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Bundesverband
Flachglas

Guide to 'Warm Edge'

for windows and facades

Guide to 'Warm Edge'

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1.0 Introduction

This guide to 'Warm Edge' is the result of the work by the BF 'Warm Edge' working group. It appeared for the first time in 2008, together with the first edition of BF data sheets with representative psi values for windows.
Since the last revision of the guide in February 2015, two further research projects have been conducted and incorporated into the current version:

- Facade psi values:
  At the suggestion of the window and facade industry the 'Warm Edge' working group has, in cooperation with ift Rosenheim and the university of Rosenheim, looked into the calculation of representative psi values for fixed glazing in mullion/transom facades. As a result, the first BF data sheets with representative psi values for facade profiles were published in early 2016.
- Glazing bar psi values:
  On behalf of the ad hoc group for 'Glazing bars' at BF, ift Rosenheim has devised a simple and practicable, yet fairer solution for the thermal treatment of windows with glazing bars inside the cavity. Before now, these windows were at a disadvantage due to standard-rate additions to the heat transfer coefficients of the window. Since this topic, like psi values for spacers, affects the determination of Uw values for windows, it is being incorporated into the 'Warm Edge' guide.

As well as providing basic information on the warm edge and presenting the results of the working group, the guide is also intended in particular as a code of practice for the correct use of the BF data sheets on 'psi values for windows' and 'psi values for facade profiles'.

2.0 What is 'Warm Edge'?

Insulating glass consists of two or more glass panes. The distance between the panes is determined by a spacer section running around the edge of the pane. This creates the cavity on which the basic insulating effect of insulating glass is based.
Together with a butyl primary seal and a polysulphide, polyurethane or silicone-based secondary sealing material or hotmelt, the spacer, which is filled with a desiccant, forms the two-stage insulating glass edge bond which has been proven over many years (Figs. 1 and 2).

Since the introduction in 1959 of the organic edge bond for insulating glass, which today is standard, hollow sections made of steel and in recent years aluminium had been used as spacers. The disadvantage of these materials is their high thermal conductivity. When incorporated into an insulating glass edge bond, the aluminium section forms a very good heat-conducting connection between the inner and outer pane. This gives rise to significant linear heat bridges in windows and facades.

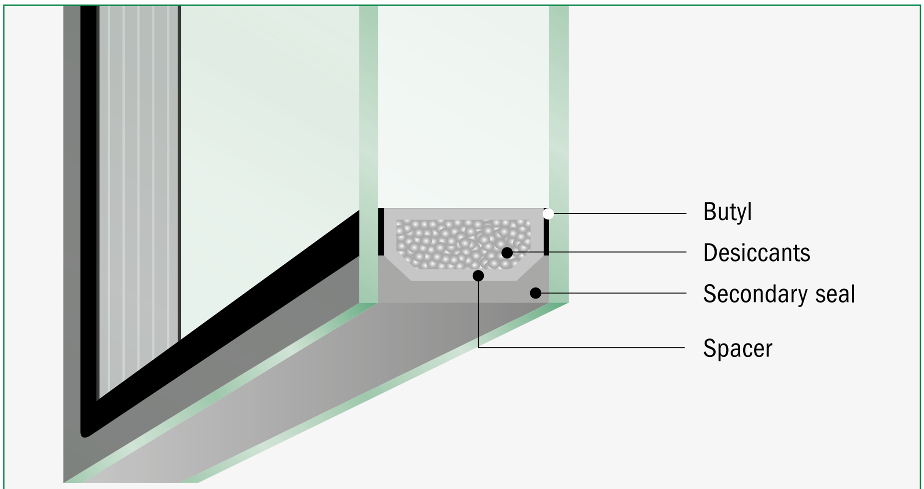


Fig. 1: Schematic construction of double insulating glass

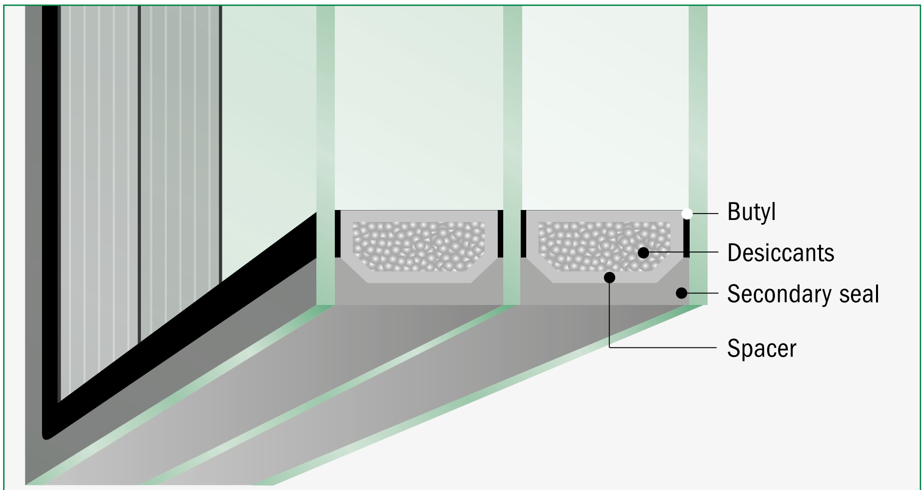


Fig. 2: Schematic construction of triple insulating glass

Guide to 'Warm Edge'

Conventional insulating glass spacers made of aluminium or steel result in unwelcome heat bridges in windows and facades.

Heat bridges are responsible for the loss of valuable heat energy in heated buildings. The surface temperature on the room side drops as a result of the heat flowing to the outside via the heat bridge. This increases the risk of condensation and the formation of mould (Figs. 3 and 4). Conversely, in air-conditioned buildings, conventional insulating glass spacers lead to the cooling system consuming more energy.

In the meantime, with functional coatings and inert gas in the cavity between the panes, modern multi-pane thermally insulating glazing has attained a thermal performance which makes highly efficient, transparent and light-flooded buildings possible. In these buildings, heat bridges are absolutely undesirable defects for reasons of climate protection and economy.

'Warm Edge' is the abbreviated designation for a thermally improved insulating glass edge bond

The first thermally improved spacer systems appeared on the market as long ago as the 1990s. By using materials with significantly lower thermal conductivity than aluminium, it was possible to more than halve the heat losses at the edge of an insulating glass pane. This saves valuable heating energy, minimises the risk of condensation and improves the U-values of windows and facades. This thermal improvement to the insulating glass edge bond is referred to as 'Warm Edge'.

Fig. 3: Condensation can easily occur at the edge of the glass pane due to the aluminium spacer in the insulating glass.

