Appearance/Visual Quality Specification for Insulating Glass Units and Maintenance

4.10 MARCH 2005

1. Introduction

The appearance/visual quality of an insulating glass unit (IGU) is dependent on the following:

- Optical quality of the component glass panes, i.e. distortion inherent with the production of the glass pane;
- Visual quality of the component glass panes, i.e. number/size/type of defects;
- Inherent characteristics of an IGU, i.e. behaviour of a hermetically sealed body.

2. Scope

This Data Sheet details all appropriate factors that influence the appearance of an installed IGU.

It should be borne in mind that the major criterion is the view through the IGU from the inside of a building. This is covered in detail within this Data Sheet. However, it is appreciated that the appearance from the outside of the building, i.e. in reflection, can also be important in certain applications and some non-specific comments are made on this subject.

3. Definitions

For the purpose of this Data Sheet the following definitions apply:

3.1 Appearance
The overall effect on the observer when looking at objects through the IGU.

3.2 Optical quality
The distortion in the appearance of an object when observed through the glass.

3.3 Visual quality
The effect of faults, e.g. spot, linear extended, etc., on the vision through the glass.

3.4 Transparent glass
Glass that transmits light and permits clear vision through it.

3.5 Translucent glass
Glass that transmits light with varying degrees of diffusion so that vision is not clear[1].

3.6 Insulating glass unit (IGU)
An assembly consisting of at least two panes of glass, separated by one or more spacers, hermetically sealed along the periphery.

3.7 Condensation
The presence of moisture and/or other liquid on a glass surface either inside or outside the IGU.

3.8 Interstitial condensation
Condensation that occurs within the hermetically sealed airspace of the IGU.

3.9 Peripheral condensation
Condensation that occurs on the inside, i.e. room surface, of the IGU around the edge of the unit approximately in line with the spacer.

3.10 External condensation
Condensation that occurs on the external, i.e. outside surface, of the IGU

4. Glass types

4.1 General

The IGU manufacturer uses glass components within the IGU that comply with other standards as to their optical and visual quality. In general the IGU manufacturer cannot alter these quality characteristics. In fact during the IGU manufacturing process there is a possibility that further visual faults, e.g. scratches, scuffs, could be added to those already present in the components.

The standards relating to the appropriate glass product will detail their optical and visual quality.

4.2 Basic and special basic glasses

These are annealed glasses that comply with one of the following standards:

BS EN 572 – Parts 2 to 6 or Part 8
BS EN 1748 – 1 – 1
BS EN 1748 – 2 – 1
BS EN 14178 – 1

Note: With the exception of soda-lime silicate glass, i.e. BS EN 572, the special basic glasses are normally used for specific purposes, i.e. fire resistant glazing.

4.3 Toughened or strengthened glasses

These are annealed glasses that have been thermally or chemically treated to modify their strength and breakage characteristics. They will comply with one of the following standards:

BS EN 1863 – 1
BS EN 12150 – 1
BS EN 12337 - 1
BS EN 13024 - 1
BS EN 14179 - 1
BS EN 14321 - 1

4.4 Laminated glasses

These are annealed, toughened or strengthened glasses, in any combination, that have been combined with an interlayer(s) to produce a product with modified characteristics. These

[1] The diffusion may be produced either by patterning the surface during manufacture or by surface treatment after manufacture, i.e. sand blasting, acid etc.

GGF
Glass and Glazing Federation

44-48 Borough High Street
London SE1 1XB
Tel 0870 042 4255
Fax 0870 042 4266
www.ggf.org.uk

modifications will affect one or more of the following:

- post-breakage behaviour
- spectrophotometric characteristics
- acoustic characteristics

They will comply with the following standard:

BS EN ISO 12543 – Parts 1 - 6

4.5 Coated glasses

A glass substrate of any of the above, that either incorporates a coating within the glass surface or has had a coating applied to the surface. The coatings are designed to modify the spectrophotometric characteristics of the glass. They will comply with the following standard:

BS EN 1096 – Parts 1 – 3

5. Optical Quality

5.1 General

The optical quality of a glass component is the result of the following:

- method of manufacture of the glass component; together with
- effect of any subsequent processing.

