Technical Note No 35

Assessing the appearance of glass

This Technical Note is one of three on assessing appearance. The series comprises:

TN 34 Assessing the appearance of new curtain walling
TN 35 Assessing the appearance of glass
TN 36 Assessing the appearance of metals and finishes

Introduction

The quality of glass is often assessed by visual inspection and disputes sometimes arise over the associated procedures and acceptance criteria. This is particularly the case where a specification is not sufficiently detailed.

This Technical Note gives advice on factors which affect the appearance of glass and how they can be specified and assessed. This Note should be read in conjunction with TN34 ‘Assessing the appearance of curtain walling’.

Factors affecting glass colour

Glass may be thought of as colourless but most glass has a green tinge due to the presence of iron. Other colours may also be apparent due to different impurities in the raw materials. Some glass is deliberately coloured by the addition of materials to the molten glass or application of coatings to the glass surface. Alternatively, coatings applied for solar control may be described as clear but may have a slight effect on colour. Appearance depends on the colour of the glass and uniformity of colour. Factors affecting colour are described in Table 1.

Tolerances in glass products

Tolerances may be given for the size of the glass panes, flatness of glass and faults as summarised in Table 2. 'Faults' is a term used in Standards to describe undesirable features of the glass however they cannot be entirely eliminated and are permitted within defined limits. Standards divide faults into three categories:

- Optical faults, which result in distortion of images viewed through the glass and relate to flatness of the glass. Optical faults are a permanent feature of the glass and should be assessed at the time of manufacture.
- Spot faults include bubbles and deposits. Many of these faults are permanent features of the glass but some may be introduced by damage during processing and erection.
- Linear/extended faults include scratches and scuffs on the surface of the glass. These faults may occur at any time in the life of the glass and inspection may be carried out at various stages including at the point of initial manufacture, after processing and after installation.

Viewing criteria for glass types

Table 3 lists the Standards for different glass products, summarises their requirements for assessment of appearance and gives guidance on specification.

The visual inspection criteria given in the Standards listed in Table 3 are generally applicable to inspection at the point of manufacture. The inspection techniques may not be possible under site conditions and different assessment criteria may be appropriate after processing and installation to allow for minor damage during these activities. The requirements for inspection of coated glass given in BS 1096 are the
exception as they may be used both at the point of manufacture and on site.

The following documents are applicable to the inspection of glass on site after installation.

GGF guidelines
i. **GGF Standard for the quality of thermally toughened glass for building**
   Refers to BS952 for optical quality and body faults, eg. seeds, bubbles which are permanent features of the glass. BS 952 does not give requirements for such faults and reference should be made to BS EN 12150.
   Gives an inspection procedure for surface faults, eg scratches which may increase with time. For assessment of surface faults the pane is to be observed from 3m under normal daylight conditions. Angle of observation is to be 90° to the surface. The pane is to be vertical and can be glazed. The pane is deemed to be acceptable if surface faults are not readily visible when viewed in transmission.

ii. **Visual quality standard for installed insulating glass units constructed from flat transparent glass**
   Both panes of the sealed unit shall be viewed at right angles to the glass from the room side standing at a distance of not less than two metres but for toughened, laminated or coated glass not less than three metres in natural daylight and not in direct sunlight. The area to be viewed is the normal vision area with the exception of a 50 mm band round the perimeter of the unit. Glass is acceptable if defects are not obtrusive when looking through rather than at the glass. Defects include totally enclosed seeds, bubbles or blisters, hairlines or blobs, fine scratches not more than 25mm long, minute embedded particles.

Hadamar 10/96

Guideline to Assess the Visible Quality of Insulating Glass Units
This document was prepared by the Institute of the Glazing Trade for Glazing Technology and Window Manufacture in Germany. The four-page document is sometimes cited by European glass suppliers. It sets out criteria for assessing defects. A viewing distance is cited of one metre for viewing the acceptability of defects it describes. (Note: the viewing distance and the associated defects to be viewed are inextricably linked; a specifier or an observer should not arbitrarily use the viewing distance from one Standard and the viewing criteria from another).

Most of the procedures for visual inspection include subjective assessment criteria. The term 'visually disturbing' is commonly used in Standards and the GGF documents use the terms 'readily visible' and 'obtrusive'. Where assessment is based on subjective assessments agreement between the relevant parties should be obtained at an early stage.

Samples may be used to overcome some of the problems relating to visual inspection however small samples viewed in office conditions can look very different to large panels viewed under site conditions.

