Window energy rating systems

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1. INTRODUCTION

Different window energy rating systems are being developed in Denmark and in Europe. The purpose of a controlled and voluntary rating system is to establish a fully validated database for the assessment of energy performance of windows to help consumers, architects and constructors to choose the most energy efficient windows for their individual purpose.

The energy consumption to cover heat loss through windows is estimated to be 8 % of the total Danish energy demand, and is thereby responsible for 30 % of the heating bill for residential buildings.

It is anticipated that the registration and labelling process will elicit a favourable public reaction and raise awareness of the issues.

This paper will give an overview of the work done at the Technical University of Denmark to secure correct physical detailed calculation methods for the different kinds of products. Rating systems are developed for: glazing, windows, inner leaves of double windows, skylights, curtain walling and energy-efficient accessories of windows.

The establishment of rating systems will be implemented from 2000-2003 depending on the products. Some of the methods described in this paper are not finally agreed upon, and should be considered as proposals of methods - all methods have been developed for each type of product based on relevant European standards.

2. GLAZING

Danish glazing rating systems are established by trade organisations, with economic support from the Danish government, as a part of the Danish energy policy to reduce energy losses through windows.

The glazing producer is responsible for the determination and documentation of the light transmittance, total solar energy transmittance (both at normal incidence), thermal transmittance and equivalent thermal conductivity of the edge construction used in the specific double-glazing.

Table 1 Necessary information documented by the glazing producer to obtain a classification on the glazing

Symbol	Data	Reference
U_g	Thermal transmission coefficient, centre value	EN 673
τ	Visible transmittance, centre value	EN 410
g	Total solar energy transmittance, centre value	EN 410
λ_k	Equivalent thermal conductivity [W/mK]	-

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2.1 Classification

The classification of glazings is based on a designed energy balance representing the heat gain through the glazing placed in a reference house in Denmark. The net energy gain is determined by the following equation:

$$E_{ref} = 196.4 \cdot g - 90.36 \cdot U_g \tag{1}$$

As can be seen from the equation the energy balance will be negative for very poor glazings and positive for good energy performing glazings.

By using this simple formula the glazing can be rated if the heat gain limits are met:

Table 2 Classification limits of glazing

Rating	Limits
A	E_{ref} > 20.0 kWh/(m² year)
B	20.0 kWh/(m² year) ≥ E_{ref} > 10.0 kWh/(m² year)
C	10.0 kWh/(m² year) ≥ E_{ref} > 0.0 kWh/(m² year)

Glazings with heat gain less then or equal to cero cannot achieve a rating.

3. INNER LEAVES OF DOUBLE WINDOWS

When old buildings in Denmark are renovated it is often a wish that the old and architecturally special windows are preserved. It is a widespread opinion that new windows do not fit into the old buildings, since especially the dimensions of the framing systems are altered compared to the old slim mullions and transoms. The mullions and transoms of the new window are made wider to provide space for double-glazing and edge construction. This will in some cases result in a window with a changed, non-matching, appearance with less glazing and less daylight.

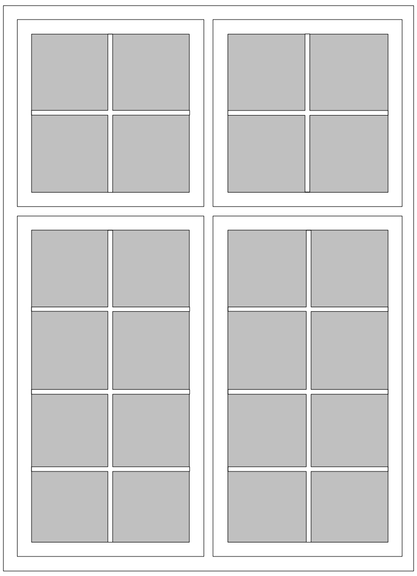


Figure 1 Old wooden window

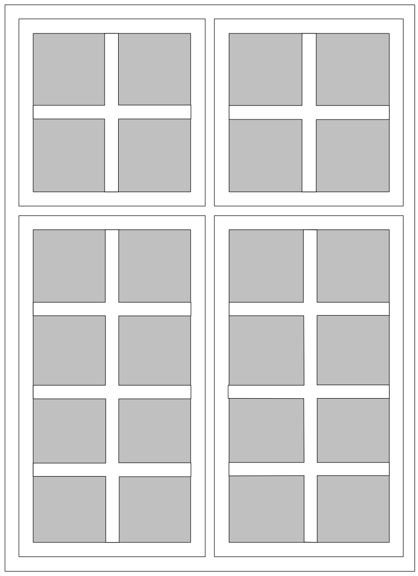


Figure 2 New wooden window

At the same time it is wished to lower the heat loss through the windows and make them airtight to improve the indoor climate. The commonly chosen solution is to mount inner leaves on the existing framing system. Such a solution has energy properties on a par with and sometimes (when the window has many mullions and transoms, see figure 1 and figure 2) better than new windows with double glazing with a low emittance coating. Of course this requires that the inner leaves will be made of hard-coated low-emissivity panes.

