# Calculating the heat transfer coefficient of frame profiles with internal cavities

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**SUMMARY:**

*Determining the energy performance of windows requires detailed knowledge of the thermal properties of their different elements. A series of standards and guidelines exist in this area. The thermal properties of the frame can be determined either by detailed two-dimensional numerical methods or by measurements in accordance to European or international standards.*

*Comparing measured and calculated heat transfer coefficients for two typical frame profiles with cavities shows considerable differences. This investigation considers two typical frame profiles in aluminium and PVC with internal cavities. The heat transfer coefficient is determined by two-dimensional numerical calculations and by measurements. Calculations are performed in Therm (LBNL (2001)), which is developed at Lawrence Berkeley National Laboratory, USA. The calculations are performed in accordance with the future European standards and measurements have been performed at two German research institutes.*

*The internal cavities have a large influence on the overall thermal performance of the frame profiles and the investigation shows that the applied method for modelling the heat transfer by radiation exchange in the internal cavities of the profiles is critical. The simple radiation model described in the pre European standard (prEN ISO 10077-2) does not yield valid results compared to measured values. Applying a more detailed, viewfactor based, grey surfaces enclosure model as described in the ISO standard (ISO/DIS 15099) gives a better correspondence between measured and calculated values. Hence, when determining the heat transfer coefficient of frame profiles with internal cavities by calculations, it is necessary to apply a more detailed radiation exchange model than described in the prEN ISO 10077-2 standard. The ISO-standard offers such an alternative.*

# 1. Introduction

The energy performance of a fenestration product can be described by three parameters: The total thermal transmittance (U-value), the total solar energy transmittance and the total light transmittance.

Evaluating the total solar energy transmittance and light transmittance for the center of the glazing can be done according to EN 410 (CEN (1998)). These values can also be based on the total area of the window in accordance to ISO/DIS 15099 (ISO (2001)).

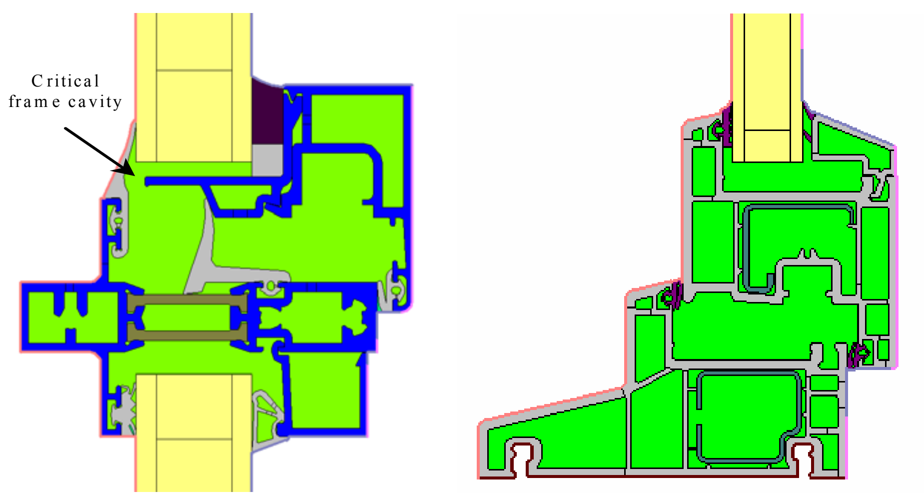
The thermal transmittance of the fenestration is based on the thermal transmittances of the frame and the glazing and the linear transmission coefficient in the assembly between the framing and glazing. Thermal transmittance of the glazing is determined using EN 673 (CEN (1997a)), EN 674 (CEN (1997b)) or EN 675 (CEN (1997c)) while the thermal transmittance of the frame and the linear transmission coefficient can be measured according to prEN 12412-2 (CEN (1997d)) or calculated according to EN ISO 10077-1 (CEN (1997e)) and prEN ISO 10077-2 (CEN (2000)).

The heat flow in a fenestration frame is complicated due to the complexity of the geometry. Consequently two-dimensional numerical methods complying with EN ISO 10211-1 (CEN (1995)) must be used. Several programs have been developed for this purpose. This study uses Therm developed at Lawrence Berkeley National Laboratory, USA. Therm is widely used at the Department of Civil Engineering at the Technical University of Denmark for calculating the thermal transmittance of fenestration frames in accordance with prEN ISO 10077-2.

