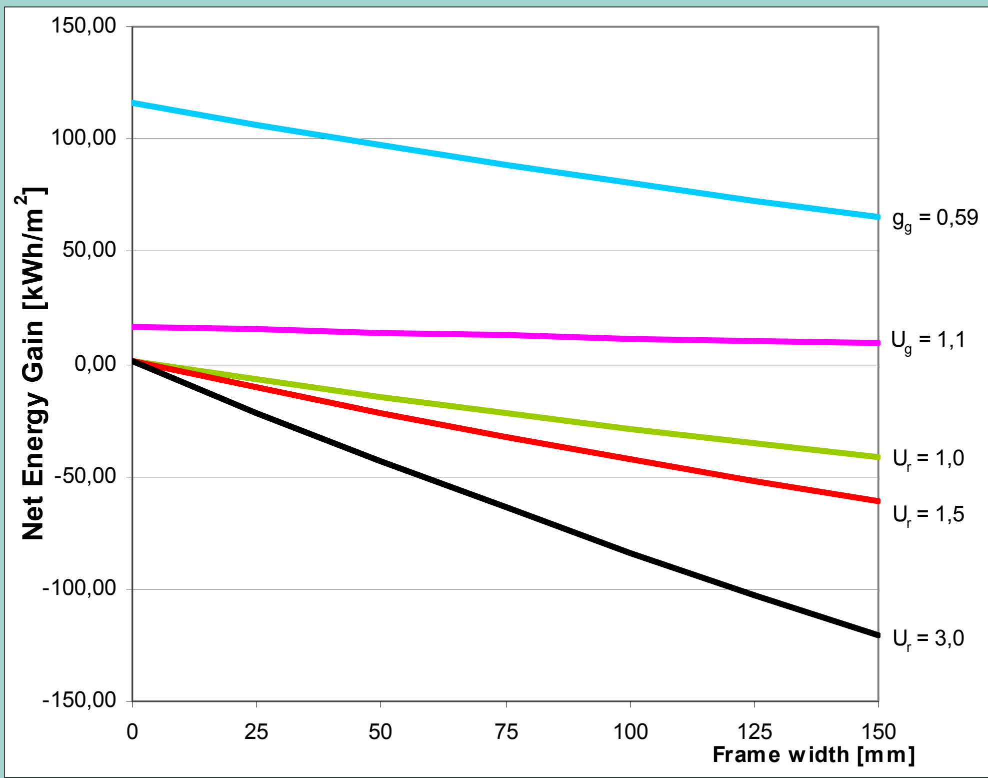
BYG•DTU

ENERGY PERFORMANCE OF GLAZINGS AND WINDOWS

compendium 9:

SUMMARY OF THE POSSIBILITIES OF DEVELOPING BETTER GLAZINGS AND WINDOWS



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Lecture note

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Foreword to the compendia in general

One of the objectives in the energy action plan of the government, Energy 21 [1], is to reduce the energy consumption in dwellings by introducing energy conservation measures. Here the development and use of better glazings and windows in terms of energy is of great importance, as a large part of the thermal loss from dwellings traditionally takes place through the windows.

According to Klima 2012 [2] there is to be an intensification of economy measures directed to product for windows etc.

The compendium forms part of a number of compendia that shall contribute to carrying through the economy measures directed to product by informing about:

- Fundamental energy performance of glazings and windows
- Energy labelling of glazings and windows
- Possibilities of developing better glazings and windows in terms of energy
- Design and use of better glazings and windows in terms of energy

The compendia treat the possibilities of determining and improving the thermal and optical properties of glazings and windows. Equally, the influence of glazings and windows on the total energy consumption and indoor climate of buildings is treated. A primary objective is to develop windows that yield a positive net energy gain in heating dominated housing.

So far the series of compendia consists of 5 finished and 8 interim compendia, which are mentioned below.

Compendium 1: " Fundamental properties in terms of energy"
The target group is producers of glazings and windows, building consultancies, professional building owners, contractors, glaziers, timber merchants, contractors.

The compendium refers to glazings and windows concerning:

- Materials and structure
- Properties in terms of energy
- Net energy gain for the building

Compendium 2: "Simplified methods for determination of energy labelling data" and compendium 3: "Detailed methods for determination of energy labelling data"
The target group is mainly producers of glazings and windows.

The compendia give guidance to the producers on how they in a simple or more detailed way can determine energy labelling data and, if necessary, energy classification for their products.

Compendium 4: "Development of energy-efficient glazings and windows"
The target group is mainly producers of glazings and windows.

The compendium contains a number of analyses of potential for improvement that can act as inspiration and help for producers who want to develop glazings and windows with better properties in terms of energy.

Compendium 5: "Energy-efficient selection of glazings and windows"
The target group is building consultancies, professional building owners, and technical administrations.

The compendium treats simple and detailed programmes and diagrams for determination of heating demand and indoor climate in buildings as a function of the energy performance of glazings and windows.

The following compendia are only available in an interim version:

Compendium 6:"Data for energy labelled glazings and windows"
The target group is producers of glazings and windows, building consultancies, professional building owners, contractors, glaziers, timber merchants, contractors.
The compendium gives a survey of energy labelled glazings and windows on the Danish market. Information is given on producers of glazings and windows as well as energy labelling data of the single products.

Compendium 7:"Net energy gain of glazings and windows"
The target group is producers of glazings and windows, building consultancies, professional building owners, contractors, glaziers, timber merchants, contractors.
In the compendium a sensitivity analysis is made of the method for classifying glazings on the basis of the net energy gain for a reference building.
Guidance is given on the application of a program that can calculate the net energy gain for glazings and windows in specific situations.

Compendium 8: solar shading devices
Being prepared

Compendium 9: " overview of the possibilities of developing better glazings and windows".
The target group is producers of glazings and windows and also architects and building consultants.
This compendium takes stock of typical windows on the market with the emphasis on the energy properties. Different possibilities of developing glazings and windows with better energy performance are gone through. This is a summary of the subsequent compendia 10 – 14, in which the possibilities of developing better glazings and windows are gone through in detail.

Compendium 10: "Glazings with greater net energy gain"
The target group is producers of glazings and windows.
In this compendium the net energy gain of glazings are investigated, calculated in two different ways. By using a simple diagram method and a detailed calculation program. Examples are given of the possibilities of improving the glazings, either by reducing the U-value of the glazing or by increasing the g-value of the glazing.

Compendium 11:" Edge structures with reduced thermal bridge"
The target group is producers of glazings and windows.
The compendium gives a survey of different edge structures and their properties with regard to thermal loss and condensation in different types of windows. Likewise information is given on better spacer profiles.

Compendium 12:"Windows with insulated frames"
The target group is mainly producers of windows.
The compendium shows how to achieve marked energy improvements of frames by insulating them, by using other materials, or making alterations to the structure.

Compendium 13:"Windows with narrow frames"
The target group is producers of glazings and windows.
In the compendium the effect of making the frame narrower is investigated. Likewise the effect of inserting a frame in staggered rebate is calculated.

Compendium 14: "Windows with less edge loss in the sealing between window and wall"

The target group is producers of glazings and windows, architects and building consultants.
The compendium covers a going through of different window designs and different wall solutions. These different designs are combined, and advantages and disadvantages with regard to the size of the assembly edge loss are illustrated. Methods are given for calculation of the total extra edge loss of the wall- and window design and the edge loss in the sealing between window and wall.

The publication of the compendia
The compendia are available in an electronic version in the format PDF, readable with Acrobat Reader. The electronic versions of the compendia and the program Acrobat Reader are available on the internet address http://www.ibe.dtu.dk/vinduer.

The compendia have been made with a grant from The Danish Energy Agency according to the act of government grant for energy savings directed to product.

Foreword to compendium 9

In the existing buildings and in new buildings there are great possibilities of obtaining energy savings by using better windows.

By the introduction of energy labelling of glazings and windows, a basis of competition on the energy properties has been formed. Thus it has its advantages to develop windows with better energy properties. There is therefore a need to support the development of glazings and windows with better energy properties.

This compendium discusses the possibilities of developing glazings and windows with a view to achieving better energy properties.