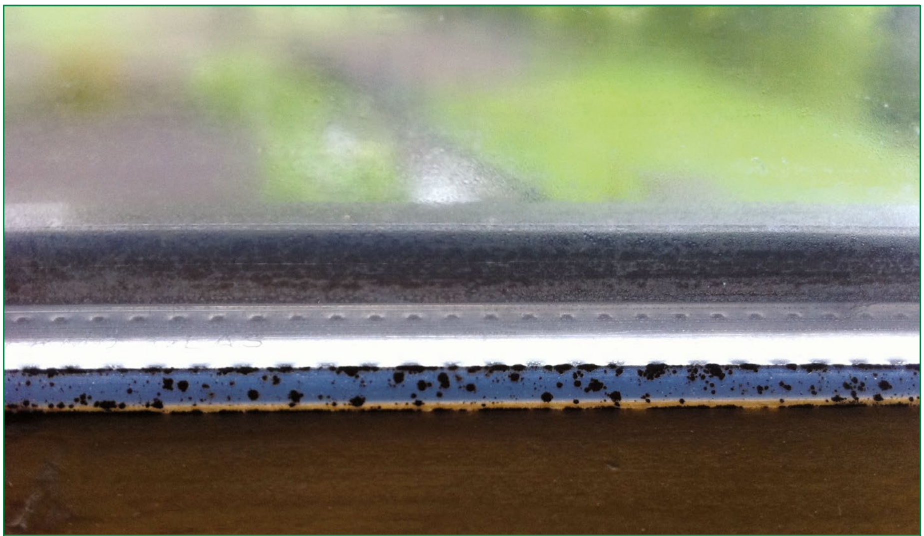


Fig. 4: In the longer term, this can lead to the formation of mould, which is unacceptable not just for hygiene reasons.

Stainless steel has a thermal conductivity more than ten times lower than that of aluminium. As stainless steel spacers also have much lower wall thicknesses, they are considerably better than aluminium or steel sections from a thermal point of view. The values can be further optimised if, in addition, areas of the section are replaced by plastic or if the stainless steel is only used purely as a diffusion barrier in an extremely thin design. Other systems follow new manufacturing avenues and dispense entirely with metal.

In the meantime, a large number of warm edge systems which have proved their worth over many years are available on the market.

'Warm Edge' means more energy efficiency for windows and facades

Hardly any heat bridge can be eliminated as easily as that caused by the aluminium spacer in the glass-to-frame transition area. For a comparable improvement in the U_W value of a window or in the U_{CW} value of a mullion/transom facade, considerably greater effort is required elsewhere – for example in the area of the window or facade profile.

A clear and equally simple definition for differentiating the warm edge from conventional spacers can be found in the relevant standards (Fig. 5): For windows in Annex E of DIN EN ISO 10077-1 [1] and for curtain walls conforming to Annex B of standard DIN EN ISO 12631 [3].

Material	***thermal conductivity λ in W/(m K)***	***Material***	***thermal conductivity λ in W/(m K)***
Aluminium	160	Polysulphide	0.4
Steel	50	Molecular Sieve	0.1
Stainless steel	17	Polycarbonates	0.2
Soda-lime glass	1	PVC hard	0.17

Table 1: Examples of the thermal conductivity of materials as per EN ISO 10077-2 [2]. As it "depends what you make of it", it is impossible to draw any conclusions regarding the thermal performance of a component solely from these pure material characteristics.

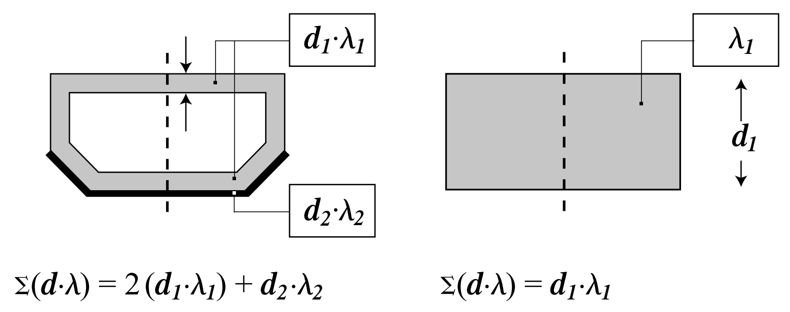


Fig. 5: A spacer is thermally improved if it satisfies the criterion $\Sigma(d \cdot \lambda) \leq 0.007$. The diagram shows using two examples how this characteristic is determined for spacers [1, 3].

3.0 Basics for the BF data sheets

3.1 The equivalent thermal conductivity $\lambda_{eq,2B}$

In late 2012, a further research project of the 'Warm Edge' working group promoted by the German Institute for Structural Engineering (DIBt) was successfully completed [9, 10]. The project was prompted by the fact that with increasingly complex spacer designs it was becoming more and more difficult or impossible to correctly determine the thermal properties of the individual components. The initial data for the detailed calculation was marred by too many uncertainties. Studies at ift Rosenheim led to a new measuring basis for the BF data sheets being developed:

- Instead of calculating representative psi values from the thermal conductivity values of the individual materials, today the so-called equivalent thermal conductivity $\lambda_{eq,2B}$ of a spacer is first ascertained by measurement. To do so, spacer section are filled with desiccants and measured when tightly packed between two glass panes in the plate apparatus. The conducting components of the spacer sections must here be thermally bonded to the glass with butyl (see Fig. 6).
- With the measured equivalent thermal conductivity $\lambda_{eq,2B}$, the representative psi values for the BF data sheets are then calculated according to the so-called Two-Box model.

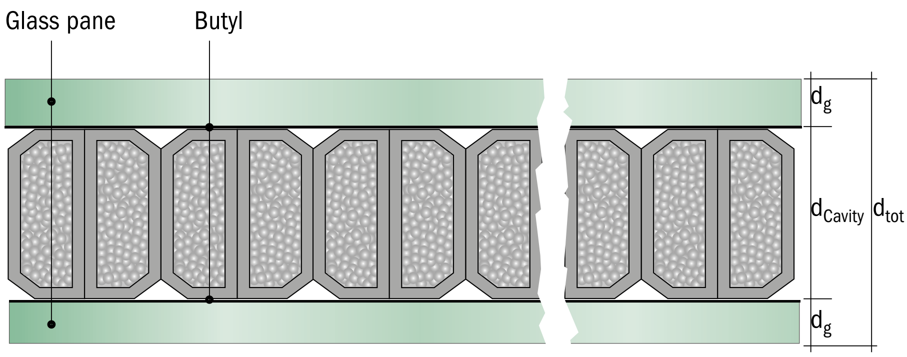


Fig. 6: Setup of test specimens for measuring the equivalent thermal conductivity of a spacer according to ift guideline WA 17/1 [5]

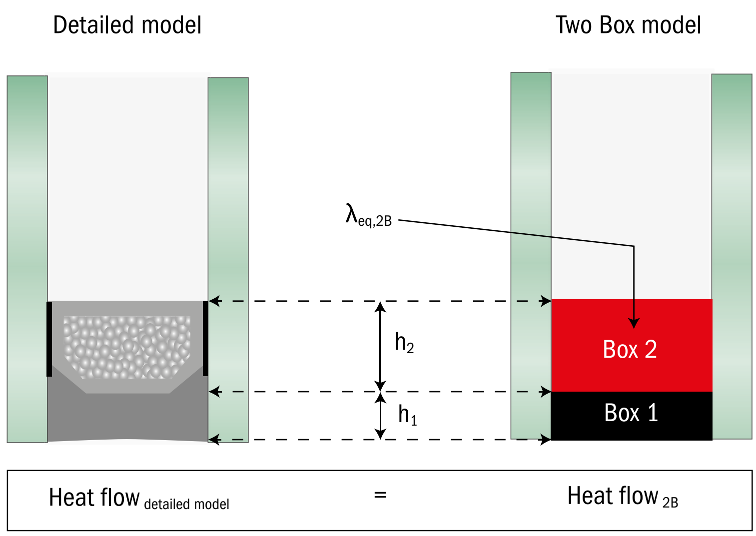


Fig. 7: Schematic diagram of the Two Box model

With this calculation, the detailed spacer model with individual geometry and different individual materials is replaced by a rectangle (box) with the width of the cavity and the same height as the detailed spacer model (h_2). With the Two-Box model, the calculation with the measured equivalent thermal conductivity $\lambda_{eq,2B}$ leads to the same heat flow as a calculation of the spacer which is modelled in detail (Fig. 7).

