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Thermal and radiometric properties of glazing —

Part 2: Method for direct measurement of *U*-value (thermal transmittance)

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Basic Data and Performance Criteria for Civil Engineering and Building Structures Standards Policy Committee (BDB/-) to Technical Committee BDB/2, upon which the following bodies were represented:

Aggregate Concrete Block Association
Association for the Conservation of Energy
Association of Building Component Manufacturers Ltd.
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Contents

Foreword

This Part of BS 6993 has been prepared under the direction of the Basic Data and Performance Criteria for Civil Engineering and Building Structures Standards Policy Committee. Part 1 of this Standard describes a method for the calculation of the steady-state *U*-value of glazing. This Part of BS 6993 describes an alternative method, of equal status, to establish the *U*-value of the central part of the glazing by direct measurement. A further Part now being developed is:

— *Part 3: Method for measurement of photometric and radiometric properties in the solar spectral region*.

This Part of BS 6993 describes the methodology to obtain *U*-values by measurement, on a basis comparable to those obtained by calculation. It is based on BS 874-3.1 which describes the construction and use of a hot-box apparatus for the measurement of *U*-values.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 8, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

1 Scope

This Part of BS 6993 describes a method for measuring the *U*-value (thermal transmittance) of the central area of single, double or multiple glazing using hot-box apparatus complying with BS 874-3.1. The edge effect, due to the thermal bridge through the spacer of double or multiple glazing, is effectively eliminated in this method.

The method is designed to measure the *U*-value of the glazing alone, i.e. the glass (or alternative glazing material) and any enclosed air space, and the additional information required in the test reports of clause **8** and **A.9** of BS 874-3.1:1987.

Appendix A specifies values to be used in the calculation of a *U*-value in accordance with BS 6993-1, when such a calculated value is to be compared with that obtained by direct measurement in accordance with this Part of BS 6993.

Appendix A gives a worked example, which illustrates the use of this Part of BS 6993.

NOTE The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purpose of this Part of BS 6993 the following definitions apply.

2.1
thermal transmittance, *U*-value[1)]

the heat flux density through a given structure divided by the difference in environmental temperatures on either side of the structure under steady-state conditions

2.2
environmental temperature, effective ambient temperature[1)]

the environmental temperature influencing a surface is a suitably weighted mean of the adjacent air (or other fluid) temperature and the mean radiant temperature of the surroundings, in order to indicate correctly the change in heat flow rate to or from the surface for a small change in surface temperature. For a fluid opaque to radiation, the effective ambient temperature is the same as the fluid temperature

3 Symbols

Symbol	Description	Unit
d	thickness of layers of glass (or alternative glazing materials)	m
q	heat flux density	W/m^2
r	thermal resistivity of glass (glazing material)	m·K/W
R	surface resistance	m^2·K/W
T	temperature	°C or K
T_m	mean temperature of gas space	°C
ΔT	temperature difference	K
U	*U*-value (thermal transmittance)	W/m^2·K
U_m	measured *U*-value	W/m^2·K
w	gas space width	m
Δw	gas space width difference between centre and edge	m
Λ	thermal conductance	W/m^2·K
Subscripts		
a	environmental (effective ambient)	
g	gas space	
s	surface	
t	total	
i	interior (hot side)	
e	exterior (cold side)	

4 Equipment

4.1 Apparatus

The construction and operation of the apparatus shall be in accordance with BS 874-3.1, except where modified by this Part of BS 6993.

4.2 Surround panels

The surround panel shall be not less than 100 mm thick and constructed of material of conductivity not greater than 0.04 W/m·K. Plywood facing on either side of the surround panel to provide rigidity is permitted, but no material of thermal conductivity greater than 0.04 W/m·K (other than thin tape) shall bridge the aperture.

[1)] Repeated from BS 874-1.

