Thermal performance of windows frames: a critical analysis of American and European standards and future directions

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Abstract

The article compares the different normative calculation methods to assess the thermal performance of windows in Europe and America. The first part zooms in on the different methodologies used to describe heat transfer through frame sections. The goal is to provide a clear overview of the often subtle differences in the description of heat transfer mechanisms between European and American standards. Furthermore, this section offers a framework for interpreting and comparing calculation results according to both American and European standards. The second part of the article aims to illustrate the impact of the different calculation methods on thermal transmittances. For two window frames, the effect of each individual difference between the European and American standards is quantified. The final part of the paper critically evaluates the strengths and weaknesses of both approaches. Building on this analysis, it highlights the potential advantages of combining the strengths of both systems and offers suggestions for improving the relevant standards in the future.

1. Introduction and literature review

The European calculation standards for the thermal performance of windows and doors, namely EN ISO 10077-1/2 [1,2] and EN 673 [5] for glazing units, differ significantly from the standard used in the United States, ISO 15099 [3]. Additionally, in the United States, the guidelines provided by the National Fenestration Rating Council (NFRC) are most widely adopted, offering a specific interpretation of ISO 15099 in NFRC-100 [4]. These differences in standards, particularly in the physical implementation of heat transfer, complicate direct comparisons between their calculation results.

The topic of heat transfer through window frames and its comparison with normative methods has been studied by several researchers. A comprehensive overview of research up to 2008 was provided in [7]. Amongst other aspects, this work compares results obtained using the calculation method defined in ISO 15099 - with empirical correlations for convection and a simplified radiation model for frame cavities - with more detailed CFD simulations for convection and a view-factor–based radiation within frame cavities. The study concluded that for low performing frames (high U-values), the deviation between the simplified and detailed methods is at most 8.5%. For frames with lower U-values, however, the deviations increase, which Gustavsen and Thue attribute in [9] to the limitations of the simplified radiation model. Earlier, [8] emphasized the importance of including detailed radiation modelling in frame cavities. The recommendations of these researchers [8,9] were formally implemented in the 2017 revision of the European standard ISO 10077-2, which introduced the option of applying detailed radiation calculations in frame cavities - an approach that has since then been widely adopted in European practice. A detailed comparison between both methods is presented in [11]. In contrast, while ISO 15099 (and NFRC 100) provided the option to include detailed radiation in frame cavities, calculations in practice have nevertheless continued to rely almost exclusively on the simplified approach in North-America. Further, [9] criticizes the EN ISO 10077-2 threshold criterion of 2 mm for subdividing interconnected frame cavities in the calculation of convection. Based on CFD analysis, [9] argues that a threshold of 7 mm would be more realistic.

[7] studied in 2014 the differences between EN ISO 10077-2, ISO 15099, and the methodology followed by the Passive House Institute. The article provides a concise overview of the differences in calculation methods, without going into much detail. Subsequently, the results for three window frame profiles and six glazing configurations are compared. The researchers concluded that differences between the American method and the European method can reach up to 25%.

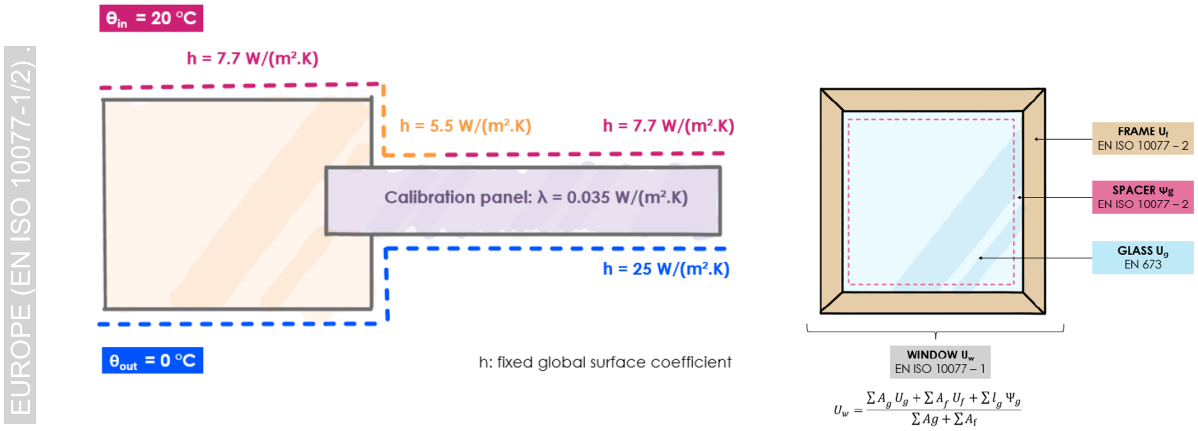
In a first step the present article aims to bring a clear overview of the differences in calculation methods used by the European and American standards. In a second step, the article seeks to contextualize the impact of these differences by analysing two reference window frames (a wooden and thermally broken aluminium profile) for each individual deviation. In this way, the reader gains practical insights into the relative importance of each modelling aspect distinguishing the European and American standards.