Windows consist of a number of single units, each of which can have a great effect on the properties of windows in terms of energy It has therefore been decided to treat the single parts of the window separately and to describe them in each separate compendium. This compendium 9 is an introductory summary of status and potentialities for windows based on the subsequent compendia, which focus on the following fields:

- Glazings with a larger net energy gain
- Edge construction of glazings with reduced thermal bridge
- Insulated frames
- Narrower frames
- Windows with less edge loss in the sealing between window and wall

These five sub-items are subsequently described in each separate compendium.

The target group of compendium 9 is mainly producers of glazings and windows.

The compendium has been made on a grant from The Danish Energy Agency according to the act of state subsidies for energy savings directed to products as part of the project: ”Projekt window, den produktrettede indsats på windowsområdet. GENEREL UNDERSTØTTELSE AF VIRKSOMHEDERS PRODUKTUDVIKLING”. Fase 1. J.nr. 75661/00-0008.

Before the publication a draft of the compendium has been circulating among the expert monitoring group for consideration.

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The contents of the compendium were last revised on 16th March 2001.

This version of the compendium with No U-008 replaces the previous version with No U-052.

1 Development of windows with better energy performance

This compendium focuses on developing better windows with regard to energy performance. Thus, the objective is to develop total window solutions that contribute to reducing the heat demand in buildings.

In connection with the development of windows with better energy properties it is necessary to investigate all the parts in terms of energy. It is also important to investigate the sealing between window and wall, as thermal bridges may occur here, caused by the window.

To profit fully from the development work it is necessary to analyse each single partial solution compared with the window's total effect on the heat demand of the building.

1.1 Glazing and frame

When developing better windows with regard to energy performance it is necessary to take into account both the thermal loss out through the window and the solar energy transmitted in through the window. Thus, the objective is to reduce the U-value of the window and increase the g-value of the window.

The best measure for estimating the total properties of the window in terms of energy is the net energy gain E. The net energy gain expresses the solar energy that is transmitted into the building through the window minus the thermal loss out through the window. Thus, this is a function of both the U-value and the g-value of the window:

$E = K_{solar}\, g - K_{loss}\, U.$

The net energy gain is determined for a reference building by means of the expression:

$E_{reference} = 196{,}4 \cdot g - 90{,}36 \cdot U \quad [W/m^2K]$

(See compendium 1).

The better solutions in terms of energy are consequently achieved through a combination of a high g-value and a low U-value. A low U-value is achieved primarily by using materials with a low thermal conductivity, but also the edge loss between window and frame and between frame and wall is important.

The g-value of the window depends on the used glazing (and coating), but also very much of the glazing area. It is therefore often possible to obtain large energy savings by reducing the frame area of the window.

This is illustrated in Figure 1, where the net energy gain for different windows is stated as a function of the frame width.
All the windows have the outside dimensions 1.2 x 1.2 m. In all the windows glazing with a centre U-value of 1.1 W/m^{2}K is used.

To analyse the single parts of the window's contribution to the net energy gain, the above is described by means of the following expression, which forms the basis of the curves in Figure 1:

$$\begin{aligned} E = \; & K_{solar} * g_g * F_A \\ & - K_{loss} * U_g * F_A \\ & - K_{loss} * U_f * (1 - F_A) \\ & - K_{loss} * \Psi * F_L \end{aligned}$$

where $F_A = (b-2a)(h-2a)/bh$
$F_L = [2(b-2a)+ 2(h-2a)]/bh$
a is the width of the frame
b is the width of the window
h is the height of the window
g_g is the total solar energy transmittance of the glazing
U_g is the centre U-value of the glazing
U_f is the U-value of the frame
ψ is the edge loss between frame and window

The upper curve in Figure 1 shows the net energy gain for the actual glazing, disregarding the thermal loss. I.e. the quantity of solar energy transmitted in through the window. It appears that the net energy gain falls when the width of the frame is increased and the glass area is reduced.

In the next curve also the thermal loss from the window is included. That is the net energy gain through the window as the thermal loss from the glazing is included. The thermal loss from the frame part is not in-

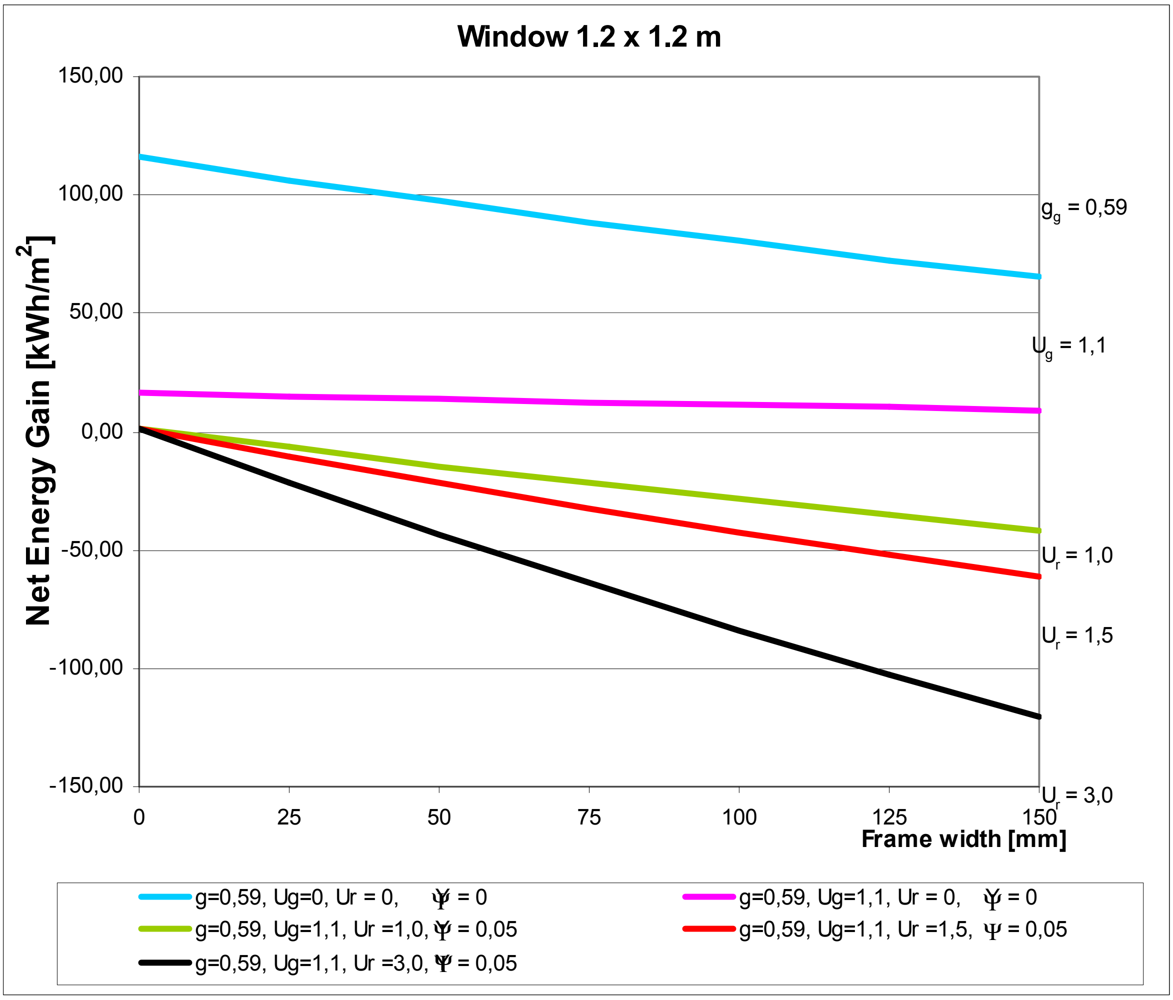

Figure 1. The net energy gain for different windows as a function of the frame width.

cluded. It appears here that the width of the frame has only an insignificant influence on the net energy gain. This is due to the fact that while the solar gain through the window falls, the thermal loss out through the window is reduced, too, as the glass area is reduced relatively to the total window.
The three lower curves show the net energy gain through three windows with the same type of glazings but different frames with U_f-values of 1.0, 1.5 and 3.0 W/m^{2}K, respectively. For these three windows the edge loss for the edge between glazing and frame is also included ($\Psi_{glazing\text{-}frame}$ = 0,05W/mK). The figure indicates that the net energy gain is reduced for all three windows when the width of the frame is increased. It also appears that the larger the U_f-value the quicker the net energy gain falls when the width of the frame is increased. That means for instance that the window with U_f of 3 W/m^{2}K has the same net energy gain at a frame width of 50 mm as the window with U_f of 1 W/m^{2}K has at a frame width of 150 mm. Consequently this means that the same net energy gain can be achieved by combinations of the frame area/the width of the frame and U-value.

