# Linear thermal transmittance of the assembly of the glazing and the frame in windows

***Svend Svendsen,Professor,***
***Technical University of Denmark;***
***ss@byg.dtu.dk; www.byg.dtu.dk***

***Jacob B. Laustsen, Assistant research professor,***
***Technical University of Denmark;***
***jbl@byg.dtu.dk; www.byg.dtu.dk***

***Jesper Kragh, Assistant research professor,***
***Technical University of Denmark;***
***jek@byg.dtu.dk; www.byg.dtu.dk***

*KEYWORDS:* Window, glazing unit, edge construction, spacer profile, linear thermal transmittance, equivalent thermal conductivity.

**SUMMARY**:
*The thermal transmittance or U-value of windows can be found by calculation according to the standards EN ISO 10077-1/2 (CEN,2000). The window U-value is calculated from the U-value of the glazing and the frame as well as the linear thermal transmittance of the assembly of the glazing and the frame. The U-value of the glazing and the frame can be calculated separately while the calculation of the linear thermal transmittance includes the design of the edge construction of the glazing unit but also the design of the frame and the glazing unit.*

*The edge construction of glazing units is made up of a spacer profile and a sealing. The spacer profile is typically made of metal and acts as a significant thermal bridge. Spacer profiles with improved thermal characteristics have been developed and are being introduced as 'warm edge'. They are typically based on thin layers of stainless steel or combinations of polymers and metallic foils. The modelling of edge constructions in detailed calculations is time consuming and may give problems with the accuracy of the finite element calculation.*

*The paper describes a methodology to characterize the thermal performance of edge constructions in glazing units by use of an equivalent thermal conductivity of a box of a fictive material that replaces the detailed spacer profile. A number of typical spacer profile products have been used in a test of the methodology where the linear thermal transmittance of the assembly of the glazing and the frame was calculated with the detailed spacer profile and with the equivalent box. The results proved that the method is accurate and easy to use. The equivalent thermal conductivity of spacer profiles can also be used in simplified calculations of windows and in this way make it easy to document the effect of use of warm edge profiles in glazing units.*

*The equivalent thermal conductivity of spacer profiles have also been used in a method to express the linear thermal transmittance for a specific frame in combinations with all types of glazing units and edge constructions. By use of this method window manufacturers can establish a general valid documentation of the linear thermal transmittance for their frame profiles for all glazing units and edge constructions and in this way make it easy to document the U-value of windows with all types of glazing units and edge constructions.*

## 1. Introduction

The heat loss through the windows in a building is typically 50% of the total transmission loss of the building. Therefore it is important to have reliable data on the thermal transmittance of the actual windows in a comparison of products for use in the design of a building.

The thermal transmittance or U-value of windows can be found by calculation according to the standards EN ISO 10077-1/2 *2* (CEN, 2000). The window U-value is calculated from the U-value of the glazing and the frame as well as the linear thermal transmittance of the assembly of the glazing and the frame. The U-value of the glazing and the frame can be calculated separately while the calculation of the linear thermal transmittance includes the design of the edge construction of the glazing unit but also the design of the frame and the glazing unit.

The window manufacturer may have a limited number of frame profiles, but he has to use many different glazing units with different edge constructions in his windows. In order to find the linear thermal transmittance it is possible to use typical values according to EN ISO 10077-1 (CEN, 2000) but not all frame profiles and edge constructions can be treated in this way or too conservative values are obtained. Alternatively a detailed finite element calculation can be used to find the linear thermal transmittance of the specific combination of glazing, edge construction and frame product.

The edge construction of glazing units is made up of a spacer profile and a sealing. The spacer profile is typically made of aluminum or steel and acts as a significant thermal bridge. Spacer profiles with improved thermal characteristics have been developed. They are typically based on thin layers of stainless steel or combinations of polymers and metallic foils. In order to calculate the correct linear thermal transmittance the spacer profile has to be modelled very detailed in a finite element program. This is time consuming and therefore it is interesting to develop methods that can simplify the calculations without loss of accuracy.