4.3 Test element

The test element is a sample glazing unit. To ensure consistency of measurement the test element dimensions and location in the surround panel shall be as follows.

a) The test element shall be square with sides measuring 1.2 m.

b) The sample shall be mounted in the aperture in the surround panel as shown in Figure 1, with all edges of the glazing unit insulated as shown to a depth of 50 mm with material of conductivity less than 0.04 W/m·K (such that the exposed area is 1.1 m × 1.1 m).

c) The cold side face shall be 25 mm in from the edge of the aperture, as shown in Figure 1.

4.4 Calibration specimens

Calibration specimens are required to set up the test conditions as specified in clause **5** and enable edge and surround panel effects to be corrected.

Each calibration specimen shall consist of two flat pieces of glass measuring 1.2 m × 1.2 m square, and of minimum nominal thickness 4 mm, enclosing an insulating material with stable and homogeneous thermal properties.

Calibration specimens shall have a uniform thermal conductance not greater than 6 $W/m^2 \cdot K$, calculated from the known thermal conductivities and thicknesses of the components. At least two calibration specimens spanning the range of thermal conductances of the test elements shall be used (see BS 874-3.1).

The thermal conductance of the calibration specimens shall be established by either measuring equivalent smaller specimens on a hot-plate apparatus at a laboratory accredited by NAMAS (the National Measurement Accreditation Service) for the measurement of thermal conductivity in accordance with BS 874-2.1, or by obtaining calibration specimens with certified properties directly from the National Physical Laboratory (NPL).

Calibration specimens shall be mounted in the surround panel aperture in the same manner as test elements (see **4.3** and Figure 1).

5 Conditions for test

NOTE 1 The *U*-value calculation method described in Part 1 of BS 6993 specifies the conditions for standardized values and presentations. The temperature difference ΔT_s between the gas space bounding surfaces of the glazing required for Part 1 is 15 K and the mean temperature of glazing T_m is 10 °C. Additionally the prescribed surface resistances, derived from the reciprocal of the heat transfer coefficients, are 0.12 $m^2 \cdot K/W$ on the hot side (conventionally corresponding to natural convection) and 0.06 $m^2 \cdot K/W$ on the cold side (corresponding to air velocities of about 2 m/s).

It is not practical to meet these conditions exactly in a hot-box test without specifying a wide range of complicated measurement conditions.

The following test conditions shall apply.

a) The environmental temperature on the cold side (T_{ae}) shall be between 0 °C and 5 °C, and on the hot side (T_{ai}) between 20 °C and 25 °C and held constant to within 1 % of the air to air temperature difference across the sample as specified in BS 874-3.1. The air temperature difference (ΔT_a) between hot and cold sides shall be 20 ± 1 K.

b) The calibration tests shall be used to set up temperature and air velocity conditions to give a total average surface resistance (hot plus cold side) of 0.18 ± 0.01 $m^2 \cdot K/W$. The total surface resistance shall be determined from the mean surface temperatures of the calibration sample and the environmental temperatures on either side.

c) For the test element measurements the apparatus shall be operated under exactly the same temperature and air velocity conditions set up for the calibration tests.

NOTE 2 For the majority of test elements with a range of *U*-values between 1 $W/m^2 \cdot K$ and 3 $W/m^2 \cdot K$, these conditions lead to surface temperature differences across the test element of between 16 K and 19 K.

NOTE 3 The procedures for deriving the parameters to be used in equivalent calculations of the *U*-value are specified in Appendix A.

6 Determination of measurements following calibration

6.1 Conditions

The conditions shall be as specified in clause **5** and in accordance with BS 874-3.1.

6.2 Procedure

Following calibration, place the test element in the aperture of the surround panel with the same temperature and air velocity conditions which have been set during calibration.

Measure any dishing or bowing of the unit at the centre point at room temperature.

NOTE Dishing and bowing are the terms used respectively for the concavity and convexity of the bounding glazing surface of a sealed unit due to pressure differences between enclosed gas space (*s*) and the atmosphere.