The tendency in Figure 1 indicates that there are many circumstances to allow for in connection with development of window solutions with better energy properties. It is not enough only to focus on one thing at a time, but the single partial solutions should be connected to a total optimal solution, where it has been weighed which initiatives are most important for the thermal loss and the solar gain through the total construction.

1.2 Window and wall

As previously mentioned, the assembly between window and wall has an effect on the thermal loss, as the complex construction in the assembly gives cause for thermal bridges resulting in extra thermal loss.

The ideal situation would be to be able to connect the glazing and the wall (without rebate) direct to each other in a assembly that does not give cause for extra thermal loss owing to 2-dimensional heat flows. In practice this is impossible, as it is necessary to have a bricking-up in the rebate and a frame construction to secure the glazing. These extra constructions contribute to 2-dimensional thermal conduction and a reduction of the U-value of the wall and the glazing. The extra thermal losses that inevitably arise in an actual assembly between glazing and wall can be united under the expanded linear thermal transmittance L and stated by the unit W/mK, see Figure 2. I.e. L includes all the extra thermal losses that arise in rebate, sealing, frame and assemblies. The single contributions are shown in Figure 3. It should be clarified that this expanded linear thermal transmittance quantity is not a standard symbol as the one described in e.g. DS418 appendix 4.

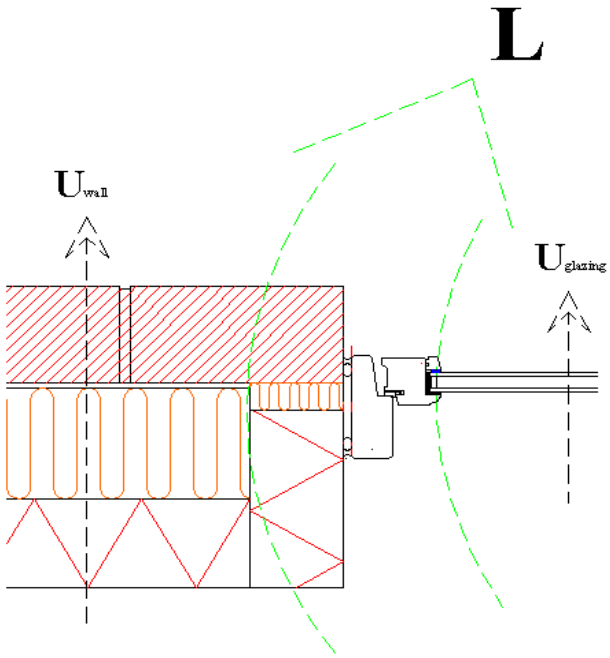

Figure 2. The expanded linear thermal transmittance between glazing and wall

I.e. in the expanded linear thermal transmittance, L, contributions are included from the 4 edge losses that arise in the thermal bridge in the rebate, $\Psi_{wall\text{-}rebate}$, in the assembly between window and wall, $\Psi_{wall\text{-}seal}$ and $\Psi_{seal\text{-}frame}$, and finally between glazing and frame, $\Psi_{franme\text{-}glazing}$. Further is included the effect of the fact that the rebate and the sealing between window and wall have a lower U-value than the wall, and that the frame has a lower U-value than the glazing.

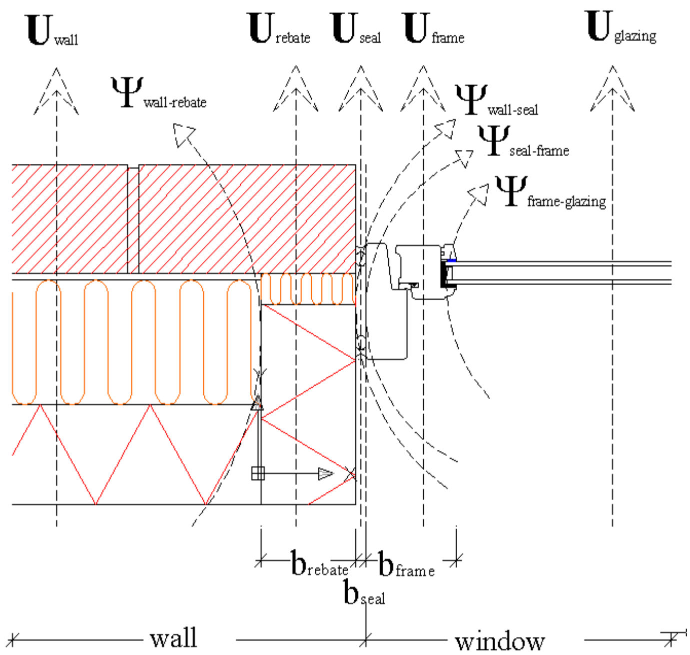

Figure 3. Division of the expanded linear thermal transmittance between glazing and wall, L.

Taken together the expanded linear thermal transmittance can be determined by the following expression:

$$
\begin{aligned}
L = {} & b_{rebate}(U_{rebate} - U_{wall}) + \Psi_{wall\text{-}rebate} \\
& + b_{seal}(U_{seal} - U_{wall}) + \Psi_{wall\text{-}seal} + \Psi_{seal\text{-}frame} \\
& + b_{frame}(U_{frame} - U_{glazing}) + \Psi_{frame\text{-}glazing}
\end{aligned}
$$

In the same way as for the glazing and the frame, a figure has been designed where the assembly between wall and window is included. Se Figure 4. The functions are based on the following expression that corresponds to the previous, but with an extra part that takes into account the extra loss through the wall/window assembly:

$$
\begin{aligned}
E = \; & K_{solar} * g_g * F_A \\
& - K_{loss} * U_g * F_A \\
& - K_{loss} * U_f * (1 - F_A) \\
& - K_{loss} * \Psi_{glazing\text{-}frame} * F_L \\
& - K_{loss} * L_{wall} * 2(h+b)/b*h
\end{aligned}
$$

In Figure 4the same tendencies are seen as in Figure 1, namely that the net energy gain generally falls when the frame width is increased. It appears that the net energy gain for the total windows of $U_f = 1$, 1.5 and 3 W/m^2K, respectively, is lower than for the corresponding windows in Figure 1. This is owing to the extra thermal loss from the wall-window assembly, described at L.

