Energy performance of windows based on net energy gain

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KEYWORDS*: Window, glazing unit, frame, net energy gain, energy performance.*

SUMMARY:

The paper presents a new method to set up energy performance requirements and energy classes for windows of all dimensions and configurations.

The net energy gain of windows is the solar gain minus the heat loss integrated over the heating season. The net energy gain can be calculated for one orientation or averaged over different orientations. The averaged value may be used for energy labeling of windows of standard size. Requirements in building codes may also be based on the net energy gain instead of the thermal transmittance of the window.

The size and the configuration of the window, i.e. number of glazing units, have a very large effect on the net energy gain. Therefore the energy labeling or the requirements based on the standard size may not give valid information on the energy performance of windows of non-standard size.

The paper presents a method to set up requirements and classes for energy performance based on the net energy gain that includes the effect of window size and configuration.

The net energy gain of windows can be divided into the net energy gain of the glazing unit and the heat losses of the frame and the assembly of the glazing unit and the frame. The glazing unit contributes proportionally to its area. The frame also contributes proportionally to its area, but as the area of the frame is the width times the length, the heat losses of the frame and the assembly both contribute proportionally to the length of the frame. Accordingly, the net energy gain of the window can be expressed as a function of two parameters representing the energy performance and two parameters representing the geometry of the window. The two energy performance parameters are the net energy gain per area of the glazing unit and the sum of the heat losses through the frame and the assembly per length of the frame. The two geometry numbers are the area of the glazing unit relative to the window area and the length of the frame profiles relative to the window area.

Requirements and classes for the energy performance of the window can be given by assigning values to the two energy performance parameters. In this way the requirements and classes for the energy performance of the window become a function of the geometry of the window. Therefore the effect of the dimension and the configuration of the actual window are taken into account and make it possible to express the energy performance of all windows in a correct manner.

The method is useful in relation to comparison of window products for replacement of existing windows, but may also be useful for handling the energy performance of windows in a general but realistic way in the early phase of the design of new buildings.

1. Introduction

The net energy gain of windows is the solar gain minus the heat loss integrated over the heating season. The net energy gain expresses in a simple way the energy performance of windows. In relation to the introduction of the directive on the energy performance of buildings in EU there is a shift from 'heat loss' to 'used energy' in the characterization of buildings with respect to energy performance. The net energy gain of windows is useful in quantifying the energy performance of windows.

The net energy gain can be calculated for glazing units separately and for complete windows based on the total solar energy transmittance and the thermal transmittance of the two types of products. For glazing units center of glass values are used and therefore the net energy gains of glazing units do not depend on the size or shape of the unit. For windows, the total solar transmittance and the thermal transmittance are averaged over the glazing unit and the frame. As these values depend on the size and configuration of the window the net energy gain will also change due to change of geometry of the window.

Therefore energy labeling or energy performance requirements based on net energy gain of a standard size may not give valid information on the energy performance of windows of non-standard size.

The paper presents a method to set up requirements and classes for energy labeling of windows based on the net energy gain that includes the effect of window size and configuration.

2. Net energy gain of windows

The product standard prEN 14351 (CEN, 2005) allows the total window performance to be based on measurements/calculations on a "standard" window, and these results are then claimed to be valid for all other window sizes.

This is not an appropriate approach, since the actual area and geometry of a window has a great influence on the overall window energy performance. This is due to the fact that a smaller window has a relatively greater frame fraction than a bigger window if using the same frame dimension. A small window dimension can therefore be expected to have a higher overall U-value and a lower total solar energy transmittance since the relative glazing area has been reduced. This can make significant changes to the result of the net energy gain of the window.

National building codes typically include requirements for windows based on EN ISO 10077-1 (CEN, 2000) and therefore need detailed information on energy properties and geometry.

Calculations have been performed to document the consequences. In table 1 basic properties of different windows have been listed for 3 window sizes

- Large window, standard size + 25% according to specimen size in prEN14351: [1.54 · 1.85] m²
- Standard size according to prEN14351: [1.23 · 1.48] m²
- Small window, standard size - 50%: [0.615 · 0.74] m²

The glazing of the windows have the same thermal transmittance, U_g = 1.2 W/m²K and the same solar energy transmittance, g_g = 0.63.