Thanks to this procedure, it is no longer necessary to determine the individual thermal conductivity values of the spacer sections made up of several materials.

In the case of individual thermal calculations as per EN ISO 10077-2 [2], it was previously necessary for the exact geometrical cross-section of a spacer to be known in addition to the individual thermal conductivities. By using the Two-Box model the complex modelling of the insulating glass edge bond is no longer needed. Once the equivalent thermal conductivity $\lambda_{eq,2B}$ has been determined, two rectangles can simply be used: Box 1 for the secondary sealant and Box 2 for the spacer including desiccant and butyl. In doing so, it is important that the heights of the rectangles match the actual structural heights of sealant and spacer. The marginal effect of the cavity width on the equivalent thermal conductivity $\lambda_{eq,2B}$ of a spacer system can be ignored here.

The simplified modelling using the Two-Box model makes the individual calculations as per EN ISO 10077-2 enormously easier. !

The sub-caption "on the basis of determination by measurement of the equivalent thermal conductivity of the spacers" can be found on the BF data sheets in reference to the new measuring technology used as the basis. BF data sheets without this sub-caption are no longer valid.

The lower part of the BF data sheets specifies the Two-Box model characteristics, i.e. the equivalent thermal conductivity $\lambda_{eq,2B}$ and the height h_2 of the respective warm edge system.

A detailed explanation of the measurement method developed as part of the research project at ift Rosenheim can be found in the ift guideline WA 17/1 [5]. The methodology of the Two Box model is described at length in ift guidelines 08/3 and WA-22/1 [4, 6].

An abridged report on the research project is available for downloading free of charge at the ift Rosenheim website (www.ift-rosenheim.de > Business Clients > Research and development > Current Research Projects) [9]. The detailed research report can be purchased from the online shop of ift Rosenheim [10].

PLEASE NOTE: Since the spacer systems have differing heights h_2, the equivalent thermal conductivity $\lambda_{eq,2B}$ alone is NOT suitable for a fair comparison of the efficiency of warm edge systems! Directly comparable are only the representative psi values (or the value $\lambda_{eq,2B} \cdot h_2$).

3.2 Issue and validity

The BF data sheets with representative psi values for thermally improved spacers are published by BF (Bundesverband Flachglas). For issuing a BF data sheet, an approval procedure must be followed, the details of which are stipulated by the 'Warm Edge' working group. In addition to documentation for determining the values, verifications to assure the suitability for use of its spacer system must also be submitted by a manufacturer. It is only assured in data sheets published by BF that this procedure is followed.

For a certain warm edge system, there are as a rule two BF data sheets under the data sheet number assigned to it. (Depending on which application the manufacturer of a certain spacer system intended, there can also only be one W or one CW data sheet for it.)

Example:
No. W043 → BF data sheet with representative psi values for windows (W = Window)

No. CW043 → BF data sheet with representative psi values for facades (CW = Curtain Wall)

Some spacers are, depending on their system, used exclusively with hotmelt as the secondary sealant. Then, and only then, they receive a separate BF data sheet clearly identified with "only valid for hotmelt edge sealing".

Hotmelt edge bonding is however only available in some geographic regions. This is why it is explicitly pointed out at this juncture that outside these specific markets there are no producers for this edge bond and it is futile to demand a hotmelt edge bond of this type.

All regular BF data sheets are, for reasons of comparability of the spacers, calculated using exactly the same boundary conditions. A back coverage of the space with secondary sealant of 3 mm for windows and 6 mm for facades is assumed. A glass mounting depth of 13 mm is generally calculated. For further details of the boundary conditions, please refer to the respective ift guideline.

In the BF data sheets, an accuracy of ± 0.003 W/(mK) is specified for the calculation method to determine the Ψ values. This tolerance indicates that not too much importance should be placed on the third decimal place of the Ψ values.

The current BF data sheets can be downloaded free of charge from the BF website. Only BF data sheets enabled for download from the BF website are currently valid.

Download address for the currently valid BF data sheets 'Psi values for windows' and 'Psi values for facade profiles': http://www.bundesverband-flachglas.de/downloads/data sheets/

TIP: Do not work with locally saved BF data sheet copies; instead please save the download link among the favourites of your internet browser. This gives you rapid access at all times to the currently valid BF data sheets and can ensure that you are working with permissible versions.

3.3 Permissible application

The representative psi values of the BF data sheets may **not** be used without restrictions for all windows and facade structures. The permissible application is governed by the ift guidelines WA-08/3 for windows and WA-22/1 for facade profiles.

The following sections explain the boundary conditions to be complied with in each case.

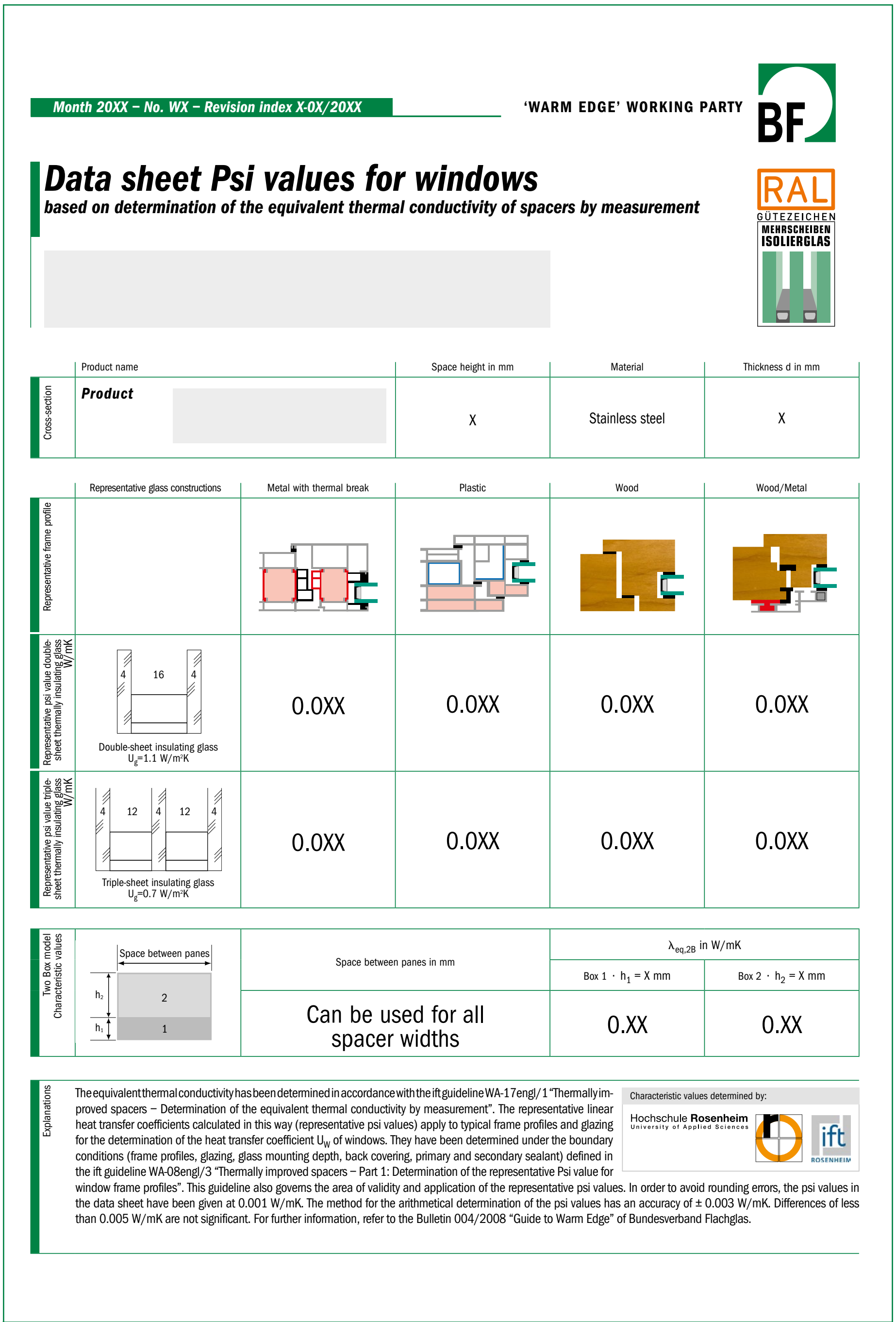
The tolerances specified on the BF data sheets 'Psi values for windows' must not under any circumstances be deducted before using the representative psi values !

