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Glass in building — Vacuum insulating glass —

Part 1:
Basic specification of products and evaluation methods for thermal and sound insulating performance

Verre dans la construction — Vitrage isolant à lame de vide —

Partie 1: Spécification de base des produits et méthodes d'évaluation des performances d'isolation thermique et acoustique

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 160, *Glass in building*, Subcommittee SC 1, *Product considerations*.

A list of all parts in the ISO 19916 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document consists of basic information about the product specification and evaluation methods for thermal and sound insulating performance of vacuum insulating glass. Test methods of vacuum insulating glass for the evaluation of performance under temperature differences are to be the subject of ISO 19916-3[1]).

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1) Under preparation.

Glass in building — Vacuum insulating glass —

Part 1:
Basic specification of products and evaluation methods for thermal and sound insulating performance

1 Scope

This document specifies product specification for vacuum insulating glass. It also specifies evaluation methods for thermal and sound insulating performance and evaluation methods for thermal insulation durability.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 717-1, *Acoustics — Rating of sound insulation in buildings and of building elements — Part 1: Airborne sound insulation*

ISO 8301, *Thermal insulation — Determination of steady-state thermal resistance and related properties — Heat flow meter apparatus*

ISO 8302, *Thermal insulation — Determination of steady-state thermal resistance and related properties — Guarded hot plate apparatus*

ISO 9050:2003, *Glass in building — Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors*

ISO 10140-2:2010, *Acoustics — Laboratory measurement of sound insulation of building elements — Part 2: Measurement of airborne sound insulation*

ISO 10292, *Glass in building — Calculation of steady-state U values (thermal transmittance) of multiple glazing*

ISO 12543-4:2011, *Glass in building — Laminated glass and laminated safety glass — Part 4: Test methods for durability*

ISO 20492-1:2008, *Glass in buildings — Insulating glass — Part 1: Durability of edge seals by climate tests*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
vacuum insulating glass
assembly consisting of at least two panes of glass, separated by an array of pillars, hermetically and durably sealed along the periphery, whereby the gaps between the glass panes are under vacuum

Note 1 to entry: The absolute pressure inside the vacuum insulating glass should be 1 Pa or lower.

Note 2 to entry: Examples of vacuum insulating glass are given in Figure 1 a) and b). The difference between the two examples lies in the structure of edge seal and evacuation port.
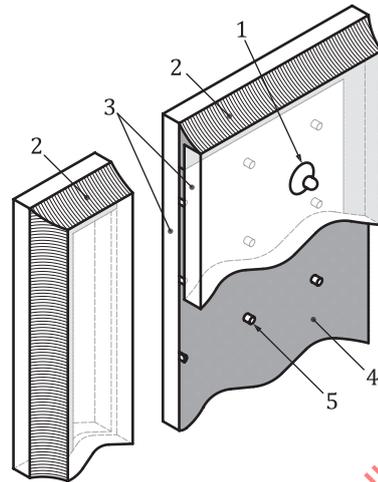
a) Example 1
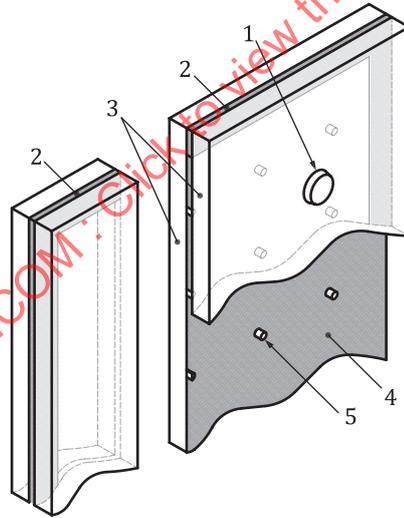
b) Example 2

Key

1 evacuation port
2 periphery sealing
3 glass pane
4 low-E coating
5 pillar

Figure 1 — Examples of vacuum insulating glass

3.2
pillar
small spacer aligned across the whole area of glass sheet such that it maintains a gap between two glass sheets

3.3
edge seal
hermetic sealing at the periphery of two glass sheets to maintain vacuum between them

Note 1 to entry: The terms "weld" and "welding" can be used instead of "seal" and "sealing" respectively, dependent upon the processing method.

3.4
evacuation port
structure through which the gas between the glass sheets is evacuated during the production process

Note 1 to entry: This is typically a small glass tube that is sealed following evacuation of air from the gap between the glass sheets.

Note 2 to entry: The evacuation port may be located on the glass sheet or at the glass edge.

3.5
getter
material which has the ability to absorb outgas in the gap between the glass sheets

3.6
displacement
misalignment at any one edge of the constituent glass panes making up the vacuum insulating glass

4   Description of components

4.1   Glass types and characteristics

The dimensions of each pane of glass can be the same or can be different.

The type of glass used for vacuum insulating glass may be:

— float glass, in accordance with ISO 16293-2;

— polished wired glass, in accordance with ISO 16293-3;

— thermally tempered glass, in accordance with ISO 12540;

— heat strengthened glass;

— heat soaked tempered glass, in accordance with ISO 20657;

— chemically strengthened glass;

— laminated glass, in accordance with ISO 12543-3;

— laminated safety glass, in accordance with ISO 12543-2;

— patterned glass, in accordance with ISO 16293-5;

— coated glass, in accordance with ISO 11479-1.

The glass may also be:

— clear or tinted;

— transparent, translucent or opaque;

— surface treated by sandblasting or acid etching.

4.2 Pillars

Pillars may be manufactured from glass, solder glass, ceramics, metal or plastics.

4.3 Edge seal

Edge seal shall consist of an appropriate hermetic sealing material (including glass sheet fusion bonding structure).

Edge seal material may be manufactured from glass, solder glass, ceramics, metal or plastics.

4.4 Evacuation port

A hermetically-sealed evacuation port may be utilized.

Hermetically-sealed evacuation port material may be manufactured from glass, solder glass, ceramics, metal or plastics.

4.5 Getter

A getter material may be present in the vacuum layer.

Getter material may be selected depending on manufacturing process of vacuum insulating glass and characteristics of outgassing absorption required.

5 Optical and thermal properties

5.1 Optical properties

Optical properties of vacuum insulating glass shall be evaluated according to ISO 9050. The properties are as follows:

— the spectral transmittance, the spectral external reflectance and the spectral internal reflectance;

— the light transmittance, the external light reflectance and the internal light reflectance;

— the solar direct transmittance and the solar direct reflectance;

— the UV-transmittance, the CIE damage factor and the skin damage factor;

— the general colour rendering index.

NOTE   It is assumed that the effect of the pillars on these optical properties is negligible, because the effect does not appear in the rounded values of these properties when the ratio of pillar area to the pillar array interval area is less than 1 %.

