BF

**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 Working Group 'Warm Edge'. It was first published in 2008, together with the first edition of BF data sheets with representative Psi values for windows. With the present edition, this BF bulletin has been extended and updated for the fifth time.

In addition to conveying the basics of warm edge and presenting the results from the Working Group, the bulletin is intended in particular to serve as a guide for the correct use of the BF data sheets 'Psi values for windows' and 'Psi values for facade profiles'.

Since the last revision of the guide in March 2017, further research projects have been or are being carried out in the BF Working Group 'Warm Edge' as a part of an overall project on the usability of spacers. The focus here is on spacer properties that can influence the durability of insulating glass units.

This includes, among others:

- The thermal expansion of rigid spacer profiles,
- Fogging of not fully metallic spacers at high temperatures in the cavity, i.e. the release of volatile substances and their condensation as a visible deposit on the glass surfaces,
- Strength of not fully metallic spacers, consisting of a plastic hollow body and a diffusion barrier made of metal or composite foil and which must not fail when subjected to tensile and shear loads occurring in the edge seal,
- UV resistance of not fully metallic spacers, the plastic parts of which remain visible when installed in the cavity.

The sub-projects that have already been completed are described in more detail in the ift Guideline VE-17/1. Further sub-projects of this overall project are still in progress or in planning (status May 2022).

In 2017, in a research project at ift Rosenheim, the influence of the two methods permitted since EN ISO 10077-2:2017 for the treatment of air cavities on the representative Psi values was examined. As a result, it was decided that the representative Psi values for the data sheets should be calculated using the new radiosity method. [13]

In addition, in 2017 the Working Group 'Warm Edge' agreed that the BF data sheets shall be issued with a limited validity period of two years. The prerequisite for an extension by two years is the re-measurement of the equivalent thermal conductivity according to ift Guideline WA-17 and confirmation of the declared data sheet value within a permissible tolerance range. Since this agreement, the equivalent thermal conductivity values have been remeasured in 2017, 2019 and 2021 (status May 2022).

The results of the research projects mentioned above have meanwhile been included in the Regulations for the creation of "Data sheets Psi values for windows and façade profiles" (see section 3.2 below).
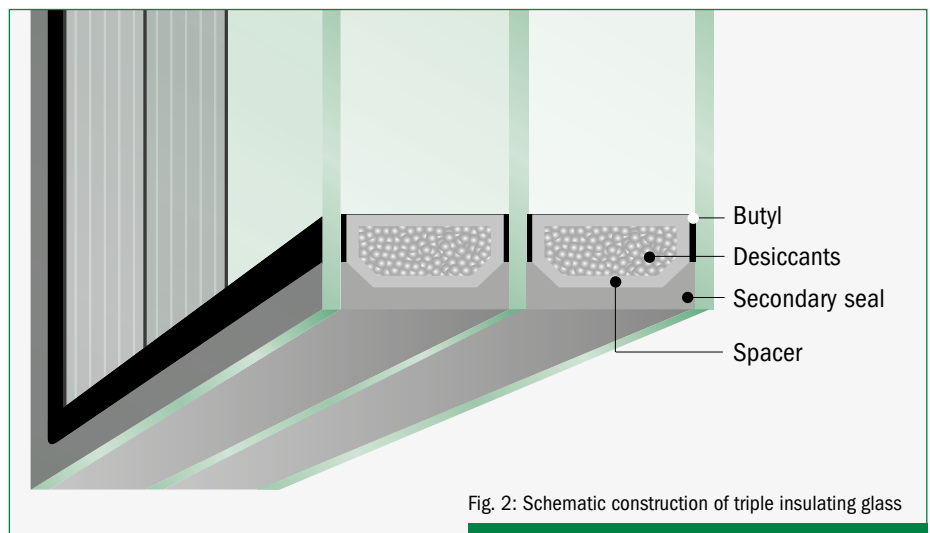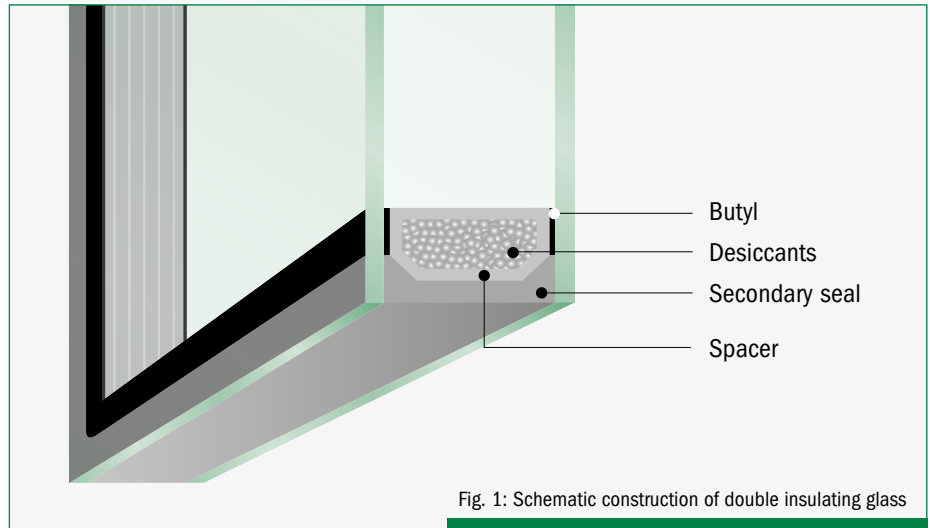
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2.0 What is 'Warm Edge'?

2.1 Insulating glass units

Insulating glass consists of two or more glass panes. The distance between the panes is determined by a spacer profile running around the edge of the pane. This creates the cavity on which the fundamental insulating effect of insulating glass is based.

Together with a butyl primary seal and a polysulphide, polyurethane, or silicone-based secondary sealant or hotmelt, the spacer, filled with a desiccant forms the dual-sealed insulating glass edge seal which has been proven over many years (Figs. 1 and 2).

Since the introduction in 1959 of the organic edge seal for insulating glass, which today is standard, hollow profiles made of steel and in recent years aluminium had been used as spacers. The disadvantage of these materials is their high thermal conductivity. When installed in an insulating glass edge seal, the aluminium profile forms a very good heat-conducting connection between the inner and outer pane. This creates linear thermal bridges of considerable extent in windows and facades.

Butyl
Desiccants
Secondary seal
Spacer

Fig. 1: Schematic construction of double insulating glass

Butyl
Desiccants
Secondary seal
Spacer

Fig. 2: Schematic construction of triple insulating glass

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

In heated buildings, thermal bridges are responsible for the loss of valuable heat energy. The surface temperature on the room side drops as a result of the heat flow to the outside via the thermal 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.

Nowadays, with functional coatings and inert gas fillings in the cavity, modern insulating glass units have attained a thermal performance that makes transparent, light-flooded buildings with high energy efficiency possible. In these buildings, thermal bridges are absolutely unwanted defects for reasons of climate protection and economy.