However, considerable differences have been found between heat transfer coefficients for framing profiles with cavities calculated in accordance with prEN ISO 10077-2 using Therm and measurements performed at Forschungsinstitut für Wärmeschutz e.v. München, Germany  and Institut für Fenstertechnik, Rosenheim; Germany. This difference between calculated and measured results have called for a further investigation performed in the following.

# 2. Profiles

An aluminium and a PVC profile have been investigated. Both profiles are typical and identical to existing products. Figures 1a and 1b show the profiles. Outdoor climate is on the left side for both profiles.




a) b)

*Figure 1. Cross-sections of frame profiles of aluminium (a) and PVC (b).*

As in most fenestration frame profiles containing cavities, the cavities in these profiles have a large influence on the thermal transmittance of the profile.

Examining the aluminium profile shows that the thermal break (centre of profile) separates the warm inside from the cold outside aluminium part of the profile. However, the frame cavity above the thermal break around the glass bearing is critical. In this cavity the warm inside aluminium part of the profile is only separated from the outside by a small cavity. Hence heat transfer across this cavity could be critical.

Compared to the cavities in the aluminium profile, cavities in the PVC profile have a less but still significant influence on the profile thermal performance due to lower thermal transmittance of PVC compared to aluminium.

## 3. Measurements of the thermal transmittance

The heat transfer coefficient for both profiles has been measured in Germany. Measurements on the aluminium profile have been performed at Forschungsinstitut für Wärmeschutz e.v. München while measurements on the PVC profile were performed at Institut für Fenstertechnik, Rosenheim.

In both cases the measurements are performed in accordance to DIN 52619 in which the profile is placed in a separation between a hot and a cold room. The temperature difference over the profile is set to approximately 20 K. Based on measured steady state surface temperatures and heat flow though the profile it is possible to calculate the thermal resistance of the profile.

Based on the measured surface to surface thermal resistance the overall thermal transmittance can be calculated if applying the surface resistances due to convection and radiation along the inside and outside of the profile. The surface resistances are applied directly to the measured surface to surface thermal transmittance in accordance to DIN 4108-4 (DIN (2002)), inside $R_i = 0.13$ $m^2K/W$ and outside $R_o = 0.04$ $m^2K/W$.

The measured data for both profiles i.e. the thermal resistance without surface resistances and the thermal transmittance of the frame including standard thermal surface resistances are shown in Table 1. In the measurements both thermal resistance and the heat transfer coefficient is based on the projected area of the profiles.

*Table 1. Measured data.*

| | Aluminium profile | PVC profile |
|---|---|---|
| Thermal resistance [m2K/W] | 0.225 | 0.507 |
| Thermal transmittance [W/m2K] | 2.5 | 1.5 |

In the measurements, the thermal resistance along the surfaces is applied over the projected area of the frame profile according to DIN 52619 (DIN (1985)). I.e. due to the large difference between the projected area and the surface area of the frame profiles, the thermal transmittance stated in the measurements is not correct. Therefore the measured thermal resistance is used in the following.

## 4. Calculation of the thermal transmittance

Calculations of the thermal performance of the profiles are performed in accordance to prEN ISO 10077-2 using the program Therm.

In Therm the two-dimensional geometry of the profile is described as shown in Figure 1a and 1b. The glazing system in the frame has been substituted with an insulation panel, materials of the frame are assigned correct thermal properties and cavities are modelled as prescribed in prEN ISO 10077-2.

Boundary conditions are applied to the surfaces in accordance to prEN ISO 10077-2. Along the surfaces of the profiles the heat transfer coefficient due to convection and radiation exchange is given as $h_o = 23$ $W/m^2K$ on outside surfaces and $h_i = 8$ $W/m^2K$ on inside surfaces. Newer versions of prEN10077-2 states $h_o = 1/0.04$ $W/m^2K$ and $h_i = 1/0.13$ $W/m^2K$. However, surface resistances are excluded from the final results hence these differences has no practical influence. Edges and junctions along the inside of the profile are given an decreased heat transfer coefficient of $h_{i,inc} = 5$ $W/m^2K$. The indoor and outside temperatures are given as $T_i = 20$ ºC and $T_o = 0$ ºC.