5.2 U-value (thermal transmittance)

5.2.1 Determination of the U-value

An outline of the determination procedure is shown in Figure 2.

| Prepare 3 specimens. | Storage at room temperature for no less than 24 hours after production |

| Measure U-value twice with the first specimen. | $U_{1,1}$: Specimen 1, first measurement
$U_{1,2}$: Specimen 1, second measurement |

Improve measurement method. ← No

Difference of two measured data ≤ 3,0 % | $100|U_{1,1} - U_{1,2}|/((U_{1,1}+U_{1,2})/2) \leq 3{,}0\%$

Yes

| Repeatability of the measurement is confirmed. Mean of the two data represents the first specimen. | $U_1 = (U_{1,1}+U_{1,2})/2$ |

| Measure each remaining specimen once. | U_2, U_3 |

| Average U-values of three specimens. | $U_{av} = (U_1+U_2+U_3)/3$ |

No

Difference of U_{av} and U_n of all specimens ≤ 10,0 % | $100|U_{av} - U_n|/U_{av} \leq 10{,}0\%$ (n=1 to 3)

Yes

U-value of the VIG is determined with U_{av}.

U-value cannot be determined because the quality of the product is regarded as unstable.

Figure 2 — Flowchart of the measurement procedure

The determination of the U-value of three vacuum insulating glass specimens shall be carried out in accordance with Annex A.

The test specimen dimensions shall meet the requirements of A.4.

The measurements shall be conducted after storage of specimens at room temperature for no less than 24 h after production.

Measurement A described in A.5 of Annex A shall be conducted twice with the first test specimen in a group having the same specification. The percentage difference of the two results shall be no more than 3,0 % as in Formula (1).

$$100|U_{1,1} - U_{1,2}|/((U_{1,1} + U_{1,2})/2) \leq 3{,}0 \% \tag{1}$$

where

$U_{1,1}$ is the first measured U-value of the first test specimen;

$U_{1,2}$ is the second measured U-value of the first test specimen.

If the percentage difference in the two results of U-value with the first specimen is more than 3,0 %, the measurement method and condition should be improved. After the improvements, the measurement should be repeated.

The U-value of the first test specimen shall be determined as mean value of the two results.

The U-value of the remaining specimens in the group having the same specification shall be measured once respectively.

The average of the measured U-value on three specimens, U_{av}, shall be calculated using Formula (2).

$$U_{av} = (U_1 + U_2 + U_3)/3 \tag{2}$$

where

    U_{av} is the average of U-value of all specimens [W/(m$^2 \cdot$ K)];

    U_n is the measured U-value of the specimen (n = 1 to 3) [W/(m$^2 \cdot$ K)].

U_{av} shall be stated to two decimal places. If U_n is measured to more than 3 decimal places, then the value shall be truncated to 3 decimal places.

The percentage deviation between U_{av} and U-value of each specimen shall be calculated using Formula (3).

$$U_{dev,n} = 100 \left(|\ U_{av} - U_n\ |/U_{av}\right) \tag{3}$$

If $U_{dev,n}$ (n = 1 to 3) does not exceed 10,0 % for all specimens, the U-value of the vacuum insulating glass can be determined as U_{av}, which shall be stated to two decimal places.

If $U_{dev,n}$ (n = 1 to 3) exceeds 10,0 % for one or more specimens, the U-value of the vacuum insulating glass cannot be determined, because the quality of the relevant set of test specimens is regarded as unstable.

NOTE   It is possible to determine the U-value of vacuum insulating glass by calculation only. This method is provided in Annex C for information.

5.2.2   Test report

The test report shall contain the following elements:

a)   identification of the specimens:

    — specimen description (e.g. manufacturer's name, product name or other reference, etc.),

    — length (mm),

    — width (mm),

    — nominal thickness (mm);

b)   for each buffer plate:

    — material,

    — nominal thickness (mm);

c)   measurement and calculation results:

    — mean surface temperature of the heating and cooling plates (°C),

    — thermal resistance of the two buffer plates [(m$^2 \cdot$ K)/W],

— internal heat transfer coefficient, h_i, and external heat transfer coefficient, h_e [W/(m$^2 \cdot$ K)], if non-standardized values have been used,

— thermal resistance of the vacuum insulating glass [(m$^2 \cdot$ K)/W], rounded to two decimal places,

— U-value of the vacuum insulating glass [W/(m$^2 \cdot$ K)], rounded to two decimal places;

d) any deviations from this document which can have affected the result;

e) description of the test equipment, including:

    — manufacturer's name and model, if using a commercially-available equipment,

    — dimensions of metering area (mm),

    — dimensions of hot and cold plates (mm).

5.2.3   Calculation method for U-value of vacuum insulating glass with different glass thickness

There may be cases where only the nominal thickness of one or more panes of glass in the vacuum insulating glass are different from that for which the U-value was previously determined. In such cases, the U-value should be calculated following the procedure below, using the measured thermal resistance in accordance with Annex A.

The thermal resistance of the vacuum insulating glass comprising glass of different thickness, R', can be calculated using Formula (4).

$$R' = R + r_g \times (\Sigma d_2 - \Sigma d_1) \tag{4}$$

where

    R' is the thermal resistance of the vacuum insulating glass with glass of different thickness [(m$^2 \cdot$ K)/W];

    R is the measured thermal resistance of the vacuum insulating glass [(m$^2 \cdot$ K)/W];

    r_g is the thermal resistivity of glass (m $\cdot$ K/W): r_g = 1 (m $\cdot$ K/W);

    Σd_2 is the total nominal thickness of glass sheets in the vacuum insulating glass with glass of different nominal thickness (m);

    Σd_1 is the total nominal thickness of glass sheets in the vacuum insulating glass measured (m).

The U-value of the vacuum insulating glass with glass of different thickness, U', can be calculated using Formula (5).

$$1/U' = R' + 1/h_e + 1/h_i \tag{5}$$

where

    U' is the U-value of the vacuum insulating glass with different thickness of panes of glass [W/(m$^2 \cdot$ K)]

    h_e and h_i are as defined in Annex A.

NOTE   Formula (4) is derived from Formula (6) and Formula (7) as follows.

The thermal resistance of the vacuum layer, R_v, can be calculated using Formula (6).

$$R_v = R - r_g \times \Sigma d_1 \tag{6}$$

where R_v is the thermal resistance of the vacuum layer [$(m^2 \cdot K)/W$].