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

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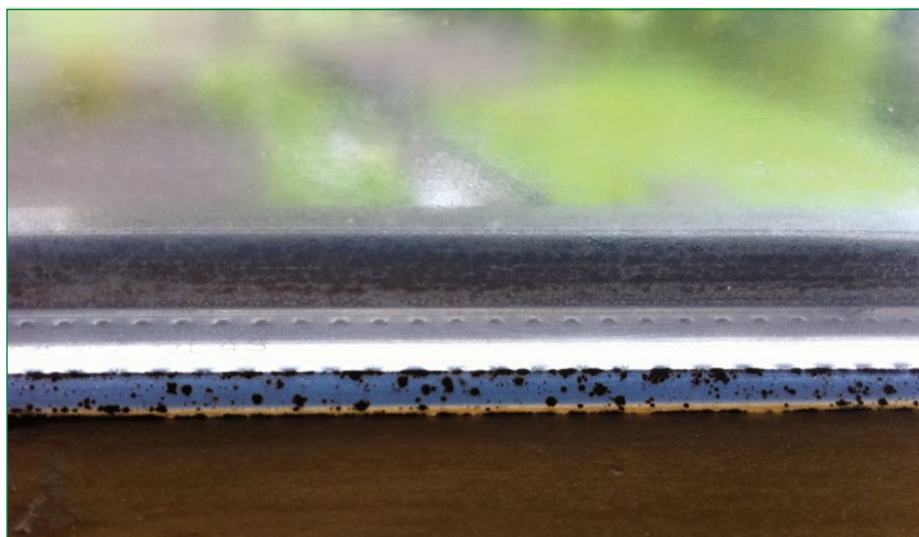

Fig. 4: In the longer term, this can lead to the formation of mould, which is unacceptable not just for hygiene reasons

Guide to 'Warm Edge'
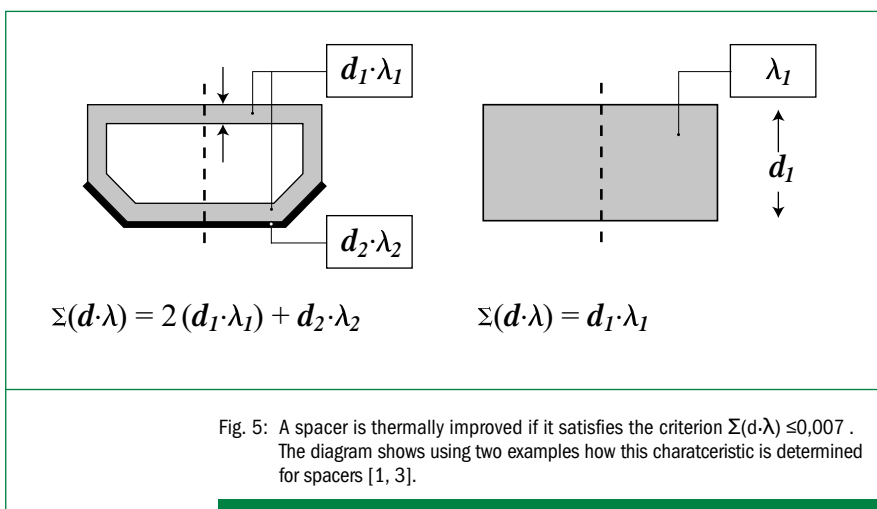
2.2 Definition "thermally improved"

Hardly any thermal bridge can be eliminated as easily as that caused by the aluminium spacer in the glazing-frame junction 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 G of EN ISO 10077-1 [1] and identical for curtain walling in Annex D of the standard EN ISO 12631 [3].

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

2.3 Spacer categories

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 of the insulating glass edge seal is referred to as 'Warm Edge'.

$$\Sigma(d \cdot \lambda) = 2\,(d_1 \cdot \lambda_1) + d_2 \cdot \lambda_2 \qquad \Sigma(d \cdot \lambda) = d_1 \cdot \lambda_1$$

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 charatceristic is determined for spacers [1, 3].

Material	thermal conductivity λ in W/(m K)	Material	thermal conductivity λ in W/(m K)
Aluminium	160	Polysulphide	0,40
Steel	50	Molecular Sieve	0,10
Stainless Steel	17	Polycarbonates	0,20
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.

Stainless steel has a thermal conductivity more than ten times lower than that of aluminium (table 1). As stainless steel spacers also have much lower wall thicknesses, they are considerably better than aluminium or steel profiles from a thermal point of view. The values can be further optimised if, in addition, parts of the profiles are replaced by plastic or if the stainless steel is only used just as a diffusion barrier in an extremely thin design. Other systems follow new manufacturing avenues and dispense entirely with metal.

The insulating glass producer has a wide range of different spacer products to choose from. Unlike the aluminum spacer, which ended up having a manufacturer-independent, uniform geometry after forty years of co-evolution with processing machines, such a system consolidation has not taken place with warm edge to date. The range is particularly large regarding the processing technology.
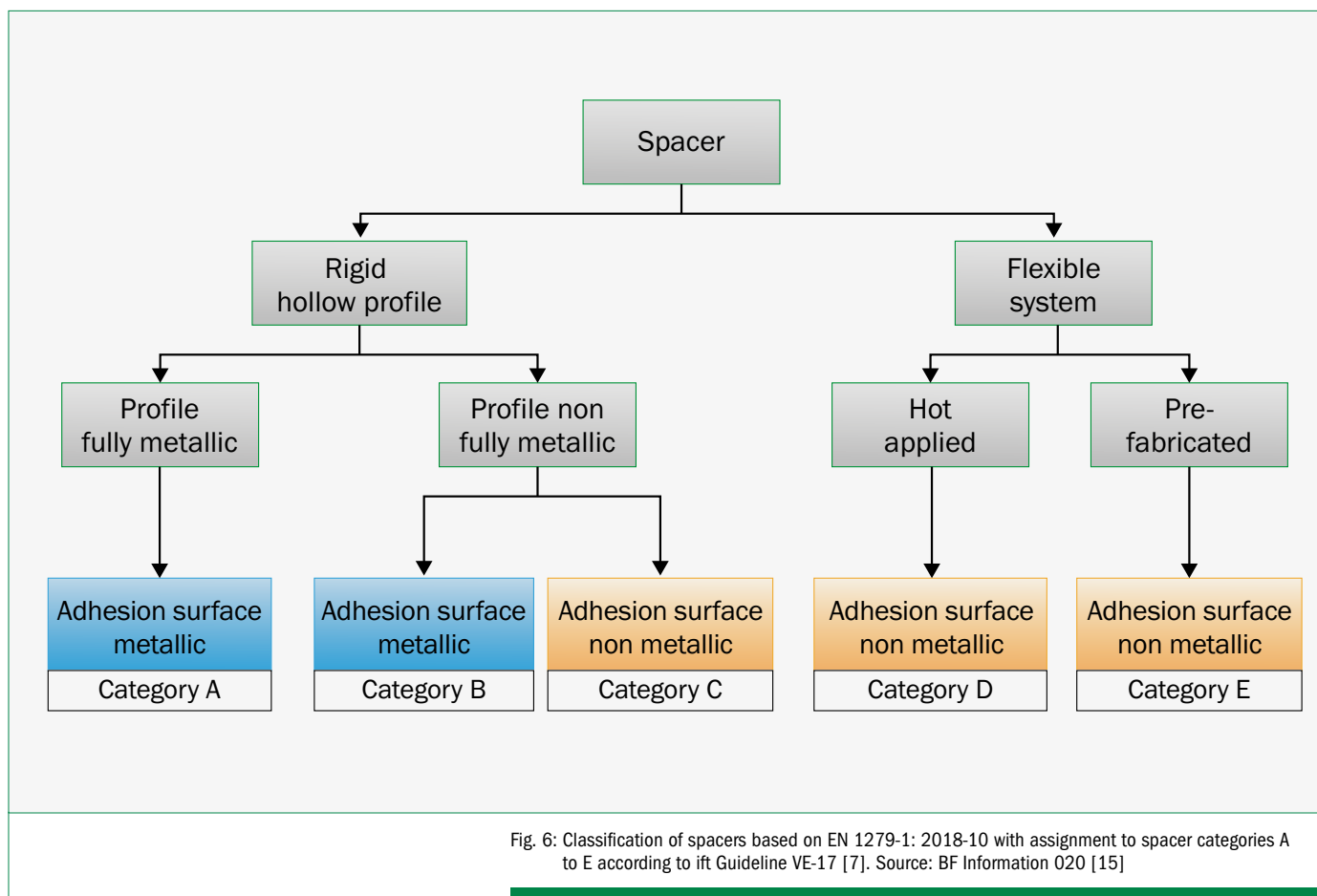
Butylated spacer frames filled with desiccant are prefabricated from **rigid hollow profiles**. It depends on whether the profile is made entirely of metal, such as alumin-ium-, steel- or stainless steel spacers (category A), or whether it is a hybrid solution made of plastic with a separate diffusion barrier (category B or C). Being the adhesion surface for the primary and secondary sealant, this diffusion barrier plays a decisive role in the durability of the entire system of insulating glass units; it can be metallic, i.e. made of rolled or extruded metal (category B), or it can consist of multilayer composite foils (category C).