5.2 Basic and special basic glasses

The optical quality of transparent glass is entirely dependent on the manufacturing method.

Generally float glass is better than drawn sheet glass. Depending on the specific product, e.g. drawn sheet glass, there may be a number of classes for optical quality.

Polished wired glass can be better than drawn sheet glass but the presence of the wire mesh may affect the optical quality.

Cast glass, patterned glass and wired patterned glass are all translucent glasses with varying degrees of diffusion. These products do not have a specific optical quality.

5.3 Toughened or strengthened glasses

Thermal toughening and heat strengthening processes adversely affect the optical quality of the float or drawn sheet glass that is processed. The heating and cooling of the glass during the process can result in bow, overall and/or local, and/or roller wave distortion[2] that will reduce the optical quality from that of the unprocessed glass.

Note: The general lack of flatness with thermally treated glasses can produce problems with reflected images. See Annex A for an example.

Chemical strengthening should not affect the optical quality of the unprocessed glass.

5.3.1 Specific effects of thermal treatment process

The process may give rise to a degree of haze, i.e. a cloudy look to the surface, especially at oblique angles of incidence.

The process also produces an effect that is known as anisotropy (iridescence). This is the result of 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 polarised light. When viewed in polarised light these areas show up as coloured zones, sometimes referred to as 'leopard spots'. The bi-refrigent effect is more noticeable at glancing angles.

5.4 Laminated glasses

The optical quality of laminated glass is dependent on the following:

- type and number of glass panes
- type, thickness and number of interlayer(s)
- presence or not of plastics glazing sheet materials
- laminating process, e.g. folio, cast in place, etc.

Generally folio lamination processes, i.e. ones using an interlayer such as pvb, eva, pvc, have only minor influences on the optical quality as the final product has relatively parallel faces. The degree of influence will increase with more panes of glass and more/thicker interlayer as a result of possible multiple surface reflections.

[2] Details on bow are given in the product standards. Specific details relating to roller wave, including method of measurement, is given in the GGF Data Sheet 4.4.

Cast in place laminating can result in a product that does not have parallel faces. This means that the laminated glass can act as a lens and hence distortion can occur. Problems may occur with slight discrepancies in uniformity of curing of the interlayer that may produce refractive index discrepancies.

5.5 Coated glasses

The optical quality of coated glass is dependent on the following:

- type of glass substrate
- type, thickness and make-up of coating, e.g. single or multilayer,
- coating process, e.g. on-line, off-line, etc

Generally the addition of a coating to a glass substrate does not significantly alter the optical quality. Therefore the optical quality of a coated glass is that of the substrate.

However, as the majority of coatings work due to thin film interference effects there can be a perceived change due to lack of uniformity in the coating. Similarly these thin films can offer variations in colour that can appear as a lack of uniformity. Modern low-e coatings on glass may produce a haze, i.e. a cloudy look to the surface, when viewed in oblique lighting (see 8.3).

6. Visual Quality

6.1 General

The visual quality of a glass component is the result of the following:

- method of manufacture of the glass component; together with
- effect of any subsequent processing

6.2 Basic and special basic glasses

The visual quality of basic glass products can be found for stock sizes in the product standards (see 4.2).

The visual quality for final cut sizes is given in the product standards for special basic glasses. The visual quality of basic soda lime silicate glass products is given in BS EN 572 Part 8.

Cutting down of stock plates into final cut sizes, i.e. panes for further processing, are an opportunity to reduce the number and size of inherent spot and/or linear extended faults. However, care should be taken to ensure that the cutting process does not introduce other defects, i.e. scratches.

The visual quality of translucent glasses also depends on the following:

- pattern type/depth
- directionality of the pattern
- wire mesh uniformity, squareness, alignment etc.

Quantification of these parameters can be found in the appropriate product standards.

Generally the visual quality is higher for a transparent glass than for a translucent glass. With translucent glasses the diffusion reduces the visible impact of the faults. Therefore the greater the degree of diffusion the less likely is it that any specific fault is visually disturbing.