The final part of the paper summarizes the respective strengths and limitations of the American and European standards. By highlighting these aspects, the analysis underscores the potential advantages of combining the strengths of both systems. This section serves a dual purpose: first, as a methodological guide for accurately evaluating the performance of windows, doors, and curtain wall systems in cases that require a more tailored approach (e.g., non-standard configurations or condensation risk analysis); and second, as a reference point for future revisions aimed at enhancing current standards.

2. Overview of differences in European and American standards

This section provides a comprehensive overview of the different modelling approaches in the European and American standards for determining the thermal transmittance of fenestration products. In Europe, the method for calculating the overall thermal transmittance of a window is defined in EN ISO 10077-1, which refers to EN ISO 10077-2 for the numerical simulation of window frame transmittance and the linear transmittance of spacers, and to EN 673 for the thermal transmittance of glazing units. In the United States, these three aspects are all covered by ISO 15099. Unlike the European standards, ISO 15099 leaves some flexibility by offering multiple modelling options. The American standard NFRC-100, however, complements ISO 15099 by prescribing uniform modelling choices. For this reason we follow the modelling choices defined in NFRC-100 when it comes to the American context in the remainder of this article.

Figure 1 and Table 1 give an overview of the different approaches. On the level of the whole window, the European approach composes the U_w from the thermal transmittance through frame (U_f) and glass (U_g) and linear thermal transmittance through the spacer (Ψ_g). Whereas the American approach includes for the latter a thermal transmittance of the edge of glass zone (U_{eg}), 63.5mm from the opaque part (so-called 'sightline'). For the same window configuration, both composition approaches will result in the same end result. The major interest of the present article is however on the impact of the different physical implementations of heat transfer through the frame and glass. For frames these differences can be categorised into three aspects (see Table 1): 1) geometry/output, 2) boundary conditions and 3) treatment of cavities. In the following sections the impact of each modelling difference will be further discussed and quantified based on 2 example window frames and 1 glazing unit.



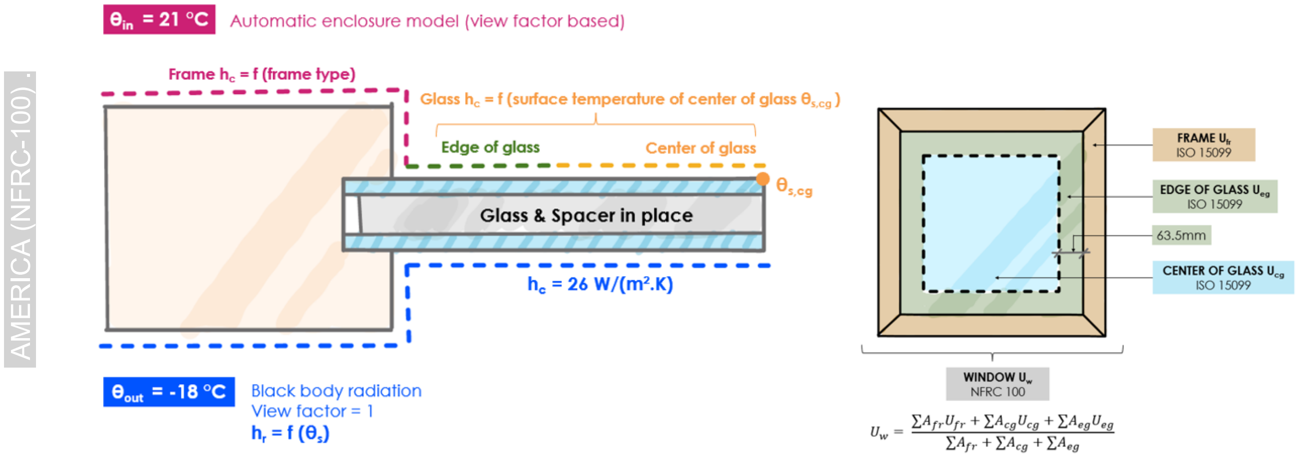


Figure 1: Different approaches in frame calculation (left) and the overall the U_w calculation (right)