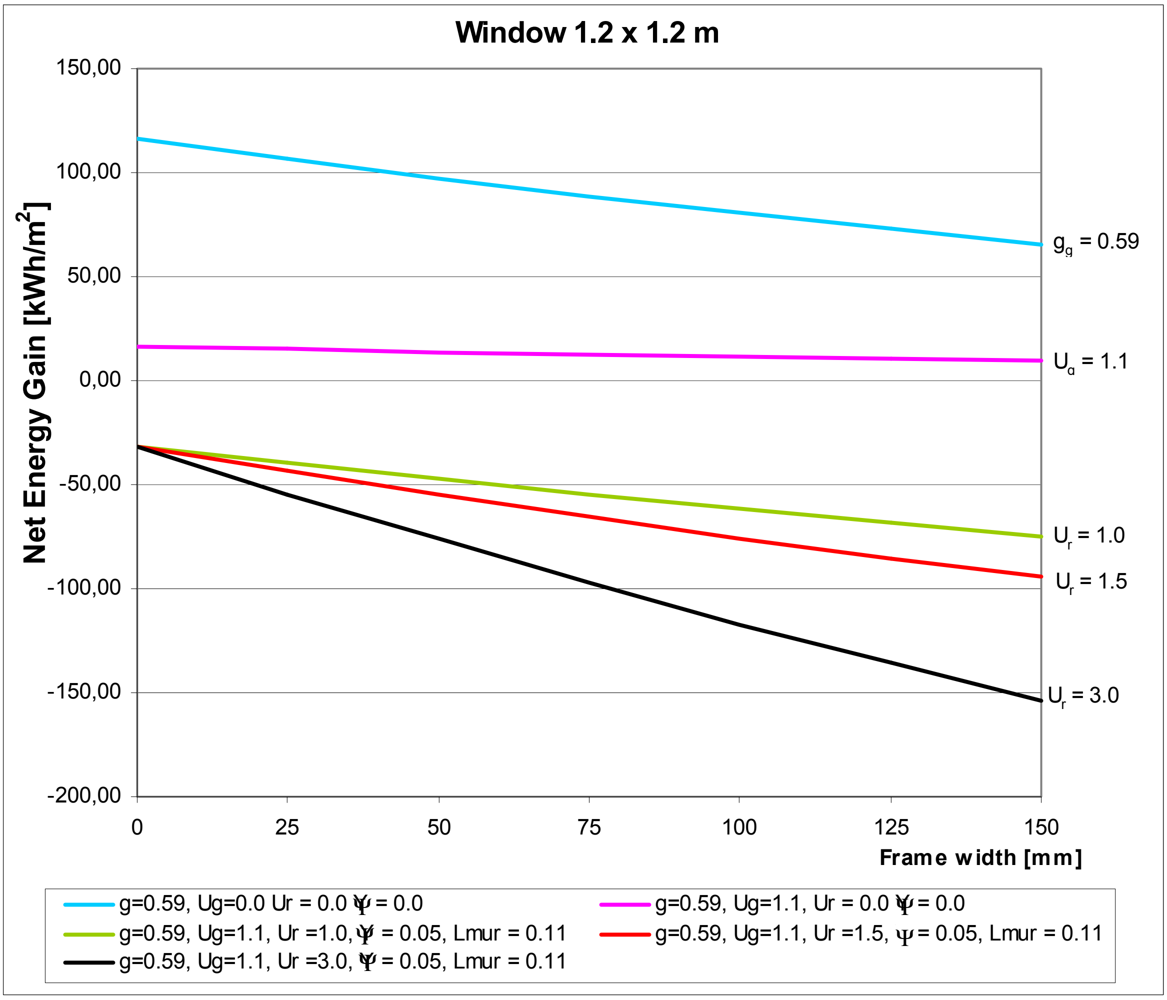

Figure 4. The net energy gain for different windows as a function of the width of the frame. The expanded linear thermal transmittance L_{mur} is included in the three lower curves.

2 Taking stock of the energy performance of typical window solutions

The basis for proposing possibilities of developing windows with better energy performance is the design and energy performance of the present windows.

2.1 Typical windows

Below examples are given of typical windows on the Danish market distributed over five typical types of profiles.

2.1.1 Frame of wood

The frame profile in Figure 5 consists of massive wood and has a U-value of U_f = 1.70 W/m^{2}K. For the total window with the standard dimensions 1.23 x 1.48 m and a glazing with a centre U-value of U_g = 1.14 we get U_{total} = 1.73 W/m^{2}K.

2.1.2 Frame of wood plated with aluminium

The frame profile in Figure 6 consists of massive wood plated with aluminium on the outside. The profile has a U-value of U_f = 1.42 W/m^{2}K. For the total window with the standard dimensions 1.23 x 1.48 m and a glazing with a centre U-value of U_g = 1.18 we get U_{total} = 1.46 W/m^{2}K.

2.1.3 Frame of PVC

The frame profile in Figure 7 has a U-value of U_f = 1.72 W/m^{2}K. For the total window with the standard dimensions 1.23 x 1.48 m and a glazing with a centre U-value of U_g = 1.13 we get U_{total} = 1.46 W/m^{2}K.

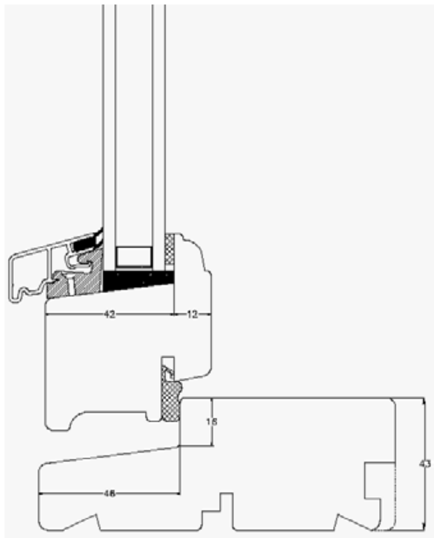

Figure 5. Type 1. Frame of wood.

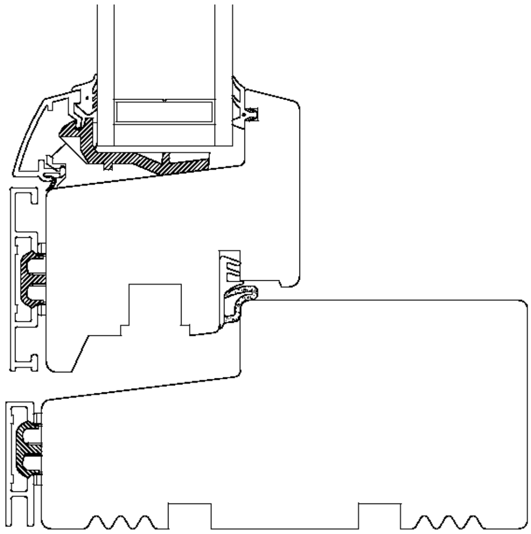

Figure 6. Type 2. Frame of wood plated with aluminium.

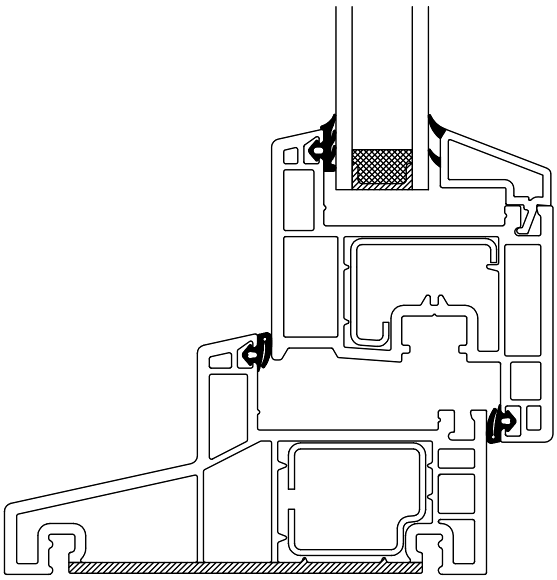

Figure 7. Type 3. Frame of plastic (left side facing outside).

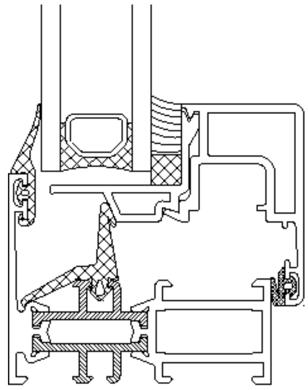

Figure 8. Type 4. Frame of aluminium.

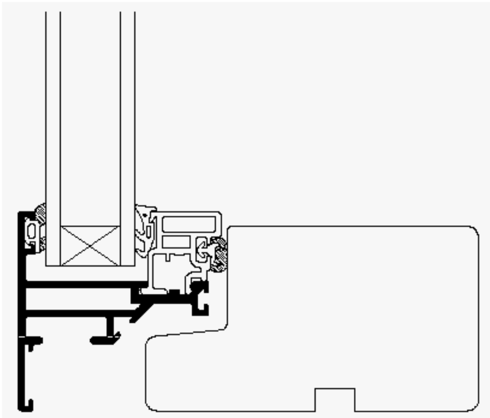

Figure 9. Type 5. Frame of mixed materials.

2.1.4 Frame of aluminium

The frame profile in Figure 8 has a U-value of $U_f = 2.76$ W/m^{2}K. For the total window with the standard dimensions 1.23 x 1.48 m and a glazing with a centre U-value of U_g = 1.14 we get $U_{total} = 1.66$ W/m^{2}K.