## 2. The two box model of the edge construction

A method to present the linear thermal transmittance as a function of the characteristic thermal properties of the edge construction and the glazing has been developed. This is called the “two box model” and refers to the spacer profile and seal that together form the edge construction. Instead of a model of the actual edge construction, a simpler two box model with an equivalent thermal conductivity, $\lambda_{eq}$, is used resulting in the same heat flows (Laustsen, J. B et al, 2003b).

The edge construction is modelled as two boxes: one replacing the sealant of polysulphide with a box having the dimensions 3mm x gap and a thermal conductivity of 0.4 W/mK and one replacing the spacer profile with a box having the dimensions 6mm x gap. The fixed height of the spacer box is chosen in order to simplify the determination of the linear thermal transmittance in the documentation of frames. The 6 mm is a typical height of spacers but for higher spacer profiles a standard spacer box of 10 mm is suggested and investigated separately. The standard dimensions of the two box model are shown in Figure 1.

In the top and the bottom of the box model adiabatic boundary conditions are applied. At the surfaces of the edge construction that normally is in contact with the glass panes a heat transfer coefficient of 200 $W/m^2K$ is used to simulate the heat transfer of the glass panes.  The boundary conditions of the two box model are shown in Figure 1.

The procedure of calculating the equivalent thermal conductivity, $\lambda_{eq}$, is to calculate the heat flow through the detailed model of the edge construction. Once this is done the thermal conductivity of the top layer in the box model is fitted, until the same heat flow is achieved, as in the detailed model. The principle of the calculation procedure is shown in Figure 1.

The equivalent thermal conductivity, $\lambda_{eq}$, can now be used to calculate the linear thermal transmittance, $\Psi$, when the two box model is inserted in a specific frame profile replacing the actual edge construction. The equivalent thermal conductivity, $\lambda_{eq}$, is only valid for the edge construction in the actual dimensions.

The connection between $\Psi$ and $\lambda_{eq}$ can be used in the documentation of frames for easy determination of $\Psi$.