Level: Frame section		**Europe**	**USA**	
		EN ISO 10077-2	**ISO 15099**	**NFRC-100**
Geometry	Glass/panel	Glass and spacer replaced by standardised panel (λ = 0.035 W/mK). Length of panel = 190mm	Option 1: Glass and spacer replaced by foam material (λ not specified) Option 2: Glass and spacer in frame calculation.	Glass and spacer in frame calculation. Length of glass = 150mm
	Output	U_f: thermal transmittance of frame (with standardized panel) Ψ_g: thermal transmittance of spacer (either from second simulation, either from tabled values)	Option 1: U_f and Ψ_g Option 2: U_{fr} and U_{eg}	U_{fr}: thermal transmittance of frame (with glass and spacer in model) U_{eg}: thermal transmittance of edge of glass (63.5mm)
Boundary conditions	Exterior surface heat transfer	Fixed global surface coefficient of 25 W/m²K for convection and radiation	Convection: surface coefficient function of windspeed Radiation: option 1: radiosity method option 2: simplified radiation	Convection: fixed surface coefficient of 26 W/m²K Radiation: option 2: simplified radiation *(Blackbody radiation)*
	Interior surface heat transfer	Fixed global surface coefficient of 7.7 W/m²K and 5 W/m²K (in corners) for convection and radiation	Convection: surface coefficient function of temperature difference and inclination angle Radiation: option 1: radiosity method option 2: simplified radiation	Convection: fixed surface based on frame type Radiation: option 1: radiosity method *(automatic enclosure method)*
	Temperature difference	0°C / 20°C	Suggests 0°C/20°C but option to use case specific temperatures	-18°C / 21°C
Air cavities	Air cavity - physics	Option 1: single equivalent conductivity method* Option 2: radiosity method *(*using maximum temperature difference across cavity)*	Option 1: single equivalent conductivity method* Option 2: radiosity method *(*using averaged temperatures on cold and warm side of cavity)*	Refers to ISO 15099
	Interconnections and surface cavities	1) Separated cavities when interconnection ≤ 2 mm. 2) Grooves are unventilated when slit ≤ 2 mm. Slightly ventilated if the slit ≤ 10 mm.	1) Separated cavities if the interconnection ≤ 5 mm. 2) Grooves are unventilated when slit ≤ 2 mm. Slightly ventilated if the slit ≤ 10 mm.	Refers to ISO 15099
	Heat flow direction/ frame position	Vertical frame position (jamb), horizontal heat flow	Distinction between sill and jamb and between horizontal, downward, upward heat flow	Refers to ISO 15099

Table 1: Summary of differences in European and American standards (frame level)

3. Methodology

The impact of the different modelling methods outlined in Table 1 will be quantified using two window frames and one type glass unit. The frames of instance are a wooden frame and a thermally broken aluminium frame (see Figure 2). The glass is a DGU (4/20/4 wooden frame, 4/16/4 aluminium frame) filled with 100% argon filling and emissivity's of 0.837/0.037. The spacer is a simplified homogeneous box with a thermal conductivity of 0.06 W/mK.

For the 2D numerical simulation of the frame cavities the software BISCO v13 by Physibel is used. Validation reports for this software tool for EN ISO 10077-2 and NFRC-100 (ISO 15099) are available on the Physibel Knowledge Base[1].

All simulations in this paper are conducted using the jamb configuration, with the single equivalent conductivity method applied for frame cavities, unless otherwise indicated.

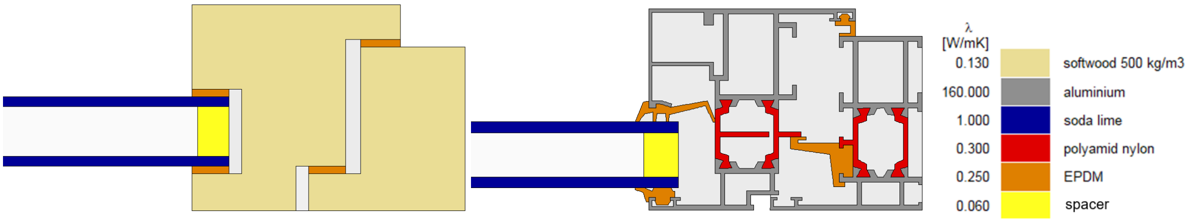


Figure 2: Geometry and thermal conductivity's of the 2 frame sections studied

	European method	**American method**
	EN ISO 10077-2	*NFRC-100*
Wooden frame	U_f = 1.351 W/m²K Ψ_g = 0.013 W/m.K	U_{fr} = 1.429 W/m²K U_{eg} = 1.581 W/m²K
Aluminium frame	U_f = 3.024 W/m²K Ψ_g = 0.017 W/m.K	U_{fr} = 3.093 W/m²K U_{eg} = 1.564 W/m²K
IGU (vertical position)	U_g = 1.089 W/m²K	U_g = 1.422 W/m²K

Table 2: Summary of thermal transmittances of frames and glass unit

4. Frame – geometry and output

A first fundamental difference between the American and European approaches lies in the geometry of the model and the resulting thermal output. In the American method, as described in NFRC-100, the frame is modelled with glass and spacer in place. The European approach, on the other hand, replaces the glass with a standardized panel having a thermal conductivity of 0.035 W/mK. The way the frame U-value is calculated also differs, making a direct comparison between both methods impossible.

In the European method, the U_f-value is based on the total heat flow through the whole model. This heat flow is divided by the temperature difference (thermal conductance L_f^{2D}), from which the one-dimensional heat transfer through the panel is subtracted. The result is then divided by the frame width (b_f) to obtain the U_f-value. In the American method, by contrast, the heat flow through the frame alone (Φ_{fr}) is extracted directly from the model. The U_{fr}-value is defined as this heat flow divided by the temperature difference and the frame width (l_{fr}).