No rating or classification system has yet been established for inner leaves of double windows.

3.1 Reference window

An inner leaf of a double window needs to be rated but it makes no sense to rate it as an independent window/frame system. Therefore all inner leaf systems are mounted upon a Danish reference window and the thermal properties are calculated together with the reference window, which represents the existing window in the building.

Using the reference window in the standard dimension [1230 by 1480 mm] makes product comparison possible. The calculation for a specific window dimension is easily made.

The reference window consists of a wooden frame, transom and sash with 3 mm float glass.

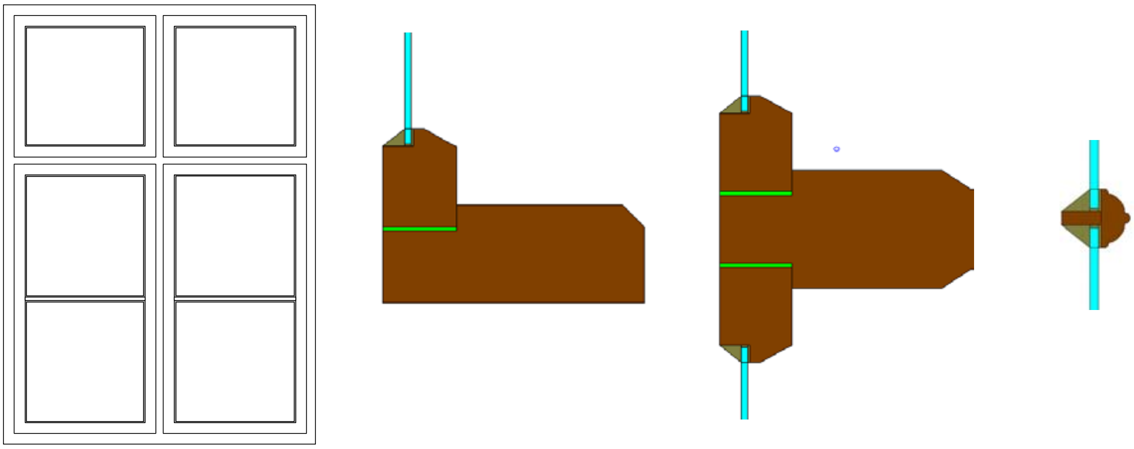


Figure 3 Reference window - used for comparison of inner leaf systems

3.1.1 Examples of inner leaf framing systems.

3.1.1 Examples of inner leaf framing systems. Different inner leaf systems are used in Denmark. Some are made of aluminium or wood and some only consist of an extra pane placed directly against the old sash and frame. This is often considered as an advantage since it is not necessary to open more than one window to get fresh air and the window system opens outwards.

Different systems are illustrated in figure 4 combined with the reference sash and frame.

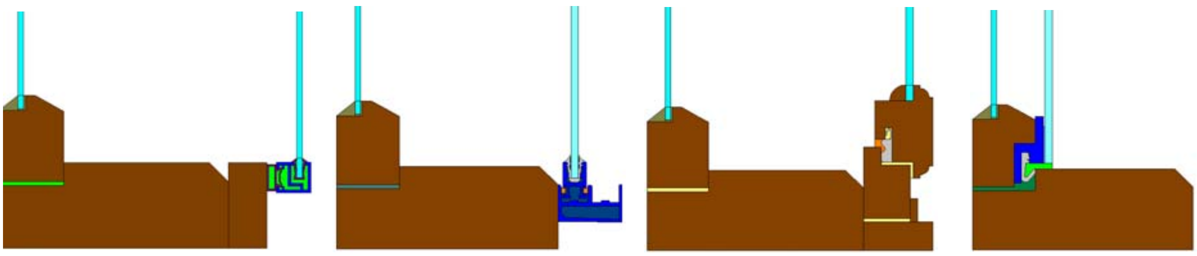


Figure 4 Examples of inner leaf systems mounted on reference window

3.2 Detailed calculation of window energy performance using inner leaves

Please note that the described calculation method is a proposal and still needs to be verified by measurements.