Apply the following constraint in respect of dishing or bowing:

$$|\Delta w| > 0.25w$$

where

$|\Delta w|$	is the total dish (–ve) or bow (+ve) (side 1 + side 2), at the centre;
w	is the gas space width at unit edges.

If $|\Delta w| > 0.25w$ then reject the unit and select another for test. Repeat the procedure until an acceptable unit is selected.

With the same temperature and air velocity conditions which have been set during calibration undertake test measurements in accordance with Appendix A of BS 874-3.1:1987.

Measure any dishing or bowing of the unit at the end of the test as close as possible to the conditions and temperatures of test (see **A.3**). Correct the measured U-value to a standardized total surface resistance (hot plus cold side) of 0.18 $m^2 \cdot K/W$ (see **6.3**).

6.3 Calculation and expression of results

The U-value (in $W/m^2 \cdot K$) for the standardized total surface resistance is calculated from the equation:

$$U = [U_m^{-1} + 0.18 - R_t]^{-1}$$

where

U_m is the measured U-value (in $W/m^2 \cdot K$);

R_t is the total surface resistance (in $m^2 \cdot K/W$) as determined from the calibration tests by interpolation (see Appendix B for worked example).

$$R_t = R_e + R_i$$

where

R_e is the exterior (cold side) surface resistance;

R_i is the interior (warm side) surface resistance.

6.4 Test report

The test report shall contain the information specified in clause **8** and **A.9** of BS 874-3.1:1987. In addition the following shall be reported.

a) The U-value corrected to the standardized total surface resistance R_t of 0.18 $m^2 \cdot K/W$.

NOTE This corresponds to the definition of U-value for normal exposure as given in CIBSE Guide A3.

b) Mean temperature T_m and environmental temperature difference ΔT_a (as calculated in accordance with Appendix A).

c) Dishing (or bowing) at the centre point of the test element (sample glazing unit) at room temperature, and at the termination of the test (see **6.2** and **A.3**).

d) Constructional details of the test elements, e.g. spacing, glass thickness and, if known, the nature of coatings, gas filling.

Appendix A Values to be used in *U*-value calculations

NOTE This appendix specifies the derivation of the values to be used in the method adopted in Part 1 of BS 6993, such that allowance is made for differences between the prescribed mean temperature and surface temperature differences therein, and conditions applied during this test.

A.1 Mean temperature of gas space

The mean temperature of the gas space, T_m (in K), is derived as follows.

$$T_m = ½ \, [(T_{ai} + T_{ae}) - (R_i - R_e) \cdot U_m \cdot \Delta T_a]$$

where

- T_{ai} is the interior (hot side) environmental temperature (°C);
- T_{ae} is the exterior (cold side) environmental temperature (°C);
- U_m is the measured *U*-value (W/m^2·K);
- ΔT_a is the environmental temperature difference (K);
- R_i is the interior (hot side) surface resistance (m^2·K/W);
- R_e is the exterior (cold side) surface resistance (m^2·K/W)

NOTE $(R_i - R_e)$ is approximately 0.06 m^2·K/W.

Alternatively, if the surface temperatures are measured then T_m is derived as follows.

$$T_m = ½ \, (T_{si} + T_{se})$$

where

- T_{si} is the interior (hot side) surface temperature (°C);
- T_{se} is the exterior (cold side) surface temperature (°C).

A.2 Temperature difference between bounding surfaces of gas space

The temperature difference between bounding surfaces of gas space, ΔT_{sg} (in K), is derived as follows.

$$\Delta T_{sg} = \Delta T_a \cdot [1 - U_m \, (R_t + d \cdot r)]$$

where

- d is the total glass thickness (m);
- r is the thermal resistivity (assumed as 1.0 m·K/W for glass).

Alternatively, if surface temperatures are measured, then ΔT_{sg} is derived as follows.

$$\Delta T_{sg} = \Delta T_s \, (1 - U_m \cdot d \cdot r)$$

where

- ΔT_s is the surface temperature difference (K).