4.0 'Psi values for windows' data sheets

4.1 Layout

Each BF data sheet is valid for a specific spacer system. Besides information on the manufacturer and on materials and geometries of the spacer system, the BF data sheet declares in the middle part the representative psi values for windows. In this case, in four representative window frame sections (metal with thermal separation, plastic, wood, wood/aluminium) and for double and for triple insulating glass, a total of eight psi values are specified. In the lower part of the BF data sheet, the already mentioned Two-Box values are listed (see Fig. 8).

> The BF data sheets 'Psi values for windows' may NOT be used for fixed glazing in mullion/transom facades. In this case only the BF data sheets 'Psi values for facade profiles' must be used (see Section 5).



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Data sheet Psi values for windows

based on determination of the equivalent thermal conductivity of spacers by measurement

RAL GÜTEZEICHEN MEHRSCHEIBEN ISOLIERGLAS

Cross-section	Product name	Space height in mm	Material	Thickness d in mm
	Product	X	Stainless steel	X

	Representative glass constructions	Metal with thermal break	Plastic	Wood	Wood/Metal
Representative frame profile					
Representative psi value double-sheet thermally insulating glass W/mK	Double-sheet insulating glass U_g=1.1 W/m²K (4 / 16 / 4)	0.0XX	0.0XX	0.0XX	0.0XX
Representative psi value triple-sheet thermally insulating glass W/mK	Triple-sheet insulating glass U_g=0.7 W/m²K (4 / 12 / 4 / 12 / 4)	0.0XX	0.0XX	0.0XX	0.0XX

Two Box model Characteristic values	Space between panes	Space between panes in mm	$\lambda_{eq,2B}$ in W/mK	
			Box 1 · h_1 = X mm	Box 2 · h_2 = X mm
	h_2: 2, h_1: 1	Can be used for all spacer widths	0.XX	0.XX

Explanations: The equivalent thermal conductivity has been determined in accordance with the ift guideline WA-17engl/1 "Thermally improved spacers – Determination of the equivalent thermal conductivity by measurement". The representative linear heat transfer coefficients calculated in this way (representative psi values) apply to typical frame profiles and glazing for the determination of the heat transfer coefficient U_W of windows. They have been determined under the boundary conditions (frame profiles, glazing, glass mounting depth, back covering, primary and secondary sealant) defined in the ift guideline WA-08engl/3 "Thermally improved spacers – Part 1: Determination of the representative Psi value for window frame profiles". This guideline also governs the area of validity and application of the representative psi values. In order to avoid rounding errors, the psi values in the data sheet have been given at 0.001 W/mK. The method for the arithmetical determination of the psi values has an accuracy of ± 0.003 W/mK. Differences of less than 0.005 W/mK are not significant. For further information, refer to the Bulletin 004/2008 "Guide to Warm Edge" of Bundesverband Flachglas.

Characteristic values determined by: Hochschule Rosenheim University of Applied Sciences; ift Rosenheim

Fig. 8: Layout of BF data sheets 'Psi values for windows'

4.2 U_W values for windows

As per EN ISO 10077-1, the heat transfer coefficient Uw of a window is made up of the area-related individual values of the glazing U_g and of the frame U_f and the length-related heat transfer coefficient Ψ_g for the transition area of frame and glass (Figs. 9 and 10). The heat transfer coefficient U_g of the glass relates to the unaffected middle of the glass, and the U_f value of the frame to the frame without glazing [1].

A heat bridge, which results from the geometry and the material, is produced where glass and frame adjoin one another. The Ψ_g value describes the additional heat losses in this area. They are mainly due to the conduction of heat via the insulating glass edge bond.

$$U_w = \frac{A_g \cdot U_g + A_f \cdot U_f + l_g \cdot \Psi_g}{A_w}$$

Fig. 9: Formula for calculating the heat transfer coefficient U_W of windows [1]

The representative psi values simplify the determination of the U_W values of windows.

Index	***English designation***	***German designation***
w	**w**indow	Fenster
g	**g**lass	Glas
f	**f**rame	Rahmen

Table 2: Key to the components of windows

	Unit	***Designation***	***Origin***
U_g	W/(m²K)	Heat transfer coefficient of glazing	(1) calculated as per EN 673
U_f	W/(m²K)	Heat transfer coefficient of frame	(1) calculated as per EN ISO 10077-2 or (2) from Annex D of EN ISO 10077-1 derived or (3) measured as per EN 12412-2
Ψ_g	W/(m²K)	Linear heat transfer co-efficient of frame glass transition area	(1) calculated as per N ISO 10077-2 or (2) taken from the tables in Annex E of EN ISO 10077-1 or (3) representative Ψ- values of thermally improved spacers determined as per ift guideline WA-08/3 [4] Data sheets 'Psi values for windows'

Table 3: Ways of determining the input data for the U_W value of windows

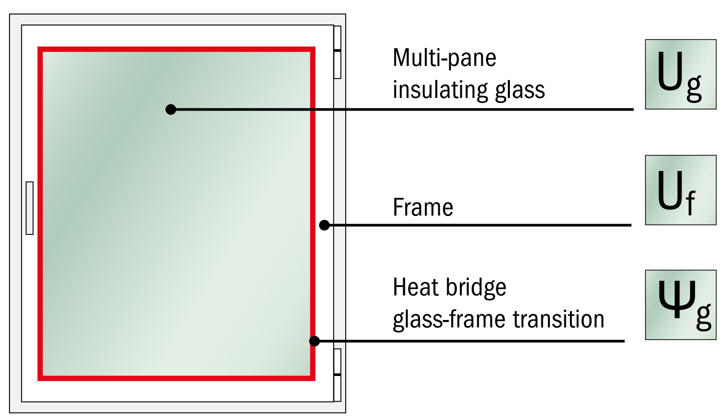

Fig. 10: The U_W value of a window is made up of two area-related heat transfer coefficients U and a linear heat transfer coefficient Ψ.