Additional heat transfer caused by the glass spacer is also handled differently in the two methods. In the European method, it is determined as a linear thermal transmittance (Ψ_g) either by means of a second numerical simulation including glass and spacer or taken from tabulated values. In the American method, on the other hand, the effect of the spacer is expressed as a thermal transmittance (U_{eg}) over the width of an edge zone of 63.5mm. The table below summarizes the differences between both calculation methods.

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[1] https://www.physibel.be/en/knowledge#a1-validation-of-the-program-bisco-according-to-en-iso-10077-22017a12025

https://www.physibel.be/en/knowledge#a14-validation-of-the-program-bisco-according-to-nfrc-100-and-iso-15099-comparison-between-bisco-and-therm

Method	Simulation	Geometry	Output
EN ISO 10077-2	Simulation 1	Panel	$U_f = \frac{L_f^{2D} - U_p.b_p}{b_f}$
	Simulation 2	Glass and spacer	$\psi_g = L_{\psi}^{2D} - U_f.b_f - U_g.b_g$
NFRC-100	Simulation	Glass and spacer	$U_{fr} = \frac{\phi_{fr}}{l_{fr}.(T_i - T_o)}$ $U_{eg} = \frac{\phi_{eg}}{l_{eg}.(T_i - T_o)}$

Table 3: Simulation geometry and thermal output

While the European method defines the effect of the spacer in comparison to a configuration with a standardized panel, the American method incorporates the spacer directly in the base calculation. As a result, in the American method, part of the spacer's influence is reflected in the thermal transmittance of the frame, rather than being limited to the thermal transmittance of the edge-of-glass zone.

To illustrate this, the simulations were repeated using a different spacer. A more conductive aluminium spacer was used which will be called 'spacer 2' here. The results, summarized in Table 4, reveal a substantial increase in the linear thermal transmittance of this spacer but of course no effect on the frame thermal transmittance according to the European method. In contrast, the American method shows that switching to an aluminium spacer leads to an increase in both the frame transmittance (U_{fr}) and the edge-of-glass transmittance (U_{eg}).

		European method			**American method**	
		Wooden frame	Aluminium frame		Wooden frame	Aluminium frame
spacer 1	U_f (W/m²K)	1.351 (ref.)	3.024 (ref.)	U_{fr} (W/m²K)	1.429 (ref.)	3.093 (ref.)
	Ψ_g (W/mK)	0.013 (ref.)	0.017 (ref.)	U_{eg} (W/m²K)	1.581(ref.)	1.564 (ref.)
spacer 2	U_f (W/m²K)	1.351 (0%)	3.024 (0%)	U_{fr} (W/m²K)	1.725 (+21%)	3.507 (+13%)
	Ψ_g (W/mK)	0.074 (+469%)	0.085 (+400%)	U_{eg} (W/m²K)	1.955 (+24%)	1.995 (+28%)

Table 4: Simulation geometry and thermal output

In summary, we can conclude that, due to their differing definitions, a U_f-value (European method) cannot be directly compared to a U_{fr}-value (American method). Moreover, the U_{fr}-value is influenced by the type of spacer used. Finally, the table demonstrates that, in the European method, the ψ_g-value of the spacer is affected by the frame type and therefore cannot be linked solely to the spacer itself.

5. Frame – boundary conditions

As indicated in Table 1, European and American standards apply different boundary conditions in terms of 1) surface radiation model, 2) convective surface coefficient relations and 3) temperature differences. These 3 aspects will be investigated in this section for the two reference frames.

5.1. Impact of simplified surface radiation EN ISO 10077-2

Where the European method uses a fixed global surface coefficient (7.7 W/m²K), the American method applies view-factor based radiation on the inner side. Although, the European standards compensates for this, by using a reduced surface coefficient in corners (5 W/m²K), it can be argued that the American method is more precise. To verify the importance of this simplification both window frames are re-calculated following the European standard but with view-factor based radiation on the inner surface.

Figure 3 below summarizes the results for both frames. The black lines correspond to the fixed global surface coefficients as proposed by EN ISO 10077-2. The grey dotted lines correspond to simulations, imposing view-factor based radiation on the inner surface. In these simulations the convective heat transfer coefficient was fixed to 2.5 W/m²K and from the resulting surface heat flux, the global local heat transfer coefficient was derived in intervals of 1 cm.