The method is valid when the glazing distance is more then 40 mm. If the glazing distance between the existing pane and the inner leaf is smaller then 40 mm the calculation is performed in accordance with prEN ISO 10077-2 "*Thermal performance of windows, doors and shutters. Calculation of thermal transmittance - Part 2: Numerical method of frames*".

Large cavities are treated according to EN ISO 6946" *Building components and building elements - Thermal resistance and thermal transmittance*".

The calculation procedure uses in general the same boundary conditions as the method described in prEN ISO 10077-2. The difference consists in the way the centre thermal transmittance of the combined glazing system is included in the model. No linear thermal transmittance of the two-dimensional thermal coupling coefficient is calculated. The effect is included in the thermal transmittance of sash and frame.

Only one model needs to be built for calculation in a finite element method program.

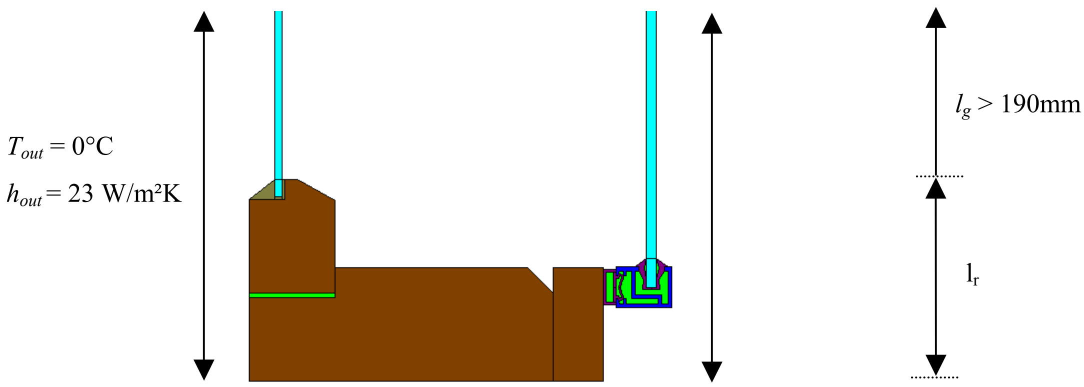


Figure 5 Boundary conditions

Usually the large cavity between the existing pane and the inner leaf is simulated as a cavity with an equivalent thermal conductivity. The procedure creates problems with the temperature profile around the sash and frame. Instead half the thermal resistivity of the cavity is placed as a heat transfer coefficient, h on each pane facing the cavity together with an air temperature of the cavity, T_{middle}.

$$R_{eq} = \frac{1}{U_g} - \left(\frac{1}{h_i} + \frac{1}{h_u} + \frac{s_{g1}}{\lambda_{g1}} + \frac{s_{g2}}{\lambda_{g2}} \right) \quad (2)$$

s_{g1} and s_{g2} : Thickness of existing pane and inner leaf respectively

λ_{g1} and λ_{g2} : Thermal conductivity of existing pane and inner leaf respectively

The temperature, T_{middle} of the air cavity is changed until the heat flows through the inner and outer boundary are equal.

The thermal transmittance of the frame section can be calculated as:

$$U_r = \frac{L_{tot} - U_g \cdot l_g}{l_f} \quad (3)$$

L_{tot} Two-dimensional thermal conductance [W/mK]

The same procedure is used for calculating the thermal properties of the transom.

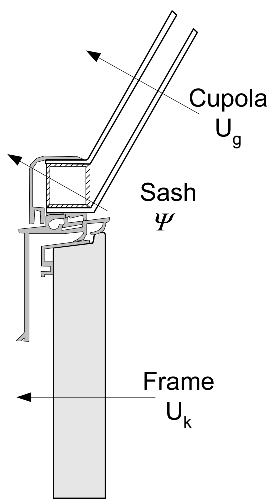
4. SKYLIGHTS

As for glazing, inner leaves of double windows and windows, a rating system is developed for skylights. The rating systems are established by trade organisations and it has been necessary to prepare a detailed calculation method to secure an unambiguous foundation. The method described is at this time submitted for comment prior to incorporation in the Danish building code and is expected to form the basis for a coming energy rating.

4.1 Detailed calculation of energy performance of skylights

The total thermal transmittance of skylights consists of 3 contributions: U_g, U_k and Ψ. The properties originate from cupola, frame and the linear thermal transmittance through the sash between cupola and frame as illustrated in figure 6.

