the direction of grinding is across the edge so that defects are aligned with the direction of potential thermal cracks. An arrissed edge may be less vulnerable to damage during handling. Types of
edge working are described in BS EN 12150 and BS EN1863. Any edge working should be by a wet process working parallel to the glass edge.

BS EN 572-8 gives limited guidance on the acceptable condition of cut edges in terms of the maximum dimensions of protrusions or indentations which are referred to as emergent or entrant faults. However, these limits only apply where there is no risk of thermal fracture. Figure 2 illustrates some edge conditions of glass and gives a practical guide to the acceptable edge condition.

![Figure 2 Degrees of edge damage](image1)

Figure 2 Degrees of edge damage

Acceptable – clean cut edge
Acceptable – good edge with little feather
Just acceptable – severely feathered edge
Unacceptable – vented edge

Figure 3 shows damage to the surface of glass at a cut edge. Shelling of the surface has occurred as a result of inappropriate methods being used to cut laminated glass. The thermal fracture may be clearly seen.

![Figure 3 Surface damage at edge](image2)

Figure 3 Surface damage at edge

Handling/glazing

Correct handling and glazing of the glass is essential to avoid edge damage and minimise the risks of thermal fracture.

Glass may suffer from thermal fracture during construction if:

- It is exposed as a pack to solar radiation, as the inner glass panes are not cooled by convection,
- It is subjected to conditions for which it was not designed. For instance a protective board placed against the inner surface may increase the temperature of the glass.

The glass should be properly supported and have adequate clearance to allow thermal and structural movements to occur without causing glass to metal contact, especially localised contact.

Checking for thermal safety

Project specific checking is necessary and all of the major glass manufacturers will undertake thermal safety checks on behalf of customers.

Alternatively a project-specific stress analysis using suitable software may be undertaken.

The safety check should take account of temporary conditions such as scaffolding and
cleaning cradles and future conditions such as trees planted in close proximity to a glazed wall.

Smaller panes of glass generally have a smaller area of edge (thickness x perimeter). The probability of edge flaws is smaller and the glass will have a lower risk of thermal fracture occurring. This may be taken into account when undertaking a safety check.

**Glass selection**

Glass should be selected to withstand thermal fracture on the basis of a thermal safety check. If it is found that basic (annealed) glass will be susceptible to thermal fracture then either the design must be changed to reduce the induced temperature stress or a different glass must be selected.

Thermally toughened and heat strengthened glasses do not normally suffer from thermal fracture as a result of solar radiation. However, there may be constraints on their use.

- These heat treated glasses will display roller wave and bow that will have an effect on the appearance of the glazing. CWCT TN35 covers the appearance of glass.
- Non-laminated glass may present a hazard if it can fall from height when broken or allows people or objects to fall from height. CWCT TN66, CWCT TN67, CWCT TN68 and CWCT TN69 cover these aspects of performance.

**Summary**

The risk of thermal fracture caused by solar heating of glass is dependent on:

- The glass used
- The position, orientation and construction of the glazing
- Shading devices
- Internal fit-out
- Workmanship

The use of thermally toughened and heat strengthened glass eliminates the risk of thermal fracture but may not be desirable on the grounds of cost or appearance.

For basic (annealed) float glass, laminated glass, patterned glass and wired glass a thermal safety check will show whether there is a risk of thermal fracture occurring.

**References**

BS EN 1748-1-1, 2004, *Glass in building – Special basic products – Borosilicate glasses – Definition and description*

BS EN 1863-1, 2000, *Glass in building - Heat strengthened soda lime silicate glass – Definition and description*

BS EN 12150-1, 2000, *Glass in building - thermally toughened soda lime silicate safety glass – Definition and description.*

BS EN 13024-1, 2002, *Glass in building – Thermally toughened borosilicate glass – Definition and description*


CWCT TN43, *Film backed glass*