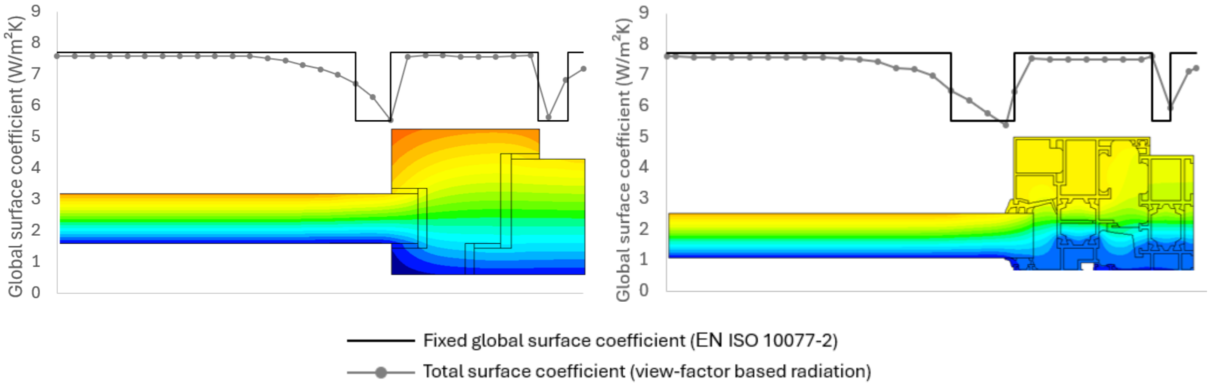

Figure 3: Global surface coefficient for detailed (re-calculated) vs. simplified radiation model.

From the graph, it can be seen that the fixed combined coefficient defined in EN ISO 10077-2 is a reasonable approximation to compensate for the reduced radiative heat transfer in corners. The results on the overall U_f-value indicate that the simplified approach of EN ISO 10077-2 underestimates the U_f-value of the wooden frame by 1.2% and aluminium frame by 1%.

5.2. NFRC impact of inner convective surface heat transfer coefficient

As indicated in Table 1, the American method applies different convective surface coefficients on the frame and glass. At the level of the frame this coefficient is fixed and depends on the frame type (e.g. thermally broken: h_c = 3 W/m²K, wooden: h_c = 2.44 W/m²K). At the level of the glass the surface coefficient is a function of the surface temperature. However, instead of using the local surface temperature, NFRC-100 explicitly states that the whole glass surface should apply the same coefficient, being calculated based on the centre of glass surface temperature. To assess the implications of this simplification, comparative simulations are performed. For both window frames the American method is followed, with the difference that the convective heat transfer coefficient is updated with local surface temperatures (with intervals of 1 cm). According to the formulas in ISO 15099 the inner convective surface coefficient for glass area is also impacted by the glass height. The height of the glass is kept constant to 1m in the comparison below. The impact of the glass height will be addressed in section 5.3.

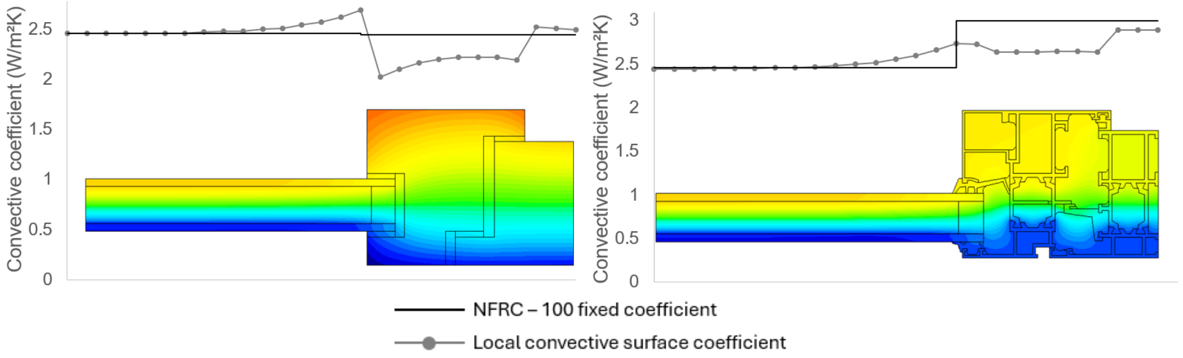

Figure 4: Convective surface coefficient : local coefficient vs. NFRC-100 fixed coefficient

The results indicate that for both frame types the convective surface coefficient at the level of the frame is over-estimated. Further, it can be observed from Figure 4 that the NFRC-100 approach underestimates the convective surface coefficient in the edge of glass zone. In this region, the surface temperature will be lower, corresponding to a higher convective surface coefficient. However, NFRC-100 imposes throughout the whole glazing surface the coefficient found at the centre of glass surface temperature. On the overall U_{fr}-value this approach overestimates the wooden frame by 0.4% and the aluminium frame by 1.6%. At the same time, the U_{eg}-value of wooden frame is underestimated by 0.4% and the U_{eg}-value of the aluminium frame by 1%.

5.3. Impact of temperature difference

The final paragraph of this section verifies the impact of the different boundary condition temperatures used by both methods. Where the European approach applies a moderate winter climate (20°C/0°C), the American approach applies a severe winter climate (21°C/-18°C). To asses the impact of the applied boundary condition temperatures, both window frames are re-calculated following the European and American method, but the temperatures are cross-changed. The temperature difference affects both convective transport and radiative transport in the frame cavities. With a higher temperature difference, convective transport increases. For radiative transport (in the single equivalent conductivity method), the average radiation temperature is decisive. This is lower under NFRC-100 conditions, which reduces radiation. This explains why, in some cases, a higher temperature difference can still result in a lower U-value. Overall, the results indicate that the impact of the temperature on the frame thermal transmittance is limited and stays below 1%.