The used net energy gain equation is described in (Nielsen T. R., Duer K and Svendsen S, 2000) and applies to Danish conditions and does not include air permeability:

$$E_{ref} = I \cdot g_w - D \cdot U_w = 196 \cdot g_w - 90 \cdot U_w \quad \text{[kWh/m²]} \qquad (1)$$

Where I is the solar radiation calculated for a reference house and D is the degree hour number during the heating season in Denmark. U_w is the total thermal transmittance and g_w is the total solar energy transmittance of the window.

It is seen that the net energy gain will be negative when energy is lost.

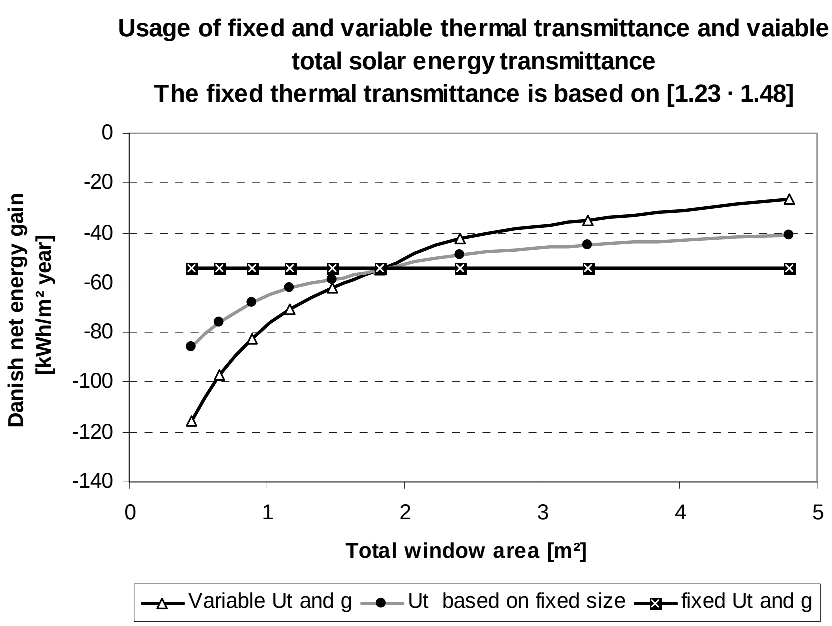
Table 1. Comparison of calculated energy properties of three window sizes for five different windows. Large: 1.54 x 1.85 m, Standard (Std.): 1.23 x 1.48m and Small: 0.615 x 0.74m. Calculations are done with same thermal transmittance of the glazing (1.2 W/m²K) and same solar energy transmittance of the glazing (g_g= 63%). U_f is the thermal transmittance of the frame and Ψ is the linear thermal transmittance of the assembly between frame and glazing. U_w and g_w is the total thermal transmittance and solar energy transmittance respectively, and E_{ref} is the net energy gain of the window in a reference house.

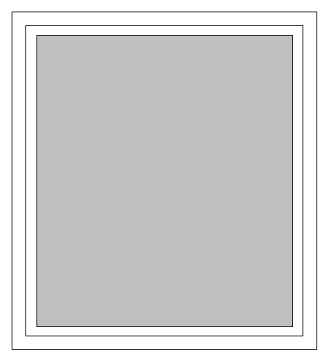
	Frame and assembly data			Solar transmittance g_w [%]			Thermal transmittance U_w [W/m²K]			Net Energy Gain E_{ref} [kWh/m²]		
	Width [mm]	U_f [W/m²K]	Ψ [W/mK]									
Window \ Size				Large	Std.	Small	Large	Std.	Small	Large	Std.	Small
Wood	97	1.67	0.089	49	46	32	1.49	1.55	1.81	-38	-49	-101
Wood / Aluminium	107	1.42	0.082	48	45	29	1.42	1.47	1.65	-34	-45	-91
PVC	115	1.72	0.054	47	43	27	1.44	1.50	1.71	-38	-50	-101
Aluminium	60	2.76	0.088	54	52	42	1.61	1.70	2.14	-38	-51	-109
Mixed material	56	3.04	0.058	55	53	44	1.57	1.65	2.05	-33	-45	-99

