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Glass in building — Determination of thermal transmittance (U value) — Calculation method

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A list of organizations represented on this committee can be obtained on request to its secretary.

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Verre dans la construction - Détermination du coefficient de transmission thermique, U - Méthode de calcul

Glas im Bauwesen - Bestimmung des U-Werts (Wärmedurchgangskoeffizient) - Berechnungsverfahren

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Foreword

This document (EN 673:2011) has been prepared by Technical Committee CEN/TC 129 “Glass in building”, the secretariat of which is held by NBN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by August 2011, and conflicting national standards shall be withdrawn at the latest by August 2011.

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Introduction

CEN/TC 129/WG9 "Light and energy transmission, thermal insulation" prepared a working draft based on the document ISO/DIS 10292, "Thermal insulation of glazing: Calculation rules for determining the steady state U value of double or multiple glazing", document that was prepared by ISO/TC 160, "Glass in building". This was published in 1997 as EN 673.

This edition is a revision of EN 673:1997. The main change in this edition is that the internal and external heat transfer coefficients have been amended slightly to avoid any ambiguities. The original annex on the determination of emissivity has been removed and reference is made to EN 12898. Other changes include the incorporation of amendments A1 and A2 to EN 673:1997 and general improvements to the text to aid understanding.

1 Scope

This European Standard specifies a calculation method to determine the thermal transmittance of glazing with flat and parallel surfaces.

This European Standard applies to uncoated glass (including glass with structured surfaces, e.g. patterned glass), coated glass and materials not transparent in the far infrared which is the case for soda lime glass products, borosilicate glass and glass ceramic. It applies also to multiple glazing comprising such glasses and/or materials. It does not apply to multiple glazing which include in the gas space sheets or foils that are far infrared transparent. The procedure specified in this European Standard determines the U value[1)] (thermal transmittance) in the central area of glazing.

The edge effects due to the thermal bridge through the spacer of a sealed glazing unit or through the window frame are not included. Furthermore, energy transfer due to solar radiation is not taken into account. The effects of Georgian and other bars are excluded from the scope of this European Standard.

The standard for the calculation of the overall U value of windows, doors and shutters (see EN ISO 10077-1 [1]) gives normative reference to the U value calculated for the glazing components according to this standard.

For the purpose of product comparison, a vertical position of the glazing is specified. In addition, U values are calculated using the same procedure for other purposes, in particular for predicting:

— heat loss through glazing;

— conduction heat gains in summer;

— condensation on glazing surfaces;

— the effect of the absorbed solar radiation in determining the solar factor (see Bibliography, [2]).

Reference should be made to [3], [4] and [5] or other European Standards dealing with heat loss calculations for the application of glazing U values determined by this standard.

A procedure for the determination of emissivity is given in EN 12898.

1) In some countries the symbol *k* has been used hitherto.

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

2 Normative references

The following referenced documents are indispensable for the application 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.

EN 674, *Glass in building — Determination of thermal transmittance (U value) — Guarded hot plate method*

EN 675, *Glass in building — Determination of thermal transmittance (U value) — Heat flow meter method*

EN 12898, *Glass in building — Determination of the emissivity*

3 Terms and definitions

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

3.1
***U* value**
parameter of glazing 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 environmental temperatures on each side

NOTE The U value is given in watts per square metre Kelvin [W/(m^2·K)].

3.2
declared value
U value obtained under standardized boundary conditions (see Clause 8)

4 Symbols, dimensionless numbers and subscripts

4.1 Symbols

A	constant	-
c	specific heat capacity of gas	J/(kg·K)
d	thickness of material layer (glass	
	or alternative glazing material)	m
F	volume fraction	-
h	- heat transfer coefficient	W/(m^2·K)
	- also thermal conductance	W/(m^2·K)
M	number of material layers	-
n	exponent	-
N	number of spaces	-

r	thermal resistivity of glass (glazing material)	m·K/W
P	gas property	-
s	width of gas space	m
T	absolute temperature	K
U	thermal transmittance	W/(m²·K)
ΔT	temperature difference	K
ε	corrected emissivity	-
ε_n	normal emissivity (perpendicular to the surface)	-
ρ	gas density	kg/m^3
σ	Stefan-Boltzmann's constant 5,67 x 10^{-8}	$W/(m^2 \cdot K^4)$
μ	dynamic viscosity of gas	kg/(m·s)
λ	- thermal conductivity of gas in space	W/(m·K)
ϑ	temperature on the Celsius scale	°C

4.2 Dimensionless Numbers

Gr	Grashof number	-
Nu	Nusselt number	-
Pr	Prandtl number	-

4.3 Subscripts

c	convection
e	external
i	internal
j	j^{th} material layer
k	k^{th} space
g	gas
m	mean
n	normal
r	radiation
s	space

t total

1;2 first, second etc.