Method	Temperatures	Wooden frame $U_{f(r)}$ (W/m²K)	Alu frame $U_{f(r)}$ (W/m²K)
EN ISO 10077-2	0°C / 20°C	1.351 (reference)	3.024 (reference)
EN ISO 10077-2	-18°C / 21°C	1.349 (-0.15%)	3.027 (+0.10%)
NFRC-100	-18°C / 21°C	1.429 (reference)	3.093 (reference)
NFRC-100	0°C / 20°C	1.418 (-0.77%)	3.101 (+0.26%)

Table 5: Impact of boundary condition temperatures on U_f-value

6. Frame – air cavities

As indicated in Table 1, European and American standards apply different approaches to treat heat transfer through frame cavities: 1) radiation model, 2) subdivision of cavities and 3) empirical relation for convective heat transport. These three aspects will be investigated in this section.

6.1. Radiation model in frame cavities

As shown in Table 1, both the European and the American methods offer two options to model heat transfer through air cavities: either by using simplified radiation or by applying a view-factor-based radiation approach. In the first option, the heat transfer through an air cavity is represented by a single equivalent thermal conductivity that accounts for both convection and radiation. For this purpose, the cavity is reduced to an equivalent rectangular shape, which allows to describe radiation across the sides with a single surface coefficient. For the description of convective heat transfer empirical relation using the equivalent cavities depth and width are used. Although the general methodology for this option is the same in the European and American approaches, significant differences exist in their actual implementation (see section 6.3). In the second option, the same method is used for describing convection, but the calculation of radiative heat exchange is performed via radiosity equations (view-factor based), taking into account the actual cavity's geometry and the surface emissivity's. To assess the impact of the cavity radiation model, the simulations for both standards and both window frames were re-calculated with the detailed radiation model. First, it should be noted that this analysis revealed that ISO 15099 does not specify how to treat slightly ventilated cavities when using detailed radiation. The wooden profile contains one slightly ventilated cavity. Due to the lack of a definition in ISO 15099, this surface cavity was modelled with simplified radiation. The results are summarized in Table 6 below illustrating that using the detailed radiation model in cavities results in lower $U_{f(r)}$-values. This confirms that the simplified radiation model – based on radiation in an equivalent rectangular cavity – leads to a conservative approach for the frames used in this study.

Method	Radiation	Wooden frame $U_{f(r)}$ (W/m²K)	Alu frame $U_{f(r)}$ (W/m²K)
EN ISO 10077-2	simplified	1.351 (reference)	3.024 (reference)
EN ISO 10077-2	radiosity	1.347 (-0.3%)	2.837 (-6.2%)
NFRC-100	simplified	1.429 (reference)	3.093 (reference)
NFRC-100	radiosity	1.407 (-1.5%)	2.949 (-4.7%)

Table 6: Impact of radiation model

6.2. Interconnection of frame cavities

In EN ISO 10077-2, cavities interconnected by a throat smaller than 2 mm are considered as separated cavities, while larger openings are treated as maintaining a single continuous cavity. In contrast, ISO 15099 applies a threshold of 5 mm. The practical implication is that for throats between 2 mm and 5 mm, EN ISO 10077-2 still classifies them as part of the same entire cavity, whereas NFRC-100 already treats them as distinct cavities. This divergence may leads to different cavity subdivision and, consequently, different outcomes in thermal performance calculations depending on which standard is applied.
The effect of the interconnection threshold on the aluminium frame is evaluated according to both standards. As shown in Table 7, increasing the threshold to 5 mm in the European method reduces the U_f-value by 1.9%, while reducing the threshold to 2 mm in the American method increases the U_{fr}-value by 1.9%.

	EN ISO 10077-2		**NFRC-100**	
	2 mm	5 mm	2 mm	5 mm
$U_{f(r)}$ (W/m²K)	3.024 (ref.)	2.967 (-1.9%)	3.152 (+1.9%)	3.093 (ref.)

Table 7: Impact of threshold for cavity subdivisions

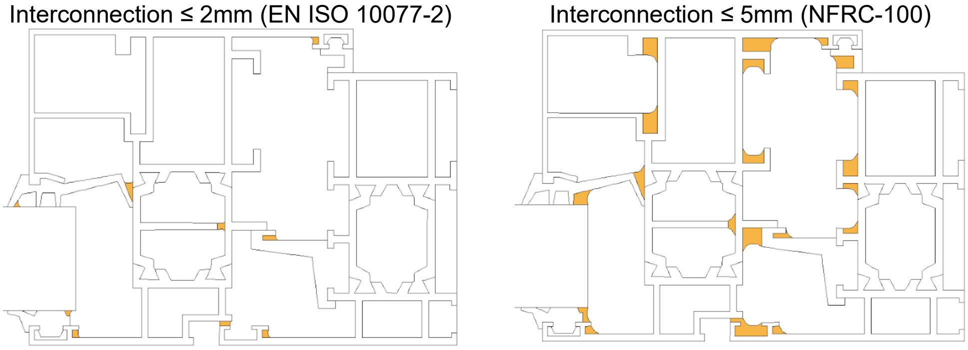
Interconnection ≤ 2mm (EN ISO 10077-2)
Interconnection ≤ 5mm (NFRC-100)

Figure 5: Cavity subdivision in EN ISO 10077-2 (left) and NFRC-100 (right) for aluminium frame.

