Improved Windows for Cold Climates

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***SUMMARY**:*

A large part of the energy consumption in countries in Nordic and Arctic climates is used for space heating in buildings. In typical buildings the windows are responsible for a considerable part of the heat losses. Therefore there is a large potential for energy savings by developing and using windows with improved energy performance.

Traditionally evaluation of the energy performance of windows has focussed on the thermal transmittance, but as windows differ from the rest of the building envelope by allowing solar energy to enter the building, the total solar energy transmittance is equally important. In the heating season in cold climates the solar gain through windows can be utilized for space heating which results in a corresponding reduction in the energy production that is often based on fossil fuels. A suitable quantity for evaluating the energy performance of windows in a simple and direct way is therefore the net energy gain, which is the solar gain minus the heat loss during the heating season. Especially in arctic climates where the heating season covers the whole year there is a large potential for exploiting the solar gain during the summer season. Furthermore the presence of snow increases the solar radiation because of the reflection.

In this paper the energy saving potentials for different window types have been examined by determining the net energy gains in Danish and Greenlandic climates. Furthermore the windows have been evaluated by performing building simulations of the heating demand in typical single-family houses in Denmark and Greenland. The examined windows are typical new windows from Nordic countries and new proposals of improved windows with low thermal transmittance and high total solar energy transmittance.

The results show that net energy gain can be increased considerably by reducing the frame width, which results in a larger transparent area causing a larger solar gain but still maintaining a low thermal transmittance. Using three layers of glass with large gaps, using very slim frame profiles, and omitting the edge constructions that normally causes thermal bridges achieve this. Applying shutters or low emissivity coated roller blinds incorporated in the glazing that are activated during night time can improve the energy performance of windows.

The results from this work show that it is possible to develop windows with a positive net energy in a fairly simple way, which means that it contributes to the space heating of the building.

1. Introduction

In this paper the possibilities of improving the energy performance of windows in cold climates are examined. The background for using windows with improved energy performance is the need to reduce the energy consumption in buildings. Since the heat loss through windows often represents half the total heat loss from houses, much energy can be saved by developing and using better windows with respect to energy performance. The main purpose of having windows in houses is that they provide daylight and view, but windows also provide solar gain that can be utilized as a contribution to the space heating in the building. Therefore the windows also have a positive influence on the energy balance of buildings.

To evaluate the possibilities for developing better windows with respect to energy performance when used in Nordic and arctic climates, seven different window types have been examined in terms of the net energy gain and simulations of the energy consumption in buildings with focus on domestic houses.

2. The net energy gain

In order to evaluate the energy performance of windows both the U value and g-value must be taken into account. The energy balance of windows over the heating season can be described by the net energy gain, which is the solar heat gain transmitted in through the window, minus the heat loss out through the window during the heating season. Thus, the net energy gain expresses the heat balance in one single number and is therefore a good measure to evaluate and compare the energy performance of windows in a simple and direct way.

The net energy gain, E, [kWh/m^2] is given by the expression below (Nielsen, T. R. et al, 2000)

$$E = I \cdot g - G \cdot U \qquad (1)$$

Where

I is the solar radiation during the heating season corrected for the g-value's dependency on the incidence angle [kWh/m^2]

G is the degree hour during the heating season [kKh]

I and G are dependent on the climate and I is also dependent on the orientation of the window.

A negative net energy gain indicates that the heat loss is larger than the solar gain.

2.1 Danish climate

The expression of the net energy gain for the Danish climate is based on the period from 24/9 to 13/5 (heating season) and the following distribution of the windows:

- South: 41%
- North: 26%
- East/West: 33%

A shadow factor of 0.7 is used for the corrections for the effects of shadows. The net energy gain for Danish conditions is then given as (Nielsen, T. R. et al, 2000)

$$E_{Dk} = 196.4 \cdot g - 90.36 \cdot U \qquad [kWh/m^2] \qquad (2)$$

2.2 Greenlandic climate

In order to evaluate the energy performance of the windows in arctic climates, an expression of the net energy gain, E_{Gl}, for Greenland were developed. E_{Gl} is based on a reference house (typical in Greenland) with the following distribution of the windows:

- South: 41%
- North: 26%
- East/West: 33%

As the climate in Greenland varies from north to south the country is divided into to two zones (Kragh, J. (2005)). The two zones cover Greenland north and south of the Arctic Circle respectively as shown in Figure 1.