As it can be seen from table 1 there are big differences in the obtained thermal transmittance and total solar energy transmittance and therefore also in the net energy gain. The difference in energy performance is for all windows larger for different sized windows than for different products. The declared values of windows according to the proposed product standard may not be directly comparable and can not be used to express the energy performance of windows with different configurations and sizes.

This is also illustrated in the following Fig. 1 where the product standard is used in three different ways.

1. *U* and *g* are calculated corresponding to the actual dimensions.
2. *U* is fixed (based on measurements) and *g* is calculated corresponding to the actual dimensions.
3. Both *U* and *g* are fixed and based on the standard size [1.23 · 1.48] m².





Window properties

Frame, U_f = 1.8 W/m²K

Glazing: U_g = 1.2 W/m²K

Edge construction: Ψ = 0.10 W/mK

Width of frame: b = 110 mm

FIG. 1. Fixed or variable U- value combined with variable g-value

As can be seen from Fig. 1 using fixed values of U and/or g has a great influence on the net energy gain when looking at various window sizes.

Seen from the consumer viewpoint, 2 levels of documentation are important.

1. Window energy properties declared for a number of typical configurations of standard size [1.23 · 1.48] m² for a preliminary comparison of products.
2. Window energy properties declared for the actual configuration and size in question for a correct comparison and use of data for windows.

2.1 Data on energy performance of actual windows

It cannot be recommended to apply prEN 14351 (CEN, 2005) in the matter of comparison of energy performance of window sizes.

It is recommended that the overall window energy performance of the thermal transmittance and total solar energy transmittance is based on the standard size for general comparison and on the actual type (configuration) and size for comparison of windows for a specific use. In both cases the U-value should be calculated in accordance with the calculation method described in EN ISO 10077-1 (CEN, 2000).

This way of documenting the basic energy performance data of windows should be based on data from test or calculations of the individual documentation and information on:

1. Radiation data of the glazing
2. Thermal transmittance of glazing
3. Thermal transmittance of frame
4. Linear thermal transmittance of edge construction in the assembly of the glazing and the frame, Ψ.

The window manufacturers already use the declared values on the glazing unit from the glazing manufacturer. The window manufacturer could in a similar way declare the U_f-value of the frame and the Ψ-value of the edge construction in the assembly based on table values in EN ISO 10077-1 (CEN, 2000) or detailed calculations according to EN ISO 10077-2 (CEN, 2003).

Based on these energy performance data on the glazing unit and the frame and edge construction, the window manufacturer could for any actual window configuration and size calculate the actual g- and U-value as well as the standard net energy gain.

3. Energy performance classes of windows

The net energy gain of windows can be divided into the net energy gain of the glazing unit and the heat losses of the frame and the assembly of the glazing unit and the frame. The glazing unit contributes proportionally to its area. The frame also contributes proportionally to its area, but as the area of the frame is the width times the length, the heat losses of the frame and the assembly both contributes proportionally to the length of the frame. Accordingly the net energy gain of the window can be expressed as a function of two parameters representing the energy performance and two parameters representing the geometry of the window. The two energy performance parameters are the net energy gain per area of the glazing unit and the sum of the heat losses through the frame and the assembly per length of the frame. The two geometry numbers are the area of the glazing unit relative to the window area and the length of the frame profiles relative to the window area.

Requirements and classes for the energy performance of the window can be given by assigning values to the two energy performance parameters. In this way the requirements and classes for the energy performance of the window become a function of the geometry of the window. Therefore the effect of the dimension and the configuration of the actual window are taken into account and make it possible to express the energy performance of all windows in a correct manner.