6.3. Empirical relations for convection in frame cavities

EN ISO 10077-2 and ISO 15099 use different empirical correlations for convective heat transfer in cavities, with notable differences in several aspects. The European standard treats all frame sections as horizontal heat transfer through a jamb section, whereas the American standard provides separate relations for sill and jamb sections and distinguishes between heat-flow orientations (horizontal, upward and downwards). Furthermore, unlike EN ISO 10077-2, ISO 15099 explicitly accounts for the effect of frame height in jamb sections. Another key difference is that EN ISO 10077-2 employs the maximum temperature difference across the cavity as the driving potential, while ISO 15099 relies on the mean surface temperatures at both sides of the cavity. Finally, in the determination of the equivalent cavity depth - a key parameter in the empirical convection relations - ISO 15099 considers variations only in orthogonal directions. In contrast, EN ISO 10077-2 (when applying the radiosity method) allows the equivalent cavity depth to be defined along the actual heat-flow direction within the cavity.

To assess the impact of the different convective heat flow models, the aluminium frame was re-calculated according to both standards by interchanging the applied air cavity model. Herein, the same cavity subdivision was maintained (see section 6.2). The results are shown in Table 8 below and illustrate that the impact on the frame thermal transmittance remains below 2% for both frames.

Method	**Cavity model**	**Wooden frame $U_{f(r)}$ (W/m²K)**	**Alu frame $U_{f(r)}$ (W/m²K)**
NFRC-100	15099	1.429 (reference)	3.093 (reference)
NFRC-100	10077-2*	1.402 (-1.89%)	3.046 (-1.52%)
EN ISO 10077-2	10077-2	1.351 (reference)	3.024 (reference)
EN ISO 10077-2	15099**	1.364 (0.96%)	3.050 (0.86%)

*Table 8: Impact of cavity heat transfer model (*split 5mm and **split 2mm)*

In addition, for ISO 15099, the difference in U_{fr}-values between sill and jamb sections is investigated, together with the influence of frame height. Herein, the cavity height is varied from 0.5m to 3m. The impact of the frame height impacts 1) the relation for convective heat transfer in jamb sections and 2) the convective surface coefficient for the glass area.

The U_{fr} and U_{eg} for the jamb section (grey) and the U_{fr} and U_{eg} for sill section (black) follow the same trends. The differences on U_{eg} between sill and jamb are neglible. The difference on U_{fr} are below 2%. From this, we can conclude that the impact of the frame height is most pronounced in the effect on the convective surface coefficient.

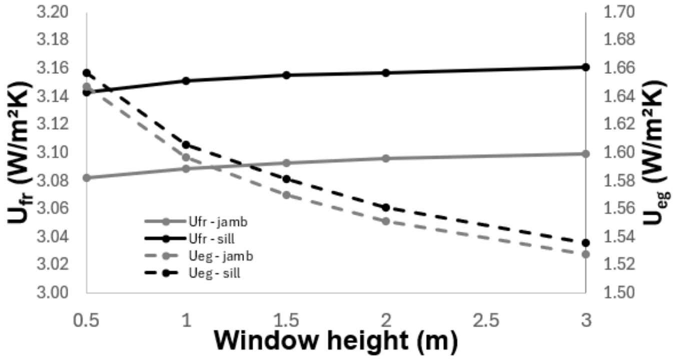

Figure 6: U_{fr} and U_{eg} for aluminium frame according to ISO 15099: 1) difference between sill and jamb section and 2) impact of frame height.

7. Summary of results

The overall results of this paragraph are summarised in Figure 7 below. The results are shown as the absolute difference with the reference results from Table 2. This figure indicates that the highest deviations can be linked to the radiation model in cavities. The $U_{f(r)}$-values with the simplified radiation model results to overestimates up to 6%. The relative impact on the other parameters studied remain lower than 2%.