The thermal resistance of the vacuum insulating glass with glass of different thickness, R', can be obtained as the sum of the thermal resistance of vacuum layer, R_v, and thermal resistance of glass sheets in the vacuum insulating glass as shown in Formula (7).

$$R' = R_v + r_g \times \Sigma d_2 \tag{7}$$

5.3   Total solar energy transmittance (g-value)

The thermal conductance of the vacuum insulating glass, Λ, shall be calculated using Formula (8) or Formula (9).

$$\Lambda = R^{-1} \tag{8}$$

where

Λ is the thermal conductance of the vacuum insulating glass [$W/(m^2 \cdot K)$];

R is the thermal resistance of the vacuum insulating glass determined with the method defined in Annex A [$(m^2 \cdot K)/W$].

$$\Lambda = R'^{-1} \tag{9}$$

where R' is the thermal resistance of the vacuum insulating glass obtained with the method defined in 5.2.3 [$(m^2 \cdot K)/W$].

The total solar energy transmittance (g-value) of the vacuum insulating glass with one vacuum layer shall be calculated using ISO 9050:2003, Formula (10) and Formula (16).

NOTE 1   Although the term "double glazing" is used in ISO 9050, the same approach can be adopted for "vacuum insulating glass".

The total solar energy transmittance (g-value) of vacuum insulating glass with two or more vacuum layers cannot be determined by the aforementioned method, as the thermal resistance of each vacuum layer cannot be obtained separately from the measurement methods defined in 5.2.

NOTE 2   Total solar energy transmittance (g-value) is also known as solar factor.

6   Dimensional requirements

6.1   Thickness

6.1.1   Nominal thickness

The nominal thickness of vacuum insulating glass shall be the sum of the nominal thickness of the constituent panes of glass and the nominal thickness of the vacuum layer.

6.1.2   Limit deviation on thickness

The limit deviation on the thickness of vacuum insulating glass shall not exceed the sum of the limit deviations of the constituent glass panes listed in the basic products standards in 4.1 and limit deviation of vacuum layer thickness of ±0,1 mm.

EXAMPLE   A vacuum insulating glass made from two sheets of float glass of 3 mm nominal thickness and a vacuum layer of 0,2 mm nominal thickness. The limit deviation of 3 mm float glass is given as ±0,3 mm and the limit deviation of the vacuum layer thickness is ±0,1 mm. Therefore, the nominal thickness is 6,2 mm and the limit deviation is ±0,7 mm.

6.1.3   Measurement of thickness

The thickness of the pane shall be calculated as the mean of measurements taken at the centre of the four sides. The measurements shall be taken to an accuracy of 0,01 mm with the mean rounded to the nearest 0,1 mm.

The individual measurements when rounded to the nearest 0,1 mm shall also be within the limit deviations.

6.2   Width B and length H

6.2.1   General

When vacuum insulating glass sizes are quoted for rectangular panes, the first dimension shall be the width B and the second dimension the length H, as shown in Figure 3.
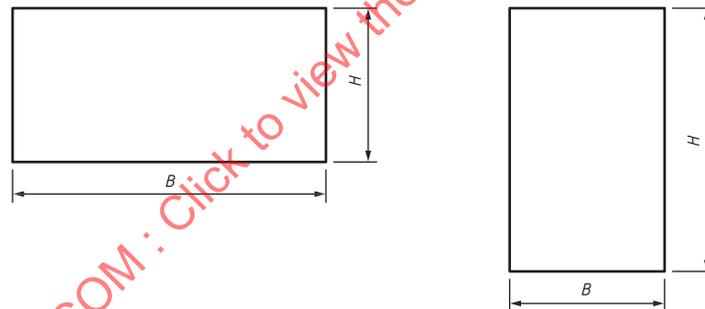
Figure 3 — Width and length relative to pane shape

The maximum width and length of vacuum insulating glass are dependent on the constituent glass used in its composition and on the manufacturing plant of each individual manufacturer. Each manufacturer should indicate the maximum size they can produce.

Dimensions shall be given in millimetres. Each dimension shall be within the specified limit deviations.

6.2.2   Limit deviations on width B and length H

Limit deviations on width B and length H are given in Table 1. Any displacement shall be included in these limit deviations.

NOTE   Displacement is covered in 6.2.4.

Table 1 — Limit deviations on width B and length H

Dimensions in millimetres

Nominal dimension B or H	Nominal thickness ≤8 mm	Nominal thickness >8 mm	
		Each glass pane <10 mm nominal thickness	At least one glass pane ≥10 mm nominal thickness
≤2 000	+3,0 −2,0	+3,5 −2,0	+5,0 −3,5
≤3 000	+4,5 −2,5	+5,0 −3,0	+6,0 −4,0
>3 000	+5,0 −3,0	+6,0 −4,0	+7,0 −5,0

6.2.3 Limit deviations on squareness

The squareness of rectangular glass panes is expressed by the difference between their diagonals. The difference between the two diagonals shall not be larger than the deviation limit as specified in Table 2.

Table 2 — Limit deviations on the difference between diagonals

Dimensions in millimetres

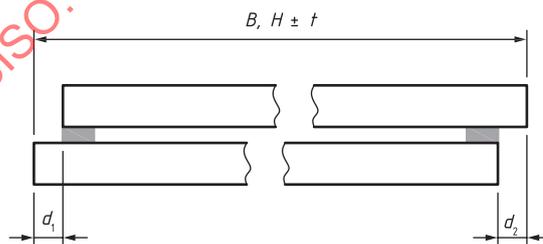| Nominal dimension B or H	Nominal thickness ≤8 mm	Nominal thickness >8 mm	
		Each glass pane <10 mm nominal thickness	At least one glass pane ≥10 mm nominal thickness
≤2 000	6	7	9
≤3 000	8	9	11
>3 000	10	11	13

6.2.4 Displacement

Figure 4 — Displacement

Displacement at the edges is shown in Figure 4.

The maximum displacement d_1 and d_2 shall be as specified in Table 3. Width B and length H shall be considered separately.

Table 3 — Maximum displacement d_1, d_2

<div align="right">Dimensions in millimetres</div>

Nominal dimension B or H	Maximum permissible displacement d_1, d_2
$B, H \leq 1\,000$	2,0
$1\,000 < B, H \leq 2\,000$	3,0
$2\,000 < B, H \leq 4\,000$	4,0
$B, H > 4\,000$	6,0

In the case where offset is made deliberately, the manufacturer should be consulted.

7 Durability

7.1 Requirements

The U-value of the specimens defined in 7.2 shall be measured in accordance with Annex A before the climate test defined in 7.3.

The measurements shall be conducted after storage of specimens at room temperature for no less than 24 h after production.