2.1.5 Frame of mixed materials

An example of a construction of mixed materials is shown in Figure 9. Aluminium and plastic form part of the sash construction and wood forms part of the frame construction. Thus we get a weatherproof exterior and a traditional interior.
The frame profile in Figure 9 has a U-value of $U_f = 2.76$ W/m^{2}K. For the total window with the standard dimensions 1.23 x 1.48 m and a glazing with a centre U-value of U_g = 1.13 we get $U_{total} = 1.56$ W/m^{2}K.

In Table 1 the energy data for the five window types are shown. In Table 2 the single part units' contributions to the net energy gain of the windows are calculated and shown. In excess of the contributions from the actual window the thermal loss through the wall-window assembly is calculated

Table 1. Data for typical windows.

Window	Width [mm]	Height [mm]	Frame width [mm]	g-total [%]	U_g [W/m^{2}K]	U_f [W/m^{2}K]	Ψ [W/mK]	U_{window} [W/m^{2}K]
1. Wood	1230	1480	97	43	1.16	1.67	0.089	1.52
2. Wood and aluminium	1230	1480	107	42	1.18	1.42	0.0817	1.46
3. PVC	1230	1480	115	41	1.13	1.72	0.0544	1.46
4. Aluminium	1230	1480	60	49	1.14	2.76	0.0877	1.66
5. Mixed materials	1230	1480	56	50	1.13	2.76	0.0491	1.56

Table 2. Contribution to net energy gain for typical windows.

Window	Solar gain [kWh/m^2]	Thermal loss [kWh/m^2]			Net energy gain [kWh/m^2]	Thermal loss [kWh/m^2]	Net energy gain [kWh/m^2]
	Glazing	Glazing	Frame	Assembly sash-frame	Total window	Assembly Window-wall	Total Window-wall
1. Wood	84.7	-76.6	-40.6	-20.5	-53.0		
2. Wood and aluminium	81.9	-75.4	-37.1	-18.5	-49.0	-10.5	-59.5
3. PVC	79.7	-70.2	-48.6	-12.2	-51.2	-11.0	-62.3
4. Aluminium	96.1	-85.4	-42.6	-21.5	-53.5		
5. Mixed materials	97.4	-85.8	-39.9	-12.1	-40.4		

from the L-value of the total construction. It appears that there is some difference between the energy performance of the different windows and thus also between their net energy gain. Here the selection of materials and the dimensions play an important role. Of the windows in the tables the frames of wood and PVC have the lowest U-values, but on the other hand the aluminium frames are thinner, resulting in a higher g-value. This contributes to the fact that the difference in the net energy gain is not larger.

3 Possibilities of developing glazings and windows with better energy performance.

Below different possibilities are gone through of improving the energy performance of windows by making alterations of the window constructions or by using other materials. Most of the calculations of different improvement proposals have been made in the program Therm. The actual analysis of the potentialities is thoroughly described in compendium 10 to 14. In these compendia the most possibilities have been gone through, whereas in this compendium only a few of the best proposals with regard to energy are reported.

3.1 Possibilities of developing glazings with larger net energy gain

By using low-iron panes of glass the total solar energy transmittance of the glazings can be increased, as the part of the solar radiation that is absorbed in the pane of glass is reduced from ca. 8% to 2%. Corresponding reductions of the absorbed solar radiation can be gained by using antireflection coated panes of glass. None of the two measures have an influence on the U-value of the glazing worth mentioning.

The thermal loss out through glazings can be reduced, by using panes of glass with low-emission coating and e.g. argon or krypton in the space between the panes of glass.

All these measures contribute to achieving larger net energy gain through the glazings to the building.

In compendium 10 ”Glazings with larger net energy gain” different potentials for improvement have been analysed, and in Table 3 below selected solutions are shown that involve improvements of the net energy gain. The net energy gain in Table 3 has been calculated by the reference building method that is used in connection with classification of glazings.

Point of reference is a glazing consisting of 4 mm ordinary float glass, 15 mm 90/10 argon/air mixture and 4 mm ordinary float glass with low-emission coating ε =0,1.

It appears from the table that the net energy gain is increased from19 to 36 kWh/m^2 by using a glazing with low-iron panes of glass, krypton/air 90/10 in the cavity between the panes of glass and low-emission coating with ε = 0.04. The increased net energy gain is mainly caused by the improved U-value that is reduced from 1.32 to 1.08 W/m^{2}K.

By using a glazing of 4 mm low-iron glass with an antireflection coating, 90/10 argon air mixture in the space, and ordinary float glass with a low-emission coating ε = 0.1, the net energy gain is increased to 37 kWh/m^2. This improvement is mainly caused by the improved g-value that has risen from 0.66 to 0.75.

Table 3. Possibilities of improving glazings.

Glazing	U-value [W/m^{2}K]	g-value	Net energy gain [kWh/m^2]
Reference: 4 mm float, 90/10 argon/air, 4 mm float m. ε =0,1	1.32	0.66	10
4 mm low-iron, 90/10 krypton/air, 4 mm float m. ε =0.04	1.08	0.64	28
4 mm antireflection + low-iron, 90/10 argon/air, 4 mm float m. ε =0.1	1.32	0.75	28

3.2 Possibilities of developing edge constructions with reduced thermal bridge

By using edge constructions with lower equivalent thermal conductivity the U-value of the window and the risk of condensation can be reduced. This is shown in compendium 11 "Edge constructions with reduced thermal bridge", where the energy performance of different edge constructions are analysed.

Traditional spacer profiles are made of aluminium or steel, which have good strength properties. Owing to the high thermal conductivities of aluminium and steel this means, however, that the edges will act as a thermal bridge in the assembly between glazing and frame. By using other materials with lower thermal conductivities, such as plastic or stainless steel, in profiles, which also are slim, the thermal bridge effect of the edge construction can be reduced.

In Table 4 the results for a spacer profile of plastic are shown together with a traditional profile of aluminium as reference.
It appears that by using a spacer profile of plastic with an insert of stainless steel improvements are achieve of the U-value of a standard window and of the risk of condensation on the inside of the glazing.

In Table 5 the contributions to the net energy gain for two different windows (1230 x 1480 mm) can be seen, where the traditional aluminium spacer profile is replaced by one of plastic with an insert of stainless steel. It appears that the thermal loss through the assembly between glazing and frame is reduced for both windows when spacer profile of plastic is used instead of aluminium.

Table 4. Edge constructions in frame of wood and aluminium. Values for spacer profiles of aluminium and plastic, respectively.

Edge construction		Alu	plastic
Dimensions incl. spacer	(h x b) [mm]	9.5 x 24	11 x 24
Equivalent thermal conductivity λ_k	[W/mK]	3.6	0.3
Coefficient of heat transfer *L*	[W/mK]	1.43	0.14
Edge loss Ψ_g	[W/mK]	0.085	0.040
U-value	[W/m^{2}K]	1.46	1.34
Condensation resistance factor f_{Rsi}		0.515	0.650
Annual hours with risk of condensation. At a moist production of 9.5 kg/d	[hours]	22	6
At a moist production of 9.5 kg/d with half air change	[hours]	2614	182

Edge construction:
a: Traditional aluminium spacer profile
e: Spacer profile of plastic with insert of stainless steel.
A moist production of 9.5 kg/d corresponds to a family of four persons.

Table 5. Contribution to net energy gain for window with frame of wood covered with aluminium and different edges.

Frame	Edge	Solar gain [W/m^{2}K]	Thermal loss [W/m^{2}K]			Net energy gain [kWh/m^2]
		Glazing	Glazing	Frame	Assembly frame	Total window
Wood and aluminium	Aluminium	81.9	-75.4	-37.0	-19.3	-49.7
	Plastic	81.9	-75.4	-37.0	-9.1	-39.1
Plastic	Aluminium	79.7	-70.2	-48.5	-12.2	-51.2
	Plastic	79.7	-70.2	-48.5	-7.5	-46.7

3.3 Possibilities of improving insulated frames

In spite of the fact that comparatively low U-values have been gained for modern frames, there is a large potential in developing frames with better energy performance. By means of the program, Therm, calculations have been carried out in compendium 12 of U- and Ψ–values for different potentials for improvement of three of the frames mentioned in paragraph 2. Further a new expanded linear thermal transmittance, $L_{glazing\text{-}ramme}$, has been calculated, which is an expression of the extra thermal loss through the assembly in proportion to the one-dimensional loss through the glazing. L can be used as a unit of measurement for the thermal loss through the frame and the assembly between glazing and frame, independent of the area of the construction. L is determined by the expression given below:

$$L = l_f(U_f - U_g) + \psi_g$$

where

l_f is the width of the frame
U_f is the U-value of the frame
U_g is the centre U-value of the glazing
Ψ_g is the edge loss coefficient for the edge construction.