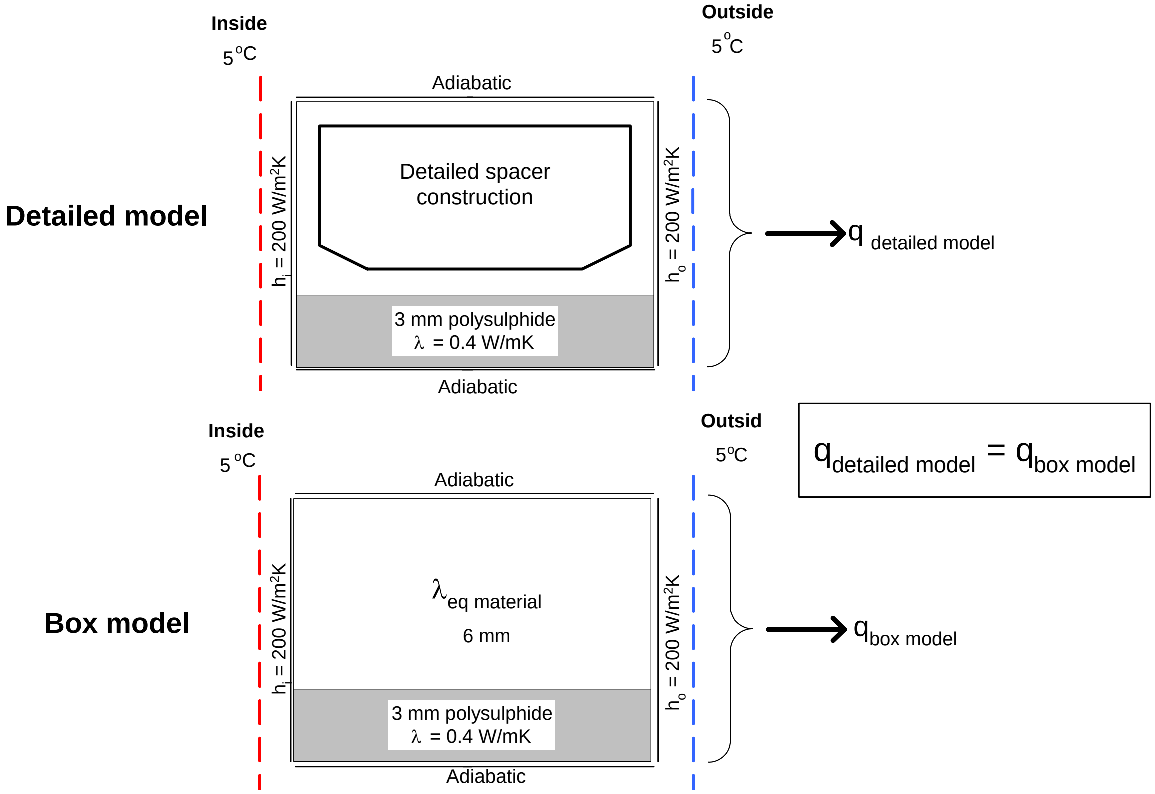



Figure 1 Calculation procedure for determining the equivalent thermal conductivity $\lambda_{eq}$. $q_{detailed\ model}$ and $q_{box\ model}$ are the heat flow through the total constructions. The two box model consists of a bottom box of 3 mm polysulphide and a spacer profile box of 6 mm (standard - independent of the actual dimensions of the spacer profile).

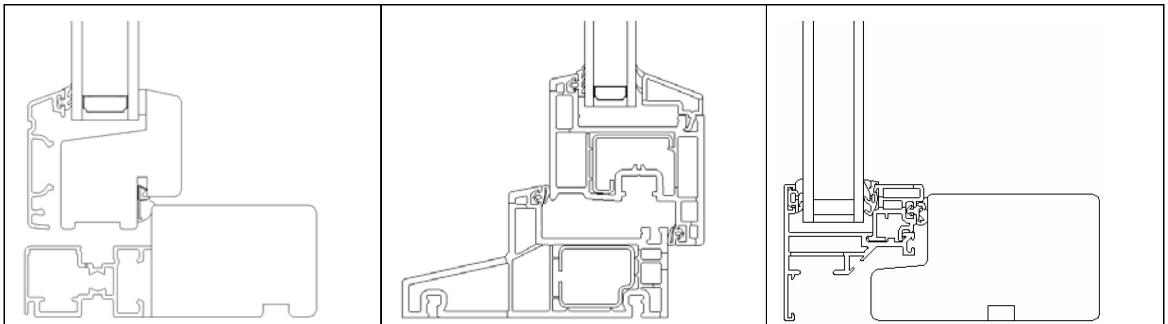
## 2.1 Validation of the two box model

The two box model method described in the previous has been tested with three different edge constructions mounted in different frame profiles. Calculations are performed in the 2-D calculation program Therm (LBNL, 2003) and in accordance with EN ISO 10077-2 (CEN, 2003). The found $\lambda_{eq}$ are shown in Table 1.

*Table 1.* ***Equivalent thermal conductivities, $\lambda_{eq}$ [W/mK] of the spacer box.***

| | | | Width of edge construction | | | |
|---|---|---|---|---|---|---|
| Spacer Material | | | 12 mm | 15 mm | 16 mm | 18 mm |
| | | Height | $\lambda_{eq}$ | $\lambda_{eq}$ | $\lambda_{eq}$ | $\lambda_{eq}$ |
| A | Spacer of aluminium | 6.5 | 4.886 | 5.778 | 6.132 | 6.585 |
| B | Spacer of stainless steel | 6.5 | 3.257 | 3.646 | 3.761 | 3.953 |
| C | Plastic with alu. foil | 6.6 | 0.626 | 0.677 | 0.691 | 0.714 |

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 2



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

*Figure 2  Frame profiles used in the test*

In Table 2 and Figure 3 the calculations of the linear thermal transmittance are compared for the detailed model of the edge construction and the two box model inserted in the frame profiles.