Inspecting double glazed units on site can be problematic if viewing criteria and viewing distances have not been agreed by all parties in advance. In the event of the above documents being unsuitable, consideration should be given to agreeing criteria on the lines suggested below:

- The total number of faults permitted shall be the sum total of those permitted by the relevant BS EN Standard for each pane of glass incorporated into the unit concerned.
- The viewing distance used shall be the furthest stated in any of the BS EN Standards for the glass types incorporated in the glazed unit. In the
event of doubt the viewing distance shall be three metres.

- The viewing shall commence at the viewing distance and shall not be preceded by viewing at a closer distance.
- The viewing shall be undertaken in normal daylight conditions without use of magnification.

The specifier should not specify viewing criteria or distances more stringent than those given in the BS EN Standards for the glass in question as the glass supplier will be unable to impose tighter standards except possibly with regard to overall bow, local bow and roller wave in heat strengthened or toughened glass.

Summary

This Technical Note gives advice on assessing the appearance of glass and provides guidance on sources of information for such inspections. This Note should be read in conjunction with TN34 ‘Assessing the appearance of curtain walling’.

In this Note, guidance is provided in tabular format on the following:

- Factors affecting glass colour
- Tolerances in glass products
- Standards for different glass types

References and bibliography


BS EN 1863-1:2000 - Glass in buildings - Heat strengthened soda lime silicate glass - Definition and description


Hadamar 10/96 ‘Guideline to Assess the Visible Quality of Insulating Glass Units’, prepared by the Institute of the Glazing Trade for Glazing Technology and Window Manufacture, Germany

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### Table 1 – Factors affecting glass colour

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<tr>
<td>Constituent materials</td>
<td>Glass has a green tinge due to the iron content. The colour may vary to some extent from plant to plant and between batches from the same plant. If required the Architect can specify &quot;low iron&quot; glass that has a lower iron content and is therefore less green. There is normally a significant cost implication.</td>
<td>The Architect should specify if low iron glass is required. If not specified, ordinary glass will be used.</td>
<td>Not applicable.</td>
</tr>
<tr>
<td>Glass thickness</td>
<td>The thicker the glass, the more noticeable the tint. If very different glass thicknesses are used on different parts of the facade, some difference in colour may be apparent.</td>
<td>The Architect should specify whether the same glass thickness should be used in all locations. This may increase the cost and may have other implications that will require resolution at an early stage.</td>
<td>Not applicable.</td>
</tr>
<tr>
<td>Body tinted glass</td>
<td>In body-tinted glass, the constituent materials forming the glass include a colouring. Thus the thicker the glass, the stronger the colour. There is a tolerance on the colour.</td>
<td>The Architect should specify whether the same glass thickness should be used in all locations. This may increase the cost and may have other implications that will require resolution at an early stage.</td>
<td>Not applicable.</td>
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### Table 1 cont’d

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<td>Low E and other thin coatings on glass</td>
<td>Very thin coatings may be applied by specialist applicators to improve the thermal performance of the glass. Such coatings can affect: (a) The apparent colour of the glass, (b) The colour of objects viewed through the glass, (c) The colour of reflections. Different coatings applied to achieve the same effect, for example hard and soft low E coatings, may give different colours. Whilst coatings are applied in tightly controlled conditions, variations in colour do occur. Whilst coating applicators keep coating colours within certain in-house parameters, these do not normally form part of the contract. It is therefore advisable for Architects to view the proposed coating(s) on existing buildings to assess the colour variation likely to occur. On any such building, the complete glass configuration should be similar to that proposed and not merely the coating if assessing the nominal colour and not merely the consistency.</td>
<td>The specification should detail: (a) The required limits on photometric properties, (b) The product details of the preferred glass type, indicating whether equivalent alternatives are acceptable, (c) Samples required, (d) Viewing criteria for acceptance. Restricting the glass to the same source will reduce variations in appearance. Samples will not show the full variations in colour that may occur. Thus the Architect should also view buildings incorporating the glass types concerned to check the full variations in colour etc that may occur. Some coatings tend to be more consistent than others. Select with care. Viewing criteria should be confirmed with the proposed applicator prior to finalisation. Viewing criteria include both the method of inspection and the acceptance criteria. BS EN 1096-1 for coated glass sets out a method of inspection but is less precise on the acceptance criteria which require that the colour variations are 'not visually disturbing'.</td>
<td>Most coatings result in unavoidable visible variations in appearance. In the event of queries regarding consistency, check against reference buildings. If this does not satisfy the query, request the coating applicator to measure on site scientifically the coating’s colour related parameters and to confirm that they are within the applicator’s normal production tolerances.</td>
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### Table 1 cont’d