Based on the reference years for the two zones developed by (Kragh, J. (2005)) the following two expressions of the net energy gain were determined assuming that the heating season is a whole year.

$$E_{Gl\_1} = 490 \cdot g - 186 \cdot U \qquad \text{Zone 1} \qquad [kWh/m^2] \qquad (3)$$

$$E_{Gl\_2} = 532 \cdot g - 223 \cdot U \qquad \text{Zone 2} \qquad [kWh/m^2] \qquad (4)$$

A shadow factor of 0.7 is used for the corrections for the effects of shadows.

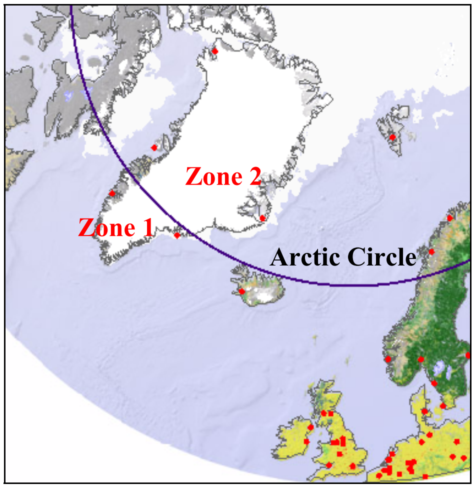
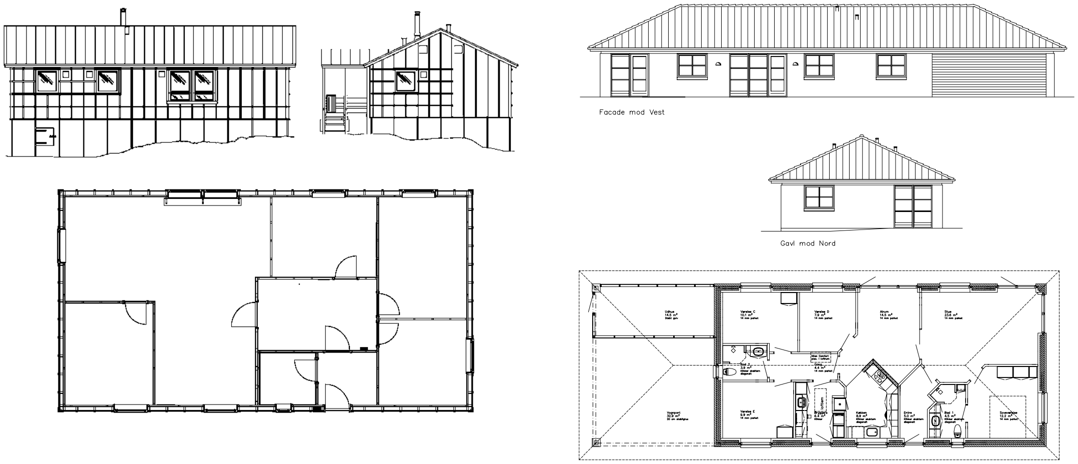


Figure 1.: Climate zones in Greenland. Zone 1 south of the Arctic Circle and zone 2 north of the Arctic Circle (Kragh, J. (2005))

2.3 Description of the reference houses

Two single-family houses were used for the calculations. The first one (A) is a typical house from Greenland that meets the Danish building code BR95, and the second house (B) is a typical Danish house that meets the new Danish building code BR2005.



House A: (Arctic climate, Greenland)

House B: (Danish climate)

Figure 2. The two houses used in the simulations in Bsim2002.

Data for the two houses used in the simulations are shown in Table 1

Table 1 Data for the two houses used in the calculations

	Area	Window area
House A, Arctic climate, Greenland	101.2 m^2	12.3 m^2
House B, Danish climate	134.5 m^2	30.1 m^2

3. Description of the examined windows

The energy performance was examined for seven different window types that will be described in the following.

Type 1

The standard window that is used in house A. The window is made of wood and has a double glazing unit with argon and low emissivity in position 3.

Type 2

The standard window that is used in house B. The window is made of wood and has a double glazing unit with argon and low emissivity in position 3.

Type 3

The third window shown in Figure 3 is developed at Technical University of Denmark. The frame profiles are made of wood covered with aluminium. The used glazing is a double layer low energy glazing 4-15-4 mm with 90/10% argon filling in the gap and a low-emittance coating on the inner pane on the surface facing the gap. To get a high g-value the outer pane is made of float glass with low iron content.

The used edge construction is a “warm edge”. The spacer is made of plastic with a very thin stainless steel film, which ensures that the edge construction is tight and the argon gas stays inside the glazing. The low thermal conductivity of the plastic material ensures that the equivalent thermal conductivity is several times lower than for traditional edge constructions of steel or aluminium.