*Table 2. Linear thermal transmittances, Ψ, for the three edge constructions in combination with the three frame profiles calculated with detailed construction and the two box model.*

| Frame profile | Ψ [W/mK] | Edge construction | | |
|---|---|---|---|---|
| | | A | B | C |
| Frame 1) | Detailed edge construction | 0.0873 | 0.0822 | 0.0536 |
| $b_{edge}$ = 18 mm | Two box model | 0.0874 | 0.0822 | 0.0546 |
| | Difference | 0.1 % | 0.0 % | 1.9 % |
| Frame 2) | Detailed edge construction | 0.0589 | 0.0567 | 0.0408 |
| $b_{edge}$ = 15 mm | Two box model | 0.0590 | 0.0567 | 0.0421 |
| | Difference | 0.2% | 0.0 % | 3.1 % |
| Frame 3) | Detailed edge construction | 0.0605 | 0.0589 | 0.0483 |
| $b_{edge}$ = 16 mm | Two box model | 0.0608 | 0.0591 | 0.0497 |
| | Difference | 0.4% | 0.3 % | 2.9 % |

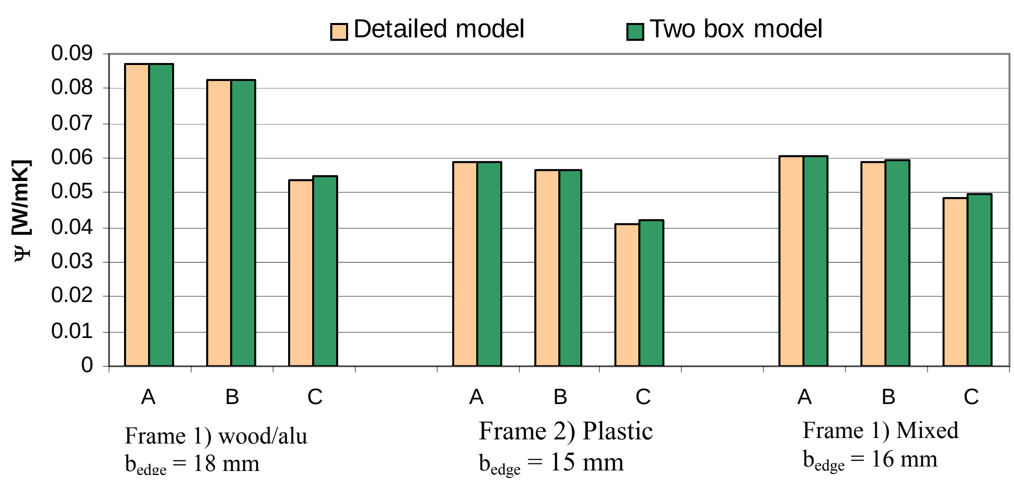
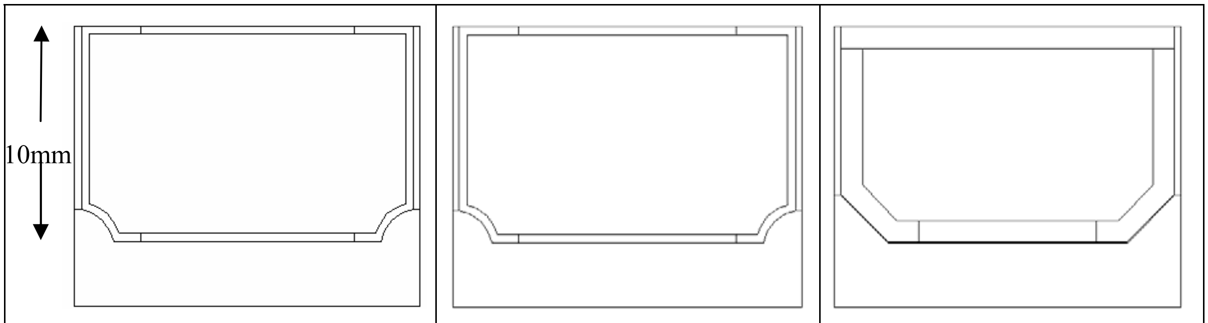



Figure 3 Ψ-value of the three frame profiles using the detailed model and the box model of the three edge constructions.

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%, and for overall U-values for total windows the error will be smaller. When the Ψ-value is rounded to two decimals the difference will in most cases be removed.