With the **flexible systems**, automatic applicators apply the spacer onto the panes directly at the insulating glass line. With thermoplastic systems (TPS), this is done by extruding a hot mass out of a barrel onto the edge of the glass (category D), or prefabricated foam profiles are unwound from a roll and applied along the edge of the glass (category E).

For further information, also on the substitution of the spacer in an insulating glass system, see BF Information 020/2021 with guidance notes to EN 1279:2018-10. [15]

Fig. 6: Classification of spacers based on EN 1279-1: 2018-10 with assignment to spacer categories A to E according to ift Guideline VE-17 [7]. Source: BF Information 020 [15]

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3.0 Basis for the BF data sheets

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

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 determined by measurement. To do so, profile sections are filled with desiccant and measured when tightly packed between two glass panes in the plate apparatus. The conducting components of the spacer sections must here be thermally connected to the glass with butyl (see Fig. 7).

With this 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. 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). 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. 8).
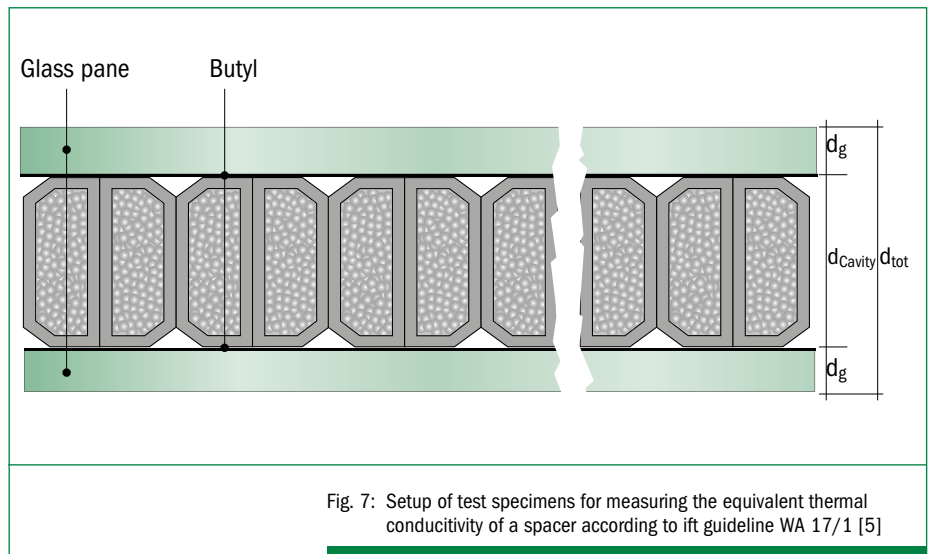
Glass pane   Butyl

d_g

d_{Cavity} d_{tot}

d_g

Fig. 7: Setup of test specimens for measuring the equivalent thermal conducitivity of a spacer according to ift guideline WA 17/1 [5]

Detailed model   Two Box model

$\lambda_{eq,2B}$

Box 2

h_2

Box 1

h_1

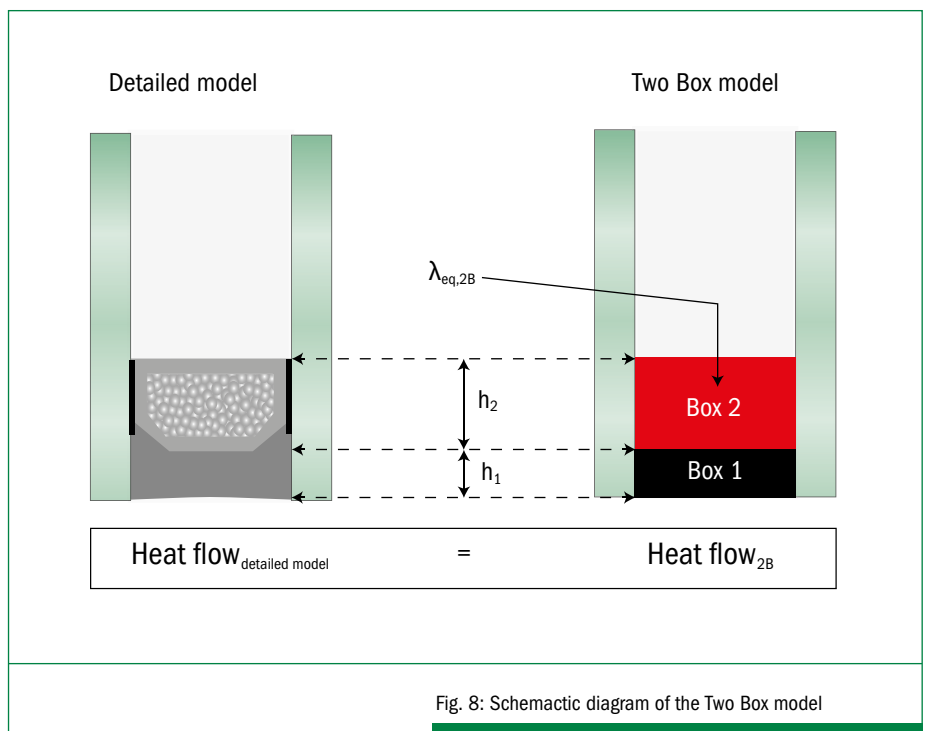Heat flow$_{detailed\ model}$ =   Heat flow$_{2B}$

Fig. 8: Schemactic diagram of the Two Box model

This approach eliminates the need to determine the thermal conductivity values of the individual spacer materials.