The average of the measured U-value in six specimens $U_{av,before}$ shall be calculated as in Formula (10).

$$U_{av,before} = (U_{1,before} + U_{2,before} + U_{3,before} + U_{4,before} + U_{5,before} + U_{6,before})/6 \tag{10}$$

where

$U_{av,before}$ is the average of U-value of all specimens before the test. [W/(m$^2 \cdot$ K)];

$U_{n,before}$ is the measured U-value of the specimen (n = 1 to 6) before the test [W/(m$^2 \cdot$ K)].

$U_{av,before}$ shall be stated to two decimal places and $U_{n,before}$ shall be truncated to three decimal places.

The deviation between $U_{av,before}$ and the U-value of each specimen shall be no more than 10,0 % as in Formula (11).

$$100 \, (| \, U_{av,before} - U_{n,before} \, |/U_{av,before}) \leq 10{,}0 \; \% \tag{11}$$

If the deviation is more than 10,0 %, the durability evaluation cannot be conducted because the quality of the relevant set of test specimens is regarded as unstable.

The specimens shall be exposed to a climate test defined in 7.3.

The U-value of the specimens after the climate test shall be measured in accordance with Annex A.

The measurements shall be conducted after storage of specimens at room temperature for no less than 24 h after the test.

The absolute change in U-value ΔU W/(m$^2 \cdot$ K) and percentage change in U-value ΔU_r % for each specimen shall be calculated using Formula (12) and Formula (13) respectively.

$$\Delta U_n = U_{n,after} - U_{n,before} \tag{12}$$

$$\Delta U_{r,n} = [(U_{n,after} - U_{n,before})/U_{n,before}] \times 100 \tag{13}$$

where $U_{n,after}$ is the measured U-value of the specimen (n = 1 ~ 6) after the test [W/(m$^2 \cdot$ K)], truncated to three decimal places.

$\Delta U_{r,n}$ shall be stated to one decimal place.

For all the tested specimens, ΔU_n shall be no more than 0,10 W/(m$^2 \cdot$ K) or $\Delta U_{r,n}$ shall be no more than 10,0 %.

EXAMPLE 1   The durability evaluation cannot be conducted because the deviation of $U_{5,\text{ before}}$ is more than 10,0 %.

n	$U_{n,\text{ before}}$ W/(m$^2 \cdot$ K)	Deviation % Formula (11)
1	0,733	1,8
2	0,655	9,0
3	0,735	2,1
4	0,692	3,9
5	0,811	12,6
6	0,682	5,3
av.	0,72	

EXAMPLE 2   The durability evaluation can be conducted because the deviations of all $U_{n,\text{ before}}$ are no more than 10,0 %. The specimens pass the test because all of ΔU_n are no more than 0,10 W/(m$^2 \cdot$ K) even though $\Delta U_{r,2}$ and $\Delta U_{r,4}$ are more than 10,0 %.

N	$U_{n,\text{ before}}$ W/(m$^2 \cdot$ K)	Deviation % Formula (11)	$U_{n,\text{ after}}$ W/(m$^2 \cdot$ K)	ΔU_n W/(m$^2 \cdot$ K) Formula (12)	$\Delta U_{r,n}$ % Formula (13)
1	0,729	1,3	0,777	0,048	6,6
2	0,701	2,6	0,781	0,080	11,4
3	0,709	1,5	0,755	0,046	6,5
4	0,713	1,0	0,806	0,093	13,0
5	0,731	1,5	0,784	0,053	7,3
6	0,722	0,3	0,778	0,056	7,8
av.	0,72				

EXAMPLE 3   The durability evaluation can be conducted because the deviations of all $U_{n,\text{ before}}$ are no more than 10,0 %. The specimens fail the test because ΔU_4 is more than 0,10 W/(m$^2 \cdot$ K) and $\Delta U_{r,4}$ is more than 10,0 %.

n	$U_{n,\text{ before}}$ W/(m$^2 \cdot$ K)	Deviation % Formula (11)	$U_{n,\text{ after}}$ W/(m$^2 \cdot$ K)	ΔU_n W/(m$^2 \cdot$ K) Formula (12)	$\Delta U_{r,n}$ % Formula (13)
1	0,729	1,3	0,777	0,048	6,6
2	0,701	2,6	0,781	0,080	11,4
3	0,709	1,5	0,755	0,046	6,5
4	0,713	1,0	0,822	0,109	15,3
5	0,731	1,5	0,784	0,053	7,3
6	0,722	0,3	0,778	0,056	7,8
av.	0,72				

EXAMPLE 4   The durability evaluation can be conducted because the deviations of all $U_{n,\text{ before}}$ are no more than 10,0 %. The specimens pass the test because all of $\Delta U_{r,n}$ are no more than 10,0 % even though ΔU_3 is more than 0,10 W/(m$^2 \cdot$ K).

n	$U_{n, before}$ W/(m$^2 \cdot$ K)	Deviation % Formula (11)	$U_{n, after}$ W/(m$^2 \cdot$ K)	ΔU_n W/(m$^2 \cdot$ K) Formula (12)	$\Delta U_{r, n}$ % Formula (13)
1	1,433	0,9	1,498	0,065	4,5
2	1,391	2,0	1,444	0,053	3,8
3	1,428	0,6	1,551	0,123	8,6
4	1,445	1,8	1,480	0,035	2,4
5	1,438	1,3	1,476	0,038	2,6
6	1,411	0,6	1,454	0,043	3,0
av.	1,42				

7.2 Test specimens

Six vacuum insulating glass test specimens shall be submitted for testing. The test specimen dimensions shall meet the requirements of A.4.

It is recommended to submit (an) additional test specimen(s) in case of breakage.

If one or more test specimen(s) is (are) broken during the test, the relevant set of test specimens shall be considered having failed the test. This excludes breakage due to laboratory handling.

A product with the smallest glass thickness facing the UV light can represent a group of products with thicker glass and identical coating.

NOTE   More UV light is transmitted through the glass surface facing the vacuum with a thinner glass compared with a thicker glass.

7.3 Test method

The test specimens shall be exposed to one of the three climate tests below:

a) Test method 1: in accordance with ISO 20492-1:2008, 6.1.3.2 to 6.1.3.3 and 6.1.4.6 to 6.1.4.14.

b) Test method 2: the climate test shall include two parts, with the first part consisting of 56 temperature cycles of 12 h from –18 °C to +53 °C with rates of temperature change of 14 °C/h, followed by a second part consisting of ISO 12543-4:2011, 7.3.1. The exact specifications of the temperature and time and tolerance of temperature cycles for the first part of the test shall be in accordance with Figure 5. Temperature cycles start with cooling segment.