## 2.2 Height of spacer box

In a test of the proposed two box model on high (9 mm) spacer profiles (Renon, O. 2003) it has been shown that using the fixed spacer box height of 6 mm could be inappropriate when modelling high spacers because it will result in very high equivalent conductivities. Therefore the two box model was tested for high edge constructions with spacer height of 10 mm. As no such spacers were available they were constructed by extending the spacers in Table 1. The large edge constructions are shown in Figure 7.




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

*Figure 4. High spacer profiles. The spacers are all 10 mm high.*

First the equivalent thermal conductivity was determined by means of the two box method for 6 mm and 10 mm spacer boxes resulting in same heat flow as in the detailed high edge construction. The results are shown in Table 3.

*Table 3 Equivalent thermal conductivities, $\lambda_{eq}$ [W/mK] calculated for spacer box heights 6 mm and 10 mm. The width of the edge construction is 16 mm and the height is 13 mm.*

| | | | Height of spacer box | |
|---|---|---|---|---|
| Spacer Material | | Spacer Height | 6 mm $\lambda_{eq}$ | 10 mm $\lambda_{eq}$ |
| A | Aluminium | 10 mm | $\rightarrow \infty$ | 4.069 |
| B | Stainless steel | 10 mm | 13.628 | 2.367 |
| C | Plastic with alu. foil | 10 mm | 0.845 | 0.425 |

The linear thermal transmittance, Ψ, was calculated for the three high edge constructions (Figure 4) inserted in frame profile 3) (Figure 2) and then Ψ was calculated for the equivalent thermal conductivities of the 6 mm and 10 mm box models found above. The results are given in Table 4.

*Table 4 Linear thermal transmittances for the three edge constructions using frame 3) calculated with detailed construction and the two box model. Width of edge construction b = 16 mm.*

| Ψ [W/mK] | Edge construction A | B | C |
|---|---|---|---|
| Detailed edge construction | 0.0698 | 0.0674 | 0.0505 |
| Two box model 6 mm | - | 0.0625 | 0.0510 |
| Difference | - | -7.3 % | 0.9% |
| Two box model 10 mm | 0.0707 | 0.0678 | 0.0535 |
| Difference | 1.3% | 0.7 % | 5.9 % |

The calculations show that using the 6 mm spacer box for higher spacers results in incorrect linear thermal transmittances. For the aluminium spacer it was not possible to calculate the equivalent conductivity because it should be above the limit in the calculation program (10.000 W/mK). Using a 10 mm spacer box instead of the standard 6 mm spacer box gives a better consistency between the detailed calculation and the two box method. It is therefore proposed to use two dimensions of the spacer box in the two box model: 6 mm for typical spacer profiles and 10 mm for special high spacer profiles.

# 3. Linear thermal transmittance as a function of equivalent thermal conductivity of the edge construction and glazing data

In order to find a way to express the Ψ-value in such a way that the dependency of the frame, edge construction and glazing are taken into account, their mutual dependencies are investigated. To develop an expression of Ψ, the connection between Ψ and the $\lambda_{eq}$ and the glazing was investigated using frame 1) on Figure 2 (Laustsen, J. B et al, 2003a). For the frame profile 1) the linear thermal transmittance, Ψ, of the assembly of the glazing unit and the frame profile was calculated for different equivalent thermal conductivities of the edge construction. The edge construction was modelled with the two box model inserted in the glazing instead of the actual edge construction. To get a representative curve λ-values have been chosen in the relevant area between 0 and 8 [W/mK]. The results together with a fitted curve are shown in Figure 5.