In the case of individual thermal calculations according to EN ISO 10077-2 [2], by using the Two-Box model the complex modelling of the insulating glass edge seal is no longer needed. Once the equivalent thermal conductivity $\lambda_{eq,2B}$ has been determined, the calculation model simply needs two rectangles: Box 1 for the secondary sealant and Box 2 for the spacer including desiccant and butyl. 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 neglected.

The simplified modeling using the Two-Box model represents an enormous simplification for individual calculations according to EN ISO 10077-2.

Since April 2013, the subtitle "based on determination of the equivalent thermal conductivity of spacers by measurement" can be found on the BF data sheets in reference to the new basis by means of measurement. BF data sheets without this subtitle 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 in ift Guidelines 08/3 and WA-22/2 [4, 6].

PLEASE NOTE: Since the spacer systems have differing heights h_2, the equivalent thermal conductivity $\lambda_{eq,2B}$ 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 $\lambda_{eq,2B} \cdot h_2$).

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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 Working Group 'Warm Edge'. These 'Regulations for the creation of data sheets Psi values for windows and facade profiles' are available on request from the BF office. In addition to the documentation for determining the representative Psi values, a manufacturer must submit proof of the material identity with the help of chemical characterization in accordance with ift Guideline VE-17/1 as well as various proofs to ensure the suitability of his spacer system for the production of insulating glass units. Only the data sheets published by the Bundesverband Flachglas ensure that this procedure is followed.

For a specific warm edge system, normally there are 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. **W**043 → BF data sheet with representative psi values for windows
(W = Window)

No. **CW**043 → BF data sheet with representative psi values for facades
(CW = Curtain Wall)

Some spacers are, depending on the 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 use with hotmelt sealant".* Hotmelt edge seal is however only available in some geographic regions. This is why it is explicitly pointed out that outside these specific markets there are no producers for this type of edge seal and it is futile to demand a hotmelt edge seal.

All regular BF data sheets are, for reasons of comparability of the spacers, calculated using exactly the same boundary conditions. A back cover of the spacer with secondary sealant of 3 mm for windows and 6 mm for facades is assumed. A glass bite of 13 mm is generally used for calculation. For further details of the boundary conditions, please refer to the respective ift Guidelines [4, 6].

In the BF data sheets, an accuracy of $\pm$ 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 addresses for the currently valid BF data sheets to be found on page 11.

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-22/2 for facade profiles. [4, 6]

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 BF data sheets 'Psi values for windows'

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 four representative window frame profiles (metal with thermal break, 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. 9).

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).
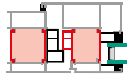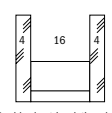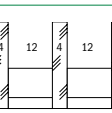

Month 20XX – No. WX – Revision index X-0X/2021 – valid until June 30th, 2023   'WARM EDGE' WORKING PARTY

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

Profile description	Product name		Spacer height in mm	Material	Thickness d in mm
	Product		X	X	X
			Spacer category		
			X		

Representative frame profiles	Representative glass constructions	Metal with thermal break	Plastic	Wood	Wood/Metal
Representative psi value double-sheet thermally insulating glass W/mK	Double-sheet insulating glass U_g=1.1 W/m²K	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	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
		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:

Fig. 9: Layout of BF data sheets ‚Psi values for windows'

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www.bundesverband-flachglas.de/en/downloads/bf-datenblaetter-fenster

www.bundesverband-flachglas.de/en/downloads/bf-datenblaetter-fassadenprofile

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4.2 U$_W$-values for windows

As per EN ISO 10077-1, the thermal transmittance U$_W$ 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 thermal transmittance Ψ$_g$ for the junction area of frame and glass (Figs. 10 and 11). The thermal transmittance 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].

Where glass and frame meet, a thermal bridge results from the geometry and the material. The Ψ$_g$ value describes the additional heat losses in this area. They are mainly due to the heat conduction via the insulating glass edge seal.

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

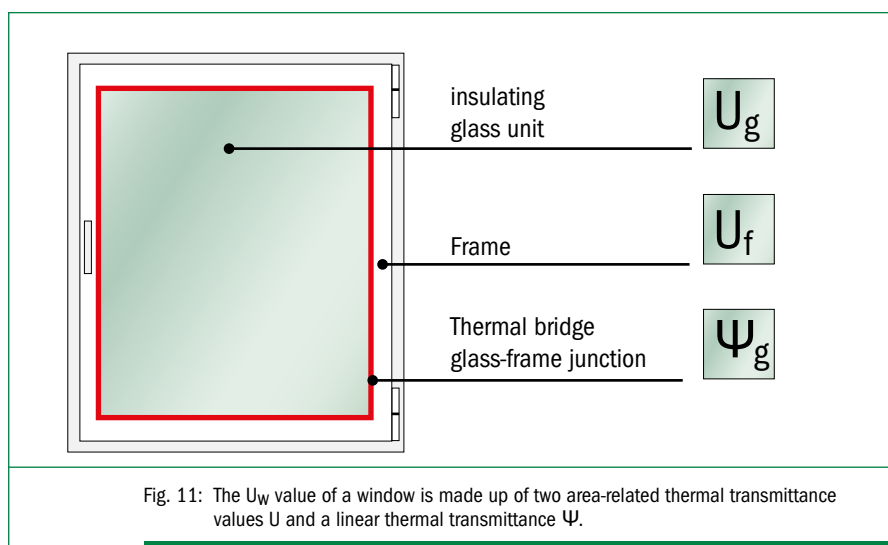Fig. 10: Formula for calculating the thermal transmittance U$_W$ of windows

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/(m^{2}K)	Thermal transmittance of glazing	(1) calculated acc. EN 673 (preferred method) or (2) measured acc. EN 674
U$_f$	W/(m^{2}K)	Thermal transmittance of frame	(1) calculated acc. EN ISO 10077-2 (preferred method) or (2) derived from Annex F of EN ISO 10077-1 or (3) measured acc. EN 12412-2
Ψ$_g$	W/(mK)	Linear thermal transmittance of frame glass junction	(1) calculated acc. EN ISO 10077-2 or (2) derived from Annex G of EN ISO 10077-1 or (3) Use of the BF data sheets 'Psi values of windows' with representatives Psi values of thermally improved spacers (preferred method)

Table 3: Ways of determining the input data for the U$_W$ value fo windows

Fig. 11: The U$_W$ value of a window is made up of two area-related thermal transmittance values U and a linear thermal transmittance 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 advantageous than the standard-rate values from Annex G 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].

The standard EN ISO 10077-2 expressly allows in its Annex F for the determination of the thermal transmittance that representative Ψ values of thermally improved spacers can be determined based on representative frame profiles and representative glass units [2]. For the description of the procedure, reference is made to the ift Guideline WA-08/3 [4].