Key
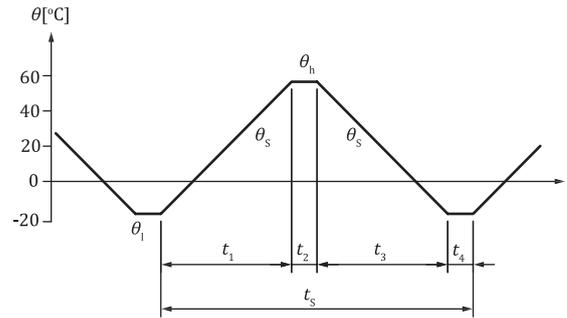
t time (h)

θ temperature (°C)

θ_h high temperature, for the centrally located test specimen during the cycle, equal to $(53{,}0 \pm 1{,}0)$ °C

θ_l low temperature, for the centrally located test specimen during the cycle, equal to $(-18{,}0 \pm 1{,}0)$ °C

θ_s temperature, for the centrally located test specimen during the cycle during a temperature change of (-14 ± 2) °C/h

Time intervals: $t_1 = 5$ h ± 1 min; $t_2 = 1$ h ± 1 min; $t_3 = 5$ h ± 1 min; $t_4 = 1$ h ± 1 min; $t_5 = 12$ h ± 1 min (total cycle time.)

Figure 5 — Temperature/time relations in cycling test

NOTE 1   This cycling test is referred to in ISO 20492-1:2008, 6.2.2.1.

c)   Test method 3: in accordance with Annex B.

NOTE 2   Annex B refers to a part of Reference [8].

NOTE 3   Constant high temperature and high humidity tests are not critical for the durability of the vacuum insulating glass, since some test results show that effect of the high temperature and high humidity tests to vacuum degradation is much smaller than that of the UV irradiation tests[9][10].

NOTE 4   Test method 1 includes a test in which one pane of the specimen faces the exterior and the other pane faces the interior of the environmental chamber. This subjects the specimen to thermal loads which results in additional mechanical stresses at the edge. This could potentially lead to a cause of failure of the specimen other than vacuum degradation.

8   Measurement of sound insulation

If a sound insulation performance is claimed for vacuum insulating glass, it shall be obtained under the conditions specified in ISO 10140-2 and ISO 717-1.

For best reproducibility it is recommended that the test opening for glass panes, as described in ISO 10140-2, be adopted.

Some variations in panel size, etc., as compared to those in ISO 10140-2, can be necessary for vacuum insulating glass. In such cases, the pane size shall be clearly stated in the test report.

Annex A
(normative)

Determination of steady-state U-value (thermal transmittance) — Heat flow meter method and guarded hot plate method

A.1 General

The thermal resistance of the vacuum insulating glass shall be determined by either the heat flow meter method in accordance with ISO 8301 or the guarded hot plate method in accordance with ISO 8302.

Within this context, further requirements are necessary. The sizes of the test specimens and the performance of the measurements to meet special requirements for measuring vacuum insulating glass are stated in A.3 to A.5.

A.2 Basic formula

The U-value at the central part of vacuum insulating glass depends on the thermal resistance of the glass and the external and internal surface heat transfer coefficients according to Formula (A.1):

$$1/U = R + 1/h_e + 1/h_i \qquad (A.1)$$

where

R is the thermal resistance of the vacuum insulating glass [$(m^2 \cdot K)/W$];

h_e is the external surface heat transfer coefficient [$W/(m^2 \cdot K)$];

h_i is the internal surface heat transfer coefficient [$W/(m^2 \cdot K)$].

The U-value shall be determined in accordance with Formula (A.1).

A.3 Test apparatus

A.3.1 Buffer plates

Buffer plates are used in the measurement as detailed in A.3.2 and A.3.3.

Requirements for the buffer plates and their setup are as follows:

— The buffer plate shall make uniform and continuous contact with the entire glass surface.

— In the case of a protruding evacuation port, the buffer plates shall be thicker than the height of the evacuation port of the vacuum insulating glass.

— In the case of a protruding evacuation port, the area of the buffer plate contacting the evacuation port shall be removed so as to make the buffer plate contact the glass surface around the evacuation port.

— The two buffer plates shall be made from the same material and have the same nominal thickness.

— The size of the buffer plates shall be the same as or larger than that of the specimen.

— To ensure constancy of thermal properties, the thickness of the buffer plate shall not change due to pressure during the measurement. The thermal conductivity of the buffer plate material shall not be influenced by absorbed water.

— The thermal resistance of each buffer plate shall be between 0,03 and 0,1 $(m^2 \cdot K)/W$ to minimize potential measurement error.

— The thickness of each buffer plate shall be between 5 mm and 20 mm.

NOTE   Estimation of the measurement error is discussed in Annex D and Annex E.

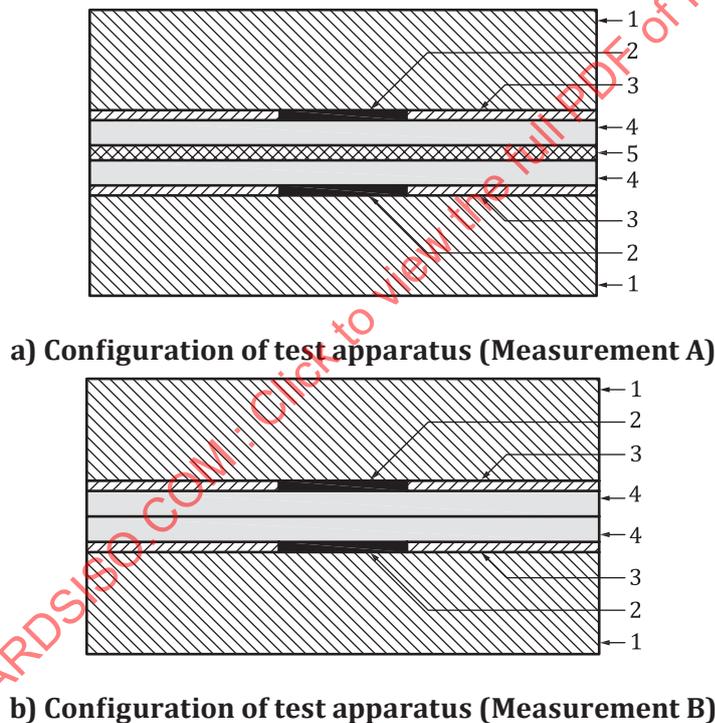### A.3.2 Heat flow meter method

The apparatus of the heat flow meter method is shown in Figure A.1.

One buffer plate shall be positioned between the heating plate and the specimen, and another buffer plate between the cooling plate and the specimen in Measurement A.

Two buffer plates are positioned between the heating plate and the cooling plate in Measurement B.