Below examples of potentialities for frames are gone through.

3.3.1 Possibilities of improving frames of wood covered with aluminium.

As the wood frame and the wood frame covered with aluminium have almost the same thermal properties they are treated together. Point of reference is thus the frame of wood covered with aluminium. By replacing the inner core of both the sash and the frame with insulating material (λ=0.039), but retaining the wood on the outside, U_f is reduced from 1.40 to 1.02 W/m^{2}K. Further, the part of the wood frame end to end to the glazing is replaced by hard insulation (purenit λ=0.07 W/mK). At the same time the glass rebate of aluminium is replaced by PVC, and the air gap between sash and frame is sealed by a rubber moulding. These changes result in an improvement of the total U-value of the window from 1.45 to 1.28 W/m^{2}K, and the L-value is reduced to less than half its original value. Consequently these measures result in considerable energy improvements. The results are shown in Table 6.

Table 6 Frame construction of wood covered with aluminium.

Measure	U_f	ψ (edge loss)	U-total	$L = l_f(U_f - U_g) + \psi$
	W/m^{2}K	W/mK	W/m^{2}K	W/mK
Reference window (Figure 6)	1.40	0.0817	1.45	0.1052
Isol. λ=0.039, sealing of air gap and glass rebate of alu.$\Rightarrow$PVC	0.88	0.0757	1.28	0.0436

3.3.2 Possibilities of improving frames of PVC.

Point of reference is the window in Figure 7, where the sash and the frame are made of PVC. To strengthen the construction strengthening profiles of steel are used both in the sash and the frame.

To reduce the thermal loss through these steel profiles, they are changed to fibre glass reinforced polyester, which has a lower thermal conductivity and good strength properties. Apart from that the cavities are filled up with insulating material (λ = 0.039 W/mK), and the air gap between sash and frame is divided into smaller cavities. The effect of the changes appears from Table 7. It appears that marked improvements are gained of both U-value and L-value.

3.3.3 Possibilities of improving frames of aluminium

Point of reference is the window in Figure 8, where the sash and the frame are made of aluminium and supplied with a built-in thermal break.

It is a well-known fact that aluminium has a very high thermal conductivity. This makes it very difficult to produce frames of aluminium with a low U-value. Therefore calculations have been carried out for a similar frame made of fibre glass reinforced polyester, which should be able to meet the demands for strength and at the same time have a considerably lower thermal conductivity.

The results of the calculations are seen in Table 8. It appears that marked improvements are gained of both U-value and L-value.

Table 7 Frame construction of PVC

Measure	U_f	ψ (edge loss)	U-total	$L = l_f(U_f - U_g) + \psi$
	W/m²K	W/mK	W/m²K	W/mK
Reference window (Figure 7)	1.72	0.0544	1.45	0.1220
Combination (iso.λ=0,039, fibre glass reinforced polyester and extra division of air gap)	1.0597	0.0597	1.26	0.0516

Table 8 Frame construction of aluminium

Measure	U_f	ψ (edge loss)	U-total	$L = l_f(U_f - U_g) + \psi$
	W/m²K	W/mK	W/m²K	W/mK
Reference window (Figure 8)	2.76	0.0877	1.66	0.1851
Profile exclusively in fibre glass reinforced polyester	1.57	0.0734	1.41	0.0992

3.3.4 Alternative design of frame

In excess of improving the traditional frames, calculations have been made for an alternative window. Figure 10 shows a proposal for a frame construction of fibre glass reinforced polyester, which is both very slim and deep. There is room for 3 panes of glass with an unusually large gap, which has the effect that the depth of the frame is as much as 150 mm. The frame can be made randomly deep, however, and thus cover large insulation thicknesses in the wall. The window is called the combination window, as it combines glazing and sash into a more total construction. The window, which is still a sketch plan, however, is a proposal from Svend Svendsen, BYG·DTU.

As the total area of the window is 1.23 m · 1.48 m and the frame width is 25 mm, the glass percentage is 93%. The centre U-value of the glazing is 0.93 W/m^{2}K and the g-value is 0.58. The results of the calculations can be seen in Table 9.

In Table 10 the single contributions to the net energy gain for the improvements in the four windows are shown. For the first three window types it appears as expected that the largest reductions of the thermal loss have taken place in the frame construction. With regard to the thermal loss through the assembly between glazing and frame, improvements as well as deterioration appear.

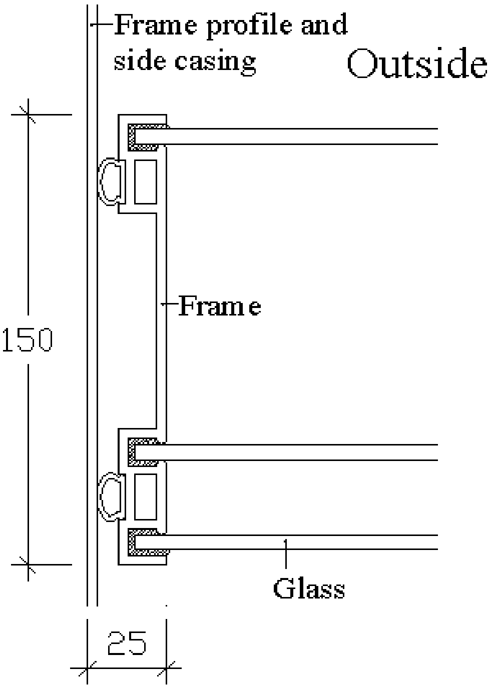

Figure 10. Alternative frame construction made of fibre glass reinforced polyester and with space for 3 panes of glass.

The net energy gain is improved for all three window types, but it is still negative, however. On the other hand, for the combination window we get a positive net energy gain as a result of a large solar gain and low thermal losses.

Table 9 Combination window

Measure	U_f	ψ (edge loss)	U-total	$L = l_f(U_f - U_g) + \psi$
	W/m^{2}K	W/mK	W/m^{2}K	W/mK
Combination window (Figure 10)	1.074	0.0222	1.226	0.0182

Table 10. Contribution to net energy gain for windows with insulated frames

Window	Solar gain [W/m^{2}K]	Thermal loss [W/m^{2}K]			Net energy gain [kWh/m^2]
	Glazing	Glazing	Frame	Assembly frame	Total window
Wood and aluminium	81.9	-75.4	-37.1	-18.5	-49.0
Wood and aluminium, insulated	81.9	-75.4	-23.3	-17.2	-33.9
PVC	79.7	-70.2	-48.5	-12.2	-51.2
PVC, insulated	79.7	-70.2	-31.4	-13.5	-35.4
Aluminium	96.1	-85.4	-42.6	-21.5	-53.5
Aluminium, fibre glass reinforced polyester	96.1	-85.4	-24.3	-18.0	-31.6
Combination window	105.6	-77.1	-7.1	-5.8	15.7

3.4 Potentialities for narrower frames.

The use of narrower frames leads to an increase of the glass area, thus gaining a larger total g-value for the window. At the same time the effect of the normally poorer U-value of the frame (compared to the glazing) is minimized.

3.4.1 Example of narrower frames

Figure 11 a) shows a typical window of wood with the dimensions 1.23 m × 1.48 m. b) shows a corresponding window, where the frame has been made narrower. Finally, Figure 12 shows a window where the frame has been made still narrower, as the sash has been moved out in front of the frame. In Table 11 the calculated energy labelling data for the three windows are shown. It appears that by making the frame narrower, the U-value of the frame is not changed for the window in Figure 11, but instead the total solar energy transmittance of the window, g, is increased, thus obtaining a larger net energy gain.

For the window in Figure 12, which has a-frame width that is considerably smaller, the U-value of the frame is reduced and the g-value is increased markedly. This results in a considerably larger net energy gain. Consequently it is possible to obtain large energy improvements by reducing the frame width in a relatively simple way.