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/(m^2K) with argon or air filling
  - Triple insulating glass: $U_g \geq 0.5$ W/(m^2K) with argon or air filling.
- The actual glass bite must be at least 13 mm.
- The representative Ψ values must **not** be used with free external glass edge.
- If the glass panes are thicker than 4 mm, the representative Ψ values must be increased by the following amounts:
  - By 0.001 W/(mK) per mm of additional thickness of the outer glass pane

- By 0.002 W/(mK) per mm of additional thickness of the inner glass pane

The thickness of the glass of the middle pane in triple glass units is not relevant.

- The frame profiles actually used must be comparable with the representative frame profiles. U_f values and glass bites of the actual frame profiles 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].

TIP: In the abridged version of BF Bulletin 004/2018 – Psi values for "windows", the procedure for determining the U_w-value is graphically shown as a flow chart. [16]

Frame material	U_f in W/(m^2K)	Glass bite 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 value 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 break 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 thermal bridge at the edge of fixed 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-22/2 for fixed glazing in mullion/transom facades, but NOT for SSG (Structural Sealant Glazing) systems.

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

Profile description	Product name	Spacer height in mm	Material	Thickness d in mm
	Product	X	X	X
		Spacer category		
		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

Two Box model Characteristic values	Space between panes in mm	$\lambda_{eq,2B}$ in W/mK	
		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: ift ROSENHEIM

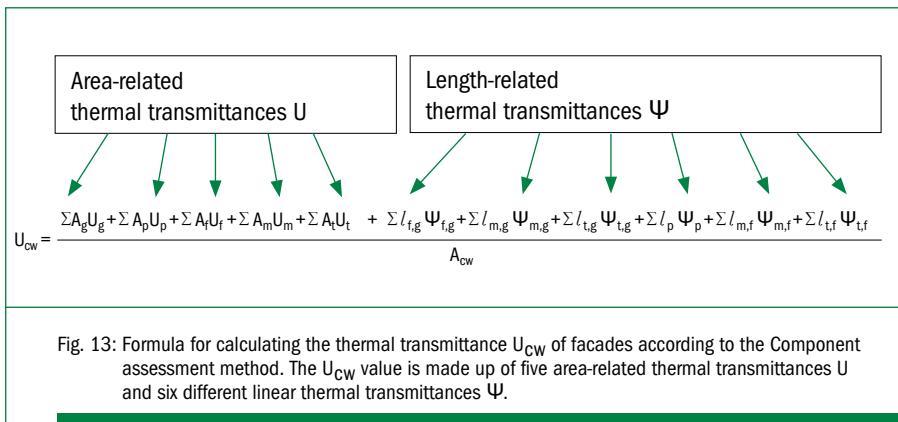Fig. 12: Layout of BF data sheets 'Psi value for facade profiles'

5.2 U_{CW} values for mullion/transom facades

The thermal transmittance U_{CW} of curtain walling is determined in accordance with EN ISO 12631 [3]. In mullion/transom facades, fixed glazing units, window elements or panels can be fitted (Fig. 14). At the transition area between the façade fillings and mullion-transom areas, diverse thermal bridges are created which must be taken into account when determining U_{CW}.

As with windows, there are several ways of obtaining the input data. Due to the many components, this is not discussed in detail here. For the installation of glazing in mullion/transom facades, the data sheets 'Psi values for facades' offer, within the limits of their applicability, a comparatively simple and pragmatic solution for the Psi values Ψ_{mg} and Ψ_{tg}. They are more precise and usually more advantageous than the standard-rate values from the tables in Annex D of EN ISO 12631 [3].

The standard EN ISO 12631 expressly allows in its Annex D for the determination of the thermal transmittance that representative Ψ-values of thermally improved spacers can be determined based on representative profile sections and representative glass units [2]. For the description of the procedure, reference is made to the ift Guidelines WA-08/3 and WA-22/2 [4, 5].

Alternatively, it is possible in the "Component assessment method " to calculate all thermal bridges in detail acc. to EN ISO 10077-2, or the so-called "Single assessment method" of EN ISO 12631 can be used.

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

Area-related thermal transmittances U

Length-related thermal transmittances Ψ

Fig. 13: Formula for calculating the thermal transmittance U_{CW} of facades according to the Component assessment method. The U_{CW} value is made up of five area-related thermal transmittances U and six different linear thermal transmittances Ψ.

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. 14: Model facade element as per EN ISO 12631 [3]
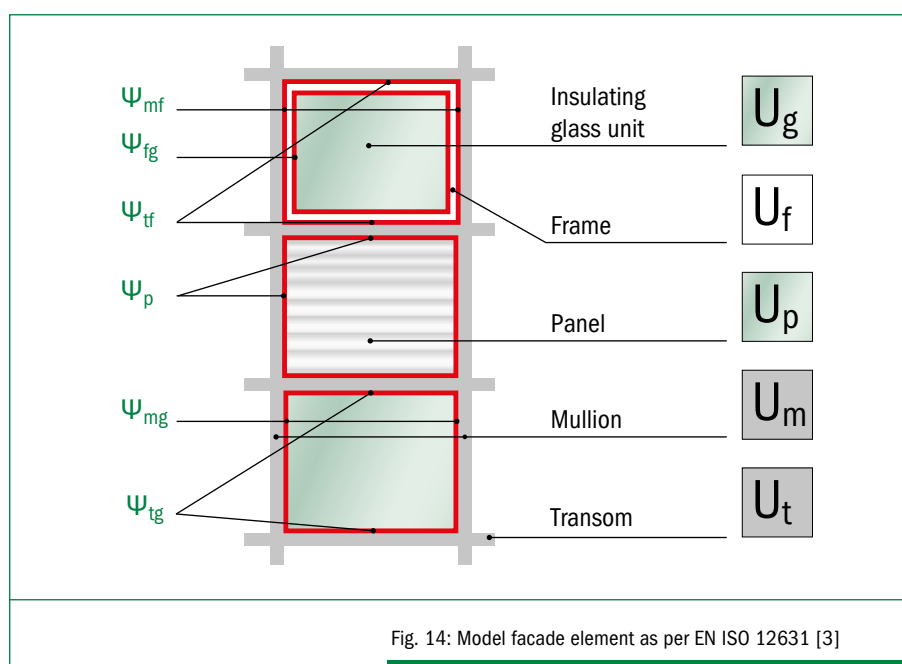
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5.3 Use of representative Psi values for facade profiles

According to ift Guideline WA-22/2 [6], facade manufacturers must take into account the following requirements for using the BF data sheets 'Psi values for façade 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/(m^2K) with argon or air filling Triple insulating glass: $U_g \geq 0.5$ W/(m^2K) with argon or air filling.
- The actual glass bite must be at least 13 mm.
- The representative Psi values must **not** be used with free external glass edge 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 thickness of the glass of the middle pane in triple glass units 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) according to Table 7.

Material	$\triangle \Psi$ in W/(mK) per mm of thickness of	
	Outer pane	**Inner pane**
Wood-metal	0.001	0.001
Metal with thermal break	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/(m^2K)
Wood-metal	for double glazing: ≥ 1.3 for triple glazing: ≥ 0.9
Metal with thermal break	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

TIP: In the abridged version of BF Bulletin 004/2018 − Psi values for "facade profiles", the procedure for determining the U_w-value is graphically shown as a flow chart. [17]

6.0 Working Group 'Warm Edge'

6.1 The members

The Working Group 'Warm Edge' is a subcommittee of the Technical Committee of Bundesverband Flachglas. The participants in the Working Group are members and supporting members of BF. Scientific support for the Working Group is provided by ift Rosenheim.