6.3 Toughened or strengthened glasses

As these products are manufactured from final cut sizes then the processing doesn't alter the visual quality of the glass. However, the cutting, edge working and toughening/strengthening could impart additional scratches/scuffs onto the glass surface. These processing faults will affect the visual quality.

The thermal treatment process may result in small imprints in the surface ('roller pick-up'). This only applies to horizontally processed glass thicker than 8mm.

6.4 Laminated glasses

The visual quality of laminated glass depends on the following:

- component glass panes
- interlayer type, thickness
- laminating process
- cutting/sawing to final cut size

The manufacture of stock size laminated glass is influenced by the visual quality of the stock size glass panes used. These panes will have a visual quality in accordance with the product standards (see 4.2). The visual quality of the laminated glass will be worse than that of any component pane. Therefore the greater number of glass panes within a laminated glass the greater number of defects (see BS EN ISO 12543 Part 6).

The production of laminated glass using final cut size glass panes can reduce the influence of the individual glass panes, as they will be to a higher visual quality than will the stock size panes.

The interlayer itself and the laminating process can result in defects that will also decrease the visual quality level. Defects such as bubbles, opaque spots, foreign bodies and creases can occur. Their prevalence will be higher in stock plates than in final cut sizes.

Cutting, sawing and edge working can impart scratches etc. The thicker/heavier the laminated glass then the probability of decreasing the visual quality during these processes is higher.

6.5 Coated glasses

The visual quality of coated glass depends on the following:

- component glass panes
- coating type, colour, spectrophotometric properties
- coating process
- cutting to final cut size

The presence of a coating on a glass substrate may increase the visibility of a spot fault, linear extended fault within the substrate. Similarly faults within and/or on the coating, e.g. pinholes, scratches, scuffs, non-uniformities, etc., may decrease the visual quality. These effects are more pronounced with coatings that are highly coloured and/or highly reflective.

The likelihood of the visual quality being decreased is dependent on the type of coating process and the number of steps involved within the coating process.

Generally on-line coating is inherently more resistant to scratching, etc. than are off-line coatings. Certain 'soft' off-line coatings need special processing, i.e. edge stripping, prior to incorporation into an IGU. This abrasion process can also result in decreased visual quality.

7. Inherent characteristics of IGU's

7.1 General

An insulating glass unit as defined is a glass product that contains hermetically sealed air space(s). The air space(s) are filled with dehydrated air or other gas, e.g. argon, xenon, etc. The IGU is intended to reduce the rate of heat loss and therefore influence the formation of condensation (see 7.2).

7.1.1 Characteristics of an hermetically sealed airspace

The properties of a hermetically sealed airspace are that they will change dependent on the following:

- temperature and barometric pressure when the airspace was sealed
- actual air temperature and barometric pressure
- temperature of the air or gas within the airspace as a result of radiation etc.

These changes will result in a volume change in the airspace. This change will result in the unit taking up the shape of either a concave or convex lens. This lens shape will cause a number of phenomena to become apparent (see 7.3, 7.4, 7.5).

7.2 Condensation

An IGU is designed to reduce the heat loss through the glazing. This means that, compared to single glazing, the incidence of moisture condensing on the room side glass surface is reduced. However, condensation can still occur as follows:

a. Internal condensation can still occur if the glass surface is the coldest surface in a room and the relative humidity is extremely high, i.e. in a kitchen, bathroom, etc. with large amounts of steam/moisture present.
b. Interstitial condensation occurs either when the unit seal has failed and the airspace is saturated with moisture or

when an internal component, e.g. Georgian bars, etc., has deteriorated and given off organic solvents. Under both of these conditions the appearance of condensation on one or both airspace surfaces can occur subject to the glass surface temperature.

c. Peripheral internal condensation occurs with units having low U-values and is the result of localised heat flow through the spacer of the unit. Using so-called 'warm edge technology' can reduce this.
d. External condensation occurs with units having low U-values. With the amount of heat being lost through the unit being significantly reduced the outer glass pane can become extremely cold. Therefore under localised climatic conditions this can lead to moisture condensing out of the atmosphere onto the outside surface of the unit.