Table 11. Calculated energy labelling data for windows with the dimensions: 1.23 m×1.48 m

Design	Width Frame	g-value Window	U-frame	net energy gain
	[m]	[-]	[W//m^2·K]	[kWh/m^2]
Reference	0.1073	0.42	1.39	-44
Narrower frame	0.0893	0.44	1.39	-38
Sash moved out in front of frame	0.0532	0.50	1.30	-23

Table 12. Calculated energy labelling data for windows with the dimensions: 0.59 m×1.19 m

Design	Width Frame	g-value Window	U-frame	net energy gain
	[m]	[-]	[W//m^{2}K]	[kWh/m^2]
Reference	0.1073	0.31	1.39	-78
Narrower frame	0.0893	0.35	1.39	-70
Sash moved out in front of frame	0.0532	0.44	1.30	-47

In Table 12 energy labelling data are shown for corresponding windows with smaller dimensions. It appears that for the small window we get a lower g-value and thus a lower net energy gain. This is due to the fact that the smaller the window is, the larger share the frame accounts for. It also appears that the importance of the frame width to the net energy gain is greater, the smaller the window is.

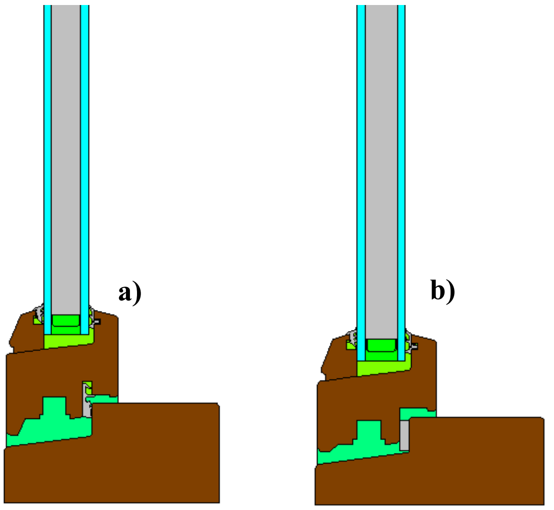

Figure 11.

a) Original design of the wooden window. Reference.
b) The wooden window with narrower sash and frame.

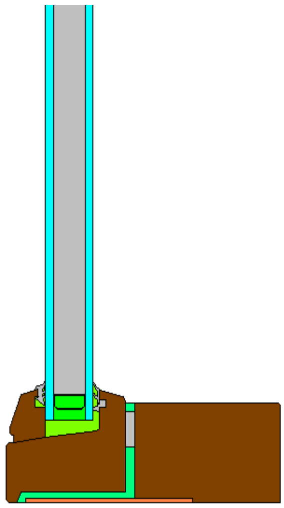

Figure 12. The wooden window with narrower sash, moved right down in front of the frame. A plastic sheet has been inserted in the frame to cover the thermal bridge insulation in the wall.

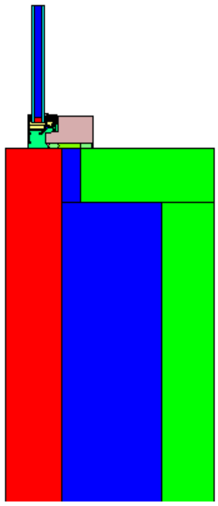

Figure 13. Window med frame of mixed materials mounted in straight rebate (reference).

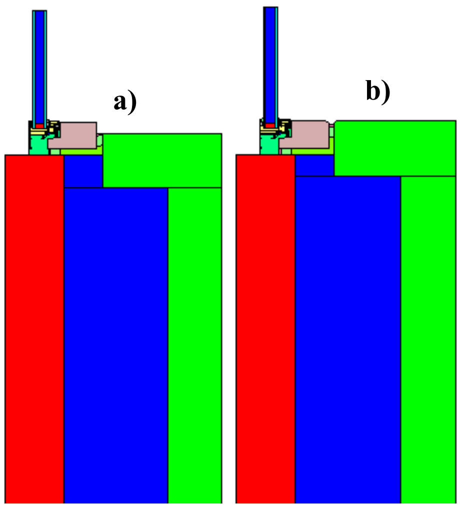

Figure 14. Two examples of window with frame of mixed materials mounted in staggered rebate.

3.5 Potentialities for mounting windows in staggered rebate

The greatest advantage by reducing the frame area is that the solar energy transmittance is increased. Attempts are made to copy this effect by mounting the window in a staggered rebate, as this allows the glass area, and therefore the g-value, to increase for a given inner wall aperture. At the same time the thermal loss in the assembly can be reduced.

To estimate the energy advantages by mounting windows in staggered rebate instead of straight rebate, calculations have been made in compendium 13 of energy labelling data for different rebate solutions. Calculations are made on a façade section of 2.0 m × 2.3 m with a window inserted.

Figure 13 shows a window mounted in straight rebate. This is used as reference. Figure 14 a) and b) show examples of windows mounted in staggered rebates. In a) the rebate is placed ca. half-way up on the frame, and in b the staggered rebate is placed so that it is level with the frame.

The used window is made of mixed materials (see Figure 9) and has the dimension 1.23 m × 1.48 m. Calculation examples of the same window are included in the dimensions1.29 m × 1.54 m and 1.33 m × 1.58 m, corresponding to the inner wall aperture having the same dimensions as by mounting in straight rebate. The calculated energy data are shown in Table 13.

From Table 13 it appears that a mounting in staggered rebate improves the expanded linear thermal transmittance coefficient, L, and the U-value for the total construction. Thus a modest increase of the net energy gain is obtained.

Table 13. Net energy gain for 2.0 m × 2.3 m wall with window.

Rebate type	Dimensions outer wall aperture [m]	U-value total [W/m^{2}K]	g-value total [-]	L-value [W/mK]	Net energy gain [kWh/m^2]
Straight (Reference)	1.23×1.48	0.835	0.197	0.239	-36.8
Staggered a)	1.23×1.48	0.798	0.197	0.208	-33.5
Staggered a)	1.29×1.54	0.844	0.216	0.208	-33.7
Staggered b)	1.23×1.48	0.790	0.197	0.201	-32.7
Staggered b)	1.33×1.58	0.866	0.230	0.201	-33.0

3.6 Potentialities for windows with less edge loss in the assembly between window and wall

By increasing the thermal break at the rebate the U-value and Ψ-value can be reduced. In compendium 14 calculations have been made of the energy performance for different wall constructions combined with some of the window types described in paragraph 2.1 and the so-called combination window (Figure 10), which is described in compendium 14, too.

Selected results from the investigation are shown in Table 14.

It appears that the wall construction has a great effect on the edge loss, Ψ_s, between window and wall and the expanded linear thermal transmittance, L. Thus a cut of the thermal bridge at the rebate with a thermal bridge insulation is important to reduce the thermal loss.

It also appears that the combination window has generally somewhat lower values of both L and Ψ_s than the traditional window of wood covered with aluminium. This can indicate that wider frames distribute the isotherms more evenly in the construction, by which the L-value is reduced, resulting in a lower thermal loss.

Table 14. Wall constructions with

L- and Ψ_s-values	Frame of wood covered with aluminium (Figure 6)	The combination window (Figure 10)
Brick-brick 125 mm insulation Solid brick rebate	L =0.3734 Ψ_s=0.0874	L =0.2290 Ψ_s=0.0455
Brick-lightweight concrete 125 mm insulation. Thermal break with 32 mm insulation in the rebate.	L =0.1656 Ψ_s=0.0206	L =0.0597 Ψ_s=0.0173
Brick-lightweight concrete 190 mm insulation. Thermal break with 32 mm insulation in the rebate.	L =0.1772 Ψ_s=0.0308	L =0.0698 Ψ_s=0.0261
Brick-lightweight concrete 190 mm insulation. Thermal break with 77 mm insulation in the rebate.	L =0.1486 Ψ_s=0.0179	L =0.0410 Ψ_s=0.0130

4 Combination of improvements

To evaluate the effect of combining the improvements made to the individual parts of the window, the following calculations were carried out.

4.1 Windows

With a typical wooden window, described in paragraph 3.4, as a starting point, a better window with regard to energy has been made by combining the best solutions for glazing, edge and frame.

