INTERNATIONAL
STANDARD

ISO
10292

First edition
1994-07-15

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

Verre dans la construction — Calcul du coefficient de transmission thermique U, en régime stationnaire des vitrages multiples

Reference number
ISO 10292:1994(E)

Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 10292 was prepared by Technical Committee ISO/TC 160, *Glass in building*, Subcommittee SC 2, *Use considerations*.

Annex A forms an integral part of this International Standard. Annex B is for information only.

International Organization for Standardization
Case Postale 56 • CH-1211 Genève 20 • Switzerland
Printed in Switzerland

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

1 Scope

This International Standard applies to glass, coated glass and materials opaque in the far infrared wavelengths. It gives the fundamental rules for calculating the thermal transmittance, *U* [1], in the glazing central area. The combined edge effects due to the thermal bridge of a glazing unit spacer and of the window frame are not included.

These rules are intended to enable the heat loss through glazing in a building to be estimated from the glazing *U* values and, together with heat losses through the opaque elements of the building, are used to determine the capacity of the heating or cooling plant.

In addition, *U* values for other purposes can be calculated using the same procedure, in particular for predicting:

a) conduction gains in summer;

b) condensation on glazing surfaces;

c) seasonal heat loss through glazing in determining overall energy use in buildings;

d) contribution of absorbed heat in determining the solar factor.

The rules have been made as simple as possible consistent with accuracy.

2 Definition

For the purposes of this International Standard, the following definition applies.

2.1 thermal transmittance of glazing, *U*: Value which characterizes the heat transfer through the central part of the glazing, i.e. without edge effects, and states the steady-state density of heat transfer rate per temperature difference between the ambient temperatures on each side. The *U* value is given in watts per square metre kelvin [W/(m^2·K)].

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[1] In some countries the symbol *k* is used.

3 Symbols and indices

3.1 Symbols

Symbol	Representation	Unit
A	constant	—
c	specific heat of gas	J/(kg·K)
d	thickness of layers of glass (or alternative glazing material)	m
Gr	Grashof number	dimensionless
h	surface heat transfer coefficient	$W/(m^2 \cdot K)$
h	conductance	$W/(m^2 \cdot K)$
N	number of spaces	—
Nu	Nusselt number	dimensionless
Pr	Prandtl number	dimensionless
r	thermal resistivity of glass (or alternative glazing material)	m·K/W
R_n	normal reflectance	—
s	width of gas space	m
T	absolute temperature	K
ΔT	temperature difference	K
U	thermal transmittance	$W/(m^2 \cdot K)$
v	wind speed	m/s
ε	corrected emissivity	—
ε_n	normal emissivity (perpendicular to surface)	—
ϑ	temperature	°C
λ	thermal conductivity of gas filling	W/(m·K)
λ	wavelength	µm
μ	dynamic viscosity of gas	kg/(m·s)
ρ	gas density	kg/m^3
σ	Stefan-Boltzmann constant $\left(= 5{,}67 \times 10^{-8}\right)$	$W/(m^2 \cdot K^4)$

3.2 Indices

Subscript	
c	convection
g	gas
e	external
i	internal
m	mean
n	normal
r	radiation
s	space
t	total
1, 2, ...	first, second, etc.

4 Basic formulae

4.1 General

The method specified by this International Standard is based on a calculation from the following first principles:

$$\frac{1}{U} = \frac{1}{h_e} + \frac{1}{h_t} + \frac{1}{h_i} \qquad \ldots (1)$$

where

h_e and h_i are the external and internal heat transfer coefficients respectively;

h_t is the conductance of the multiple glazing unit.

$$\frac{1}{h_t} = \sum^{N} \frac{1}{h_s} + \sum^{M} d_m r_m \qquad \ldots (2)$$

where

h_s	is the gas space conductance;
N	is the number of spaces;
M	is the number of materials;
d_m	is the total thickness of each material;
r_m	is the thermal resistivity of each material (the thermal resistivity of glass is 1 m·K/W).

$$h_s = h_g + h_r \qquad \ldots (3)$$

where

h_r	is the radiation conductance;
h_g	is the gas conductance (conduction and convection).

