WinDat Thematic Network

www.windat.org

Windows as Renewable Energy Sources for Europe
Window Energy Data Network

Project supported by DG for Energy and Transport
of the European Commission

contract NNE5-2000-122

WIS DATABASE

Data Submission Procedure for Databases on

1. **Spacer profiles and edge constructions**
2. **Window frame profiles**

Version 1.0

S. Svendsen
J. B. Laustsen

Technical University of Denmark
Department of Civil Engineering
Brovej, Building 118
DK-2800 Kgs. Lyngby, Denmark
Email: ss@byg.dtu.dk; jbl@byg.dtu.dk

WinDat document N2.11 - Public **May 2004**

This document was produced within WinDat, with active contribution by the members of this European Thematic Network. See www.windat.org for more information.

Contact:

On data submission procedures for spacer profiles, edge constructions and window frame profiles:
The author of the document: Svend Svendsen (see above)
On Thematic Network WinDat:
WinDat coordinator: Dick van Dijk, TNO Building and Construction Research, Delft, The Netherlands
Email: H.vanDijk@bouw.tno.nl

Research funded in part by
THE EUROPEAN COMMISSION
in the framework of the Community activities
in the Field of the specific programme for RTD
and demonstration on Energy, Environment and
Sustainable Development

Contents

1. Introduction

The purpose of this document is to provide instructions to manufacturers of spacer profiles in edge constructions of glazing units and frames profiles of windows about the procedures to be followed when submitting information about their products for inclusion in the WIS database. The document gives an overview of the structure and information flow for edge and frame data and it describes the methods used in WIS to determine the thermal properties of complete windows. The approach is to focus on individually determined energy properties of each component and on this basis to calculate the overall window energy properties.

The product data for edge constructions and frames are provided in WIS on different levels for calculation of the overall thermal properties of windows.

- Detailed drawings and material data from which exact thermal properties can be calculated in 2D-programs in accordance with prEN ISO 10077-2.
- Equivalent thermal conductivities and regression model parameters for facilitating determination of Ψ for a specific frame in combination with any edge construction and glazing.
- Values for U and Ψ based on tables in EN ISO 10077-1.

2. Spacer profiles and Edge constructions

The manufacturer of spacer profiles/edge constructions shall apart form identification data supply thermal property data on two levels: detailed drawing and/or equivalent thermal conductivity, $\lambda_{eq,}$ and overall thermal conductance, *L*. This allows the user of WIS to choose a simple approach providing values fast or a more detailed approach.

2.1. Database

The database of spacer profiles and edge constructions should include:

- **Identification:**
  - Manufacturer, product name of spacer profile
  - Sealant system (materials)

- **Product description:**
  - Materials, dimensions and detailed drawing of spacer profile (dwg/dxf file preferred)
  - Materials and dimensions of sealants

  This information allows users to import the drawing in a 2D- program for calculating the thermal performance of the edge construction (separate or in a glazing in a frame)

- **Product data according to the two box model:**
  - Equivalent thermal conductivity, λ_{eq}, of spacer-box for either 6 mm or 10 mm height based on the two box model described in A1

  The equivalent thermal conductivity allows users to make use of a two-box model in a frame profile calculation when determining the linear thermal transmittance.
  - Overall thermal conductance, *L*, of the edge construction, based on the method described in Appendix A1.

  The overall thermal conductance is used as parameter in the regression model of the linear thermal transmittance. The L-value facilitates a simple determination of the linear thermal transmittance of the assembly of the glazing unit and the frame.

The properties definitions and the corresponding information required for submission of edge constructions are shown in Table 1.

Table 1. Product information and data for Edge constructions

Field name	Definition	Comments
Manufacturer	Name of the company manufacturing the spacer	
Product name	Trade name of the spacer	
Product code		
Materials, Spacer	Names of materials and their thermal conductivity λ in [W/mK]	
Materials, Sealants	Names of materials and their thermal conductivity λ in [W/mK]	
Dimensions, Spacer	Height x width [mm]	
Dimensions, Edge construction	Height x width [mm]	
Equivalent thermal conductivity of spacer box	λ_{eq} [W/mK]	Based on Two box model See section 2.2
Overall thermal conductance of edge construction	L [W/mK]	Based on Two box model See section 2.2
Drawing of edge construction	AutoCad (dwg or dxf-file) preferred	
Comments		

2.2. The two box model

The manufacturer of spacers/edge constructions shall document the equivalent thermal conductivity, λ_{eq}, and the overall thermal conductance, L, of the edge construction determined in accordance with the two box model method given in Appendix A1. The principle of the two box model method is to replace the actual edge construction with a two box model consisting of a 3 mm box with thermal conductivity of 0.4 W/mK and a 6 mm box with a thermal conductivity, λ_{eq}, that results in the same heat flow as in the actual edge construction. See also example 1.