5 Basic formulae

5.1 General

The method of this standard is based on a calculation according to the following principles.

5.2 *U* value

The U value is given by:

$$\frac{1}{U} = \frac{1}{h_\mathrm{e}} + \frac{1}{h_\mathrm{t}} + \frac{1}{h_\mathrm{i}} \tag{1}$$

where

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

h_t is the total thermal conductance of the glazing.

$$\frac{1}{h_\mathrm{t}} = \sum_{1}^{N} \frac{1}{h_\mathrm{s}} + \sum_{1}^{M} d_\mathrm{j} \cdot r_\mathrm{j} \tag{2}$$

where

h_s is the thermal conductance of each gas space;

N is the number of spaces;

d_j is the thickness of each material layer;

r_j is the thermal resistivity of each material (thermal resistivity of soda lime glass = 1,0 m·K/W);

M is the number of material layers.

$$h_\mathrm{s,k} = h_\mathrm{r,k} + h_\mathrm{g,k} \tag{3}$$

where

$h_\mathrm{s,k}$ is the heat transfer of the k[th] space;

$h_\mathrm{r,k}$ is the radiation conductance;

$h_\mathrm{g,k}$ is the U value of gas.

NOTE The thermal resistivity of components other than glass (e.g. interlayers in laminated glass) may be taken into account in determining the U value. For the purpose of this standard, thermal conductivity values used for glass in building should be obtained from the table of generally accepted values in the relevant product standard (e.g. EN 572-1 for basic soda lime silicate glass). In instances where the effects are not considered significant or important, a simplified approach may be taken, i.e. ignoring the effects of components other than glass.

5.3 Radiation conductance h_r

The radiation conductance is given by:

$$h_r = 4\sigma \left(\frac{1}{\varepsilon_{1,k}} + \frac{1}{\varepsilon_{2,k}} - 1 \right)^{-1} T_{m,k}^3 \qquad (4)$$

where

σ is the Stefan-Boltzmann's constant;

$T_{m,k}$ is the mean absolute temperature of the gas space;

$\varepsilon_{1,k}$ and $\varepsilon_{2,k}$ are the corrected emissivities of the surfaces bounding the enclosed space between the panes at $T_{m,k}$.

5.4 Gas conductance h_g

5.4.1 General

The gas conductance is given by:

$$h_{g,k} = Nu \frac{\lambda_k}{s_k} \qquad (5)$$

where

s_k is the width of the k[th] space;

λ_k is the thermal conductivity of the k[th] gas;

Nu is the Nusselt number.

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

where

A is a constant;

Gr is the Grashof number;

Pr is the Prandtl number;

n is an exponent.

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

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

where

ΔT is the temperature difference between glass surfaces bounding the gas space;

ρ is the density;

μ is the dynamic viscosity;

c is the specific heat capacity;

T_m is the mean temperature.

The Nusselt number is calculated from Equation (6).

If *Nu* is less than 1, then the value unity is used for *Nu* in Equation (5).

5.4.2 Vertical glazing

For vertical glazing:

A is 0,035

n is 0,38

5.4.3 Horizontal and angled glazing

For horizontal or angled glazing and upward heat flow the heat transfer by convection is enhanced.

This effect shall be considered by substituting the following values of *A* and *n* in Equation (6).

Horizontal spaces	*A* = 0,16	*n* = 0,28
Space at 45°	*A* = 0,10	*n* = 0,31

For intermediate angles linear interpolation is satisfactory; however, the linear interpolation shall be between the two nearest points.

When the direction of heat flow is downward the convection shall be considered suppressed for practical cases and *Nu* = 1 is substituted in Equation (5).