3.1 Net energy gain as a function of the windows dimension and construction

The solar and thermal transmittance of the window depends on the glazing and frame area and the assembly length between the glazing and frame profile. The net energy gain of the window is therefore also a function of the window geometry.

A specification of the energy quality of a window can be established by using the data of each specific component and then calculate the net energy gain of the window using the actual geometry.

A good energy window on the Danish market can be based on the following data:

- Low energy glazing with net energy gain of 15 kWh/m²
- Frame with a thermal transmittance of 1.6 W/m²K, width 0.10 m giving a product of 0.16 W/mK
- Good assembly of the glazing and frame using a warm edge construction. Linear thermal transmittance 0.06 W/mK
- Spacer profiles inside sealed glazing units that make them look as multi-units. Linear thermal transmittance 0.06 W/mK corresponding to the length of the internal spacer profile (0.06 W/mK covers both sides of the spacer profile)

The geometrical data can be expressed by the following relative values:

Glazing part: Area of the glazing units, A_g, in proportion to the window area, A:

$$R = \frac{A_g}{A} \tag{1}$$

Assembly part of the profiles: The length of the assembly between glazing and frame profile in proportion to the window area, A:

$$P = \frac{L_{Assembly}}{A} \tag{2}$$

Assembly part of the window bars: The length of the window bars in proportion to the window area, A:

$$S = \frac{L_{Assembly-window-bars}}{A} \tag{3}$$

Where $L_{Assembly}$ is the length of the assembly between the glazing and frame profile and $L_{Assembly-window-bar}$ is the length of the window bars. The length of the window bar corresponds to the actual length and not both side lengths.

The relative length of the frame profile is the same as P. Hereby the corners of the windows are not included in the calculation. The four corners are therefore assumed each to have an area of 0.01 m².

The limit of the net energy gain of a window can then be expressed as a function of the geometry. Again applied to Danish conditions with a degree hour number of 90 kKh gives:

$$\begin{aligned} E &= 15 \cdot R - 90 \cdot 0.16 \cdot P - 90 \cdot 0.06 \cdot (P + S) - 90 \cdot 0.04 \cdot \frac{1.6}{A} \\ &= 15 \cdot R - 19.8 \cdot P - 5.4 \cdot S - \frac{5.76}{A} \\ &\approx 15 \cdot R - 20 \cdot P - 6 \cdot S - \frac{6}{A} \end{aligned} \tag{4}$$

It is suggested that today's standard windows fulfilling equation (4) is classified as B-windows. Improved windows with triple glazing, 1+2 glazing, better insulated frame profiles, and warm edge construction could then be classified as A-windows.

- Triple glazing or 1+2 glazing with net energy gain of 25 kWh/m²
- Frame with a thermal transmittance of 1.8 W/m²K, width 0.05 m giving 0.09 W/mK
- Good assembly of the glazing and frame using a warm edge construction. Linear thermal transmittance 0.06 W/mK

- Window bars with closed glazing units. Linear thermal transmittance 0.06 W/mK corresponding to the length of the window bar (0.06 W/mK covers both sides of the window bar)

The net energy gain limit of windows classified as A is then expressed as:

$$E \approx 25 \cdot R - 14 \cdot P - 6 \cdot S - \frac{2}{A} \quad (5)$$

Example of calculation of the net energy gain demand for a new window of PVC with two different edge constructions.

The window is shown in Fig. 2 and the window data in Table 2.