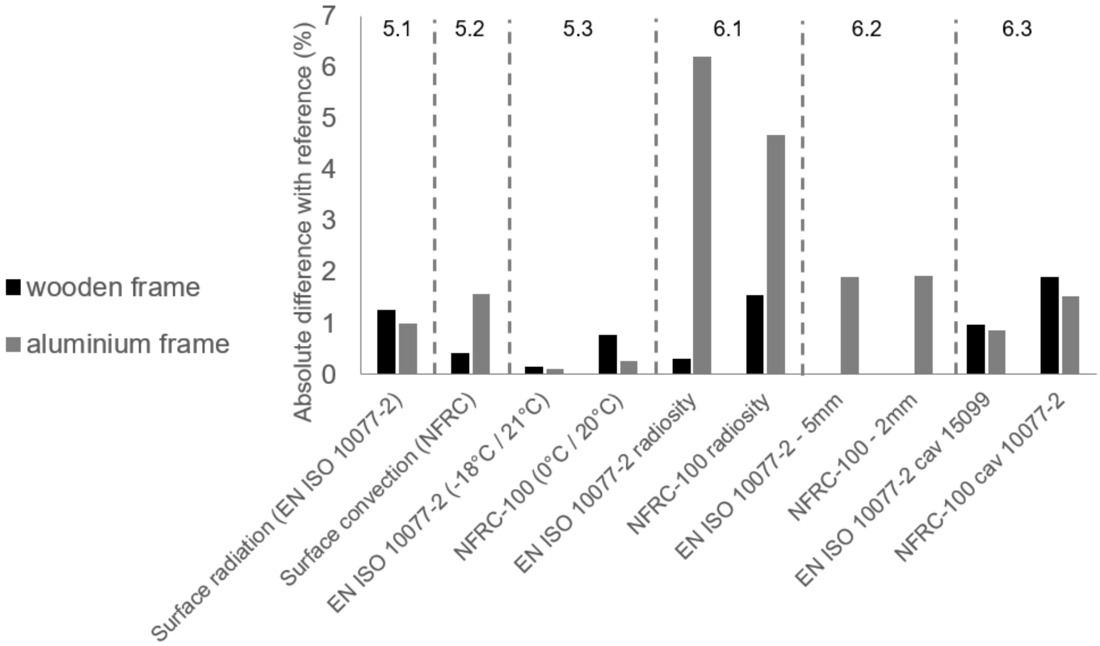

Figure 7: Impact of each parameter studied in section on the $U_{f(r)}$-value (results are show as absolute percentage difference compared to reference case (Table 3).

8. Discussion and recommendations for future standard revisions

Based on the findings of this study, suggestions for future improvements of the relevant standards are proposed.

Empirical relations for convection in frame cavities

Although the empirical relations for natural convection in ISO 15099 are more detailed than those in EN ISO 10077-2, their practical impact on results remains limited (<2%). Furthermore, with the ongoing development of better-performing frame systems (featuring smaller cavities), the relative importance of convection in frame cavities will further decrease. This suggests that additional research into improved empirical relations – as proposed by Gustavson in [6] is unlikely to provide significant added value.

Subdivision of cavities.

The threshold for distinguishing separate cavities is also under debate. ISO 15099 applies a value of 5 mm, whereas EN ISO 10077-2 uses 2 mm. CFD studies by Gustavson [9], however, indicate that a threshold of 7 mm would be more physically accurate. From this, we can conclude that the 5 mm threshold used in the American method represents an appropriate limit value and that it should preferably be adopted in the European method as a replacement for the current 2 mm. This would then also result in improved performance of American-developed profiles within the European framework, as they are typically designed with a 5 mm subdivision in mind.

Radiation model within frame cavities.

EN ISO 10077-2 and ISO 15099 currently allow both a simplified and a detailed radiation model for cavities. Apart from the fact that this dual option creates confusion in practice, the results of the present study—as well as findings reported in the literature—demonstrate that the detailed model provides more accurate results. We therefore advocate eliminating the simplified model from both EN ISO 10077-2 and ISO 15099.

Radiation at the interior surface.

Although simplified surface radiation has proven to be a reasonably good approximation, we propose adopting the detailed radiation model used in the American method for the European standard as well. This would ensure consistency with the detailed radiation treatment in cavities. Also, at present, an inconsistency arises for non-ventilated cavities in the European standard when detailed cavity radiation is applied. Here, a view-factor based zone (cavity) touches a zone with simplified radiation (boundary condition). Implementing the detailed radiation model at the inner surface would resolve this issue.

Slightly ventilated cavities.

A shortcoming of ISO 15099 is the absence of a description of slightly ventilated cavities when applying the radiosity method. We propose adopting the approach used in EN ISO 10077-2, in order to ensure consistent and reproducible results in such cases.

Convective surface heat transfer coefficients.

Further, we recommend updating the convective surface heat transfer in the American approach by using the local surface temperatures. The equations from ISO 15099 can also be applied at the frame level, instead of relying on the fixed coefficients currently used in NFRC-100. We propose updating the surface heat transfer coefficients for three zones: 1) frame, 2) edge of glass, and 3) centre of glass.

Thermal output

The article demonstrates that European and American method use fundamentally different approaches to express the thermal transmittance of a window frame profile, which makes the results not directly comparable. Since both methods are well established in practice, changing them would be difficult. However, we recommend that the American standard NFRC-100 adopts the corresponding definitions of both methods as described in ISO 15099. According to this document, when calculations are based on a reference panel (European method), the thermal transmittance should be expressed as U_f, while when glass and spacer are included, the notation U_{fr} should be used. This would help avoid confusion in practice between the two methods.

9. Conclusion

The article presented an in-depth comparison of the calculation methods for the thermal transmittance of window profiles according to European and American standards. Based on the application to two window profiles, the impact of the differences between both standards was assessed. Building on the these results, proposals were made to improve both standards.

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