The leading manufacturers of warm edge systems for insulating glass and the glass industry are represented in the working group: Status of the member list: May 2022

Allmetal GmbH Abstandhalter für Isolierglas, D

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

BAUWERK – Ingenieurbüro für Bauphysik und Fenstertechnik, Rosenheim, D

Edgetech Europe GmbH, Heinsberg, D

Ensinger GmbH, Nufringen, D

FENZI S.p.A., Tribiano, I

Flachglas MarkenKreis GmbH, Gelsenkirchen, D

Glas Trösch Holding AG, Bützberg, CH

HELIMA GmbH, Wuppertal, D

hics-hausstetter irina chemical support, Rosenheim, D

IGK Isolierglasklebstoffe GmbH, Hasselroth, D

Ingrid Meyer-Quel Beratungsbüro für warme Kante und Glas, D

Interpane Entwicklungs- und Beratungsgesellschaft mbH, Lauenförde, D

Isolar Glas-Beratung GmbH, Kirchberg/Hunsrück, D

Kömmerling Chemische Fabrik GmbH, Pirmasens, D

Nedex Chemie Deutschland GmbH, Moers, D

Pilkington Holding GmbH, Gelsenkirchen, D

Rolltech A/S, Hjorring, DK

SANCO Beratung Glas Trösch GmbH, Nördlingen, D

Technoform Glass Insulation GmbH, Lohfelden, D

Thermoseal Group Limited, Birmingham, GB

Uniglas GmbH & Co. KG, Montabaur, D

Vetrotech Saint Gobain (International) AG Swisspacer Kreuzlingen, CH

Wolftech GmbH, Cham, D

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6.2 Results of previous activity

The Working Group 'Warm Edge' 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 [8]. 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 most important influences on the Psi values in different frame models were investigated mathematically according to EN ISO 10077-2 and compared with experimental results in a second research project for the Deutsches Institut für Bautechnik (DIBt) in 2002 to 2003. A total of six testing institutes and calculating centres as well as eight industrial partners were involved in this project [9].

In order to protect the industry and consumers against products which only pretend to provide thermal improvement at the insulating glass edge seal, a definition of 'thermally improved edge seal' 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 G and EN ISO 12631, Annex D [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 window'. This project was presented to the industry in the BF 'Warm Edge' symposium on April 23rd, 2008, in Hanau, Germany.

A further research project of the Working Group 'Warm Edge' funded by the Deutsches Institut für Bautechnik (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 Working Group 'Warm Edge' decided to contribute to financing a project to widen the appli-

cability of the representative Psi values for windows to lower U_f values. This fifth project of the group resulted in a revision of the ift Guideline WA-08, which since Version 3 has permitted the application of the representative Psi values for high-insulating window frames too with an appropriately greater glass bite (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.

The research projects carried out since the last revision of the Guide to Warm Edge in March 2017 are listed in the introduction to this bulletin.

6.3 Outlook

The BF Working Group will continue to dedicate itself to the development of 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 installations inside the cavities of double or triple insulating glass that can cause thermal bridges. Glazing bars are 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 (Fig. 15).

No distinction is made here as to whether they are "muntin bars" that are still covered on the outside by a cover bar, 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 there are glazing bars in one or in both cavities of triple insulating glass is irrelevant when determining the addition. Furthermore, the distance between the glazing bar and the glass pane as well as the width of the glazing bar is not taken into account.

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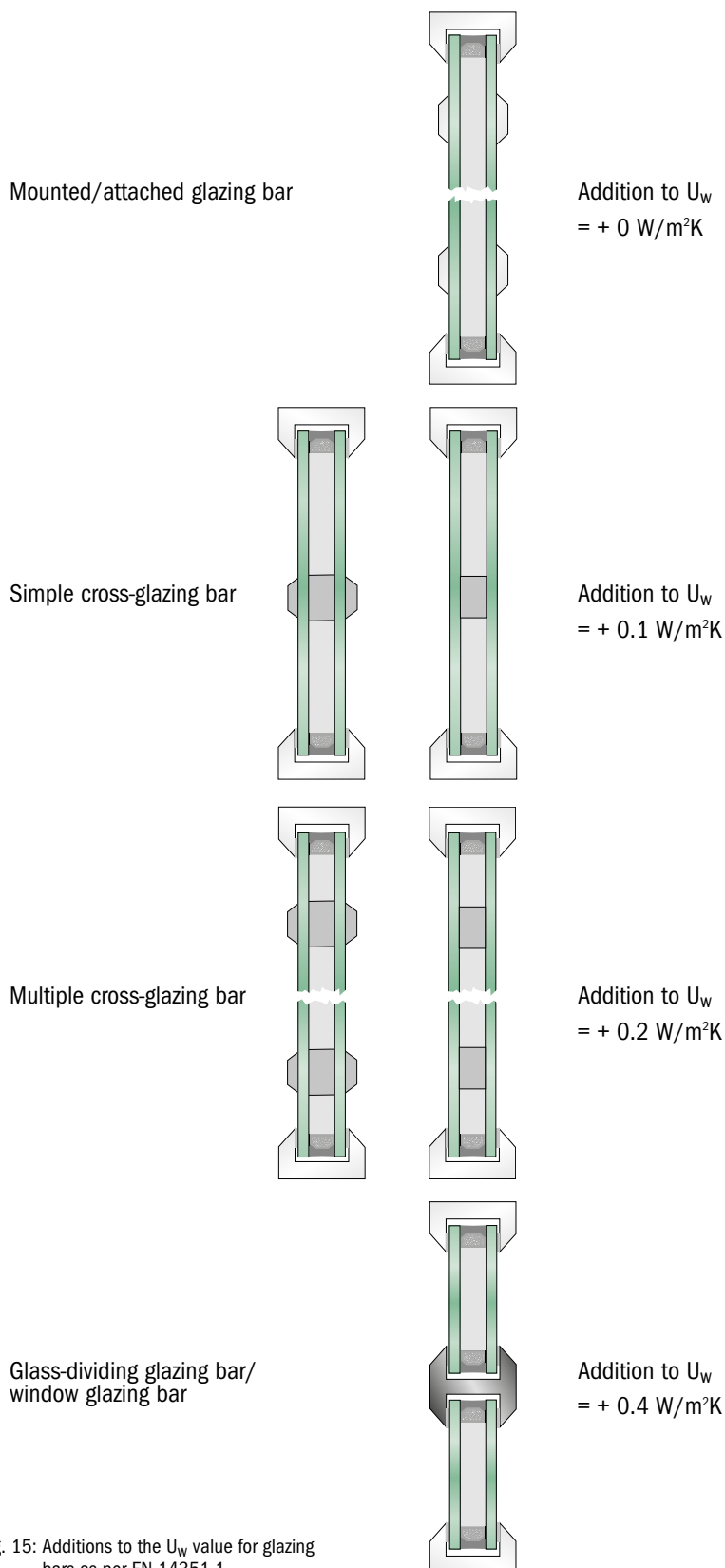
Mounted/attached glazing bar