3. Frames

The manufacturer of window frames shall apart from identification data supply thermal property data on three levels: detailed drawing, actual U-value (calculated or table/diagram values) and regression model coefficients for determination of the linear thermal transmittance.

3.1. Database

The database of window frame profiles should include:

- **Identification:**
  - Type, materials, (for specific products: producer and product name)

- **Product description:**
  - Materials, thermal conductivities, dimensions and detailed drawing of frame profile

  This information allows users to import the drawing in a2D- program for calculating the thermal performance of the frame.

- **Product data:**
  - Thermal transmittance (U-value) of the frame profile based on tables/diagrams in EN ISO 10077-1 or detailed calculation in a 2D-program according to prEN ISO 10077-2
  - Linear thermal transmittance (Ψ-value) given in one of the following ways
    1. Ψ-value given as a table value for a group: type of frame profile, glazing U-value and type of edge construction (Table E1 in EN ISO 10077-1)
    2. Ψ-value given as a value for one specific combination of frame profile, glazing U-value, glass thickness and edge construction
    3. Ψ-value given as a function of glazing U-value, glass thickness, *d*, and overall thermal conductance of edge construction, *L*.

The properties definitions and the corresponding information required for submission of frame profiles are shown in Table 2.

Table 2. Product information and data for frames.

Field name	**Definition**	**Comments**
Manufacturer	Name of the company manufacturing the frame profile	
Product name	Trade name of the frame profile	
Product code		
Materials	Names of materials and their thermal conductance λ in [W/mK]	
Position	Sill, head, jamb, mullion, transom etc.	
Opening direction	In, out, sliding	
Width	[m]	
Depth	[m]	
Thermal transmittance	U_f [W/m^{2}K] (Curtain walls: U_{joint})	Tabular values from EN ISO 10077-1 OR Calculated in accordance with prEN ISO 10077-2 (preferred)
Linear thermal transmittance (Not curtain walls)	Ψ [W/mK] 1. method ← 2. method ←	Ψ- value for combination of specific glazing and edge construction Tabular values from EN ISO 10077-1 OR Calculated in accordance with prEN ISO 10077-2 (preferred)
Regression model coefficients (Not curtain walls)	3. method Ψ = function of L, d, and U_g	Determined on basis of detailed calculations of Ψ for different combinations of L, U_g and d. A common and verified data fitting tool must be used e.g. “DataFit 8.0”. see section 3.2
Drawing of edge construction	AutoCad (dwg or dxf-file) preferred	
Comments		

For profiles in curtain walls U_{joint} is used instead of U_f and Ψ. U_{joint} is the thermal transmittance of the curtain wall profile including the additional heat flow caused by the interaction of the frame and the glass edge, including the effect of the spacer.

3.2. Ψ as a function of *L*, *d* and U_g

Ψ is given for the actual frame combined with a specific glazing and edge construction. This is useful to get an impression of the value when using a typical glazing unit. On the other hand using this approach alone would require a detailed calculation of every combination of frame, spacer and U-value of the glazing when using other glazing units, because Ψ is dependent on these factors. Therefore, to extend the flexibility of WIS, Ψ is also expressed as a function of centre U-value of the glazing, U_g, the glass thickness d, and the overall thermal conductance, L.

The principals in the method is to describe the linear thermal transmittance as a function of L , d and U_g by fitting a regression model of Ψ to a limited number of detailed calculations of Ψ, made with a 2D-program. The regression analysis will result in seven coefficients, b1 to b7, belonging to the actual frame, which should be determined and supplied by the frame manufacturer.
The general expression of Ψ as a function of the three parameters is:

$$\Psi = b1L^{b2} + b3 + b4L + b5d + b6d^{2} + b7U_{g} \qquad (1)$$

The method requires approximately 9-12 calculations for different combinations of U_g, d and L for each frame profile but when this is done the Ψ–value can be determined very easy for every combination of the three parameters without performing time-consuming 2-D calculations. When the model coefficients b1 to b7 are known and implemented in the database for the actual frame the user can chose a glazing unit and an edge construction from the database and then Ψ s calculated directly from the regression model expression (1).

The method is described in details in Appendix A2 and in the report “A method for characterizing the thermal properties of window frame profiles” [3]. See also example 2.