4.2 Radiation conductance, h_r

The radiation conductance, h_r, is given by

$$h_r = 4\sigma\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1\right)^{-1} \cdot T_m^3 \qquad \ldots (4)$$

where

σ	is the Stefan-Boltzmann constant;
ε_1 and ε_2	are the corrected emissivities at the mean absolute temperature T_m of the gas space.

4.3 Gas conductance, h_g

The gas conductance, h_g, is given by

$$h_g = Nu \frac{\lambda}{s} \qquad \ldots (5)$$

where

s	is the width of the space, in metres (m);
λ	is the gas thermal conductivity, in watts per metre kelvin [W/(m·K)];
Nu	is the Nusselt number, given by

$$Nu = A(Gr \cdot Pr)^n \qquad \ldots (6)$$

where

A	is a constant,
Gr	is the Grashof number,
Pr	is the Prandtl number,
n	is an exponent,

$$Gr = \frac{9{,}81 s^3 \Delta T \rho^2}{T_m \mu^2} \qquad \ldots (7)$$

$$Pr = \frac{\mu c}{\lambda} \qquad \ldots (8)$$

where

ΔT	is the temperature difference on either side of the glazing, in kelvins (K),
ρ	is the gas density, in kilograms per cubic metre (kg/m^3),
μ	is the gas dynamic viscosity, in kilograms per metre second [kg/(m·s)],
c	is the gas specific heat, in joules per kilogram kelvin [J/kg·K)],
T_m	is the gas mean temperature, in kelvins (K).

For vertical spaces, the Nusselt number is calculated from formula (6) using $A = 0{,}035$ and $n = 0{,}38$ under the following condition (see also ref. [1]).

If $Nu \leqslant 1$, the value unity is used in formula (5), corresponding to $Gr \cdot Pr$ less than 6 800. If $Nu > 1$, the greater value is used in formula (5) corresponding to a regime with convection.

5 Basic material properties

5.1 Emissivity

The corrected emissivities ε of the surfaces bounding the enclosed spaces are required to calculate the radiation conductance, h_r, in formula (4).

For glass surfaces, the corrected emissivity to be used is 0,837.

For coated surfaces, the normal emissivity, ε_n, is obtained from infrared spectrometer measurements (see A.1 in annex A).

The corrected emissivity is obtained from table A.2, in annex A.

The mean temperature of the space, T_m, is fixed at 283 K, for purposes of comparison.

NOTE 1 Two different definitions of emissivity should be theoretically used to describe radiation exchange:

- between glass surfaces facing each other in multiple glazing, or
- between a glass surface and the inside of a room.

However, in practice numerical differences are found to be negligibly small. Thus corrected emissivity can be used to describe both types of heat exchange with sufficient approximation.

5.2 Gas properties

The following properties of the gas filling the space are required:

a) the thermal conductivity, λ [W/(m·K)];

b) the density, ρ (kg/m³);

c) the dynamic viscosity, μ [kg/(m·s)];

d) the specific heat, c [J/(kg·K)].

The relevant values are substituted in formulae (7) and (8) for the Grashof and Prandtl numbers, and the Nusselt number is determined from formula (6).

If the Nusselt number is greater than 1, this indicates that convection is occurring, enhancing the heat flow-rate.

If the Nusselt number is less than or equal to 1, this indicates that heat flow is by conduction only and the Nusselt number is given the limit value of 1.

Substitution of Nu in formula (5) gives the gas conductance h_g.

Values of gas properties for a range of gases used in sealed multiple glazing units are given in table A.3, annex A.

For gas mixtures, the gas properties are proportioned in the ratio of the volumes.

If we have

- gas 1 with a ratio of the volume R_1,
- gas 2 with a ratio of the volume R_2, etc.,

then

$$F = F_1 R_1 + F_2 R_2 + \dots \qquad \dots (9)$$

where F represents the relevant property, i.e. thermal conductivity, density, dynamic viscosity or specific heat.

5.3 Infrared-absorbing gases

Some gases absorb infrared radiation in the 5 µm to 50 µm range.