A.3 Allowance for dishing or bowing

An appropriate correction for the effects of dishing or bowing on the mean width of the gas space, *s*, for use in **4.2** of BS 6993-1:1989 is given as follows.

$$s = w + 0.4 \, \Delta w$$

where

- w is the gas space width at unit edges;
- Δw is the gas space width difference between centre and edge, i.e. the dishing (–ve) or bowing (+ve) measured at the end of the test as close as possible to the conditions and temperatures of test.

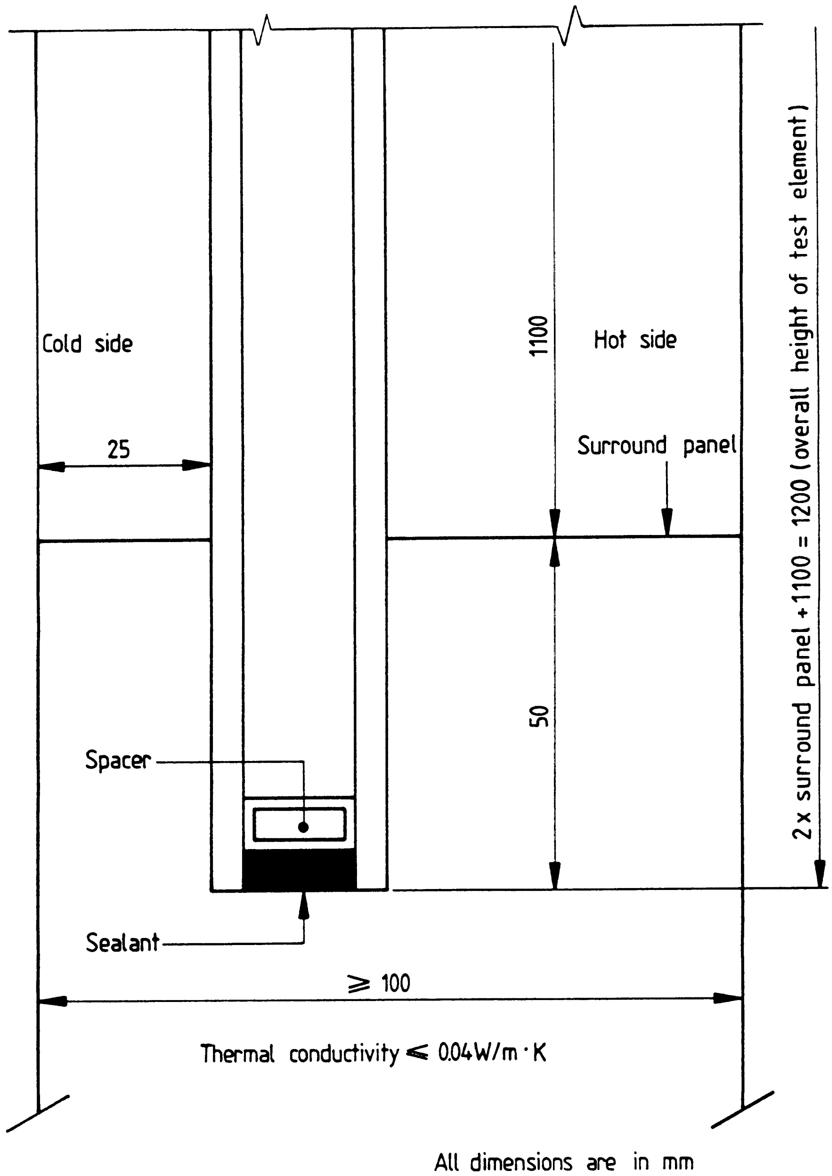

Figure 1 — Location of test element in surround panel

Appendix B Worked example of correction to standardized total surface resistance

B.1 Calibration data and calculations

Assume calibration specimens with thermal conductances Λ as follows.

Calibration specimen 1	$\Lambda = 6.0\ W/m^2 \cdot K$
Calibration specimen 2	$\Lambda = 3.0\ W/m^2 \cdot K$

Assume that the temperature and air velocity conditions are as follows.