4. Comments

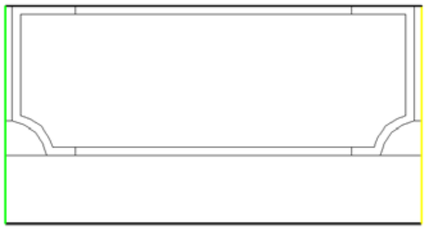
It is recommended that the database in WIS is extended in such a way that the described product data for spacers and edge constructions and frame profiles can be included. Moreover the mentioned calculations methods should be applied. This will make WIS more flexible and it will be easy to select the different elements (panes, gab widths, gas fillings, shadings, edge constructions, frame profiles) and calculate the characteristic energy performance data of a number of different windows.

Example 1. Edge construction documentation for WIS database

The example describes the procedure of determining the thermal properties of an edge construction and which data and information should be given in the WinDat database.

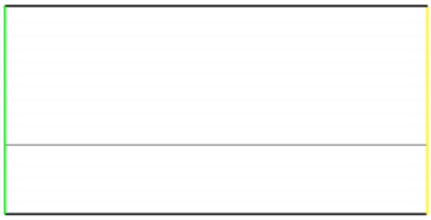
Determination of λ_{eq} and L

1. The heat flow through the edge construction using a detailed model and the boundary condition shown in Figure A1. 1 in appendix A1 is calculated using a 2d-calculation program.



   Heat flow = 0.5049 W/mK

2. Make a two box model (with the same width as the actual edge construction) consisting of the 3mm sealant bottom box with a thermal conductivity of 0.4 W/mK and a spacer box where the height is 6mm.



3. Fit the thermal conductivity, $\lambda_{\text{spacer box}} = \lambda_{eq}$, of the spacer box until the same heat flow through the model is achieved, as in the detailed model of the edge construction (from 1.).

   Heat flow = 0.5049 W/mK is obtained for an equivalent thermal conductivity of ***λ_{eq} = 3.95 W/mK***

4. Calculate the overall thermal conductance, L , of the edge construction

$$L = \lambda_{spacer\ box} \cdot \frac{h_{\text{spacer box}}}{b} + \lambda_{sealant} \cdot \frac{h_{sealant}}{b}$$

$$L = 3.95\, W/mK \cdot \frac{6mm}{18mm} + 0.4W/mK \cdot \frac{3mm}{18mm} = \mathbf{1.38\ W/mK}$$

Edge construction in database

In Table 3 and Table 4 an example of the WIS database with edge constructions is shown.

Table 3. Example of edge construction database in WIS

Field name	**Definition**
Manufacturer	Rolltech
Product name	Ferrotech 18
Product code	Ferrotech 18
Materials, Spacer	Galvanized steel, λ= 50 W/mK Desiccant λ= 0.13 W/mK
Materials, Sealants	Polysulfide, λ= 0.4 W/mK Butyl, λ= 0.24 W/mK
Dimensions, Spacer	17.5 x 6.5 mm
Dimensions, Edge construction	18.1 x 9.5 mm
Equivalent thermal conductance	λ_{eq} = 3.95 W/mK
Overall thermal conductance	L = 1.38 W/mK
Drawing of edge construction	Rf.dwg
Comments	

Table 4. Example of edge construction database in WIS

Manufacturer	Product name	Product code	Materials	Materials, Sealants	Dimensions Spacer mm	Dimensions Construction mm	λ_{eq} W/mK	L W/mK	Comments	Drawing CAD	Drawing
Rolltech	Ferrotech 18	Ferrotech 18	Galvanized steel, λ= 50 W/mK Desiccant, λ= 0.13 W/mK	Polysulfide, λ= 0.4 W/mK Butyl, λ= 0.24 W/mK	17.5 x 6.5	18.1 x 9.5	3.95	1.38		RF 18.dwg	

Example 2. Frame documentation for WIS database

The example describes the procedure of determining the thermal properties of a window frame and which data and information should be given in the WinDat database. The used frame is made of wood and aluminium shown in Figure E.2.1.

Determination of U_f, Ψ

- The thermal transmittance U_f is determined in accordance with pr EN ISO 10077-2. The calculation is carried out using a detailed drawing of the frame profile and a 2D-calculation program with an insulation panel inserted instead of the actual glazing.

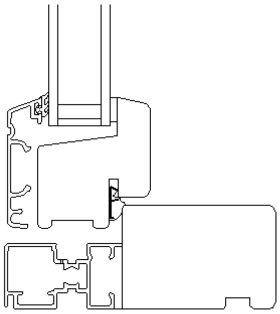
  

  Figure E.2.1. Frame of wood and aluminium.