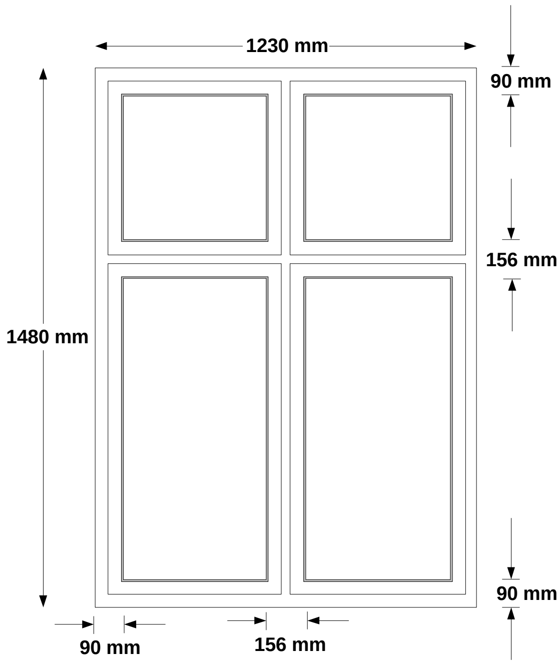


FIG. 2: New window of PVC

Table 2: Window data

Total thermal transmittance:			
Edge construction of plastic (warm edge)	U_w	1.65	W/m²K
Edge construction of aluminium	U_w	1.79	W/m²K
Total solar transmittance	g_w	0.35	-
Window dimensions			
Height		1.480	m
Width		1.230	m
Total area	A_{tot}	1.820	m²
Frame profile height		0.090	m
Transom/Mullion height		0.156	m
Glazing area	A_g	1.02	m²
Frame area	A_f	0.2	m²
Glazing part (1)	R	0.56	
Assembly lengths:			
Frame profile (vertical)		2.288	m
Frame profile (horizontal)		1.788	m
Length mullion (2 sides)		2.288	m
Length transom (2 sides)		1.788	m
Total length	l_g	8.15	m
Assembly part of profiles (2)	P	4.48	m

The net energy gain of the window with a warm edge construction of plastic:

$$E = 196 \cdot g - 90 \cdot U \quad (6)$$
$$= 196 \cdot 0.35 - 90 \cdot 1.65 = -80 kWh/m^2$$

The net energy gain of the window with an edge construction of aluminium:

$$E = 196 \cdot g - 90 \cdot U \quad (7)$$
$$= 196 \cdot 0.35 - 90 \cdot 1.79 = -93 kWh/m^2$$

The limit of the net energy gain of the specific window using equation (4) (B-window):

$$E = 15 \cdot R - 20 \cdot P - 6 \cdot S - \frac{6}{A} = 15 \cdot 0.56 - 20 \cdot 4.48 - \frac{6}{1.82} = -84 kWh/m^2 \quad (8)$$

The limit of the net energy gain of the specific window using equation (5) (A-window):

$$E = 25 \cdot R - 14 \cdot P - 6 \cdot S - \frac{2}{A} = 25 \cdot 0.56 - 14 \cdot 4.48 - \frac{2}{1.82} = -50 kWh/m^2 \quad (9)$$

The window is seen to be classified as a B-window if a warm edge construction is used.

Example of calculation of the net energy gain demand for a small bathroom window

The small bathroom window is shown in *Fig. 3* and the window data in Table 3.

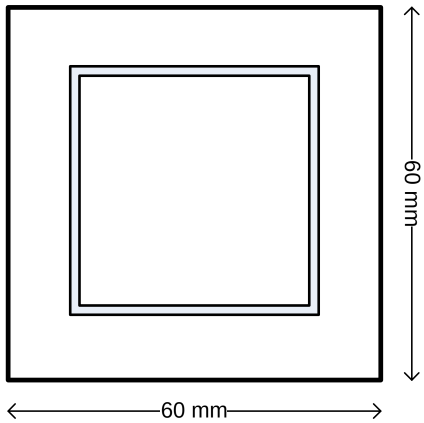


FIG. 3: Small bathroom window

Table 3: Window data

Window dimensions:		
Height		0.600 m
Width		0.600 m
Total area	A_{tot}	0.360 m²
Frame profile height		0.100 m
Glazing area	A_g	0.16 m²
Frame area	A_f	0.2 m²
Glazing part (1)	R	0.44
Assembly lengths:		
Frame profile (vertical)		0.8 m
Frame profile (horizontal)		0.8 m
Total length	l_g	1.60 m
Assembly part of profiles (2)	P	4.44 m