Differences between assumed thermal properties in the modelling and actual properties of the real profiles materials are expected to be negligible. As the profiles are extruded based on CAD drawings also implemented in Therm, actual differences in geometry in material thickness are minimal.

The two-dimensional numerical methods performed in Therm are considered very accurate. Hence differences between calculated and measured properties of the profiles are primary caused by the thermal modelling of cavities and uncertainties during measurements.

### 4.1 Cavity models

In the prEN ISO 10077-2, cavities in the examined profiles are divided into ventilated and non-ventilated cavities, and effects regarding natural convection and radiation exchange between surfaces in the cavities are separated. Thus specific models for convection and radiation exchange are specified separately. In the examined profiles no ventilated cavities exist, therefore this investigation solely considers unventilated cavities.

The convection and radiation models implemented in prEN ISO 10077-2 are relatively simple and are both based on the transformation of all cavities into rectangular cavities with the same area and aspect ratio. Hence the convection model is based on simple convection analyses for enclosed cavities, whereas the radiation exchange model only consider radiation exchange between the surfaces orthogonal to the heat flow of the transformed cavities.

However, for profiles with significant internal cavities investigations show that the radiation exchange model in internal cavities has a considerable influence on the overall thermal performance. In profile a) Figure 1, this effect is expected especially important in the critical frame cavity at the glass bearing. Therefore an effort has been made to find a more detailed radiation exchange model than the one described by prEN ISO 10077-2. ISO/DIS 15099 offers such an alternative.

ISO/DIS 15099 describes a detailed, view factor based, radiation model where cavities are treated as diffuse, grey body enclosures. Contrary to the prEN model the ISO/DIS model considers the actual geometry of the cavities. Emissions factors of the cavity surfaces must be stated.

Therm implements the ISO/DIS 15099 model as a more detailed cavity model for radiation exchange and has been applied on the considered profiles. In the following, the effect of the applied radiation exchange model in cavities are examined.

### 4.2 Assignment of surface resistances

The surface resistances in the prEN ISO 10077-2 are applied over the entire area of the profile, whereas the DIN 52619 used in the measurements only applies the surface resistance over the projected area of the frame. Hence the calculated and measured thermal transmittance $U_{frame}$ values are not directly comparable.

However, if the calculated thermal properties of the frame profile are based on the calculated surface temperatures of the profiles and the inserted insulation panel, it is possible to calculate the thermal resistance $R_{calculated}$ of the profile excluding effects from surface resistances. This is directly comparable to the stated thermal resistance from the measurements. To reduce uncertainties to a minimum, calculated surfaces temperatures on the profile and the inserted insulation panel are stated in positions corresponding to the positions used during the measurements of the thermal performance of the profiles. Temperatures are stated within a span corresponding to the uncertainties in location of the temperature measurement on the profile surface.

## 5. Calculation results

Two variations of the calculations have been performed in accordance with prEN ISO 10077-2, with the following exceptions: In case 1, the reference case, convection and radiation exchange are modelled as prescribed in accordance to prEN ISO 10077-2. In case 2, convection exchange is modelled in accordance to prEN ISO 10077-2 and radiation exchange is modelled in accordance to ISO/DIS 15099. The variations are summarised in Table 2:

*Table 2. Performed calculations.*

| Performed calculations | Aluminium profile | | PVC profile | |
|---|---|---|---|---|
| | Convection model | Radiation model | Convection model | Radiation model |
| Case 1 (reference) | prEN ISO 10077-2 | prEN ISO 10077-2 | prEN ISO 10077-2 | prEN ISO 10077-2 |
| Case 2 | prEN ISO 10077-2 | ISO/DIS 15099 | prEN ISO 10077-2 | ISO/DIS 15099 |

Using Therm, the thermal properties calculated with convection and radiation model in accordance to prEN ISO 10077-2, Case 1 (reference), are shown in Table 3.