  $U_f = 2.15\ W/m^2K$

- Ψ is calculated in accordance with prEN ISO 100077-2 with a specific glazing and edge construction inserted in the frame.
  Used glazing: 4 – 18 – 4 mm
  $U_g = 1.1$ W/m^{2}K
  Edge: Aluminium
  $\lambda_{eq} = 3.95$ W/mK

  Ψ = 0.0822

- Calculate Ψ for 12 combinations of *L, d* and U_g using the two box model instead of the actual edge construction. The results are given in Table 5.

Table 5. Ψ calculated for 12 combinations of overall thermal conductance, *L*, of the edge construction, the glass thickness, *d* and the thermal transmittance of the glazing, U_g.

Series	***L*** [W/mK]	***d*** [mm]	U_g [W/m²K]	*Ψ* [W/mK]
1	0.133333	4	1.1	0.036268
	0.4	4	1.1	0.060824
	1.733333	4	1.1	0.084817
2	0.133333	4	1.5	0.032337
	0.4	4	1.5	0.055004
	1.733333	4	1.5	0.077446
3	0.133333	4	2	0.027823
	0.4	4	2	0.048122
	1.733333	4	2	0.068618
4	0.171429	6	1.1	0.046442
	0.514286	6	1.1	0.072182
	2.228571	6	1.1	0.095103

- Carry out a regression analysis by entering the values (Table 5) in e.g. DataFit 8.0 as described in Appendix A2 and in **[3]**.

- The result from DataFit 8.0 is the seven coefficients b1 to b7:

  b1 = 0.58492997
  b2 = 0.040326029
  b3 = 2.077814876
  b4 = -0.007724378
  b5 = -1.070195533
  b6 = 0.107347637
  b7 = -0.013817993

  These values are entered in the WIS database for the actual frame profile.

- The found expression of Ψ for the actual frame profile is then:

$$\Psi = 0.585L^{0.0403} + 2.0778 + L - 1.0702d + 0.1073d^2 - 0.0138U_g \qquad (2)$$

The expression is plotted in the Figure E.2.2 below.

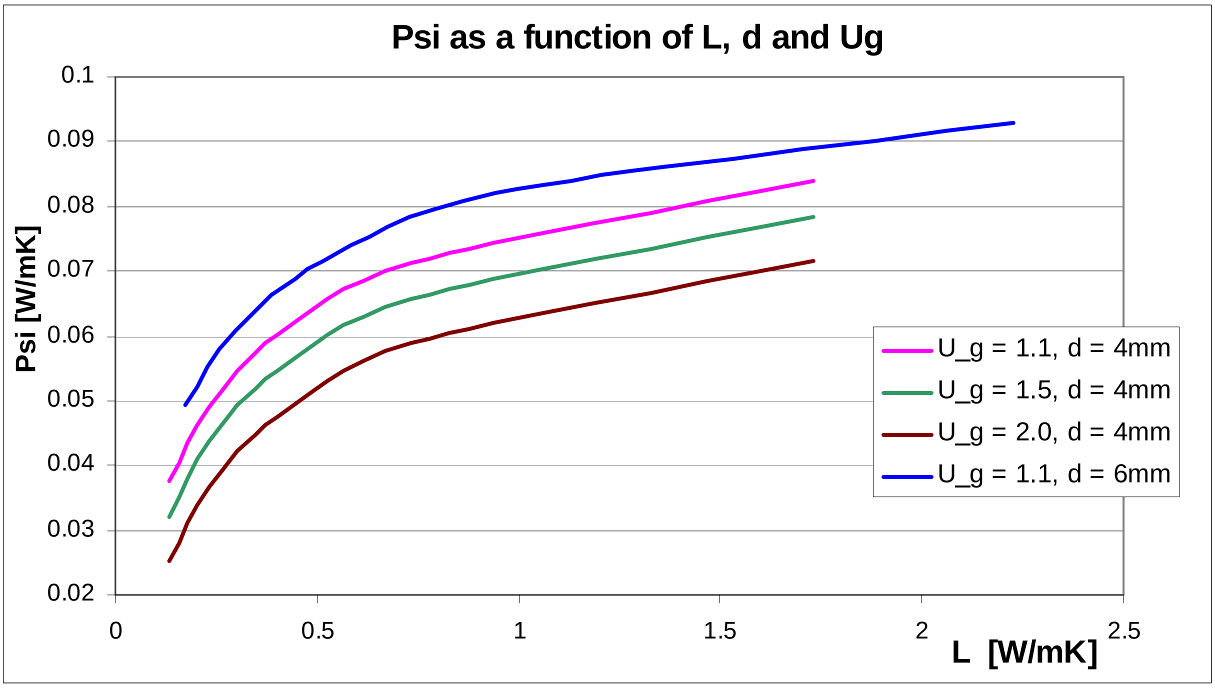


Figure E.2.2. Linear thermal transmittance, Ψ, plotted as a function of L, d and Ug, based on the expression (2)