There are several ways of obtaining the input data for the U_W value calculation (Table 3). Within the limits of their applicability, the data sheets 'Psi values for windows' offer a comparatively simple and pragmatic solution for the Ψ_g values. They are more precise and, in any event, more useful than the standard-rate values from Annex E of EN ISO 10077-1. With the table values from the standard, no differentiation is made between warm edge systems of differing performance. As a result, they appear to be unfavourable [1].

Alternatively, the whole window can be measured using the Hot-Box method in accordance with EN ISO 12567-1.

The standard EN ISO 10077-2 expressly allows in its Annex C representative Ψ values of thermally improved spacers to be determined based on representative section areas and representative glass units [2]. The process to do so is described in ift guidelines WA-08/3 and WA-17/1 [4, 5]. In addition, the use of representative Ψ values in the determination of U_W values is governed in guideline WA-08/3.

4.3 Use of representative psi values for windows

According to ift guideline WA-08/3, window manufacturers must take into account the following requirements for using the data sheets 'Psi values for windows' when declaring the U_W values of their windows [4]:

- The calculated representative Ψ values can be used for the following U_g values:
  Double insulating glass: $U_g \geq 1.0$ W/(m²K) with argon or air filling
  Triple insulating glass: $U_g \geq 0.5$ W/(m²K) with argon or air filling.
- The actual glass mounting depth must be at least 13 mm.
- The representative Ψ values must not be used when the glass edge is exposed on the outside.
- If the glass panes are thicker than 4 mm, the representative Ψ values must be increased by the following amounts:
  - By 0.001 W/(m²K) per mm of greater thickness of the outer glass pane
  - By 0.002 W/(m²K) per mm of greater thickness of the inner glass pane

  The thickness of the glass of the middle pane in triple-glazed structures is not relevant.

- The frame sections actually used must be comparable with the representative frame sections. U_f values and glazing channels of the actual frame sections must meet the requirements according to Table 4.

For windows which do not meet the above requirements, the individual Ψ value for each glass/frame combination must be calculated in detail in accordance with EN ISO 10077-2 [2]. Alternatively, the comparatively unfavourable values from the table in EN ISO 10077-1 can be used [1].

Frame material	*U_f in W/(m²K)*	*Glass mounting depth in mm*
Wood	≥ 1.0 ≥ 0.80	≥ 13 ≥ 18
Wood-aluminium	≥ 1.0 ≥ 0.80	≥ 13 ≥ 18
Plastic	≥ 1.0 ≥ 0.80	≥ 13 ≥ 18
Metal	≥ 1.3 ≥ 1.0	≥ 13 ≥ 18

Table 4: Frame requirements for application of the representative Ψ values for windows

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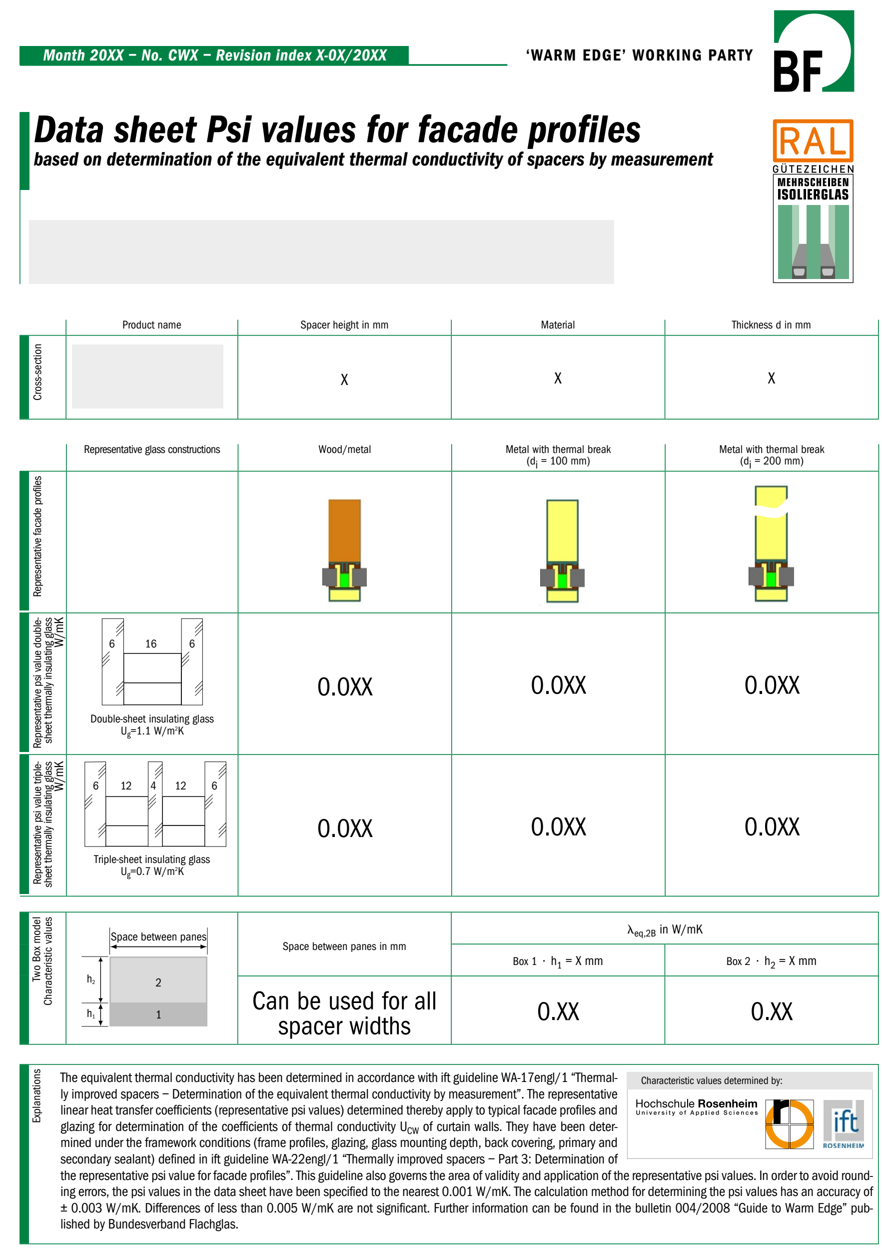
5.0 BF data sheets 'Psi values for facade profiles'

5.1 Layout

The BF data sheets for facade profiles are structured like the BF data sheets 'Psi values for windows'. The middle part indicates for the three representative facade profiles (wood-metal and metal with thermal separation for two profile depths) for double and for triple insulating glass a total of six representative psi values. These are the psi values for the heat bridge at the edge of permanently fitted glazing in mullion/transom sections, Ψ_{mg} and Ψ_{tg} (see Section 5.2).

The BF data sheets 'Psi values for facade profiles' can be used within the permissible application range according to the ift guideline WA-22/1 for fixed glazing in mullion/transom facades, but NOT for SSG (Structural Sealant Glazing) systems.