6 Basic material properties

6.1 Emissivity

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

For uncoated soda lime glass surfaces or for soda lime glass surfaces with coatings which have no effect on the emissivity, the corrected emissivity to be used is 0,837.

NOTE 1 With reasonable confidence the same value may be used for uncoated borosilicate glass.

For other coated surfaces the normal emissivity ε_n shall be determined with an infrared spectrometer in accordance with EN 12898. The corrected emissivity shall be determined from the normal emissivity in accordance with EN 12898.

NOTE 2 Two different definitions of emissivity should be theoretically used to describe radiation exchange between:

a) glass surfaces facing each other in glazing;

b) a glass surface facing a room.

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

NOTE 3 For laminated glass and laminated safety glass where a low emissivity coating is in direct contact with an interlayer, the effect of the low emissivity coating is negated, in terms of U value.

6.2 Gas properties

The properties of the gas filling the space are required.

These are:	thermal conductivity	λ
	density	ρ
	dynamic viscosity	μ
	specific heat capacity	c

The relevant values are substituted in Equations (7) and (8) above for the Grashof and Prandtl numbers and the Nusselt number is determined from Equation (6) above.

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

If the calculated value of the Nusselt number is less than 1 this indicates that heat flow in the gas is by conduction only and the Nusselt number is given the bounding value of 1.

Substitution in Equation (5) gives the gas conductance h_g.

Values of gas properties for a range of gases used in sealed glazing units are given in Table 1.

For all practical gas mixtures the gas properties are proportioned in the ratio of the volume fractions, F_1, F_2..., with sufficient approximation:

Gas 1: F_1; Gas 2: F_2 etc.

Thus $P = P_1 F_1 + P_2 F_2$ (9)

where

P represents the relevant property: thermal conductivity, density, viscosity or specific heat capacity.

Table 1 — Gas properties

gas	temperature ϑ ° C	density ρ kg/m^3	dynamic viscosity μ kg/(m·s)	conductivity λ W/(m·K)	specific heat capacity c J/(kg·K)
Air	- 10	1,326	1,661 x 10^{-5}	2,336 x 10^{-2}	1,008 x 10^3
	0	1,277	1,711 x 10^{-5}	2,416 x 10^{-2}	
	10[a]	1,232	1,761 x 10^{-5}	2,496 x 10^{-2}	
	20	1,189	1,811 x 10^{-5}	2,576 x 10^{-2}	
Argon	-10	1,829	2,038 x 10^{-5}	1,584 x 10^{-2}	0,519 x 10^3
	0	1,762	2,101 x 10^{-5}	1,634 x 10^{-2}	
	10[a]	1,699	2,164 x 10^{-5}	1,684 x 10^{-2}	
	20	1,640	2,228 x 10^{-5}	1,734 x 10^{-2}	
Krypton	-10	3,832	2,260 x 10^{-5}	0,842 x 10^{-2}	0,245 x 10^3
	0	3,690	2,330 x 10^{-5}	0,870 x 10^{-2}	
	10[a]	3,560	2,400 x 10^{-5}	0,900 x 10^{-2}	
	20	3,430	2,470 x 10^{-5}	0,926 x 10^{-2}	
Xenon	-10	6,121	2,078 x 10^{-5}	0,494 x 10^{-2}	0,161 x 10^3
	0	5,897	2,152 x 10^{-5}	0,512 x 10^{-2}	
	10[a]	5,689	2,226 x 10^{-5}	0,529 x 10^{-2}	
	20	5,495	2,299 x 10^{-5}	0,546 x 10^{-2}	
SF6 (see Note b)	-10	6,844	1,383 x 10^{-5}	1,119 x 10^{-2}	0,614 x 10^3
	0	6,602	1,421 x 10^{-5}	1,197 x 10^{-2}	
	10[a]	6,360	1,459 x 10^{-5}	1,275 x 10^{-2}	
	20	6,118	1,497 x 10^{-5}	1,354 x 10^{-2}	

[a] Standardized boundary conditions

[b] Sulphur hexafluoride

NOTE The use of SF_6 gas has been banned in some parts of the world, including the European Union. For this reason, the gas properties of SF_6 have been given primarily for the purposes of historical comparison.