The total thermal transmittance is calculated in accordance with prEN ISO 10077-2. Treatment of boundary conditions and cavities is altered so that cavities larger then 2 mm are treated as well ventilated.



$$U = \frac{A_g \cdot U_g + A_k \cdot U_k + \psi \cdot l_\psi}{A'}, \qquad A' = A_g + A_k + A_r$$

U_g	Thermal transmittance of cupola [W/m²K]
U_k	Thermal transmittance of frame [W/m²K]
ψ	Linear thermal transmittance of sash [W/mK]
l_ψ	Perimeter of skylight [m]
A_g	Area of cupola [m²]
A_k	Area of frame [m²]
A_r	Area of sash [m²]
A'	Total area [m²]

Figure 6 3 contributions: U_g, U_k and Ψ

The thermal transmittance of the cupola (U_g) can be calculated in accordance with EN 673 "*Glass in building - Determination of thermal transmittance (U-value) - Calculation method*". To calculate the thermal transmittance (U_k) of the frame the frame's actual cross section is transformed to an equivalent uniform one.

The linear thermal transmittance is obtained by calculating the two-dimensional thermal conductance (L_{tot}) of the complete skylight cross section in a simulation program. The linear thermal transmittance is then calculated as:

$$\psi = L_{tot} - U_k \cdot l_k - U_g \cdot l_g \tag{4}$$

L_{tot}	Two-dimensional thermal conductance [W/mK]
l_k	Height of frame used in the simulation [m]
l_g	Cupola section used in the simulation [m]

The total heat loss is related to an approximate outer area of the total skylight construction (A') calculated as the sum of A_g, A_k and A_r (all outer area). By this method it is assumed that the outer area of the sash profile is a part of the transmission area. The calculations are done using the divisions illustrated in figure 7.

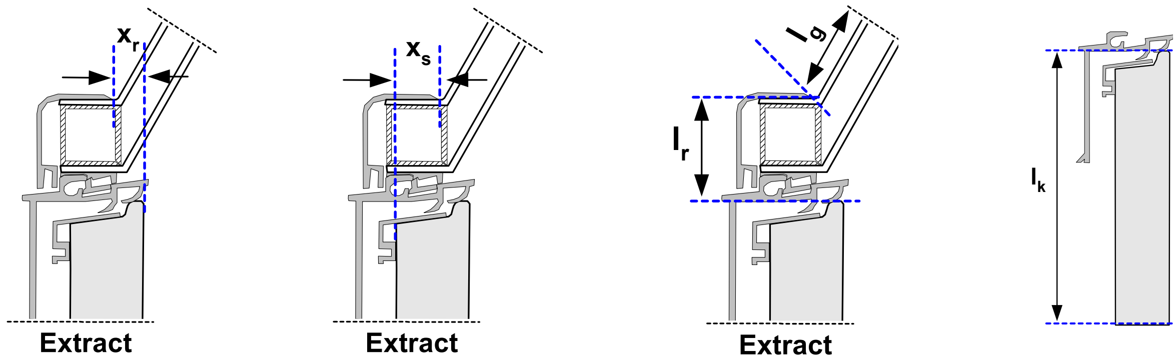


Figure 7 Profile section of skylight - dimensions used for detailed calculation

The cupola area A_g is calculated as the outer surface area from the place the cupola meets the sash.

The frame area A_k is calculated as the outer perimeter of the frame multiplied by the height of the frame l_k.

The frame height (l_k) is defined as the distance between the horizontal levels under the frame to a horizontal level above the frame measured at a straight line parallel to the frame geometry. The horizontal level under the frame is defined as the upper situated of two levels:

1. Horizontal level under frame
2. Topside of roof insulation level

The sash area is calculated as the perimeter of the outer frame at the sash multiplied by the height of the sash (l_k). The area is added the horizontal projected area between the cupola end and the vertical level determined by the outer demarcation of the frame.

The horizontal projected area is determined as the distance X_s (figure 7) multiplied by the perimeter of the outer frame at the sash.

The linear thermal transmittance is related to the perimeter of the skylight. The perimeter is again calculated in accordance with the outer frame.

5. WINDOWS

In both Denmark and in Europe energy rating systems for complete windows are being developed. The method described in this paper is to be taken as an expression of the Technical University of Denmark's view of how the development could proceed.

5.1 4 levels

The proposed system is divided into 4 levels, which is explained in the next 4 clauses.

5.1.1 Level 1 information is the fundamental physical window performance, based upon data from the producers of the products in accordance with the relevant European Standards. The data are thermal transmittance and dimensions of framing systems, thermal transmittance and total solar energy transmittance of glazing.

Table 3 Energy labelling data for glazings and windows.