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Data sheet Psi values for facade profiles
based on determination of the equivalent thermal conductivity of spacers by measurement

	Product name	Spacer height in mm	Material	Thickness d in mm
Cross-section		X	X	X

	Representative glass constructions	Wood/metal	Metal with thermal break (d_i = 100 mm)	Metal with thermal break (d_i = 200 mm)
Representative facade profiles				
Representative psi value double-sheet thermally insulating glass W/mK	6 / 16 / 6 Double-sheet insulating glass U_g=1.1 W/m²K	0.0XX	0.0XX	0.0XX
Representative psi value triple-sheet thermally insulating glass W/mK	6 / 12 / 4 / 12 / 6 Triple-sheet insulating glass U_g=0.7 W/m²K	0.0XX	0.0XX	0.0XX

			$\lambda_{eq,2B}$ in W/mK	
Two Box model Characteristic values	Space between panes; h_2 2; h_1 1	Space between panes in mm	Box 1 · h_1 = X mm	Box 2 · h_2 = X mm
		Can be used for all spacer widths	0.XX	0.XX

Explanations: The equivalent thermal conductivity has been determined in accordance with ift guideline WA-17engl/1 "Thermally improved spacers – Determination of the equivalent thermal conductivity by measurement". The representative linear heat transfer coefficients (representative psi values) determined thereby apply to typical facade profiles and glazing for determination of the coefficients of thermal conductivity U_{CW} of curtain walls. They have been determined under the framework conditions (frame profiles, glazing, glass mounting depth, back covering, primary and secondary sealant) defined in ift guideline WA-22engl/1 "Thermally improved spacers – Part 3: Determination of the representative psi value for facade profiles". This guideline also governs the area of validity and application of the representative psi values. In order to avoid rounding errors, the psi values in the data sheet have been specified to the nearest 0.001 W/mK. The calculation method for determining the psi values has an accuracy of ± 0.003 W/mK. Differences of less than 0.005 W/mK are not significant. Further information can be found in the bulletin 004/2008 "Guide to Warm Edge" published by Bundesverband Flachglas.

Characteristic values determined by: Hochschule Rosenheim University of Applied Sciences; ift Rosenheim

Fig. 11: Layout of BF data sheets 'Psi values for facade profiles'

5.2 U_{CW} values for mullion/transom facades

The heat transfer coefficient U_{CW} of curtain walls is ascertained in accordance with EN ISO 12631 [3]. In mullion/transom facades, fixed glazing units, window elements or panels can be fitted (Fig. 13). At the transition area between the facade filling areas and mullion-transom areas, widely differing heat bridges are created which must be taken into account when determining U_{CW}.

Like in windows, for facades too there are several ways to access the initial data. Due to the many components, this is not be dealt with in detail here. For the installation of glazing in mullion/transom facades, the data sheets 'Psi values for facades' offers, within the framework of its applicability, a comparatively simple and pragmatic solution for the psi values Ψ_{mg} and Ψ_{tg}. They are more precise and as a rule more useful than the standard-rate values from the tables in Annex E of EN ISO 12631 [3].

Alternatively, it is possible in the "method involving assessment of the individual components" to calculate all heat bridges in detail too as per EN ISO 10077-2, or the so-called "simplified assessment method" as per EN ISO 12631 can be used.

Area-related heat transfer coefficients U | Length-related heat transfer coefficients Ψ

$$U_{cw} = \frac{\Sigma A_g U_g + \Sigma A_p U_p + \Sigma A_f U_f + \Sigma A_m U_m + \Sigma A_t U_t + \Sigma l_{f,g} \Psi_{f,g} + \Sigma l_{m,g} \Psi_{m,g} + \Sigma l_{t,g} \Psi_{t,g} + \Sigma l_p \Psi_p + \Sigma l_{m,f} \Psi_{m,f} + \Sigma l_{t,f} \Psi_{t,f}}{A_{cw}}$$

Fig. 12: Formula for calculating the heat transfer coefficient U_{CW} of facades according to the method involving assessment of the individual components. The U_{CW} value is made up of five area-related heat transfer coefficients U and six different linear heat transfer coefficients Ψ [3].

Index	*English designation*	*German designation*
cw	**c**urtain **w**alling	Fassade
m	**m**ullion	Pfosten
t	**t**ransom	Riegel
f	**f**rame	Rahmen
p	**p**anel	Paneel
g	**g**lass	Glas

Table 5: Key to the components of a facade element

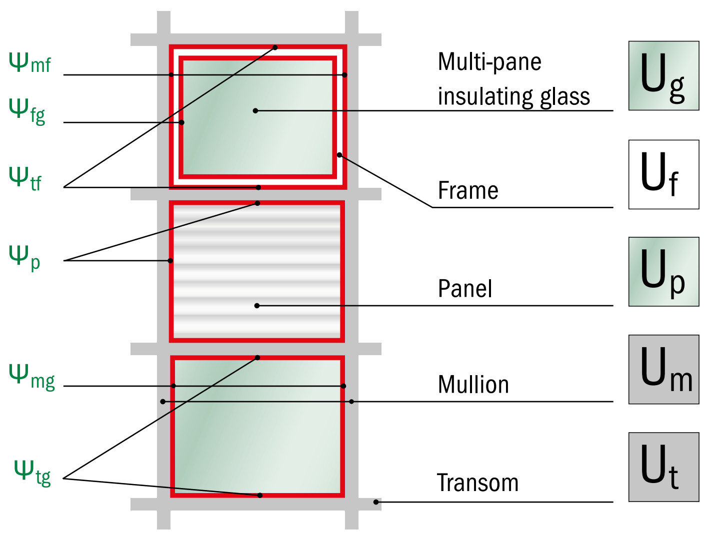

Fig. 13: Model facade element as per EN ISO 12631 [3]

5.3 Use of representative psi values for facade profiles

According to ift guideline WA-22/1 [6], facade manufacturers must take into account the following requirements for using the BF data sheets 'Psi values for facade profiles' when declaring the U_{cw} value:

- The calculated representative Ψ values can be used for the following U_g values:
  Double insulating glass: $U_g \geq 1.0$ W/(m²K) with argon or air filling
  Triple insulating glass: $U_g \geq 0.5$ W/(m²K) with argon or air filling.
- The actual glass mounting depth must be at least 13 mm.
- The representative psi values must **not** be used when the glass edge is exposed on the outside and for SSG (Structural Sealant Glazing) systems.
- If the glass panes are thicker than 6 mm, the representative Ψ values must be increased by the amounts according to Table 6: The glass thickness of the middle pane in triple-glazed structures is not relevant. If the glass thicknesses are lower than 6 mm, the correction values according to Table 6 can be deducted from the representative Psi values.
- The facade profiles actually used must be comparable with the representative profiles of the BF data sheets 'Psi values for facade profiles'. U_m and U_t values of the actual facade profiles must meet the requirements (incl. the influence of screws) the requirements according to Table 7.