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<td>Colour streaking</td>
<td>Coatings on glass affect the transmission and reflection of radiation. If the application of the coating is not properly controlled, unintended visual effects can occur. For example, low E coatings are designed to reflect infrared radiation but allow transmission of visible light. Variation in coating thickness can cause the coating to give increased reflection of visible light at the red end of the spectrum which may be visible as pink streaking under certain lighting conditions.</td>
<td>See above.</td>
<td>See above.</td>
</tr>
<tr>
<td>Soft coatings near the exposed perimeter of double glazed units. (Note: This does not occur if the units are retained by pressure plates).</td>
<td>Soft coatings incorporated in double glazed units are “edge stripped” around the glass perimeter. Due to legitimate tolerances in production, the exact position of the edge of the soft coating will vary from the nominal position. Where the soft coating intrudes between the black primary seal of the double glazed unit and the glass, a metallic interference reflection of a colour depending on the coating will be apparent in bright sunlight. The most common colours are blue or reddish-pink. Conversely, where the soft coating’s edge stops short of the black perimeter seal, a narrow band of bright light may be apparent at night when the building’s lights are on.</td>
<td>The visual effects can be limited by tight control of tolerances on edge stripping and double glazing unit assembly. However, the visual effects will still remain unless the perimeter of the double glazing unit is hidden by pressure plates or the edge of the glass is silk-screened. The Architect should specify: (a) The tenderers should advise the nominal position of the edge stripping and the associated tolerances. (b) The tenderers should advise the colour of reflections at the critical locations. (c) The Architect should specify if silk screening is required.</td>
<td>Inspection on site should be confined to establishing whether the edge stripping complies with tolerances agreed at tender stage.</td>
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### Table 1 cont’d

| Factor          | Technical guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Specification                                                                                                                                                                                                                                                                                                                                                     | Site inspection                                                                                                                                                                                                                                                                                                                                                       |
|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Silk screen printing | Silk screening is a process used to apply a thin enamel coating to the glass to form a pattern or a complete film. The coating is then fired in at temperature.  
Silk screening may be used for general patterns, modesty printing, manifestation, and concealing any visible edges of double glazed units. Silk screening adds to the cost and time of glass supply. Thus it will not normally be priced unless specified.  
Soft coatings on the glass can affect the apparent colour of the silkscreen printing.  
Where the enamel is viewed through the glass the apparent colour will be affected by the glass. | The Architect should specify:  
(a) Colour reference  
(b) Degree of opacity  
(c) Pattern required  
(d) Position(s) of pattern(s) required  
(e) Viewing criteria for acceptance  
Samples should be requested at the appropriate stage. The coating sample should be applied to a sample of the proposed glass configuration, including any soft coatings.  
If possible, buildings with the proposed silkscreen print colour should be viewed prior to final selection.  
Viewing criteria should be confirmed with the proposed applicator prior to finalisation. | Check consistency prior to delivery to site where practicable. Any checking should be against samples and reference buildings. A high degree of consistency should be expected but some variations in colour and opacity will occur.                                                                                                                                                                                                                                   |
| Spandrel panels | Opacified glass for spandrel panels may be formed by spray application of enamel or paint. The coating is translucent (but less so than screen printing) and should be used in non vision areas as variations in coating thickness, pinholes etc are very obvious if the glass can be viewed back lit.  
The coating is normally applied to the back face of the glass and the apparent colour will be affected by the glass. |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Check consistency prior to delivery to site where practicable. Any checking should be against samples and reference buildings. A high degree of consistency should be expected but some variations in colour will occur.                                                                                                   |
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<tr>
<td>Anisotropy</td>
<td>Heat strengthening or toughening glass produces areas of different stress in the cross section of the glass. These areas of stress produce a bi-refringent effect in the glass, which is visible in polarized light. When such glass is viewed in polarized light, the areas of stress show up as coloured zones. This is referred to as “anisotropy” and is also known as ‘leopard spots’. Polarized light occurs sometimes in normal daylight conditions, often for a few hours at a time. The amount of polarized light depends on the weather and the angle of the sun. When this occurs, the stress marks in such glass become very visible. There is no known means of mitigating this effect in heat strengthened or toughened glass.</td>
<td>The specification should recognise that: (a) anisotropy can occur in heat strengthened or toughened glass; (b) there is no known means of mitigating the effect in such glass types; (c) anisotropy is an unavoidable feature in heat strengthened and toughened glasses.</td>
<td>Anisotropy is a feature permitted in BS EN 1863 for heat strengthened glass and in BS EN 12150 for toughened glass. It is not a defect. Thus no inspection criteria apply.</td>
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Table 2 – Tolerances in glass