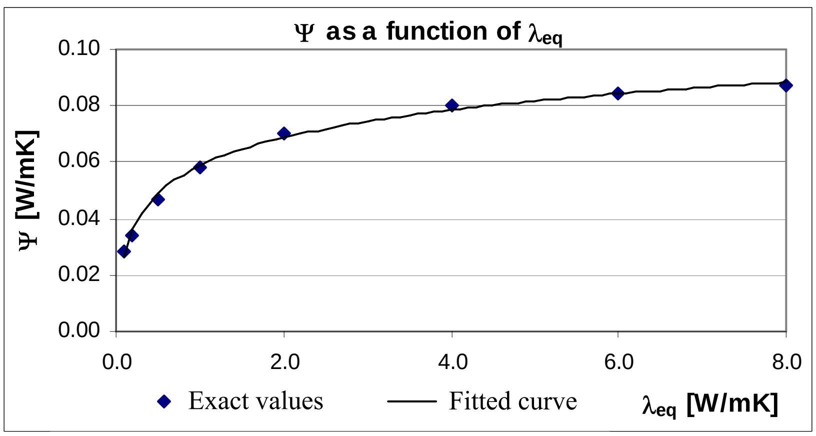



*Figure 5 The linear thermal transmittance, Ψ, for different values of the equivalent thermal conductivity, $\lambda_{eq}$, of the edge construction. The thermal transmittance of the glazing $U_g$= 1.2 W/m$^2$K and the glass thickness is 4 mm. The "Exact" values are based on calculation with two box model.*

It appears that there is a connection between Ψ and $\lambda_{eq}$, which can be described by a logarithmic function. By using curve fitting the following expression is found.

$$\Psi = 0.0142 \cdot \ln(\lambda_{eq}) + 0.0588 \qquad [1]$$

This expression is only valid for the specific width of the edge construction used in the actual frame, but it can be generalized to be valid for any arbitrary frame as:

$$\Psi = a \cdot \ln(\lambda_{eq}) + b \qquad [2]$$

where a and b are constants connected to the specific frame.

## 3.1 Investigation on the method of describing Ψ as a function of $\lambda_{eq}$

The linear thermal transmittance also depends on the U-value of the glazing and the thicknesses of the glass panes. To evaluate the influence of the glass thickness on Ψ, calculations with different glass thicknesses of 4 mm and 6 mm have been carried out for frame 1 made of wood/alu. The glass thickness is increased by reducing the gap between the glass panes, which results in a change in the edge construction/two box model. The results are shown in Figure 6.

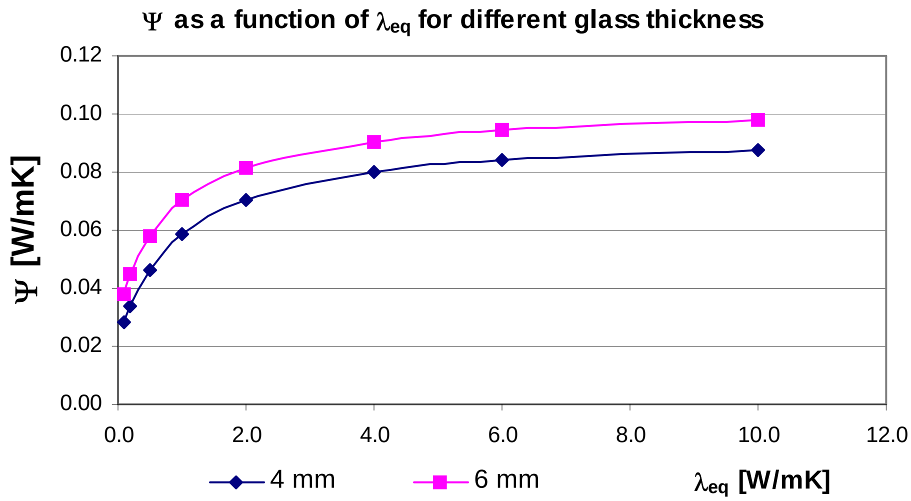



Figure 6 Linear thermal transmittance for frame 1 with glass thicknesses of 4 mm and 6 mm.

To evaluate the influence of the glazing U-value on Ψ, calculations of the linear thermal transmittance for different values of $\lambda_{eq}$ have been performed for frame 1 in combination with three U-values of the glazing ($U_g$ = 1.1, 1.5 and 2.0 $W/m^2K$). The results are shown in Figure 7.