7.3 Interference phenomena

These are visual phenomena, similar to oil on water, which is the result of the IGU acting as a lens/prism.

7.3.1 Brewster's fringes

The appearance of the optical phenomena known as Brewster's Fringes is not a defect of the insulating glass unit and can occur with any glass of high optical and surface quality, i.e. float glass. This phenomenon is a result of the high quality now being achieved by glass manufacturers.

Brewster's Fringes occur if wavelengths of light meet up with each other when they are exactly 180° out of phase. This is an example of the phenomena known to physicist as the interference of light. The effect is similar to, although usually much smaller than, the interference fringes that can sometimes be seen on toughened glass windscreens.

Brewster's Fringes occur when the surfaces of the glass are optically flat and the two panes are parallel to each other, i.e. when the light transmission properties of the installation are of a very high order. This phenomenon is not a defect of the product and is solely dependent on the laws of physics.

7.3.2 Newton's rings

This optical effect only occurs in faulty/defective insulating glass units when the two panes of glass are touching or nearly touching in the centre. The optical effect is a series of concentric coloured rings with the centre being at the point of contact/near contact of the two panes. The rings are roughly circular or elliptical.

7.4 Multiple images

As a result of the numerous reflective surfaces, four in a standard IGU manufactured from monolithic glass; there exists the likelihood of multiple images being formed. Whist this is only of minor significance when the observer is looking directly through the IGU, i.e. at normal incidence, this will increase considerably as the angle of incidence.

The presence of other reflective surfaces, e.g. laminated glass, coatings, will enhance the phenomena. Also the lens effect within the unit will also have an influence.

Annex B will give a diagrammatic representation of the phenomena resulting from the inherent properties of an insulating glass unit.

7.5 Reflected image

As a result of the hermetically sealed airspace the IGU acts as a lens. The result of this is that in reflection the reflected images can appear separated. This will be further exacerbated by the presence of multiple images that are being displaced different amounts.

The likelihood of this occurrence is dependent on the extent of lens formation in the IGU as a result of the difference in atmospheric temperature and pressure between the manufacturing conditions and the service conditions. The effect will be more noticeable when reflective coatings are incorporated within the IGU.

Annex B will give a diagrammatic representation of the phenomena resulting from the inherent properties of an insulating glass unit.

8. Appearance

8.1 General

This is extremely subjective. However, it must relate to the limitations that are placed upon the insulating glass unit manufacturer. These limitations are as a result of the following:

- Incoming glass components,
- Specification of the unit,
- Inherent properties of the unit, and last but not least,
- Framing and glazing systems.

The perceived appearance of an installed IGU can be adversely affected by distortions induced by the framing system and the installation.

8.2 Normal incidence

When viewed at normal incidence, i.e. at 90° to the glass surface, the appearance relates to:

- For IGUs containing transparent glass components – the vision through.
- For IGUs containing translucent glass components – the visual quality of the translucent glass component.

8.3 Oblique incidence

The effects such as multiple images, haze, etc. are inherent characteristics of an IGU when viewed at angles of incidence less than 60° to the surface.

8.4 Reflection

Not generally considered. See Annexes A and B for further information.

9. Method of assessment

9.1 General

The standards for the component glass panes detail the method of observation and the distance and criteria for acceptance. However, in an IGU no such recommendations are given in the applicable European standard, i.e. BS EN 1279-1.

As there is no standardised method of assessment this Data Sheet lays down an appropriate methodology that is dependent on the type of application, e.g. domestic, commercial, etc.

9.1.1 Area of IGU to be examined

The glass area to be viewed is the entire vision area with the exception of a 50mm wide band around the whole perimeter of each of the glass panes.

See Figure 1.

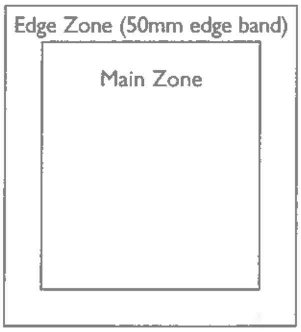

Figure 1

This edge zone, in terms of size, is similar to that given for the determination of coated glass in final cut sizes (see BS EN 1096-1).