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<tr>
<td>Glass sizes</td>
<td>Accuracy in glass cutting will depend on the methods used. Modern computer controlled equipment tends to cut to tighter tolerances than manual methods. If using annealed laminated glass, steps at the edges can be avoided by laminating prior to cutting although this limits the extent of edge working that can then be undertaken.</td>
<td>The specification of finished glass sizes should have due regard to practical tolerances and to the effects on tolerances of any required edge grinding or polishing. Standards for toughened, heat strengthened and laminated glass give tolerances on cut sizes of glass. A part of EN 572 giving tolerances on cut sizes of annealed glass is in preparation.</td>
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<td>Annealed glass flatness</td>
<td>Glass is not perfectly flat and flatness will depend on the method of production. Most annealed glass is produced by the float process and is remarkably flat although subtle variations may be observed when viewing from oblique angles.</td>
<td>Standards for annealed glass do not give explicit requirements for flatness. Standards require assessment for optical faults which are defined as faults resulting in distortion of objects viewed through the glass. Lack of flatness may cause distortion. The inspection procedure given in the Standards should be carried out on samples of the glass production and is not suitable as a site test.</td>
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Table 2 cont’d

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<tr>
<td>Flatness of heat strengthened or toughened glass</td>
<td>The process of heat-treating such glass results in ‘roller wave distortion’. The distortion occurs in a fairly regular wave pattern at approximately 300mm centres. The degree of distortion will depend on the process control.</td>
<td>The specification should set out the maximum permissible roller wave distortion in the main part of the pane and at the edges where slightly greater local bow tends to occur. Standards give limits on roller wave for both heat strengthened and toughened glass. The limits vary according to the type of annealed glass used as the source material and the orientation of the glass during heat treatment. For float glass processed in a horizontal oven the limit is 0.5mm over a length of 300mm. The limits given in the Standards may give unacceptable appearance and the specifier may require tighter tolerances. Many processors are able to produce glass with roller wave of less than 0.15mm and the best producers can achieve better than 0.1mm for glass thicknesses of 8mm and above. The supplier should confirm his ability to comply prior to an order being placed. If it is also specified that all roller waves should be horizontal when the glass is on the building, then greater regularity of reflections and of outward views through the glass will tend to be achieved. However, with limitations on the width of most ovens, this tends to limit the maximum width of heat treated glass to approx. 2100mm; there are however a few ovens across Europe that accept a width of up to 2800mm.</td>
<td>Roller wave distortion can be measured using a British Standard calibrated straight edge and feeler gauges or a purpose made measuring device. Measurements should take account of any overall bow in the glass. This is particularly important when taking measurements on insulating glazing units. The correction to the measured roller wave is given by (\frac{(300/L)^2 d}{2}), where (d) is the overall bow measured over length (L). The correction should be added to the measured roller wave when the bow is toward the accessible face and subtracted from the measured roller wave when the bow is away from the accessible face.</td>
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<tr>
<td>Glass bow on single glass panes of heat strengthened and toughened glass</td>
<td>Processed glass tends to incorporate a certain degree of bow. Some of this bow may be taken out when glass is incorporated in to double-glazed units.</td>
<td>The specification should specify the maximum glass bow permitted for individual glass panes prior to incorporation in any double glazed units. Standards give limits, which vary according to the type of annealed glass used as the source material and the orientation of the glass during heat treatment. For float glass processed in a horizontal oven the limit is 0.003mm/mm. The supplier should then confirm ability to comply prior to an order being placed.</td>
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<tr>
<td>Bow in double glazed units</td>
<td>Some bow of double glazed units is inevitable due to differences between the atmospheric pressure and the pressure of the air or gas in the cavity of the unit. The pressure of the gas in the cavity will vary with temperature and will depend on the atmospheric pressure and temperature prevailing in the factory at the time the units were manufactured. Control of the conditions during manufacture, particularly the temperature of the glass, will reduce bow. The choice of desiccant will also have an effect as some desiccants will absorb gas from the cavity. Some bow may also arise if the unit was assembled in a factory at a markedly different altitude from the site. The visual effect of bow is most noticeable on the outer pane of a glazing unit. Increasing the thickness of the outer pane will reduce the bow incurred in that pane to some extent however this will have cost implications. It may also adversely affect acoustic performance if the thickness of the outer pane becomes close to that of the inner pane.</td>
<td>Standards do not give bow criteria for panes once they have been incorporated in double glazed units. Specifiers may set limits but as bow will vary with temperature of the unit and atmospheric pressure the measurement conditions should also be specified. If required, the bow due to pressure variations can be predicted by calculations using methods given in prEN13474</td>
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<td>Visual faults</td>
<td>Visual faults are defined in Standards as faults which alter the visual quality of the glass. Visual faults are divided into spot faults (small bubbles, stones, pinholes etc), and ‘linear/extended faults’ (scuff marks, scratches, lines, deposits, impressions, etc). All commercially produced glass includes a certain degree of such faults with the practical limits on minimization varying with the manufacturing processes involved. Thus different acceptance criteria can apply to glass products manufactured using different processes governed by different Standards. Glass should be inspected during manufacture to ensure that the size and frequency of faults is within the range permitted by the Standards. Scratches and surface damage may occur during processing, installation or cleaning down and thus may not be detected until a site inspection is undertaken.</td>
<td>The specification should stipulate that the glass is produced and processed to the relevant Standards (see Table 3). If the specification endeavours to impose tighter tolerances or requirements than the Standards stipulate, then those aspects should be duly identified at an early stage and an explicit commitment to comply obtained from the glass supplier.</td>
<td>Site inspection is required to check for damage caused during erection and cleaning down. Procedures and acceptance criteria should be specified.</td>
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### Table 3 – Standards for glass