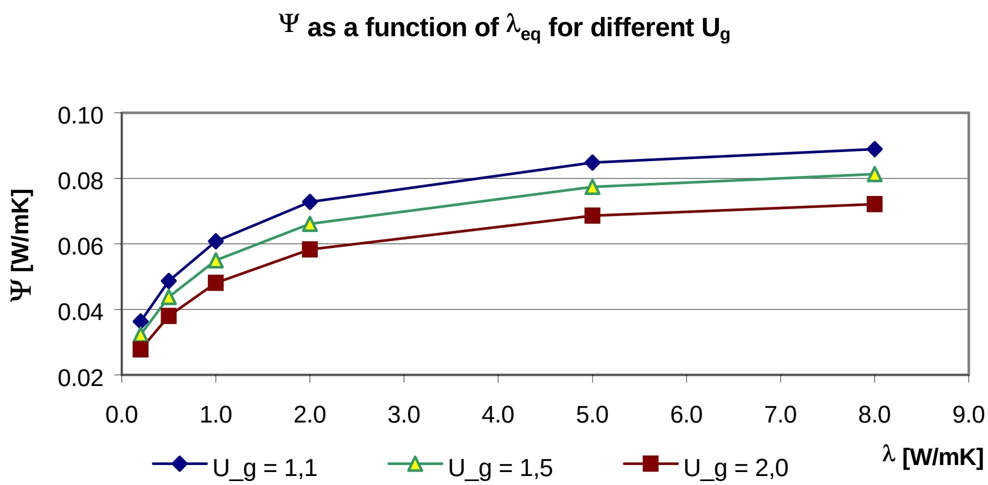



*Figure 7 Linear thermal transmittance for frame 1 with different equivalent thermal conductivities of the spacer and different $U_g$ of the glazing*

From *Figure 6* it appears that the linear thermal transmittance is increased for a higher glass thickness. Figure 7 shows that the linear thermal transmittance decreases when the U-value of the glazing increases, but the three curves follow almost the same pattern. These connections might be exploited for developing an extended version of the expression of Ψ as a function of L where also $U_g$ and the glass thickness are taken into account. In this way Ψ would be given as a function of L, $U_g$ and the glass thickness.

# 4. Database with data on spacer profiles and edge constructions

In order to make characteristic data on the thermal performance of spacer profiles and edge constructions easily available a database has been established as part of the EU-project WinDat. A data submission procedure of thermal properties of edge constructions and frame profiles has been developed (Svendsen, S. et al, (2004)). An example is shown in Table 5.

*Table 5 Example of data for the WinDat database.*

| Field name | Definition |
|---|---|
| Manufacturer | x |
| Product name | x 18 |
| Product code | x 18 |
| Materials, Spacer | Galvanized steel, $\lambda$= 50 W/mK, Desiccant $\lambda$= 0.13 W/mK |
| Materials, Sealants | Polysulfide, $\lambda$= 0.4 W/mK, Butyl, $\lambda$= 0.24 W/mK |
| Dimensions, Spacer | 17.5 x 6.5 mm |
| Dimensions, Edge construction | 18.1 x 9.5 mm |
| Equivalent thermal conductance | $\lambda_{eq}$ = 3.95 W/mK |
| Drawing of edge construction | Rf.dwg |

A number of commercial spacer profiles have been treated and data for them are available on the homepage of WinDat.

# 5. Conclusion

A methodology to characterize the thermal performance of spacer profiles and edge constructions of sealed glazing units has been developed and investigated. The methodology is based on a two box model of the edge construction and makes use of an equivalent thermal conductivity of the spacer profile found by detailed finite element calculations of the edge construction with boundary conditions that represent the thermal conductance of the glass panes.

A number of typical spacer profile products have been used in a test of the methodology where the linear thermal transmittance of the assembly of the glazing and the frame was calculated with the detailed edge construction and with the two box model. The results proved that the method is accurate and it makes the calculations of the linear thermal transmittance easier to perform.

The equivalent thermal conductivity of the edge construction has been used in a method to express the linear thermal transmittance for a specific frame in combinations with all types of glazing units and edge constructions. By use of this method, window manufacturers can establish a general valid documentation of the linear thermal transmittance for their frame profiles for all glazing units and edge constructions and in this way make it easy to document the U-value of windows with all types of glazing units and edge constructions.

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