Frame data in database

Table 6. Example of frame database in WIS

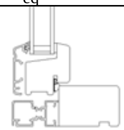
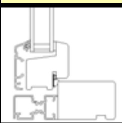
Field name	Definition	Comments
Manufacturer	X	
Product name	X	
Product code	X	
Materials	Wood λ= 0.13 W/mK Aluminium λ= 160 W/mK EPDM λ= 0.25 W/mK	
Position	Sill	
Opening direction	Out	
Width	0.092 m	
Depth	0.115 m	
Thermal transmittance	U_f = 2.15 W/m^{2}K	Calculated in accordance with prEN ISO 10077-2
Linear thermal transmittance	Ψ = 0.0822 W/mK	Glazing: 4-18-4 mm U_g = 1.1 W/m^{2}K λ_{eq} = 3.95 W/mK
Drawing of edge construction	DK f6.dxf	
Regression model coefficients	b1 = 0.58492997 b2 = 0.040326029 b3 = 2.077814876 b4 = -0.007724378 b5 = -1.070195533 b6 = 0.107347637 b7 = -0.013817993	Determined on basis of detailed calculations of Ψ for different combinations of L, U_g and d.

Table 7

Manufac-turer	Product name	Product code	Materials	Position	Opening direction	Width m	Depth m	U_f W/m^{2}K	Ψ for specific glazing and spacer	Comments	Drawing CAD	Drawing
xx	xx	DK f6	Wood: λ= 0.25 W/mK Aluminium: λ= 160 W/mK EPDM: λ= 0.25 W/mK	Sill	Out	0.092	0.115	2.15	Glazing: 4-18-4 mm U_g = 1.1 W/m^{2}K λ_{eq} = 3.95 W/mK Ψ = 0.0822 W/mK		Dk f6.dxf	

References

[1] WinDat WP2.3, Edge seals, Frames and Windows. Edge constructions and frames. Report for WINDAT meeting in Dublin April 2003. Technical University of Denmark, April 2003.

[2] Pedersen, F., Laustsen, J.B., Svendsen, S., A Method for Characterising the Thermal Properties of Window Frame Profiles. DTU. Copenhagen September 2003 (**WinDat_N2.09**)

[3] Pedersen, F. Solving non-linear data fitting problems using DataFit 8.0. DTU. Copenhagen march 2004 (**WinDat_N2.10**)

[4] CEN (2000): EN ISO 10077-1. 2000. European Standard. Thermal performance of windows, doors and shutters – calculation of thermal transmittance – Part 1: Simplified method.

[5] CEN (2003):prEN ISO 10077-2. 2003. European Standard. Thermal performance of windows, doors and shutters – calculation of thermal transmittance – Part 2: Numerical method for frames.

Appendix A1. The two box model

The two box model method is summarised in the following.
Instead of a model of the actual edge construction, a simple two box model with an equivalent thermal conductivity, λ_{eq}, is used resulting in the same heat flows.
The edge construction is modelled as two boxes: one replacing the sealant of polysulphide with a box having the dimensions of 3mm x width of the edge construction and a thermal conductivity of 0.4 W/mK and one replacing the spacer profile with a box having the dimensions 6mm x width of the edge construction. For particularly high spacers a spacer box having the dimension of 10 mm x width of the edge construction can be used. The standard dimensions of the two box model is shown in Figure A1. 1.

In the top and the bottom of the box model adiabatic boundary conditions are applied.
The boundary conditions of the two box model are shown in Figure A1. 1.