*Table 3. Calculated results, case 1 (reference).*

| Case 1 (reference) | Aluminium profile | | PVC profile | |
|---|---|---|---|---|
| Thermal transmittance, Utot [W/(m2K)] | 1,654 | | 1,445 | |
| Total length*, ltot [m] | 0.4496 | | 0.301 | |
| Surface temperatures | Inside | Outside | Inside | Outside |
| Panel (center), [ºC] | 16.6 | 1.2 | 16.6 | 1.2 |
| Frame, [ºC] | 14.2 +/-0.1 | 1.8 | 16.5 +/-0.4 | 0.9 |

*With insulation panel

Using Therm, the thermal properties calculated with convection model in accordance to prEN ISO 10077-2 and radiation model in accordance to ISO/DIS 15099, Case 2 (reference), are shown in Table 4.

*Table 4. Calculated results, case 2.*

| Case 2 | Aluminium profile | | PVC profile | |
|---|---|---|---|---|
| Thermal transmittance, Utot [W/(m2K)] | 1.585 | | 1,407 | |
| Total length*, ltot [m] | 0.4496 | | 0.301 | |
| Surface temperatures | Inside | Outside | Inside | Outside |
| Panel (center), [ºC] | 16.6 | 1.2 | 16.6 | 1.2 |
| Frame, [ºC] | 14.7 +/-0.3 | 1.5 | 16.6 +/-0.4 | 0.8 |

*With insulation panel

Due to a high temperature span on the inside surface of the profile the variation on the indoor surface temperature of the profile has been stated.

The heat flow through the profile not including one dimensional heat flow through the insulation panels can be found as:

$$\Phi = U_{tot} \cdot l_{tot} \cdot \Delta T - \frac{\lambda_{ins}}{d_{ins}} \cdot l_{panel} \cdot (T_{surface,p,i} - T_{surface,p,o})$$

Where:

| | |
|---|---|
| $U_{tot}$ | (Calculated thermal transmittance) |
| $l_{tot}$ | (Total length of frame and insulation panel) |
| $\Delta T = 20\ K$ | (Temperature difference between hot and cold side) |
| $\lambda_{ins}$ = 0.04 W/mK | (Thermal conductivity of insulation material) |
| $d_{ins}$ = 0.023 m | (Thickness of insulation panel) |
| $l_{panel}$ | (Total length of insulation panel) |

Hence the thermal resistance of the frames are:

$$R_f = \frac{(T_{surface,f,i} - T_{surface,f,o}) \cdot (l_{tot} - l_{panel})}{\Phi}$$

Table 5 shows the thermal transmittance of the frames calculated according to case 1 and case 2. The table also states measured values. Calculated uncertainties of the calculated thermal transmittance are calculated in relation to the calculated temperature span on the surfaces.

*Table 5. Thermal resistance of frame, measured and calculated values.*

| Resistance, frame, | Measurements | Calculations | |
|---|---|---|---|
| Without surface resistances | | Case 1 (reference) | Case 2 |
| Aluminium profile, [$m^2K/W$] | 0.225 | 0,184 +/-0.0015 | 0.225 +/-0.005 |
| PVC profile, [$m^2K/W$] | 0.507 | 0.480 +/- 0.013 | 0.519 +/- 0.013 |

For both profiles a considerably difference between calculated case 1 and case 2 can be found. Largest relative difference between case 1 and case 2 is found for are aluminium profile. The calculations consideration of the critical cavity around the glass bearing and the emissivity of the aluminium are expected to influence this.

## 6. Discussion

Calculated and measured thermal resistance in Table 5 show a considerable difference between calculated and measured results in the reference case 1 performed in full accordance to the prEN ISO 10077-2 standard. The magnitude of the difference is clearly unsatisfactory.

Utilizing a more detailed method of modelling radiation exchange in accordance to ISO/DIS 15099, case 2 shows a good and clearly satisfactory correspondence between measured and calculated values.

Questions can be asked about the choice of only focusing on the applied radiation exchange model in cavities, when trying to get accordance between measured and calculated thermal properties of the frame profiles. However, prEN ISO 10077-2 utilizes a detailed two-dimensional numerical method to describe conduction though the solids of the frame, which is very accurate. Whereas cavities are described, especially with respect to radiation exchange, with a quite simple and approximated model. In profiles in which cavities have a large influence on the thermal performance, as these considered in this work, it seems obvious to improve the assumptions of the calculations on this point. The ISO/DIS 15099 offers such an alternative.

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