Material	***ΔΨ in W/(mK) per mm of thickness of***	
	Outer pane	***Inner pane***
Wood-metal	0.001	0.001
Metal with thermal separation	0.001	0.000

Table 6: Correction values for taking into account the influence of the glass thickness in facades

Material	***U_m or U_t in W/(m²K)***
Wood-metal	for double glazing: ≥ 1.3 for triple glazing: ≥ 0.9
Metal with thermal separation	for double glazing: ≥ 1.3 for triple glazing: ≥ 0.9

Table 7: Facade profile requirements for use of the representative Ψ values for facade profiles

6.0 Working Group on 'Warm Edge'

6.1 The members

The 'Warm Edge' working group is a sub-committee of the Technical Committee of Bundesverband Flachglas. The participants in the working group are members and sponsoring members of BF. Scientific support for the working group is provided by Prof. Dr. Franz Feldmeier, Rosenheim University of Applied Sciences and by Mr. Norbert Sack, ift Rosenheim.

Date of member list: May 2016

All leading manufacturers of warm edge systems for insulating glass and of the glass industry are represented in the working group:

Allmetal GmbH, spacers for insulating glass, Wiedemar, D

BAUWERK – Ingenieurbüro für Bauphysik und Fenstertechnik, Rosenheim, D

Ensinger GmbH, Niederlassung Ravensburg, Ravensburg, D

FENZI S.p.A., Tribiano, I

GED Integrated Solutions, Chichester, GB

Glas Trösch Holding AG, Bützberg, CH

HELIMA GmbH, Wuppertal, D

IGK Isolierglasklebstoffe GmbH, Hasselroth, D

Ingrid Meyer-Quel Consultant for Warm Edge and Glass, D

Isolar Glas-Beratung GmbH, Kirchberg/Hunsrück, D

Kömmerling Chemische Fabrik GmbH, Pirmasens, D

Nedex Chemie Deutschland GmbH, Moers, D

Quanex Building Products Inc. Edgetech Europe GmbH, Heinsberg, D

Rolltech A/S, Hjorring, DK

Alu-Pro S.r.l., Noale, IT

SANCO Beratung Glas Trösch GmbH, Nördlingen, D

Technoform Glass Insulation GmbH, Lohfelden, D

Thermoseal Group Limited, Birmingham, GB

Vetrotech Saint Gobain (International) AG Swisspacer Kreuzlingen, CH

6.2 Results of previous work

The 'Warm Edge' working group has been in existence since 1998. It can look back on a number of notable results.

ift Rosenheim's final report on the first 'Warm Edge' research project was presented in July 1999 [7]. This was the first comparison of spacer systems with calculations based on identical boundary conditions. The results formed the basis for the system manufacturers' own system-related psi value tables.

The main factors affecting the psi values in different frame models according to EN ISO 10077-2 were investigated mathematically and compared with experimental results in a second research project for the German Institute for Structural Engineering (DIBt) in 2002 to 2003. A total of six test institutions and processing centres as well as eight industrial partners were involved in this project [8].

In order to protect the industry and also the consumer against products which only pretend to provide thermal improvement at the insulating glass edge bond, a definition of 'thermally improved edge bond' was developed in the working group. This definition was initially incorporated in DIN V 4108-4:2004-07, Annex C, but was then quickly adopted in the European standards (see EN ISO 10077-1, Annex E and EN ISO 12631, Annex B [1, 3]).

As the frame models of the first research projects no longer appeared to be up-to-date, four new frame models, which were representative of their class and whose U_f values represented the state of the art, were developed in a third research project from 2007 to 2008. Then the representative Ψ values of the individual warm edge systems were calculated in these frame models with double and triple insulating glass and published in the form of BF data sheets 'Psi values for widnows'. This project was presented to the industry in the BF 'Warm Edge' symposium on 23.4.2008 in Hanau, Germany.

A further research project of the 'Warm Edge' working group promoted by the German Institute for Structural Engineering (DIBt) was carried out at ift Rosenheim and at Rosenheim University of Applied Sciences early in 2013. The result of this fourth project was the new measurement basis for the BF data sheets 'Psi values for windows' described in Section 3 [9, 10].

At the end of 2013, the 'Warm Edge' working group decided to contribute to financing a project to widen the applicability of the representative window psi values to lower U_f values. This fifth project of the group was followed by a revision of the ift guideline WA-08, which since Version 3 has permitted the application of the representative psi values for high-insulating windows too with an appropriately greater glass mounting depth (see Section 4.3, Table 4).

The BF data sheets 'Psi values for facade profiles' are based on the sixth research project of the working group that was launched in January 2014.

6.3 Outlook

The working group will continue to dedicate itself to producing usable methods for evaluating and taking into account the thermal improvement potential which the warm edge provides. The subject of the 'warm edge' is to be promoted with the aid of the quality criteria created for the representative psi values, and efforts made for an ongoing, serious and reliable market presentation. This will be supported by joint press activities and marketing campaigns.

7.0 Thermal treatment of glazing-bar windows

7.1 Standard-rate additions for glazing bars as per EN 14351-1

It is not only the spacer in the edge seal, but also other items inside the cavities of double and triple insulating glazing that can cause heat bridges. Glazing bars are therefore also thermal "defects" that have to be taken into account when determining the U_W value of windows. The product standard for windows (EN 14351-1) specifies additions for glazing-bar windows in Annex J (Fig. 14).

No distinction is made here as to whether they are "Georgian glazing bars" that are still covered on the outside by a cover strip, or purely decorative bars inside the cavity and remaining visible in a plan view. Conventional glazing bars made of aluminium and thermally improved glazing bars made of plastic are not differentiated. Whether glazing bars are provided in one or both cavities in triple insulating glazing is not important when determining the addition.

These additions to the U_W value are easy to use, but are incommensurately high for glazing-bar windows in many cases.