6.3 Infrared absorption of the gas

Some gases absorb infrared radiation in the 5 µm to 50 µm range. Where the gas concerned is used in combination with a coating with corrected emissivity less than 0,2 this effect is neglected because of the low density of the net infrared radiant flux.

For other cases the U value shall be measured according to EN 674 or EN 675, if the possible improvement is to be taken into account.

7 External and internal heat transfer coefficients

7.1 External heat transfer coefficient h_e

The external heat transfer coefficient h_e is a function of the wind speed near the glazing, the emissivity and other climatic factors.

For ordinary vertical glass surfaces the value of h_e is standardised to 25 W/(m²·K) for the purposes of comparison of glazing U values.

NOTE The reciprocal $\frac{1}{h_e}$ is 0,04 m²·K / W

This procedure does not consider the improvement of the U value due to the presence of externally exposed coated surfaces with an emissivity lower than 0,837.

For the h_e values of non-vertical surfaces reference is made to [3].

7.2 Internal heat transfer coefficient h_i

The internal heat transfer coefficient h_i is given by the following formula:

$$h_i = h_r + h_c \tag{10}$$

where

h_r is the internal radiative heat transfer coefficient;

h_c is the internal convective heat transfer coefficient.

For the purposes of this standard, the radiation conductance for uncoated soda lime glass surfaces is 4,1 W/(m²·K).

If the internal surface of the glazing has a lower emissivity the radiation conductance is given by:

$$h_r = \frac{4,1\varepsilon}{0,837} \tag{11}$$

where

ε is the corrected emissivity of the coated surface;

0,837 is the corrected emissivity of uncoated soda lime glass (see 6.1).

This is only applicable if there is no condensation on the coated surface. A procedure for determining the corrected emissivity of a coating is given in EN 12898.

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 vertical soda lime glass surfaces and free convection

$$h_i = 4{,}1 + 3{,}6 = 7{,}7 \qquad \text{W/(m}^2\text{·K)} \tag{12}$$

which is standardised for the purposes of comparison of glazing U values.

NOTE The reciprocal $\frac{1}{h_i}$ for soda lime glass surfaces is 0,13 m²·K/W.expressed to two decimal figures.

For the h_i values of non-vertical surfaces reference is made to [3].

7.3 Design values

For the application of glazing U values in building design the use of a declared value may not always be sufficiently accurate. In special circumstances, a design value shall be determined using this standard. Design U values appropriate to the position of the glazing and the environmental conditions shall be determined using the correct boundary values of h_s, h_e and h_i which shall be stated.

NOTE The application of the declared value of an external building element for calculating heat losses is not strictly consistent on the basis of dry resultant temperature in internally heated spaces. In most practical cases, it is adequate, but for glazing elements with relatively large surface area and particularly with internal low emissivity surface, errors may arise.

For heat loss calculations reference is made to [3], [4], [5] or other relevant European Standards.

8 Declared values: standardized boundary conditions

For all cases where U values are stated for promotional purposes the standardized boundary conditions defined below shall be used.

The standardized boundary conditions for declared values are:

r	thermal resistivity of soda lime glass	1,0 m·K/W
ε	corrected emissivity of uncoated soda lime and	
	borosilicate glass surface	0,837
ΔT	temperature difference between bounding glass surfaces	15 K
T_m	mean temperature of gas space	283 K
σ	Stefan-Boltzmann's constant	$5{,}67 \times 10^{-8}$ W/(m²·K⁴)
h_e	external heat transfer coefficient	
	for uncoated soda lime glass surfaces	25 W/(m²·K)
h_i	internal heat transfer coefficient	

	for uncoated soda lime glass surfaces	7,7 W/(m^2·K)
A	constant	0,035
n	exponent	0,38

Standardized boundary conditions for the gas properties are given in Table 1 for a temperature of 10 °C (283K).

9 Expression of the results

9.1 U values

In all cases, U values shall be expressed in W/(m^2·K) rounded to one decimal figure.

If the second decimal is five, it shall be rounded to the higher values.

Example 1: 1,53 becomes 1,5;

Example 2: 1,55 becomes 1,6;

Example 3: 1,549 becomes 1,5.