9.2 Domestic

The IGUs shall be viewed at near normal incidence, i.e. at right angles, to the glass surface from the room side, standing at a distance of not less than 2 metres away from the inner glass surface for annealed float glass and 3 metres away for all other glass types.

The assessment of visual quality of the panes of glass should be carried out in natural daylight but not in direct sunlight and with no visible moisture on the surface of the inner or outer glass panes. The use of strong lamps and/or magnifying devices is not allowed.

It is not permissible to find defects at close range and then mark them so as to be visible from the given viewing distance.

9.3 Commercial

The IGUs shall be viewed at near normal incidence, i.e. at right angles, to the glass surface. This shall be from the room side and relates only to transmission and not reflection. The units shall be viewed from distance of not less than 2 metres away from the inner glass surface for annealed float glass and 3 metres away for all other glass types. For certain glass types, i.e. coated glass, the product standard gives a specific length of time in which the observation shall be made.

The assessment of visual quality of the panes of glass should be carried out in natural daylight but not in direct sunlight and with no visible moisture on the surface of the inner or outer glass panes. The use of strong lamps and/or magnifying devices is not allowed.

It is not permissible to find defects at close range and then mark them so as to be visible from the given viewing distance.

If the IGUs have to be examined in reflection, e.g. for appearance of coated glass, then the method given within the appropriate standard shall be followed.

10 Acceptance criteria

10.1 General

Insulating glass units shall not be deemed unacceptable for any phenomena relating to the inherent characteristics of an IGU with the exception of 'Newton's Rings' see 7.3.2.

10.2 Domestic

When viewed in accordance with 9.2 the IGU will be deemed acceptable as long as, where appropriate, none of the following apply:

- there are no defects noticed that are visually disturbing,
- any defects that are noted comply with the visual quality, (see 6), for the glass component,
- any visual disturbance, e.g. from roller wave, bow, etc., is within the tolerances given in the appropriate product standard,
- coated glass quality, e.g. pinholes, colour variation, etc. comply with the appropriate product quality,
- condensation, internal or external, is not related to a seal failure.

10.3 Commercial

When viewed in accordance with 9.3 the IGU will be deemed acceptable as long as, where appropriate, none of the following apply:

- there are no defects noticed that are visually disturbing,
- any defects that are noted comply with the visual quality, (see 6), for the glass component,
- any visual disturbance, e.g. from roller wave, bow, etc., is within the tolerances given in the appropriate product standard,
- coated glass quality, e.g. pinholes, colour variation, etc. comply with the appropriate product quality,
- condensation, internal, peripheral, or external, is not related to a seal failure
- distortion is a result of the framing system and/or installation.

11 References

11.1 European and/or national standards

BS 952-1: Glass for glazing – Part 1. Classification
BS EN 572-1: Glass in building – Basic soda lime silicate glass products - Part 1: Definition and general physical and mechanical properties
BS EN 572-2: Glass in building – Basic soda lime silicate glass products - Part 2: Float glass
BS EN 572-3: Glass in building – Basic soda lime silicate glass products - Part 3: Polished wired glass
BS EN 572-4: Glass in building – Basic soda lime silicate glass products - Part 4: Drawn sheet glass
BS EN 572-5: Glass in building – Basic soda lime silicate glass products - Part 5: Patterned glass
BS EN 572-6: Glass in building – Basic soda lime silicate glass products - Part 6: Patterned wired glass
BS EN 572-8: Glass in building – Basic soda lime silicate glass products - Part 8: Supplied and final cut sizes
BS EN 1096-1: Glass in building – Coated glass products - Part 1: Description and definitions
BS EN 1096-2 Glass in building – Coated glass products - Part 2: Test method for the durability of class A, B and S coatings