Addition to U_W
= + 0 W/m²K

Simple cross-glazing bar

Addition to U_W
= + 0.1 W/m²K

Multiple cross-glazing bar

Addition to U_W
= + 0.2 W/m²K

Glass-dividing glazing bar/ window glazing bar

Addition to U_W
= + 0.4 W/m²K

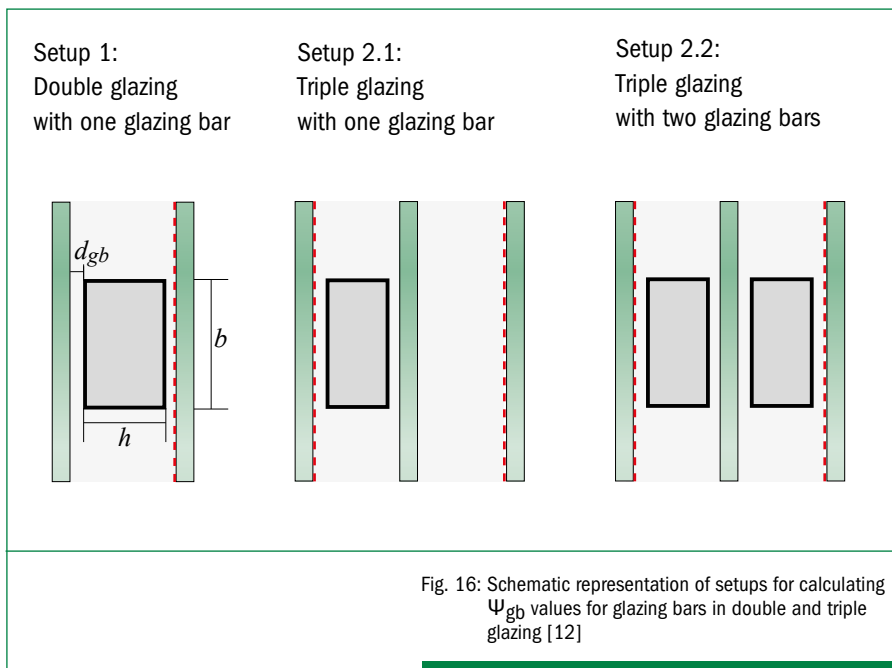Fig. 15: Additions to the U_W value for glazing bars as per EN 14351-1

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

With a detailed calculation acc. to EN ISO 10077-2, linear thermal transmittances for glazing bars (glazing bar Psi values) can be determined. In most cases, this results in more advantageous U_W values than when standard-rate additions are used. However, this procedure involves considerable effort, since the range of glazing bar variants is considerably greater than with a spacer system.

In a research project at ift Rosenheim, initiated and funded by the BF ad hoc group 'Glazing bars', 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 thermal transmittances Ψ_{gb}, standard-rate glazing bar Psi values for different glazing bar types. These were proposed in table form for incorporation into EN ISO 10077 and have been included in Annex G of the standard since the 2018-01 edition [1].

In September 2015 the final report appeared, entitled "Development 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. 16 and Table 8). [12]

Fig. 16: Schematic representation of setups for calculating Ψ_{gb} values for glazing bars in double and triple glazing [12]

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
Height of glazing bar h	No significant effect (decisive factor is the distance d_{gb} to glass)

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 standard glazing bar Psi values

Similar to the thermal bridge at the glass edge, the standard glazing bar Psi value Ψ_{gb} (gb = glazing bar) is multiplied by the total length of the installed 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. 17: Formula for calculating the thermal transmittance U_w of glazing-bar windows [1]

As the result of the research project [12], two tables (see Tables 9 und 10) with standard glazing bar Psi values were integrated into EN ISO 10077-1, for the following area of application:

- For glazing bars (hollow-chamber profile) of metal and plastic
- Glazing bar width b ≤ 30 mm (see Fig. 16)
- Distance d_{gb} ≥ 2 mm and d_{gb} ≥ 4 mm (see Fig. 16)

Type of glazing	Distance between glass pane and glazing bar d_{gb} in mm	Linear thermal transmittance for different types of glazing Ψ_{gb}	
		Double or triple insulating glass, uncoated glass, air or gas filled cavity	Double[a] or triple[b] insulating glass, low emissivity glass, air or gas filled cavity
Double glazing	≥ 2	0,03	0,07
	≥ 4	0,01	0,04
Triple glazing with glazing bar in one cavity	≥ 2	-/-	0,03
	≥ 4	-/-	0,01
Triple glazing with glazing bar in both cavities	≥ 2	-/-	0,05
	≥ 4	-/-	0,02

[a] With one coated pane for double glazing   [b] With two coated panes for triple glazing

Table 9: Values for linear thermal transmittances of glazing bars integrated in insulating glass units, made of metal (λ ≤ 160 W/mK) [1]

Type of glazing	Distance between glass pane and glazing bar d_{gb} in mm	Linear thermal transmittance for different types of glazing Ψ_{gb}	
		Double or triple insulating glass, uncoated glass, air or gas filled cavity	Double[a] or triple[b] insulating glass, low emissivity glass, air or gas filled cavity
Double glazing	≥ 2	0,00	0,04
	≥ 4	0,00	0,02
Triple glazing with glazing bar in one cavity	≥ 2	-/-	0,02
	≥ 4	-/-	0,01
Triple glazing with glazing bar in both cavities	≥ 2	-/-	0,03
	≥ 4	-/-	0,02

[a] With one coated pane for double glazing   [b] With two coated panes for triple glazing

Table 10: Values for linear thermal transmittances of glazing bars integrated in insulating glass units, made of plastic (λ ≤ 0,30 W/mK) [1]

Note: The content of section 7 was published in March 2017 in a slightly modified form as a separate BF Information 007/2017. [14]

Guide to 'Warm Edge'

8.0 References

At the time of publication of this bulletin, the specified documents listed below were valid. It may be necessary to ensure that the current versions of these documents are used.

[1] EN ISO 10077-1:2020-10
Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 1: General
Berlin, Beuth Verlag GmbH

[2] EN ISO 10077-2:2018-01
Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 2: Numerical method for frames
Berlin, Beuth Verlag GmbH

[3] EN ISO 12631:2018-01
Thermal performance of curtain walling – Calculation of thermal transmittance
Berlin, Beuth Verlag GmbH

[4] ift Guideline WA-08/3
Thermally improved spacers – Part 1: Determination of representative Ψ values for profile sections of windows
Rosenheim, ift Rosenheim, February 2015

[5] ift Guideline WA-17/1
Thermally improved spacers – Part 2: Determination of the equivalent thermal conductivity by means of measurement
Rosenheim, ift Rosenheim, October 2013

[6] ift Guideline WA-22/2
Thermally improved spacers – Part 3: Determining the representative Ψ-values of facade profiles
Rosenheim, ift Rosenheim, August 2016

[7] ift Guideline VE-17/1
Product characteristics and test methods for verifying the usability of spacer systems in the edge-sealing of insulating glass units; Part 1: Hollow profiles – not fully metallic spacers (Category B and C)
Rosenheim, ift Rosenheim, May 2021