The reference window is shown in Figure 15 and the improved window is shown in Figure 16. In the improved window is used an energy glazing with a new improved low-emission coating on the innermost layer of glass, which allows more solar energy to pass in compared to traditional low-emission coatings. At the same time low-iron glass has been used in the outer layer, which also improves the g-value. Data and the calculated net energy gain for the two windows are shown in Table 15.

It appears from Table 15, that by combining the single energy-improved parts of the window, a considerable improvement of the total net energy gain can be obtained. The investigation shows that by introducing relatively simple changes and using units available on the Danish market, it is possible to produce windows with two layers of glass that yield a positive net energy gain.

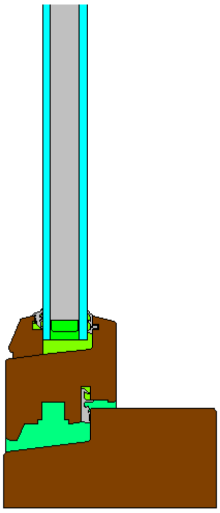

Figure 15. The original design of the wooden window. Reference.

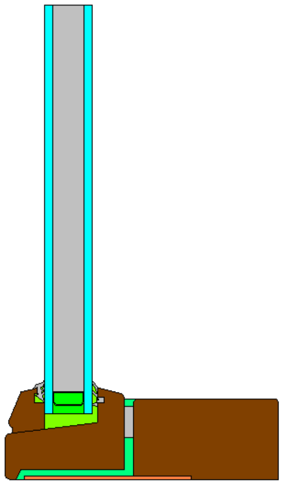

Figure 16. The energy-improved window.

Table 15. Data for the two windows

Reference window (Figure 15)			Net energy gain
Glazing 4 mm ordinary float 16 mm 90% argon 4 mm ordin. float w. low-emission coating ε = 0,04	g = 0.59	U = 1.1 W/m^{2}K	
Edge, aluminium	λ = 1.77 W/mK	Ψ=0.0740 W/mK	
Frame, wood	width = 10.7 cm	U = 1.39 W/m^{2}K	
Window	g = 0.42	U = 1.39 W/m^{2}K	**-44 kWh/m^2**
Improved window (Figure 16)			Net energy gain
Glazing 4 mm low-iron glass 16 mm 90% argon 4 mm ordin. float w. low-emission coating ε = 0,04 Coating has improved solar transmittance	g = 0.68	U = 1.1 W/m^{2}K	
Edge construction, plastic	λ = 0.34 W/mK	Ψ=0.0466 W/mK	
Frame, wood	width = 5.0 cm	U = 1.32 W/m^{2}K	
Window	g = 0.58	U = 1.26 W/m^{2}K	**1 kWh/m^2**

4.2 Window-wall solutions

Two wall types have been used:

Reference: 108 mm brick, 125 mm insulation and 100 mm lightweight concrete. The thermal bridge insulation at the wall rebate consists of 32 mm insulation.

Improved: 108 mm brick, 190 mm insulation and 100 mm lightweight concrete. Thermal bridge insulation at the wall rebate consists of 77 mm insulation.

These two types of wall are put together with the following windows:

PVC reference: Frame as described in paragraph 3.3.2. $U_g = 1.13$ W/m2K. The g-value of the glazing is 0.59.

PVC improved: The frame is insulated ($\lambda = 0.039$ W/mK), and the steel strengthening profiles are replaced by fibre glass reinforced polyester (see paragraph 3.3.2). The cavity between sash and frame is divided up into two spaces, and in the glazing a spacer of plastic and stainless steel is used (see paragraph 3.2). $U_g = 1.13$ W/m2K. The g-value of the glazing is 0.59.

The combination window

The window is described in paragraph 3.3.4.

Calculations

The constructions have been built in Therm, see Figure 17 and Figure 19. Figure 18 and Figure 20 show the calculated isotherms through the constructions.
The results of the calculations are shown in Table 16.

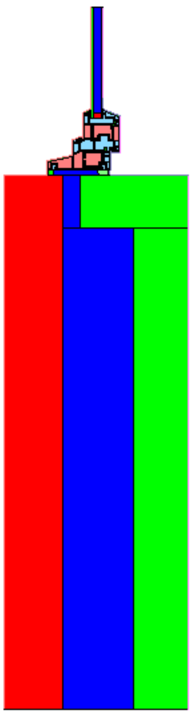

Figure 17. Window-wall construction composed of energy-improved part units. Frame of PVC.

Figure 18. Isotherms in the construction. Frame of PVC.

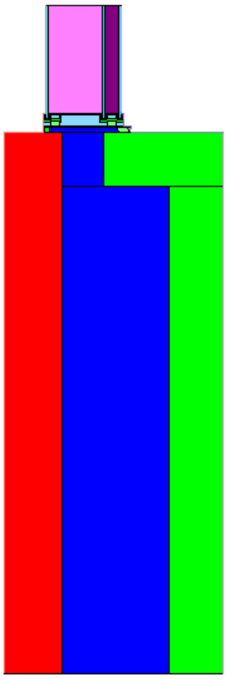

Figure 19. Window-wall construction with combination window.

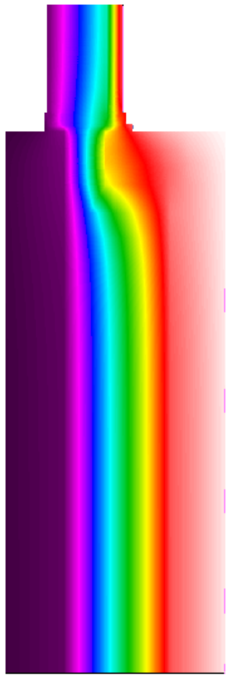

Figure 20. Isotherms in the construction with combination window.

Table 16. Net energy gain for 2.0 m × 2.3 m combinations of walls and windows.

Wall	Window	Width Frame	g-value glazing	U-value Total	L-value (see paragr. 1.2)	Total net energy gain
		[m]	[-]	[W/m^{2}K]	[W/mK]	[kWh/m^2]
Reference Brick-lightweight concrete, 125 mm insulation. 32 mm thermal break insulation.	Ref. PVC. Figure 7	0.115	0.59	0.81	0.1848	-41.6
Reference Brick-lightweight concrete, 125 mm insulation. 32 mm thermal break insulation.	Improved PVC Figure 7	0.115	0.59	0.68	0.0754	-29.9
Improved Brick-lightweight concrete, 190 mm insulation. 77 mm thermal break insulation.	Improved PVC Figure 7	0.115	0.59	0.62	0.0607	-24.7
Reference Brick-lightweight concrete, 125 mm insulation. 32 mm thermal break insulation.	Combination window Figure 10	0.025	0.58	0.61	0.0845	-13.5
Improved Brick-lightweight concrete, 190 mm insulation. 77 mm thermal b break insulation.	Combination window Figure 10	0.025	0.58	0.55	0.0666	-7.9

Table 16 shows that the U-value for the total construction consisting of walls and the PVC-window is improved from 0.81 to 0.68 [W/m^{2}K], by carrying out the above-mentioned improvements on the window. Likewise the net energy gain of the construction is considerably improved. The L-value described in paragraph 1.2 is reduced to ca. one half.
By using the improved wall with increased insulation thicknesses, we get further improvements both in U- and L-value and in the net energy gain.
This indicates that the combined improvements have a good effect.

At the same time it appears that the isotherms in the assembly between wall and glazing through the frame are smooth and almost parallel to the vertical wall surface without sharp changes in direction near the frame. This clearly indicates a low edge loss for the assembly.

The construction with the reference wall and the combination window gives a somewhat lower total U-value and a considerably larger net energy gain, than the construction with improved wall and improved PVC-window. When the combination window is put together with the improved wall we get further improved values of both U, L and the net energy gain.

These calculations for combinations of the single improved parts are just examples of possible integral solutions. There is a need for making further analyses of different combinations of the single parts in total window constructions.

More details of the analyses of the different parts of the window constructions are described in compendium 10 – 14, based on selected potentialities. There is a need for further analyses that can look at different possibilities of improving the energy performance of windows.

5 Literature

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[7] Kompendium 14: Vinduer med mindre linjetab i samlingen mellem vindue og mur, *Institut for Bygninger og Energi, Danmarks Tekniske Universitet, August 2000*

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