BS EN 1096-3 Glass in building – Coated glass products - Part 3: Test method for the durability of class C and D coatings
BS EN 1279-1: Glass in building – Insulating glass units - Part 1: Generalities, dimensional tolerances and rules for the system description
BS EN 1748-1-1: Glass in building – Special basic product – Borosilicate glasses - Part 1-1: Definition and general physical and mechanical properties
BS EN 1748-2-1: Glass in building - Special basic product – Glass ceramics - Part 2-1: - Definition and general physical and mechanical properties
BS EN 1863-1: Glass in building – Heat strengthened soda lime silicate glass products - Part 1: Description and definitions
BS EN 12150-1: Glass in building – Thermally toughened soda lime silicate safety glass products - Part 1: Description and definitions
BS EN 12337-1: Glass in building – Chemically strengthened soda lime silicate glass – Part 1: Description and definitions
BS EN 13024-1: Glass in building – Thermally toughened borosilicate safety glass – Part 1: Description and definitions
BS EN 14178–1: Glass in building – Alkaline earth silicate glass products – Part 1: Float glass
BS EN 14179-1: Glass in building – Heat soaked thermally toughened soda lime silicate safety glass products – Part 1: Description and definitions
BS EN 14321-1: Glass in building – Thermally toughened alkaline earth silicate safety glass products – Part 1: Description and definitions
BS EN ISO 12543-1: Glass in building – Laminated glass and laminated safety glass - Part 1: Definitions and description of component parts
BS EN ISO 12543-2: Glass in building – Laminated glass and laminated safety glass - Part 2: Laminated safety glass
BS EN ISO 12543-3: Glass in building – Laminated glass and laminated safety glass - Part 3: Laminated glass
BS EN ISO 12543-4: Glass in building – Laminated glass and laminated safety glass - Part 4: Test methods for durability
BS EN ISO 12543-5: Glass in building – Laminated glass and laminated safety glass - Part 5: Dimensions and edge finishing
BS EN ISO 12543-6: Glass in building – Laminated glass and laminated safety glass – Part 6: Appearance

11.2 Evaluation of conformity/product standards

With the publication of the harmonised European standards, hENs, the glass components will become available as CE marked products. The CE marking will be a declaration that the glass product conforms to the appropriate hEN.

The hENs are as follows:

BS EN 572-9: Glass in building – Basic soda lime silicate glass products - Part 9: Evaluation of conformity/Product standard
BS EN 1096-4: Glass in building – Coated glass products - Part 4: Evaluation of conformity/Product standard
BS EN 1279-5: Glass in building – Insulating glass units - Part 5: Evaluation of conformity/Product standard
BS EN 1748-1-2: Glass in building – Special basic product – Borosilicate glasses - Part 1-2: Evaluation of conformity/Product standard
BS EN 1748-2-2: Glass in building - Special basic product – Glass ceramics - Part 2-2: - Evaluation of conformity/Product standard
BS EN 1863-2: Glass in building – Heat strengthened soda lime silicate glass products - Part 2: Evaluation of conformity/Product standard
BS EN 12150-2: Glass in building – Thermally toughened soda lime silicate safety glass products - Part 2: Evaluation of conformity/Product standard
BS EN 12337-2: Glass in building – Chemically strengthened soda lime silicate glass – Part 2: Evaluation of conformity/Product standard
BS EN 13024-2: Glass in building – Thermally toughened borosilicate safety glass – Part 2: Evaluation of conformity/Product standard
BS EN 14178–2: Glass in building – Alkaline earth silicate glass products – Part 2: Evaluation of conformity/Product standard
BS EN 14179-2: Glass in building – Heat soaked thermally toughened soda lime silicate safety glass products – Part 2: Evaluation of conformity/Product standard
BS EN 14321-2: Glass in building – Thermally toughened alkaline earth silicate safety glass products – Part 2: Evaluation of conformity/Product standard
BS EN 14449: Glass in building – Laminated glass and laminated safety glass - Evaluation of conformity/Product standard

11.3 GGF standards

Heat treated glasses Data Sheet 4.4.
Flat laminated glass Data Sheet 3.3.