[8] Final report for research project 'Warm Edge'
Rosenheim, ift Rosenheim, July 1999

[9] *Forschungsvorhaben ‚Psi-Wert Fenster – Qualitätskriterien für die Berechnung des längenbezogenen Wärmedurchgangskoeffizienten Ψg (Psi-Wert) des Übergangs Rahmen-Glasrand-Glas und Vergleich mit experimentellen Daten' (Reseach project on 'Psi value for windows – Quality criteria for calculation of the linear thermal transmittances Ψg (psi value) of the frame/glass edge/glass transition and comparison with experimental data)
Berlin, Deutsches Institut für Bautechnik, April 2003
Fraunhofer IRB Verlag, 2003, ISBN 3-8167-6526-2

[10] *Kurzbericht ‚Äquivalente Wärmeleitfähigkeit Warme Kante'
(brief report on equivalent thermal conductivity of warm edge)
Rosenheim, ift Rosenheim, Dezember 2012

[11] *Abschlussbericht ‚Ermittlung der äquivalenten Wärmeleitfähigkeit von wärmetechnisch verbesserten Abstandhaltern' (Final report on determination of equivalent thermal conductivity of thermally improved spacers)
Rosenheim, ift Rosenheim, Dezember 2012
ISBN 978-3-86791-339-3 – ift Rosenheim

[12] *ift Forschungsbericht ‚Psi-Werte von Sprossen - Erarbeitung von vereinfachten Tabellen zur Berücksichtigung des Einflusses von Sprossen im Rahmen der Ermittlung des U-Wertes von Fenstern' (ift research report ‚Psi values of glazing bars – simplified tables for taking account of effects of glazing bars when determining the U values of windows)
Rosenheim, ift Rosenheim, September 2015 (unveröffentlicht)

[13] *ift-Forschungsbericht ‚Ψ-Wert Vergleichsrechnungen. Abschlussbericht Ermittlung des Einflusses auf Ψ-Werte durch die Anwendung der beiden unterschiedlichen Verfahren für die Behandlung von Hohlräumen in EN ISO 10077-2:2017' (ift research report ‚Comparative Ψ-value calculations. Final report Determination of the influence on Ψ-values by applying the two different methods for the treatment fo cavities in EN ISO 10077-2:2017')
Rosenheim, ift Rosenheim, Dezember 2017 (unveröffentlicht)

[14] *BF-Information 007/2017 ‚Uw-Wert Berechnung von Sprossenfenstern' (BF information 007/2017 ‚Uw calculation of windows with glazing bars')
Troisdorf, Bundesverband Flachglas, 2017

[15] *BF-Information 020/2021 – Änderungsindex 1 – Januar 2022 ‚Erläuterungen und Hinweise zur DIN EN 1279:2018-10' (BF information 020/2021 – revision index 1 – January 2020 Guidance notes to EN 1279:2017-10)
Troisdorf, Bundesverband Flachglas, 2022

[16] Abridged version of BF Bulletin 004/2018 – Psi values for windows
Troisdorf, Bundesverband Flachglas, 2018

[17] Abridged version of BF Bulletin 004/2018 – Psi values for façade profiles
Troisdorf, Bundesverband Flachglas, 2018

*Only available in German language

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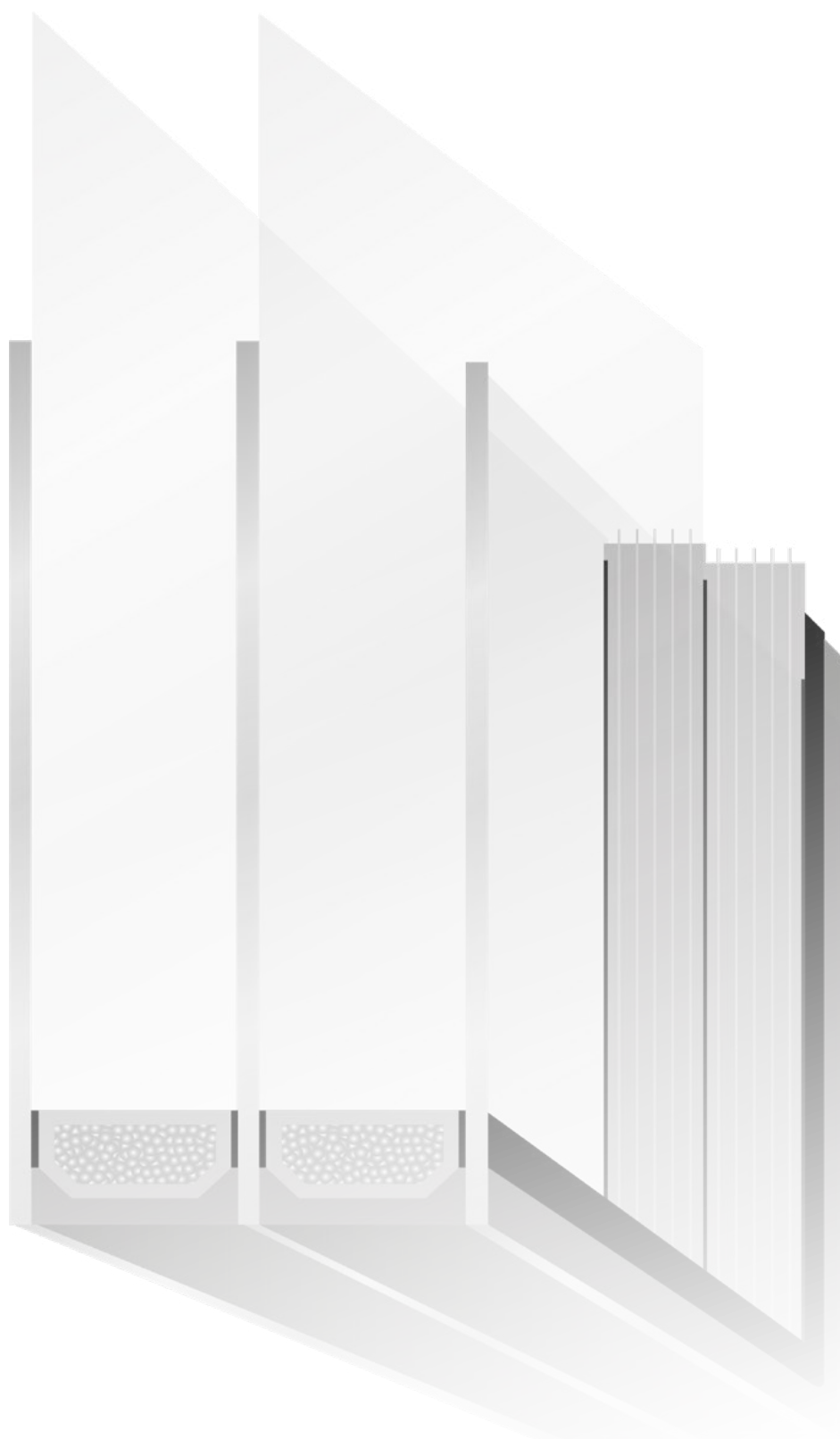
Bundesverband Flachglas e. V.
Mülheimer Straße 1
53840 Troisdorf