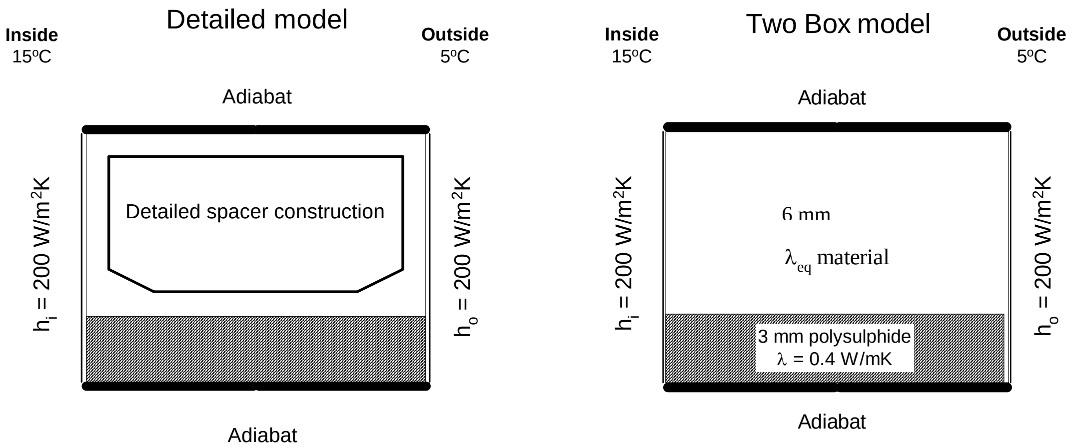


Figure A1. 1: Boundary condition around the edge construction. On the right the two-box model is shown consisting of a bottom box of 3 mm polysulphide and a spacer profile box of 6 mm (standard - independent of the actual dimensions of the spacer profile). The indside and outside surfaces of the spacer profile are covered with a 0.3 mm layer of butyl sealant.

Equivalent thermal conductivity, λ_{eq}

Calculation of the equivalent thermal conductivity, $\lambda_{eq,}$ of the detailed edge construction follows step 1 – 3 below. Calculations must be performed in a 2d-simulation program.

1. Calculate the heat flow through the actual edge construction using a detailed model and the boundary condition shown at Figure A1. 1.
2. Make a “two box” model consisting of the 3mm sealant bottom box with a thermal conductivity of 0.4 W/mK and a spacer box with the height 6mm and the boundary conditions as shown in Figure A1. 1.
3. Fit the thermal conductivity, λ_{eq}, of the spacer box until the same heat flow through the model is achieved, as in the detailed model of the edge construction (from 1.).

The found equivalent thermal conductivity, λ_{eq}, can now be used to calculate the linear thermal transmittance, Ψ, when the two box model is inserted in a specific frame profile replacing the actual edge construction.

Overall thermal conductance, *L*

To take the dimensions of the actual edge construction into account the overall thermal conductance, *L*, of the edge construction is introduced. *L* is given by

$$L = \lambda_{\text{spacer box}} \cdot \frac{h_{\text{spacer box}}}{b} + \lambda_{\text{sealant}} \cdot \frac{h_{\text{sealant}}}{b}$$

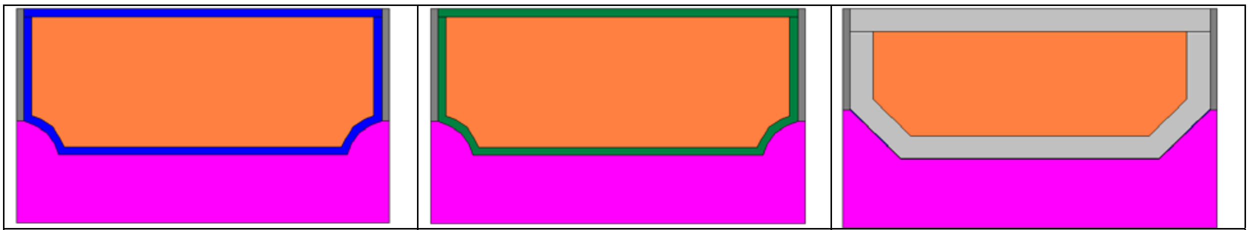
Where

b	is the width of the edge construction
$h_{\text{spacer box}}$	is the height of the spacer box = 6 mm (10 mm)
h_{sealant}	is the height of the sealant box = 3 mm
$\lambda_{\text{spacer box}}$	is the equivalent thermal conductivity of the edge construction = λ_{eq}
λ_{sealant}	is the conductivity of the sealant = 0.4 W/mK

The connection between Ψ and L can be used in the documentation of frames for easy determination of Ψ. See Appendix A2.

Validation of the Two box model

The two box model has been used in calculations of the linear thermal transmittance, Ψ, for three different frames and three different edge constructions. The used spacers are shown in Figure A1. 2.