The measurement procedure is described in A.5.

a) Configuration of test apparatus (Measurement A)

b) Configuration of test apparatus (Measurement B)

Key

1   heating and cooling plate
2   heat flow meter (metering section)
3   protective material
4   buffer plate
5   specimen

**Figure A.1 — A setup for measurement with heat flow meter method**

A.3.3 Guarded hot plate method

The apparatus of the guarded hot plate method is shown in Figure A.2.

One buffer plate shall be positioned between the heating plate and the specimen, and another buffer plate between the cooling plate and the specimen in Measurement A.

Two buffer plates are positioned between the heating plate and the cooling plate in Measurement B.

The measurement procedure is described in A.5.
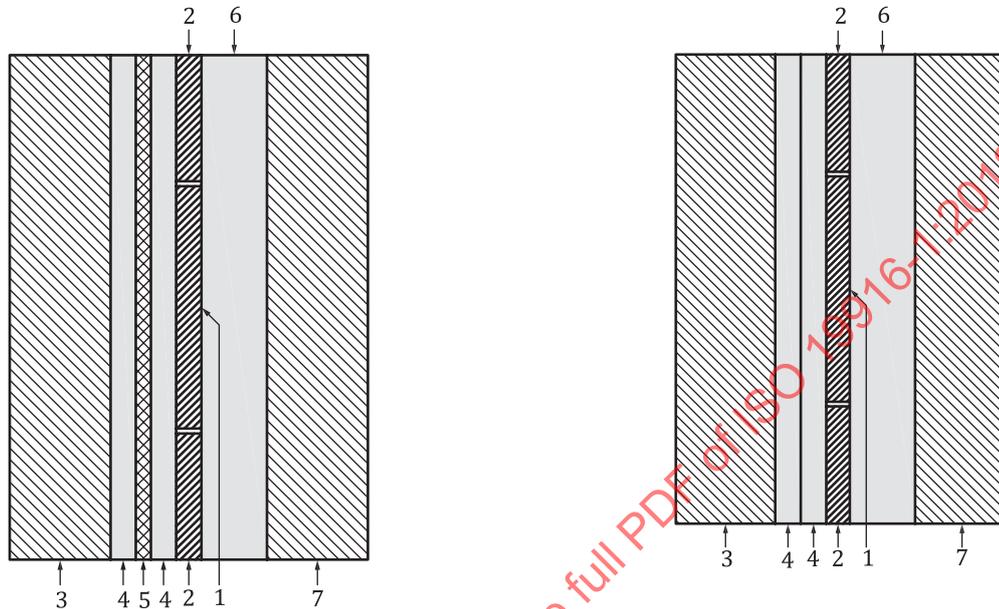
a) **Configuration of test apparatus (Measurement A)**

b) **Configuration of test apparatus (Measurement B)**

Key

1   metering section heater

2   guarded section heater

3   cooling unit

4   buffer plate

5   specimen

6   guard plate insulation

7   guard plate

Figure A.2 — Guarded hot plate measurement setup

A.4 Dimensions of specimen and metering area

A.4.1 Distance from edge seal

The size of specimens shall be determined so that the distance from the edge seal (see Figure A.3) is at least 90 mm from the metering area.
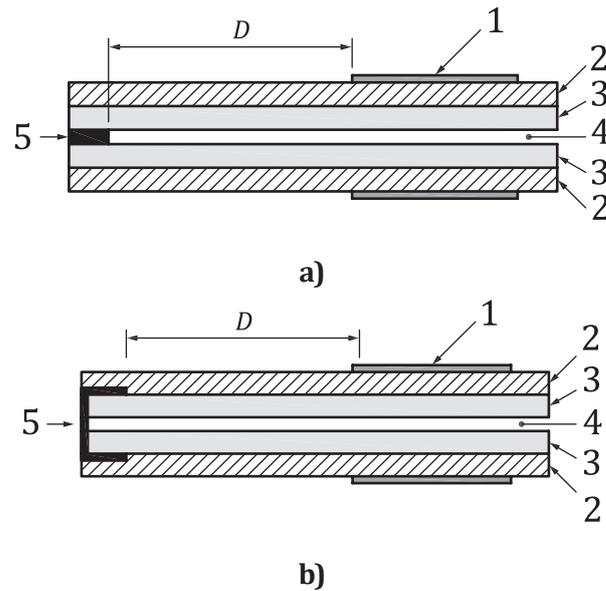
Key

D   distance from edge seal

1   metering area

2   buffer plate

3   glass

4   vacuum layer

5   edge seal

Figure A.3 — Distance from edge seal

NOTE   If the distance from the edge seal is less than 90 mm, the measured U-value might be larger due to effect of heat flow through the edge seal. Investigation of the edge effect is described in Annex D.

A.4.2   Dimensions of metering area

The linear dimension of the metering area shall be at least 100 mm.

NOTE   If the linear dimension of the metering area is less than 100 mm, errors in the measured U-value might be larger. Investigation of the edge effect is described in Annex D and Annex E.

A.5   Measurements

Two measurements shall be performed using the method in accordance with A.3.2 or A.3.3.

Measurement A: the thermal resistance R_A is measured with the test specimen sandwiched between two buffer plates as shown in Figure A.2 a) or Figure A.3 a).

Measurement B: the thermal resistance R_B is measured with two buffer plates used in the measurement A as shown in Figure A.2 b) or Figure A.3 b). The buffer plates shall be positioned at the same place in the apparatus as with measurement A. This measurement shall be conducted at least once during the measurements with a group of the specimens having the same specification.

The test condition for Measurement A and Measurement B shall be set as follows.

The mean surface temperature of the heating plate shall be 17,5 °C ± 0,5 °C and the mean temperature of the cooling plate shall be 2,5 °C ± 0,5°C.

If necessary, the temperature difference between the hot and cold plates may be reduced in Measurement B so that the heat flow through the buffer plates does not exceed the limitations of the measuring apparatus. If this is done, the temperature of the hot plate should not exceed 17,5 °C and the temperature of the cold plate should not be below 2,5 °C.

The thermal resistance of the specimen is calculated from Formula (A.2):

$$R = R_A - R_B \tag{A.2}$$

where

R is the thermal resistance of the specimen $[(m^2 \cdot K)/W]$;

R_A is the thermal resistance determined in Measurement A $[(m^2 \cdot K)/W]$;

R_B is the thermal resistance determined in Measurement B $[(m^2 \cdot K)/W]$.

R, R_A and R_B shall be truncated to 3 decimal places.

NOTE   The thermal resistance of each buffer plate is nominally $R_B/2$.

The U-value is calculated from Formula (A.1). For vacuum insulating glass, the external and internal heat transfer coefficients as given in ISO 10292 shall be used.