Where the gas concerned is used in combination with a low emissivity coating ($\varepsilon < 0{,}2$), this effect is ignored because of the low density of the net infrared radiant flux.

For other cases the U value shall be measured if a possible benefit to the U value from the absorption of the gas might be realized.

5.4 Horizontal or angled glazing

For upward heat flow, the heat transfer by convection is enhanced.

This effect is taken into account by substituting the following A and n values in formula (6):

for horizontal spaces: $A = 0{,}16$ and $n = 0{,}28$

for spaces at 45°: $A = 0{,}10$ and $n = 0{,}31$

When the direction of heat flow is downward, the convection can be considered suppressed, for practical cases, and $Nu = 1$ is substituted in formula (5) (see also ref. [1]).

6 External and internal heat transfer coefficients

6.1 External heat transfer coefficient, h_e

The external heat transfer coefficient, h_e, in watts per square metre kelvin [W/(m²·K)], is a function of the wind speed, v, near the glazing given by the following approximate formula:

$$h_e = 10{,}0 + 4{,}1v \qquad \dots (10)$$

where v is the wind speed, in metres per second (m/s).

The value h_e equal to 23 W/(m²·K) is used for the purposes of comparison of glazing U values.

NOTE 2 The reciprocal $1/h_e$ is 0,04 m²·K/W expressed to two significant decimals.

This procedure does not take into account the improvement of the *U* value due to the presence of externally exposed coated surfaces with a modified emissivity.

If other values of h_e are used to meet special experimental conditions, they shall be recorded in the test report.

6.2 Internal heat transfer coefficient, h_i

The internal heat transfer coefficient, h_i, in watts per square metre kelvin [W/(m²·K)], is given by the following formula:

$$h_i = h_r + h_c \qquad \ldots (11)$$

where

h_r is the radiation conductance;

h_c is the convection conductance.

The radiation conductance for normal glass surfaces is 4,4 W/(m²·K). If the internal surface of the glazing has a low corrected emissivity, the radiation conductance is given by:

$$h_r = 4{,}4\varepsilon/0{,}837 \qquad \ldots (12)$$

where ε is the corrected emissivity of the coated surface (0,837 is the corrected emissivity of clear, uncoated glass).

This only applies if there is no condensation on the coated surface. The relation between the corrected emissivity and normal emissivity of a coated surface is given in table A.2, annex A.

The value of h_c is 3,6 W/(m²·K) for free convection. Where a fan-blown heater is situated below or above a window, this value will be larger if a current of air is blown over the window.

For ordinary vertical glass surfaces and free convection,

$$h_i = 4{,}4 + 3{,}6 = 8{,}0\ \mathrm{W}/\left(\mathrm{m}^2\cdot\mathrm{K}\right) \qquad \ldots (13)$$

This value is standardized for purposes of comparison of glazing *U* values.

NOTE 3 The reciprocal $1/h_i$ is 0,13 m²·K/W expressed to two significant decimals.

If other values of h_i are used to meet special experimental conditions, they shall be recorded in the test report.

For non-vertical surfaces, the coefficient is greater for upward heat flow and less for downward heat flow.

NOTE 4 Values lower than 0,837 for ε due to surface coatings with higher reflection in the far infrared are only to be taken into account if condensation on the coated surfaces can be excluded.

7 Reference values

The principal reference values are as follows:

thermal resistivity of glass	$r = 1$ m·K/W
corrected emissivity of ordinary glass surface	$\varepsilon = 0{,}837$
temperature difference between the outer limiting glass surfaces	$\Delta T = 15$ K
mean temperature of glazing	$T_m = 283$ K
Stefan-Boltzmann constant	$\sigma = 5{,}67 \times 10^{-8}$ W/(m²·K
external heat transfer coefficient	$h_e = 23$ W/(m²·K)
internal heat transfer coefficient	$h_i = 8$ W/(m²·K)

Gas properties are given in table A.3, annex A.

U values shall be quoted in watts per square metre kelvin [W/(m²·K)], only to one decimal figure.