Thermal transmittance:

$$U = \frac{U_g \cdot A_g + U_f \cdot A_f + \psi \cdot l_g}{A_{tot}} = \frac{1.2 \cdot 0.16 + 1.6 \cdot 0.2 + 0.06 \cdot 1.6}{0.36} = 1.7\ W/m^2K \qquad (10)$$

Solar transmittance: $g_{glazing} = 0.63$; $g_{window} = 0.28$

The net energy gain of the window:

$$E = 196 \cdot g - 90 \cdot U = 196 \cdot 0.28 - 90 \cdot 1.7 = -98 kWh/m^2 \qquad (11)$$

The limit of the net energy gain of the specific window using equation (4) (B-window):

$$E = 15 \cdot R - 20 \cdot P - \frac{6}{A} = 15 \cdot 0.44 - 20 \cdot 4.44 - \frac{6}{0.36} = -99 kWh/m^2 \qquad (12)$$

The net energy gain of the small bathroom window is seen to be just under the limit value of a B-window.

Example of calculation of the net energy gain demand for a window classified as A

An improved window with narrow frame profiles, glazing with low iron content increasing the solar transmittance and warm edge construction of plastic is developed and produced at the Technical University of Denmark. The total thermal transmittance (U_w) of the window is 1.28 W/m²K and the solar transmittance (g_w) is 0.57. The window is shown in Fig. 4 and the window data in Table 4.

FIG. 4: Improved window

Table 4: Window data

Window dimensions:		
Height		1.23 m
Width		1.48 m
Total area	A_{tot}	1.82 m²
Frame profile height		0.054 m
Glazing area	A_g	1.53 m²
Frame area	A_f	0.29 m²
Glazing part (1)	R	0.84
Assembly lengths		
Frame profile (vertical)		2.744 m
Frame profile (horizontal)		2.244 m
Total length	l_g	4.988 m
Assembly part of profiles (2)	P	2.74 m

The net energy gain of the window:

$$E = 196 \cdot g - 90 \cdot U \tag{13}$$

$$= 196 \cdot 0.57 - 90 \cdot 1.28 = -3.5 \text{kWh} / \text{m}^2$$

The limit of the net energy gain of the specific window using equation (5) (A-window):

$$E = 25 \cdot R - 14 \cdot P - 6 \cdot S - \frac{2}{A} = 25 \cdot 0.84 - 14 \cdot 2.74 - \frac{2}{1.82} = -18.5 \text{kWh} / \text{m}^2 \tag{14}$$

The net energy gain of the improved window is seen to be well under the limit value of the A-window classification even though only double glazing is used.

4. Conclusion

The proposed method of declaring the energy performance of windows based on data on the glazing units and the frame profiles would make it easier and better for both the manufacturer and the buyer or specifier of windows. The manufacturer could easier document his declaration of energy performance of his product by use of the data on the profiles used in the windows. The buyer and specifier of windows could get the relevant energy performance data on the actual window products to be used in new or existing buildings.

The proposed method of energy labeling with classes based on energy performance of the glazing unit, the frame profile and the edge construction would make it possible to compare window products for an actual window geometry. This would be useful in relation to comparison of window products for replacement of existing windows, but may also be useful for handling the energy performance of windows in new buildings as the designer of the building would be able to see the effect of the geometry and the basic energy performance of windows separately.

The two methods are suited to be combined and would offer a better and easier way of treating the energy performance of windows in relation to the CE-marking of windows and energy labeling of buildings.

5. References

Nielsen T. R., Duer K and Svendsen S, (2000), Energy performance of glazings and windows. Solar Energy, Vol. 69 (Suppl.), Nos. 1-6, pp. 137-143.

CEN (2005), prEN 14351, Windows and pedestrian doorsets - Product standard, performance characteristics Part 1: Windows and external pedestrian doorsets without resistance to fire and smoke leakage characteristics but including external fire performance for roof windows.

CEN (2000), EN ISO 10077-1, Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 1: Simplified method.

CEN (2003), EN ISO 10077-2, Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 2: Numerical method for frames.