Annex A

Appearance in reflection

A1 Problem due to lack of flatness

A1.1 General description

A glass, especially a thermally treated one, can never be glazed perfectly flat. This is a difficulty with the framing system, glazing system, installation and the inherent flatness of the glass.

Imagine a rectilinear feature, e.g. a telegraph pole, some 10 metres from a glazed panel. The observer is viewing the feature by reflection from a similar distance.

If the plane of the glazing changes by one tenth of one degree, 0.1° between two points on its surface, then the viewer will see either two images apparently displaced by 70mm or one image distorted by this amount.

A1.2 Is one tenth of one degree, 0.1°, significant?

YES. This amount of flatness change is equivalent to a deflection of 0.8mm over a one-metre length.

This should be compared with the allowable deflection limits for framing, i.e. L/125 for single glazing, L/175 for double-glazing. This would mean for an L of 1 metre deflections of either 8mm for single-glazing or 5.7mm for double-glazing. Deflections of greater magnitude can occur due to wind-loading.
For thermally treated glass, i.e. thermally toughened, heat strengthened, etc., the standards allow overall bows of 2mm/m and local bows of 3mm/300mm.

For insulating glass units the deflection due to barometric/temperature effects can be significantly greater than 0.8mm/m.

A1.3 Optical explanation

Figure A1 shows the geometry involved.

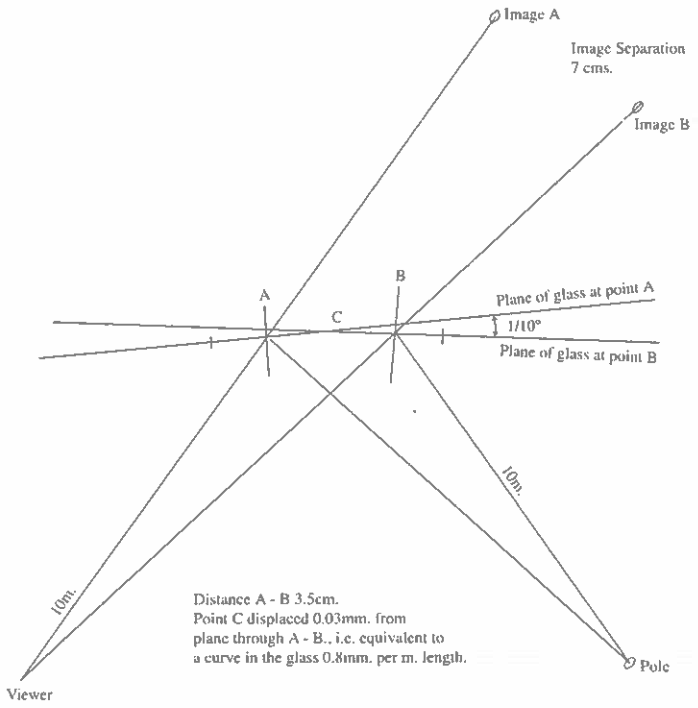

Figure A1 Explanation of lack of flatness

Annex B

Diagrammatic explanation: Phenomena exhibited by IGUs as a result of their inherent properties

B1 Multiple images

B1.1 General

When light hits a smooth glass surface; some is transmitted through, some is reflected and some is absorbed.

It is a law of physics that _the angle of incidence is equal to the angle of reflection_. Therefore if the incident ray is at normal incidence, i.e. at right angles to the glass surface then it is reflected directly back, (see Figure (B1A)). If the incident ray falls obliquely on the surface then the reflected ray bounces back at the same angle but on the other side of the perpendicular, (see Figure (B1B)).