NOTE 5 For glazing with more than one gas space, the mean temperature and the mean temperature difference for each unit of glazing should be found by iteration of the calculation procedure.

Annex A

(normative)

Determination of emissivity and gas properties

A.1 Determination of normal emissivity, ε_n

The normal emissivity of a coated surface, ε_n, is computed from its spectral reflectance curve measured at nearly normal incidence with an infrared spectrometer using the following procedure.

Normal reflectance R_n for a temperature of 283 K is determined from the curve by taking the mathematical average of spectral reflectance $R_\mathrm{n}(\lambda_i)$ measured at the 30 wavelengths given in table A.1:

$$R_\mathrm{n} = \frac{1}{30}\sum_{i=1}^{30} R_\mathrm{n}(\lambda_i) \qquad \ldots (\mathrm{A.1})$$

Normal emissivity, ε_n, at 283 K [2] is given by

$$\varepsilon_\mathrm{n} = 1 - R_\mathrm{n} \qquad \ldots (\mathrm{A.2})$$

A.2 Determination of corrected emissivity, ε

The corrected emissivity, ε, is determined by multiplying normal emissivity, ε_n, by the coefficient given in table A.2.

A.3 Gas properties

The relevant properties of gases used for commercial sealed multiple glazing are given in table A.3.

Table A.1 — Wavelengths for determining normal reflectance, R_n, at 283 K

Values in micrometres

No.	Wavelength	No.	Wavelength
1	5,5	16	14,8
2	6,7	17	15,6
3	7,4	18	16,3
4	8,1	19	17,2
5	8,6	20	18,1
6	9,2	21	19,2
7	9,7	22	20,3
8	10,2	23	21,7
9	10,7	24	23,3
10	11,3	25	25,2
11	11,8	26	27,7
12	12,4	27	30,9
13	12,9	28	35,7
14	13,5	29	43,9
15	14,2	30	50,0[1] [2]

1) 50 µm is chosen because this wavelength is the limit of common commercial infrared spectrometers. This approximation has only a negligible effect on the accuracy of the calculation.

2) If spectral reflectance data are not available for wavelengths greater than 25 µm, missing $R_\mathrm{n}(\lambda_i)$ data may be substituted by the highest wavelength point available. This procedure is valid only if the spectral reflectance curve is reasonably constant. When this extrapolation is used it shall be indicated in the test report. This provision is limited to five years after the publication of this International Standard.

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[2] For other ambient temperatures, emissivity is not strongly dependent on the mean temperature.

Table A.2 — Relationship between corrected emissivity, ε, and normal emissivity, ε_n

Normal emissivity, ε_n	Coefficient, $\varepsilon/\varepsilon_n$ 1)
0,03	1,22
0,05	1,18
0,1	1,14
0,2	1,10
0,3	1,06
0,4	1,03
0,5	1,00
0,6	0,98
0,7	0,96
0,8	0,95
0,89	0,94

1) Other values may be obtained with sufficient accuracy by linear interpolation or extrapolation.

Table A.3 — Gas properties

Gas	Temperature, ϑ °C	Density, ρ kg/m^3	Dynamic viscosity, μ 10^{-5} kg/(m·s)	Thermal conductivity, λ 10^{-2} W/(m·K)	Specific heat, c 10^3 J/(kg·K)
Air	− 10	1,326	1,661	2,336	1,008
	0	1,277	1,711	2,416	
	+ 10	1,232	1,761	2,496	
	+ 20	1,189	1,811	2,576	
Argon	− 10	1,829	2,038	1,584	0,519
	0	1,762	2,101	1,634	
	+ 10	1,699	2,164	1,684	
	+ 20	1,640	2,228	1,734	
SF_6	− 10	6,844	1,383	1,119	0,614
	0	6,602	1,421	1,197	
	+ 10	6,360	1,459	1,275	
	+ 20	6,118	1,497	1,354	
Krypton	− 10	3,832	2,260	0,842	0,245
	0	3,690	2,330	0,870	
	+ 10	3,560	2,400	0,900	
	+ 20	3,430	2,470	0,926	