	Data	Reference
Glazing	Thermal transmission coefficient, centre value	EN 673
	Visible transmittance, centre value	EN 410
	Total solar energy transmittance, centre value	EN 410

	Equivalent thermal conductivity of edge construction	-
Window	Linear thermal transmittance	prEN ISO 10077-2
	Thermal transmission coefficient based on total area	prEN ISO 10077-2
	Visible transmittance based on total area	ISO DIS 15099
	Total solar energy transmittance based on total area	ISO DIS 15099

Level 1 data are independent of specific building type, orientation and climate data.

Today the determination of the thermal transmittance of the framing system can be based upon simulation or measurements in accordance with the relevant European standard. Nevertheless it is recommended to base thermal performance on simulations. This is due to lessons learnt from operating rating system in other countries.

1. Simulation only has been a real asset in terms of low cost, speed and acceptance. (Canadian experience)
2. Measurements incur relatively high cost due to the need for testing of every product line. The testing is very time consuming. (US experience)
3. Simulation is always within 10 % of measurements. (US experience)

Correctly performed simulations can be secured by using accredited simulators or by an appropriate control organisation to perform random checking of simulation files.

Self-regulation by the industry is preferable, based on mutual control of open documentation. Reliable technical information has to be calculated and presented in a uniform way by all participating manufactures across the industry. This gives the possibility for competitors to complain if the documented product is not the product sold.

5.1.2 Level 2 is "*level 1*" data used in an energy balance equation. The equation does not take the air leakage into account, since earlier reports[1] indicate that air permeability has only small impact on the energy balance and thereby on the overall window energy rating.

- New windows are very tight compared to old windows
- If the windows are tight, "draught" may not be caused by infiltration, but from indoor air being cooled by the window surface.
- Air leakage rating is an expression of a worst-case scenario. Outdoor wind speed is normally lower than that used in test conditions, which results in lower infiltration.

It is important to note that air permeability of windows varies with installation method, material design, pressure differences, user stresses and local weather conditions such as humidity and temperature. No test method can take these factors into account.

By using typical climatic data (here shown for Denmark) and by choosing a reference building the relative areas for the main orientations of the windows can be used in calculating the net energy gain as a function of the U-value and the g-value of the glazing.

The net energy gain is calculated from the same formula as used for glazing only except that g and U are evaluated for the whole window including the frame:

[1] In accordance with: Report on "The Development of a UK Domestic Window Energy Rating System". This report refers to: Carenter, S, Mcgowan A and Miller S, of Enermodal Engineering Limited, 1998, Window annual energy rating systems: What they tell us about residential window design and selection, ASHRAE meeting June 98.

$$E_{ref} = 196.4 \cdot g_w - 90.36 \cdot U_w \quad (5)$$

The thermal transmittance and total solar energy transmittance shall correspond to the complete window and be calculated for a standard window size [1230 by 1480 mm], which is the size, specified in CE-mark Product Standard " *Windows and external pedestrian doors*".

The calculated energy performance given for "standard size" should not be used for all sizes but only for comparison of products.

No classification system has yet been agreed upon.

5.1.3 Level 3. The purpose of this level is to perform calculations using a reference house in which the windows are included with their actual dimensions, rather then the standard ones.

This gives the possibility to determine the window energy performance for various orientations and sizes to determine the correct net energy gain.

This level can only be performed correctly if the basic physical data from "*level 1*" are available since the reference house does not only consist of standard size windows. All necessary energy performance data in accordance with table 3 will not be available if "*level 2*" is based on energy properties from measurements only. Measurements can only determine the thermal transmission coefficient based on total area from the fixed standard size.

At this level only the impact from the windows is evaluated.

5.1.4 Level 4. The purpose of this level is to perform very detailed calculations on specific houses with all detailed information on building components, sizes, and orientations. This level is aimed towards architects and building constructors in the design stage. This stage will most likely be of no interest to the common consumer. This level calculates the energy consumption to cover heat loss through the complete building and not only windows.

Again detailed basic physical data from "*level 1*"must be available.

6. CONCLUSION

It is anticipated that the registration and labelling process will elicit a favourable public reaction and raise awareness of the issues. The availability of a method allowing consumers to easily compare products will provide a market force for product improvement. The labelling system is comparable to the EU labelling for white goods and is therefore a known, simple and reliable classification system.

A product energy performance is obtained for standard dimensions with the possibility to derive that for other geometries by a simple calculation.

7. REFERENCES

prEN ISO 10077-2 "*Thermal performance of windows, doors and shutters. Calculation of thermal transmittance - Part 2: Numerical method of frames*".

EN ISO 6946" *Building components and building elements - Thermal resistance and thermal transmittance*".

EN 673 "*Glass in building - Determination of thermal transmittance (U-value) - Calculation method*".