A. Spacer of aluminium	B. Spacer of stainless steel	C. Plastic with alu. foil

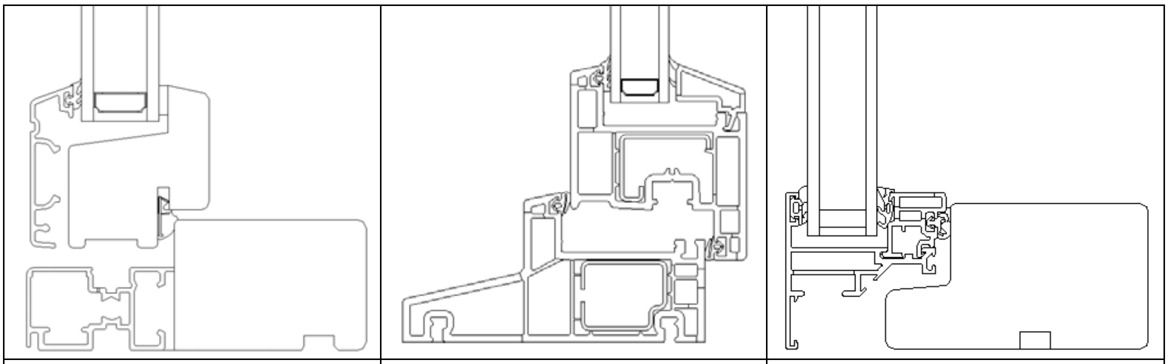
Figure A1. 2. Three edge constructions investigated. Sealants: Butyl and polysulfide.

The equivalent thermal conductivity, λ_{eq}, and overall thermal conductance, L, are calculated according to the two box model. The results are shown in Table A1. 1.

Table A1. 1. Equivalent thermal conductivities, λ_{eq} and L [W/mK] of the spacer box.

			Width of edge construction							
Spacer Material			12 mm		15 mm		16 mm		18 mm	
		Height	λ_{eq}	L	λ_{eq}	L	λ_{eq}	L	λ_{eq}	L
A	Spacer of aluminium	6.5	4.886	2.52	5.778	2.38	6.132	2.36	6.585	2.25
B	Spacer of stainless steel	6.5	3.257	1.71	3.646	1.53	3.761	1.48	3.953	1.38
C	Plastic with alu. foil	6.6	0.626	0.41	0.677	0.35	0.691	0.33	0.714	0.30

The used frame profiles are typical in Denmark. Frame 1) is made of wood and aluminium. Frame 2) is made of PVC with internal profiles of steel. Frame 3) is made of wood, aluminium and PCV. The frame profiles are shown in Figure A1. 3.



1) Wood and aluminium	2) Plastic	3) Mixed materials

Figure A1. 3. Frame profiles used in the test

The results of Ψ calculated using the detailed edge construction and the two box method are shown in Table A1. 2.

Table A1. 2. Linear thermal transmittance calculated with the detailed model of the edge construction and the two box model inserted in three different frame profiles. Edge constructions: A = Aluminium, B =stainless steel, C = plastic.

	Frame: Wood/alu			Frame: Plastic			Frame: Wood/alu/PVC		
Ψ [W/mK]	Edge construction			Edge construction			Edge construction		
	A	B	C	A	B	C	A	B	C
Detailed edge construction	0.0873	0.0822	0.0536	0.0589	0.0567	0.0408	0.0605	0.0589	0.0483
Two box model	0.0874	0.0822	0.0546	0.0590	0.0567	0.0421	0.0608	0.0591	0.0497
Difference	0.1 %	0.0 %	1.9 %	0.2%	0.0 %	3.1 %	0.4%	0.3 %	2.9 %

There is in general a good consistency between the Ψ-values calculated using the two box model and the detailed edge constructions. The two box model gives slightly higher values, so the method is conservative. The differences between the results are highest for the edge constructions with low equivalent conductivity, but still the differences are less than 3.1 %, which is acceptable.

Appendix A2. Ψ as a function of *L*, *d* and U_g

The linear thermal transmittance *Ψ* describes the additional heat flow caused by the interaction of the frame and the glass edge, including the effect of the spacer. Therefore *Ψ* for a frame is dependent on both the actual glazing and edge construction used.
To extend the flexibility of WIS, *Ψ* is expressed as a function of the centre thermal transmittance of the glazing, U_g, the glass thickness *d*, and overall thermal conductance, *L*.

The method is to describe the linear thermal transmittance as a function of L , d and U_g by fitting a regression model of Ψ to a limited number of detailed calculations of Ψ, made with a 2D-program. This is done by carrying out a regression analysis on a number of Ψ-values determined for different values of L, d, and U_g.