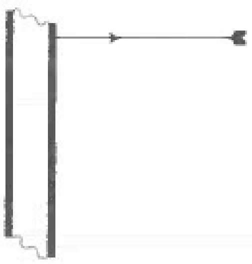

Figure B1(A)

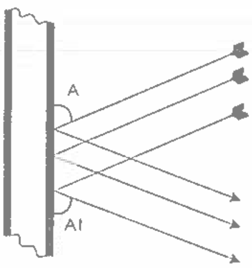

Figure B1(B)

B1.2 Refraction

Another law of physics is that _when a ray enters a medium of differing density it is bent (refracted)._

When a ray enters the glass from the air the angle of refraction is less than the angle of incidence. Therefore when reflected from the second surface it is displaced with respect to the incident ray. When the ray leaves the glass into the air the angle of refraction is greater than the angle of incidence. Therefore when leaving the first pane of glass the ray is parallel to the incident ray but displaced. A similar situation occurs when the ray meets the second pane.

For each pane of glass there are two reflected images, a primary and a secondary image. The primary images result from surfaces 1 and 3 and the secondary images from surfaces 2 and 4, (see Figure B2).

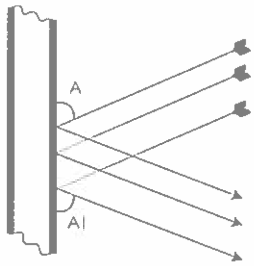

Figure B2

B1.3 Influencing factors

The following will increase the spacing between images:

- Increasing glass thickness,
- Increasing airspace width,
- Decreasing the angle of incidence.

The effects of coatings and body tints are dependent upon their spectrophotometric properties, i.e. transmittance, reflectance, absorbtance, and their position.

Generally body tinted glasses will enhance the primary image and reduce the secondary image produced by the pane. Coatings will enhance the image reflected from the coating.

B2 Distorted images

B2.1 General

When light rays strike a curved glass surface, they reflect in different directions. However, they will still obey the law that the angle of incidence equals the angle of reflection. Therefore the image of an object will be distorted. The curvature of the glass surface causes it to act as a lens.

B2.2 Concave curvature

This is when the surface is bowed inwards.

A concave curvature will cause the light rays to be projected inwards towards a central point. This causes the reflected image to appear short and thin, (see Figure B3 (A)).

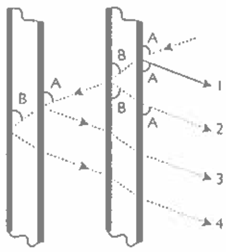

Figure B3(A)

B2.3 Convex curvature

This is when the surface is bowed outwards.

A convex curvature will cause the light rays to be projected outwards away from a central point. This causes the reflected image to be stretched out in all directions, (see Figure B3 (B))

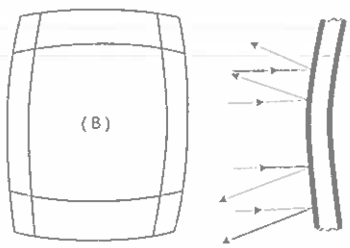

Figure B3(B)

B2.4 Curvature in IGUs

When an IGU is subjected to barometric and/or temperature and/or altitude effects the whole unit will change shape.

If the effects on the unit cause it to shrink inwards then this will result in pane #1 being concave and pane #2 being convex, (see Figure B4 – Type (A)). Similarly if the effects on the unit cause it to swell outwards then this will result in pane #1 being convex and pane #2 being concave, (see Figure B4 – Type (B)).

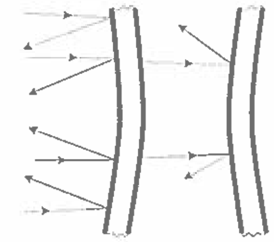

Figure B4(A)
Surface 1 - Primary image - shrunk
Surface 3 - Primary image - spreadout

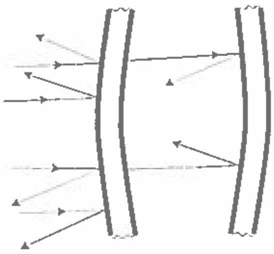

Figure B4(B)
Surface 1 - Primary image - spreadout
Surface 3 - Primary image - shrunk

The outcome of having different curvatures on the panes will result in some images being made smaller/thinner and others being stretched out.

Note: Figure B4 only examines the first reflection of the light ray.

B3 Composite factors

The combination of multiple images, B1, and distorted images, B2, is extremely difficult to describe.

What is certain is that nothing can be done to stop these effects occurring.