Annex B
(normative)

Test method for durability

B.1 Durability test

B.1.1 General

The test procedure shall be as follows:

a) Conduct the test specified in B.1.2 for 7 days, then conduct the test specified in B.1.3 for 12 cycles.

b) In the sequence to test procedure in a), conduct the test specified in B.1.2 for 7 days, then conduct the test specified in B.1.3 for 12 cycles.

c) In the sequence to test procedure in b), conduct the test specified in B.1.2 for 28 days, then conduct the test specified in B.1.3 for 48 cycles.

B.1.2 Moisture and light resistance test

The specimens are placed in a constant temperature-moisture oven with atmosphere of (55 ± 3) °C and relative humidity 95 % and light is irradiated on the glass surface by ultraviolet fluorescent lamps FL 40 BL(1) or FL 40S BL (1) as illustrated in Figure B.1. The distance between the axial centre of fluorescent lamps and the surface of glass shall be (50 ± 3) mm.

NOTE   The meaning of the symbols for types and kinds is as follows:

— Item 1 FL: straight tube type;

— Item 2 40 or 40S: 40 means the rated lamp capacity is 40 W and S means thinner glass tube;

— Item 3 BL: mainly emitting near ultraviolet radiation (range of wavelength 315 nm to 400 nm).

Record the temperature and humidity at the place representing the mean temperature in the oven by continuous recorder. Conduct the exchange of fluorescent lamps by taking as reference a total lighting time of 5 150 h.

Dimensions in millimetres
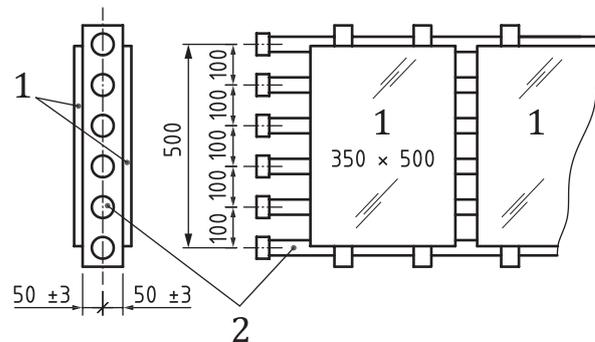
Key
1   specimen
2   ultraviolet fluorescent lamp

Figure B.1 — Arrangement of fluorescent lamps

B.1.3   Thermal repeating test

Place the specimens in a thermostatic vessel, hold at (−20 ± 3) °C for 1 h and then hold at (50 ± 3) °C for 1 h as shown in Figure B.2. Take this procedure as one cycle to repeat. Record the temperature at the place representing the mean temperature in the thermostatic vessel by continuous recorder.
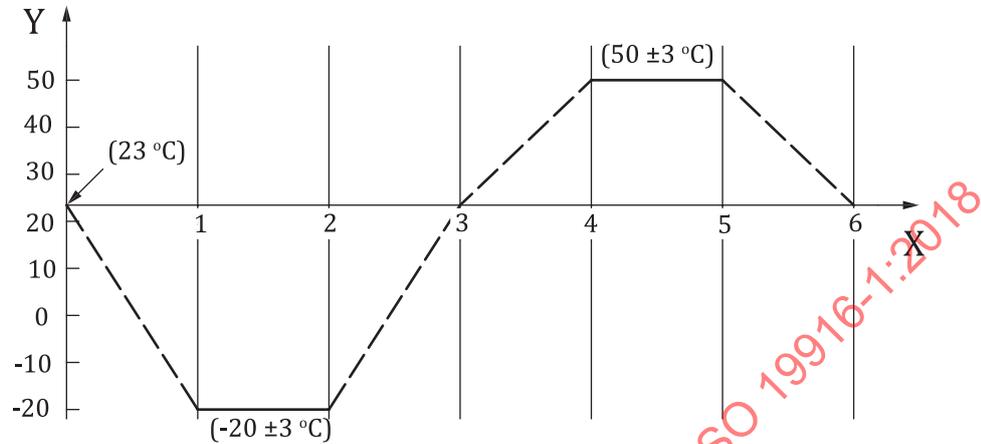
Key

X   passed time (h)

Y   temperature in thermostatic vessel (°C)

Figure B.2 — Thermal repeating cycle

Annex C
(informative)

Calculation method for thermal transmittance (U-value)

If the calculation method based on ISO 10292 is to be used for the calculation of the U-value, the gas space conductance, h_s, described in Formula (2) shall be replaced by the vacuum space conductance, h_v, calculated using Formula (C.1):

$$h_v = h_p + h_r + h_a \tag{C.1}$$

where

h_v is the vacuum space conductance [W/(m$^2 \cdot$ K)];

h_p is the thermal conductance of the pillar array [W/(m$^2 \cdot$ K)];

h_r is the thermal conductance due to radiation [W/(m$^2 \cdot$ K)];

h_a is the thermal conductance of the low pressure gas [W/(m$^2 \cdot$ K)].

The thermal conductance of pillar array, h_p, is calculated using Formulae (C.2) to (C.4):

$$h_p = \frac{1}{\dfrac{1}{h_s} + \dfrac{1}{h_{pc}}} \tag{C.2}$$

$$h_s = \frac{2 \times \lambda_g \times r_p}{l_p^{\;2}} \tag{C.3}$$

$$h_{pc} = \frac{\lambda_p}{d_p} \times \frac{\pi \times r_p^{\;2}}{l_p^{\;2}} \tag{C.4}$$

where

h_s is the thermal conductance associated with the spreading resistance in glass [W/(m$^2 \cdot$ K)];

h_{pc} is the thermal conductance of the pillars [W/(m$^2 \cdot$ K)];

r_p, d_p, l_p are the radius, the thickness and the separation of the pillars (m);

λ_g, λ_p are the thermal conductivities of the glass and the pillar material [W/(m $\cdot$ K)].

The thermal conductance by radiation, h_r, is calculated using Formulae (C.5) and (C.6):

$$h_r = 4 \times \varepsilon \times \sigma \times T_m^{\;3} \tag{C.5}$$

$$\varepsilon = \frac{1}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_2} - 1} \tag{C.6}$$

where

ε is the effective emissivity between two glass surfaces facing vacuum layer (-);

$\varepsilon_1, \varepsilon_2$ are the values of corrected emissivity of each glass surface facing vacuum layer (-);

σ is the Stefan-Boltzmann constant [$5{,}67 \times 10^{-8}$ W/(m$^2 \cdot$ K^4)];

T_m is the mean temperature of two glass surfaces facing vacuum layer (K).