Investigations have shown that a regression model with seven coefficients gives a good match with the exact Ψ-values for all types of typical frame profiles. The following general expression of Ψ as a function of the three parameters is found:

$$\Psi = b1L^{b2} + b3 + b4L + b5d + b6d^2 + b7U_g \qquad (1)$$

Where

L is the overall thermal conductance of the edge construction [W/mK] (See appendix A1)
d is the average thickness of the glass panes in the glazing [m]
U_g is thermal transmittance of the centre of the glazing [W/m²K]
b1 to *b7* are coefficients for the actual frame found in datafitting program

The method requires approximately 9-12 calculations for different combinations of U_g, d and L for each frame profile:

Table A2. 1. Parameter values for regression analysis.

L	0.1	0.5	2.0	0.1	0.5	2.0	0.1	0.5	2.0	0.1	0.5	2.0
d	4	4	4	4	4	4	4	4	4	6	6	6
U_g	1.1	1.1	1.1	1.8	1.8	1.8	2.8	2.8	2.8	1.1	1.1	1.1

The coefficients *b1* to *b7* can be found using a data fitting program e.g. DataFit 8.0 (see http://www.curvefitting.com/).

The method is described in details in the report "A method for characterizing the thermal properties of window frame profiles" [3].

The regression model is validated for different frame profiles of wood, PVC, aluminium and one made of mixed materials. It was found that the residuals are always below 0.005. The results for the Wood/alu frame profile is shown in Figure A2. 1 where the regression model with the found model coefficients is plotted together with the exact Ψ- values calculated in a detailed simulation program. The second and fourth (L= 0.23 and L=0.73) values in each series are control values, which were not used in the regression analysis.

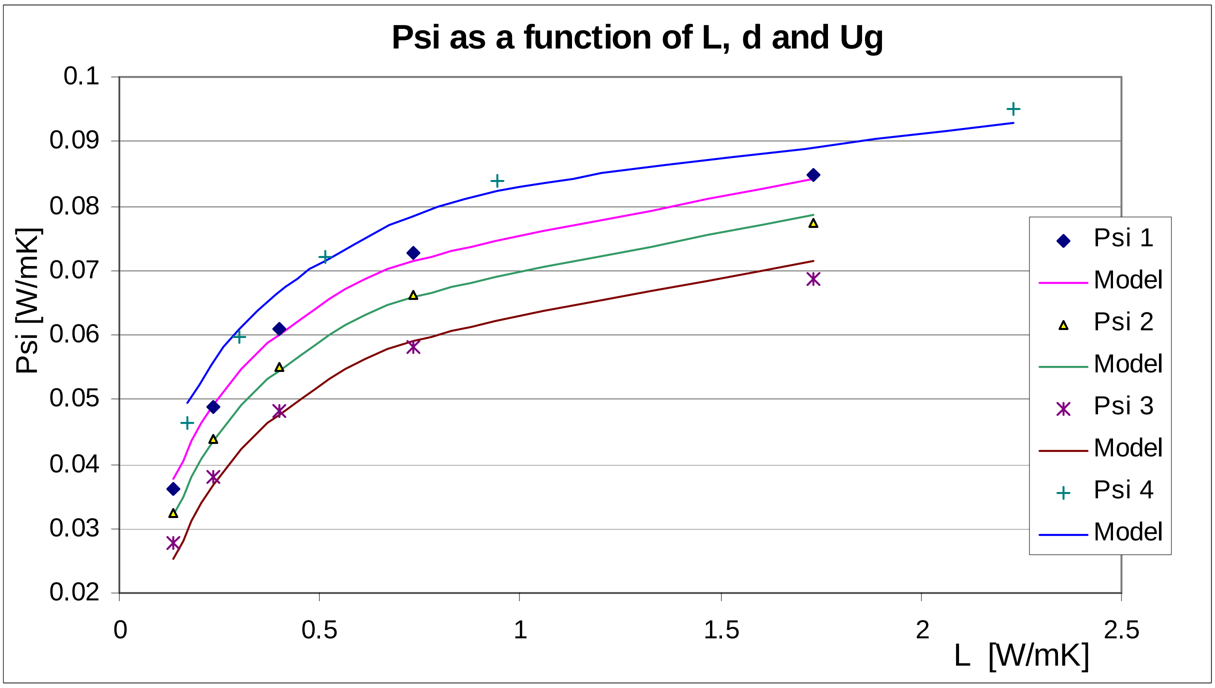


Figure A2. 1. Regression model plotted together with the exact Ψ- values calculated in a detailed simulation program.

There is in general a good consistency between the regression model of Ψ and the exact values. Corresponding validation tests have shown that the residual between the regression model and detailed calculations of Ψ, for various combinations of L, d and U_g is never above 0.005, which is acceptable.