Exterior (cold side)	Interior (hot side)
Air velocity is 2.2 m/s	Natural convection
T_{ae} is 2.0 °C	T_{ai} is 22.0 °C

where

T_{ae} is the exterior environmental temperature;

T_{ai} is the interior environmental temperature.

Thus the environmental temperature difference ΔT_a between the interior (hot side) and the exterior (cold side) is 20 K (as required by clause **5**).

Suppose that under calibration the following mean surface temperatures are measured and the surface temperature difference derived.

	T_{se}	T_{si}	ΔT_s
Calibration specimen 1	5.23	15.04	9.81
Calibration specimen 2	4.31	17.23	12.92

where

T_{se} is the exterior (cold side) surface temperature (°C);

T_{si} is the interior (hot side) surface temperature (°C);

ΔT_s is the surface temperature difference (K).

The heat flux density and the *U*-value (thermal transmittance) are derived from the following:

$$q = \Lambda \cdot T_s$$

and

$$U = q/\Delta T_a$$

where

q is the heat flux density (W/m^2);

U is the *U*-value (W/m$^2 \cdot$K);

Λ is the thermal conductance (W/m$^2 \cdot$K);

ΔT_s is the surface temperature difference (K);

ΔT_a is the environmental temperature difference (K).

When substituting in the derived values for Λ, ΔT_s and ΔT_a, the heat flux density q and *U*-value are as follows.

	q	*U*-value
Calibration specimen 1	6.0 × 9.81 = 58.86	58.86/20 = 2.943
Calibration specimen 2	3.0 × 12.92 = 38.76	38.76/20 = 1.938

Given that the total average surface resistance R_t (m$^2 \cdot$K/W) is derived as follows:

$$R_t = 1/U - 1/\Delta$$

where

U is the *U*-value (W/m$^2 \cdot$K);

Λ is the thermal conductance (W/m$^2 \cdot$K);

then substituting in the known values of U and Λ:

	R_t
Calibration specimen 1	1/2.943 – 1/6.0 = 0.1731
Calibration specimen 2	1/1.938 – 1/3.0 = 0.1827

the total average surface resistances are therefore within the tolerance range 0.18 ± 0.01 m$^2 \cdot$K/W required by the conditions for test (see clause **5**).

B.2 Interpolation and calculation of *U*-value

A simple graph to enable interpolation is shown in Figure 2.

Suppose that under test, with the conditions maintained the same as under calibration, the measured *U*-value U_m of a test element is 2.5 W/m$^2 \cdot$K. From Figure 2, the interpolated total average surface resistance R_t is 0.1773 m$^2 \cdot$K/W.

Therefore

$$U = [U_m^{-1} + 0.18 - R_t]^{-1}$$

where

U is the *U*-value for the standardized total surface resistance (see **6.3**);

U_m is the measured *U*-value;

R_t is the interpolated total average surface resistance (see Figure 2).

Then substituting in the known values for U_m and R_t:

$$U = [1/2.5 + 0.18 - 0.1773]^{-1}$$
$$= 2.48 \text{ W/m}^2 \cdot \text{K}$$

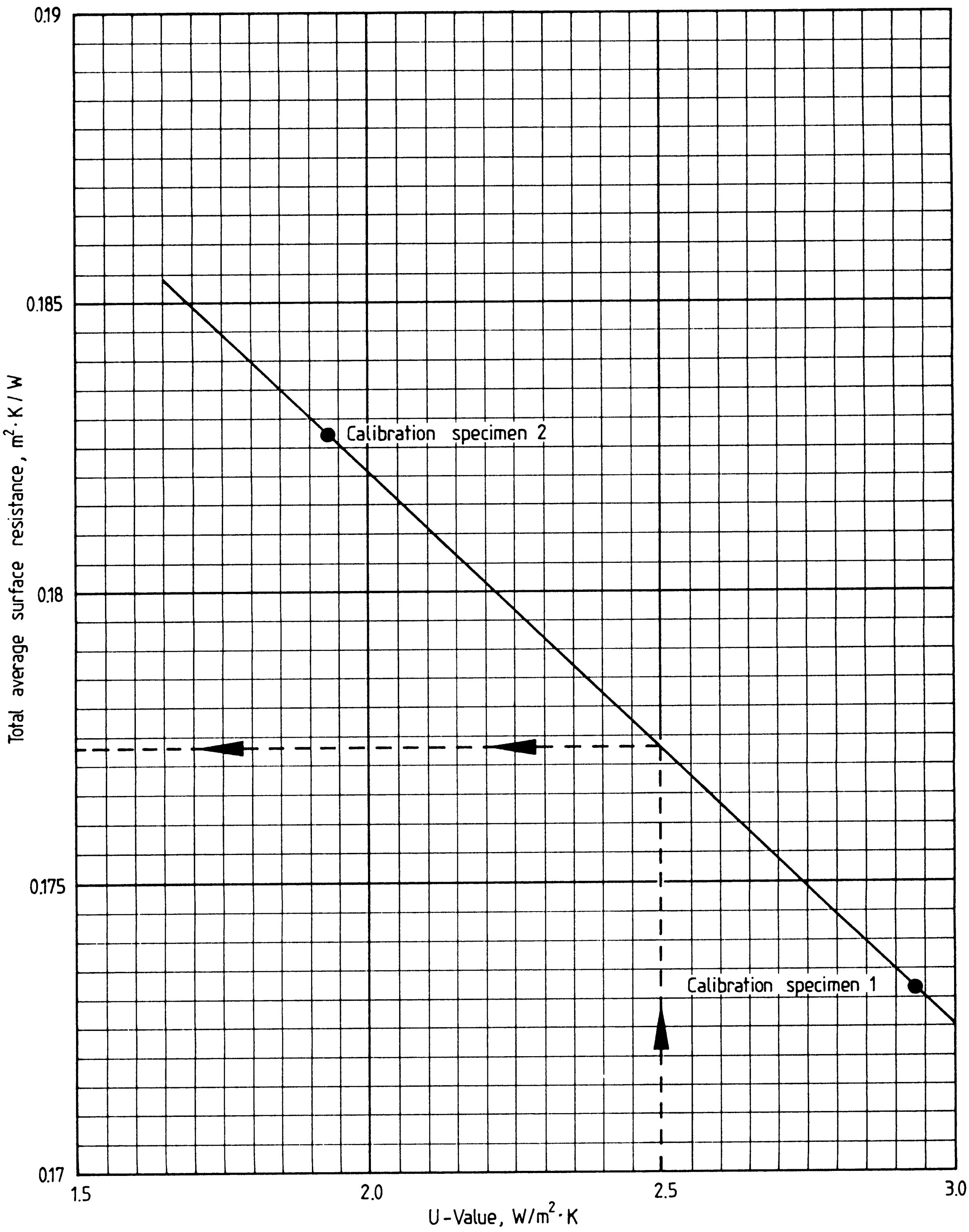

Figure 2 — Interpolation of total average surface resistances

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Publications referred to

BS 874, *Methods for determining thermal insulating properties.*
BS 874-1, *Introduction, definitions and principles of measurement.*
BS 874-2, *Tests for thermal conductivity and related properties.*
BS 874-2.1, *Guarded hot-plate method.*
BS 874-3, *Tests for thermal transmittance and conductance.*
BS 874-3.1, *Guarded hot-box method.*
BS 6993, *Thermal and radiometric properties of glazing.*
BS 6993-1, *Method for calculation of the Steady state U-value (thermal transmittance).*
CIBSE Guide A3 1980. The thermal properties of building structures[2).

[2) This publication is obtainable from the Chartered Institution of Building Services Engineers, Delta House, 222 Balham High Road, London SW12 9BS.

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