The thermal conductance in a low pressure gas, h_a, is calculated using Formula (C.7):

$$h_a = \alpha \times \frac{\gamma+1}{\gamma-1} \times \sqrt{\frac{R}{8\pi}} \times \frac{P}{\sqrt{M \times T'_m}} \qquad (C.7)$$

where

α is the combined accommodation coefficient of the two surfaces;

γ is the specific heat ratio (= c_p/c_v);

R is the gas constant 8,314 J/(mol $\cdot$ K);

P is the absolute pressure of the gas (Pa);

M is the molar weight of the gas (kg/mol);

T'_m is the mean temperature of the low pressure gas in the vacuum layer (K);

h_a is approximately 0,4 P, where P is measured in Pa[11]. This value can be adopted in calculations in the absence of any other data.

Annex D
(informative)

Contribution from the edges to the measurement of the thermal transmittance (U-value) of vacuum insulating glass

The edge seal in vacuum insulating glass results in additional heat flow through the glazing that shall be considered when measuring the centre-of-glazing U-value as described in Annex A. The effect of this heat flow can extend to a considerable distance across the surface of the glass sheets.

The effect of the heat that flows through the vacuum insulating glass as a result of a single edge seal can be determined by an analytic model of the measurement system similar to that described in Reference [12]. The results of the analytic model have been validated by finite element modelling and by comparison with experimental measurements on test samples.

Figure D.1 represents part of the vacuum insulation glass in the vicinity of a single edge seal. In the analytic model, it is assumed that all of the parameters depend only on the distance x from the inner extremity of the edge seal.

The vacuum insulating glass sample is surrounded by buffer plates of thermal conductance h_b that are in contact with hot and cold plates of temperatures T_H and T_C respectively. The glass sheets of the vacuum insulating glass are modelled as thin plane slabs of thickness t and thermal conductivity λ_g. The temperature of each glass sheet is assumed to be uniform through its thickness. The temperature of the hot glass sheet is written as $T(x)$. All heat flow through the buffer plates and the evacuated space is assumed to be perpendicular to the surface of the glass sheets. The heat flow through the evacuated space due to radiation, the pillar array, and the residual gas conductance, is characterised by thermal conductance h_v in the space between the glass sheets. The buffer plates are modelled by slabs of material having thermal conductance h_b. The size of the sensor of the measurement device is $w \times w$. D is the distance from the edge of the sensor to the inner extremity edge of the edge seal.
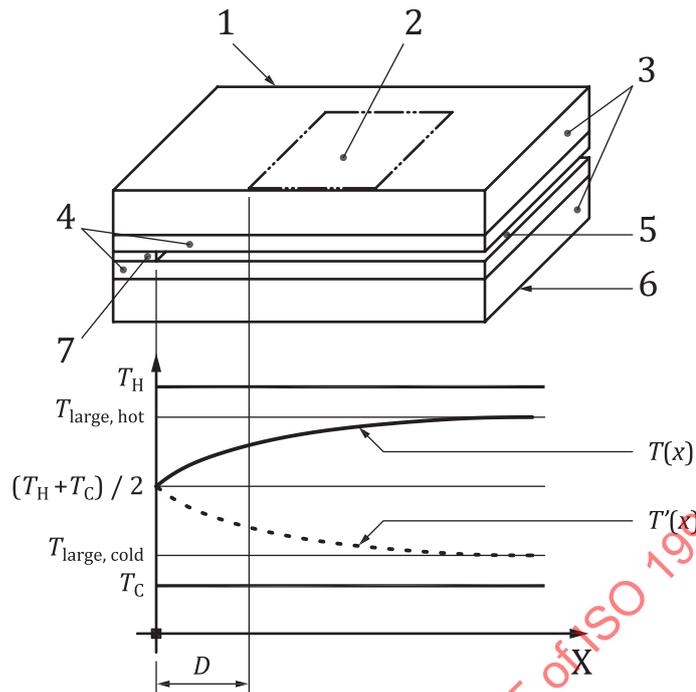
Key

1	hot plate, temperature T_H
2	measurement area, dimensions $w \times w$
3	buffer plates, conductance h_b
4	glass sheets, thickness t
5	evacuated glass, conductance h_v
6	cold plate, temperature T_C
7	edge seal
$(T_H + T_C)/2$	edge seal temperature
$T'(x)$	temperature of cold glass sheet
$T_{large,hot}$	temperature of hot glass sheet remote from edge seal
$T_{large,cold}$	temperature of cold glass sheet remote from edge seal

Figure D.1 — Geometry of the analytic model for calculating the effect of the edge seal

The analytic model shows that the temperatures of the hot and cold sheets approach the values remote from the edge seal exponentially. The characteristic distance L of the exponential is given by Formula (D.1):

$$L = \sqrt{\lambda_g t / (h_b + 2h_v)} \tag{D.1}$$

Formula (D.2) shows the additional heat flow through the measuring area due to the presence of the edge seal, expressed as the ratio of the heat flow due to the edge Q_{me} to the heat flow far from the edge Q_{ms}:

$$\frac{Q_{me}}{Q_{ms}} = \frac{h_b L}{2w h_v} \left[\exp\left(-\frac{D}{L}\right) - \exp\left(-\frac{D+w}{L}\right) \right]. \tag{D.2}$$

To describe better the effect of the edge on the measured U-value, Formula (D.2) needs to be transformed to represent the additional contribution to the U-value measurement of a sample. This is done by first

determining the hot surface (T_H)-to-cold surface (T_C) thermal conductance of the vacuum insulating glass (VIG) plus the two buffer plates (BP):

$$h_{s-s}^{VIG+BP} = \left[1 + \frac{Q_{me}}{Q_{ms}}\right] \times \left[\frac{2}{h_b} + \frac{1}{h_v}\right]^{-1} \tag{D.3}$$

From this, the glass-to-glass thermal conductance of the vacuum insulating glass, including the additional edge contribution due to an edge seal, can be calculated as:

$$h_{s-s}^{VIG} = \left[\frac{1}{h_{s-s}^{VIG+BP}} - \frac{2}{h_b}\right]^{-1} \tag{D.4}$$

The air-to-air U-value is now determined by accounting for the inside and outside heat transfer coefficients, as described in Formula (A.1).

The results from combining Formula (D.4) with the inside and outside heat transfer coefficients are presented in Figure D.2 as the additional (percentage) contribution from the edge seal to the centre-of-glazing air-to-air U-value as a function of the distance, D, from the edge of the measuring area to the edge seal. The data in Figure D.2 are for four different vacuum insulation glass sample designs that have centre-of-glazing U-values of 1,6; 1,0; 0,6 and 0,3 W/(m² · K), and glass thicknesses of 3 mm and 5 mm.