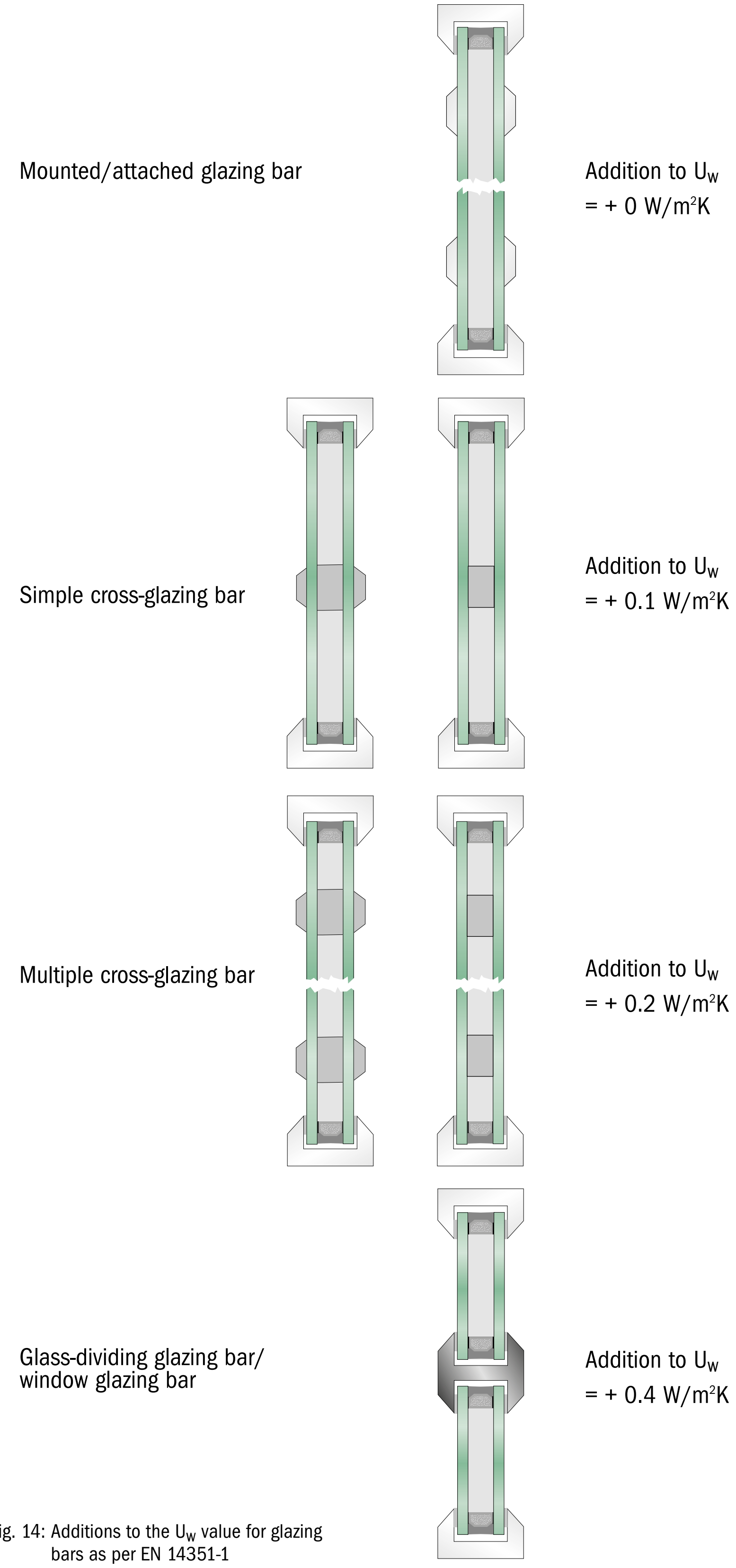

Fig. 14: Additions to the U_W value for glazing bars as per EN 14351-1

7.2 The research project of the ad hoc group 'Glazing bars' of BF

A detailed calculation as per EN ISO 10077-2 and the determination of linear heat transfer coefficients for glazing bars (glazing bar psi values) result in the vast majority of cases in more advantageous U_W values than when standard-rate additions are used. However, this course of action involves considerable expense, since the range of glazing bar variants is considerably greater than in a spacer system.

In a research project at ift Rosenheim, initiated and funded by the ad hoc group on 'Glazing bars' at BF, the topic of glazing bars was therefore studied in terms of their thermal behaviour. The aim was to determine, by the calculation of length-related heat transfer coefficients Ψ_{gb} for different glazing bar types, standard-rate glazing bar psi values to be proposed in table form for incorporation into EN ISO 10077.

In September 2015 the closing report appeared, entitled "Creation of simplified tables to take into account the effect of glazing bars while determining the U value of windows". The influencing factors on glazing bar Psi values were analysed by typical calculations (Fig. 15 and Table 8).

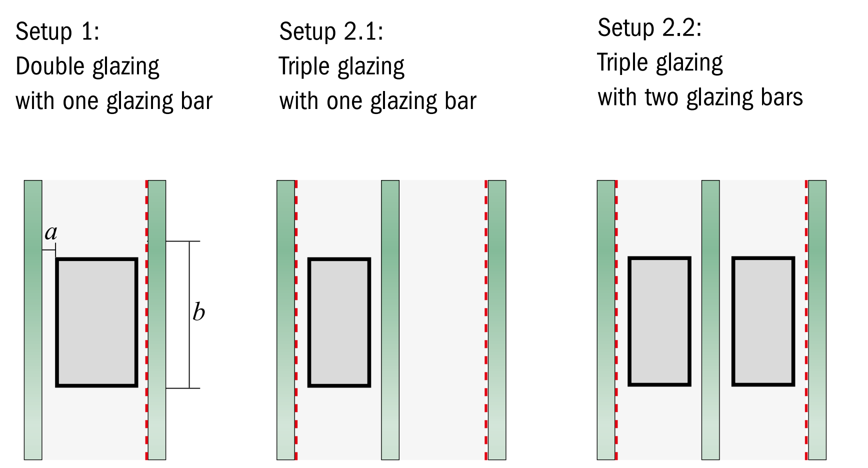

Fig. 15: Schematic representation of setups for calculating Ψ_{gb} values for glazing bars in double and triple glazing [11]

Influencing factor	***Relevance***
Coating (emissivity) of glass panes	Coating has effect on Ψ_{gb} values
Thermal conductivity of material of glazing bar	Division into two material groups (aluminium or plastic) recommended
Distance a on both sides between glazing bars and glass	The greater a is, the lower the Ψ_{gb} value
Width b of glazing bar	Ψ_{gb} values increase as glazing bar width increases
In triple insulating glass: Glazing bars inside one or both cavities *)	Significant effect
Wall thickness of glazing bars	No significant effect

Table 8: Influencing factors for glazing bar psi values and their relevance

*) Note:
BF recommends for triple insulating glass that glazing bars are only provided in one cavity. This is recommended for both thermal and visual reasons.

7.3 Tables with general glazing bar psi values

Similar to the heat bridge at the glass edge, the standard glazing bar psi value Ψ_{gb} (gb = glazing bar) is multiplied by the total length of the fitted glazing bars and added proportionately to the U_W value.

$$U_w = \frac{A_g \cdot U_g + A_f \cdot U_f + l_g \cdot \Psi_g + l_{gb} \cdot \Psi_{gb}}{A_w}$$

Fig. 16: Formula for calculating the heat transfer coefficient U_W of glazing-bar windows [1]

As the result of the research project [11], two tables (see Tables 9 und 10) with standard glazing bar psi values were proposed to supplement EN ISO 10077-1, and valid in the following application:

- For glazing bars (hollow-chamber profile sections) of metal and plastic
- Glazing bar width b ≤ 30 mm (see Fig. 15)
- Distance a ≥ 2 mm and a ≥ 4 mm (see Fig. 15)

It is regarded as very probable that these tables will be incorporated into the next edition of EN ISO 10077-1. In the view of BF, application of the general glazing bar psi values according to Tables 9 and 10 with reference to the research project can already be advocated today.

Glazing	***Distance a in mm***	**Ψ *value in W/(mK)***	
		Glazing without low e coating	Glazing with low e coating
Double	≥ 2	0.03	0.07
	≥ 4	0.01	0.04
Triple with glazing bar inside one cavity	≥ 2	-/-	0.03
	≥ 4	-/-	0.01
Triple with glazing bar inside both cavities	≥ 2	-/-	0.05
	≥ 4	-/-	0.02

Table 9: Values for the length-related heat transfer coefficient Ψgb for glazing bars of metal (λ ≤ 160 W/(mK)) inside cavity.

Glazing	***Distance a in mm***	**Ψ *value in W/(mK)***	
		Glazing without low e coating	Glazing with low e coating
Double	≥ 2	0.00	0.04
	≥ 4	0.00	0.02
Triple with glazing bar inside one cavity	≥ 2	-/-	0,02
	≥ 4	-/-	0.01
Triple with glazing bar inside both cavities	≥ 2	-/-	0.03
	≥ 4	-/-	0.02

Table 10: Values for the length-related heat transfer coefficient Ψgb for glazing bars of plastic (λ ≤ 0.30 W/(mK)) inside cavity.

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