9.2 Intermediate values

In computations, intermediate values shall not be rounded.

10 Test report

10.1 Information included in the test report

The test report shall state the following elements.

10.2 Identification of the glazing

— total thickness of the glazing (millimetres);

— thickness of each glass pane (millimetres);

— thickness of each material layer, if any (millimetres);

— thickness of gas space(s) (millimetres);

— type of gas filling;

— position of IR-reflecting coating, if any;

— inclination of glazing (angle to horizontal);

— any other condition diverging from the standardized boundary conditions.

10.3 Cross section of the glazing

A figure shall show the structure of the glazing (position and thickness of glass panes and of material layers, position of coating(s), position and thickness of gas space(s), type of gas filling).

The layers of glass and of other materials and the gas spaces shall be numbered starting from the pane facing outside.

10.4 Results

- corrected emissivity of the coating, in the case of coatings
- which modify the emissivity
- internal heat transfer coefficient h_i, in the case of coatings which
- modify the emissivity [W/(m²·K)]
- total thermal conductance of the glazing, h_t [W/(m²·K)]
- U value of the glazing [W/(m²·K)]
- h_s, h_e and h_i if used to calculate a design U value in which case the expression "design U value" shall be used [W/(m²·K)]

Annex A
(normative)

Iteration procedure for glazing with more than one gas space

For glazing with more than one gas space (N>1), the calculation shall be performed by an iteration procedure (exemplified in Table A.1), in which the gas space conductance h_s of each gas space is determined at a mean temperature of 283 K (sufficient accuracy is obtained because the influence of small deviations from 283 K can be neglected).

For the first step of the iteration procedure a temperature difference of ΔT = 15/N (K) for each space is used in Equation (7).

With gas space conductances h_s obtained, new ΔT_s -values for each space shall be calculated from the equation:

$$\Delta T_s = 15 \frac{1/h_s}{\sum_1^N 1/h_s} \qquad \text{(A.1)}$$

These ΔT_s values are used for the second iteration, and so on.

The iteration procedure shall be repeated until the resistance of the glazing $\sum_1^N 1/h_s$ from Equation (2) converges at the third significant figure (usually no more than 3 iterations, and exceptionally 4).

This converged resistance shall be used in Equations (2) and (1) to calculate the U value.

Where the initial h_s values are equal the respective temperature differences are given by $\Delta T = 15 / N \ (K)$ and iteration is unnecessary.

Table A.1 — Example of iteration for a triple glazing with the following characteristics: structure 4/12/4/16/4; one coating in the space 2 with ε_n = 0,03 (ε =0,037); both spaces argon gas-filled (90 % fill).

Iteration number	1	2	3	4
$1/h_s$ for space 1 [$m^2 \cdot K/W$]	0,1934	0,1934	0,1934	0,1934
$1/h_s$ for space 2 [$m^2 \cdot K/W$]	0,7739	0,7644	0,7650	0,7649
$\sum_{1}^{2} 1/h_s$ [$m^2 \cdot K/W$]	0,9673	0,9578	0,9584	0,9584
ΔT for space 1 [K]	2,9990	3,0289	3,0270	3,0271
ΔT for space 2 [K]	12,0010	11,9711	11,9730	11,9729
U value [$W/(m^2 \cdot K)$] - rounded	0,870	0,877	0,877	0,877 0,9

Bibliography

[1] EN ISO 10077-1, *Thermal performance of windows, doors and shutters — Calculation of thermal transmittance — Part 1: General (ISO 10077-1:2006)*

[2] EN 410, *Glass in building — Determination of luminous and solar characteristics of glazing*

[3] EN ISO 6946, *Building components and building elements — Thermal resistance and thermal transmittance — Calculation method (ISO 6946:2007)*

[4] EN ISO 13790, *Energy performance of buildings — Calculation of energy use for space heating and cooling (ISO 13790:2008)*

[5] EN ISO 10211, *Thermal bridges in building construction — Heat flows and surface temperatures — Part 1: Detailed calculations (ISO 10211:2007)*

[6] EN ISO 10456, *Building materials and products — Hygrothermal properties — Tabulated design values and procedures for determining declared and design thermal values (ISO 10456:2007)*

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