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<td><strong>Monolithic glass panes:</strong></td>
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| Annealed glass              | BS EN 572-2: 1994 Section 5 sets out permissible optical and visual faults. The method of viewing is structured to facilitate production line inspection, not on-site inspection. | Specify the relevant standards. Require the glass supplier to:  
  - provide samples;  
  - confirm viewing criteria;  
  - confirm any relevant tolerances;  
  - confirm any visual features that may be apparent on the completed glass installation;  
  - advise of buildings where the same glass type can be viewed. |                 |
|                             |                                                                                     | As above for annealed glass.                                                   |                 |
| Heat strengthened glass     | BS EN 1863-1: 2000. Section 6 sets out tolerances for dimensions and bow. Section 7 sets out classifications for edge working for choices to be made from and provides guidance on machined holes and cut-outs. Section 10 includes information on optical distortion and anisotropy. | As above for annealed glass.                                                   |                 |
| Thermally toughened glass   | BS EN 12150-1:2000. Section 6 sets out tolerances for dimensions and bow. Section 7 sets out classifications for edge working for choices to be made from and provides guidance on machined holes and cut-outs. Section 9 includes information on optical distortion and anisotropy.  
  EN 14179 will cover heat soaked thermally toughened glass but is currently only available as a draft | As above for annealed glass plus specify the relevant Standard for heat soaking if precautions required to limit the risk of nickel sulphide inclusions. |                 |
| Coated glass                | BS EN 1096-1: 1999. Section 3.4 defines appearance defects. Section 7 describes Appearance and discusses defects that may occur and conditions of examination. A minimum viewing distance of 3m is cited and viewing angles are stipulated. A time limit of 20 seconds is imposed on inspections of glass. Table 1 provides acceptance criteria for coated glass defects. | As above for annealed glass                                                   |                 |
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<tr>
<td><strong>Laminated glass:</strong></td>
<td>BS EN ISO 12543-6: 1998. Section 4 sets out permissible defects in the vision area and Section 5 in the edge area. Section 9 sets out that the laminated glass should be viewed in a vertical position, in front of and parallel to a matt grey screen, lit by diffuse light or equivalent. The observer should be 2m from the glass observing it perpendicularly. Defects that are disturbing should be marked. No time limit is set.</td>
<td>Laminated glass may be made from annealed, heat strengthened or toughened glass. Thus all relevant standards need to be specified and the tolerances for each pane are cumulative.</td>
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<tr>
<td><strong>Double glazed units:</strong></td>
<td>BS5713: 1979. Section 6 sets out dimensional tolerances. No other tolerances cited. There is an inspection procedure to check for dirt or contamination on the internal faces of the unit. BS 5713 is being replaced by BS EN 1279 which will be in 6 parts. Part 1 will cover dimensional tolerances.</td>
<td>Specify BS 5713: 1979, or the European equivalent, plus the relevant standards for the individual components used in the glazed assembly.</td>
<td></td>
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