The aluminium on the outside reduces the need for maintenance. Moving the sash out in front of the outer frame reduces its width to approximately 5 cm. Hereby the glazing area is increased by 15% (for the standard window dimensions: 1.48 x 1.23 m) compared to a corresponding window of wood with a frame width of 10 cm. In the bottom between the aluminium and the wood a weather strip of flexible elastomeric foam is mounted to prevent ventilation of the cavity between the aluminium and the wood. This reduces the U-value. (Laustsen, J. B et al (2003)).

When optimising the energy performance of windows, it should be taken into account that the wall construction has a great effect on the edge loss between window and wall. Thus a cut of the thermal bridge at the rebate with a thermal bridge insulation is important to reduce the thermal loss. By increasing the thermal break at the rebate the U-value and Ψ-value can be reduced. Therefore the frame is made very deep (226 mm) to make it possible to cover a wide layer of insulation in the wall. Mounting a 3mm PVC plate in the bottom of the frame facilitates this.

Type 4

Window type 4 shown in Figure 4 is 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 even deeper, 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.

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 glazing consists of three layers of glass: 4 mm float glass with hard low-e coating, 100 mm air, 4 mm float glass, 25 mm air and 4 mm float glass with hard low-e coating.

Type 5

This window is identical with type 4, but insulating shutters are mounted on the outside of the window. When the shutters are closed the U-value is reduced considerably. Closing the shutter when it is dark outside and there is no need for view out will therefore result in a reduced heat loss from the windows. The thermal resistance of the shutters is set to 1 m^{2}K/Wm, which corresponds to a thickness of 40 mm and a thermal conductivity of 0.039 W/mK. The thermal resistance of the extra cavity between the glazing and the shutter is neglected.

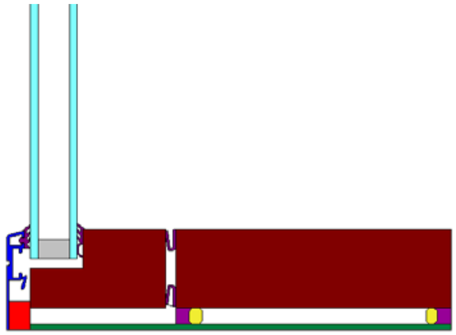


Figure 3. Type 3. Slim frame profile (5 cm) made from wood covered with aluminium.

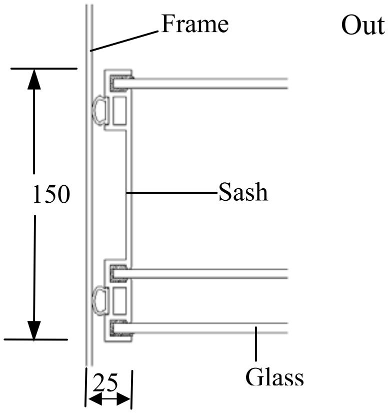


Figure 4. Type 4. Frame profile made from fibre glass reinforced polyester with three layers of glass.

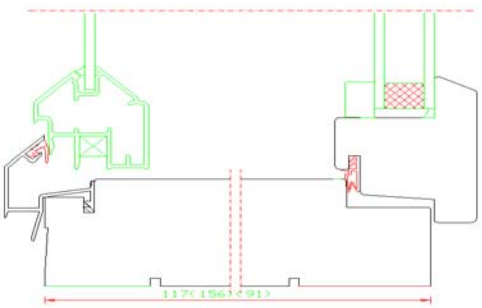


Figure 5. Type 6. Finnish window, 1+2 glazing. Frame made from wood and aluminium

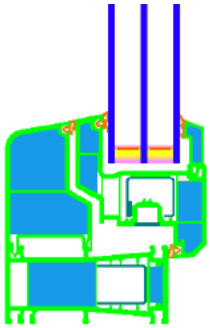


Figure 6. Type 7. PVC frame profile with PU foam in the cavities. Triple glazing unit. (Passivhaus.de.)

Type 6

Typical Finnish window with a so-called “1+2” glazing. Frame and sash are made of wood and aluminium. The glazing consists of one 4 mm layer float glass outermost, a large cavity of air and an insulating double glazing unit to the inside. The DGU has argon in the cavity and low emissivity coating in position 5. Window type 6 is shown in Figure 5.

Type 7

This is a German window that fulfils the requirements for the Passivhaus standard system. The frame profile is made of PVC insulated with PU-foam in the internal cavities, which results in a very low U-value. The glazing is a three layer low energy glazing (4/16/4/16/4) with argon in the cavities and two low emittance coatings. Window type 6 is shown in *Figure 6*.

3.1 Data for windows

For each of the windows the thermal and optical properties were determined. The thermal transmittance, U, the linear thermal transmittance, Ψ, and the total solar energy transmittance, g, were determined in accordance with the standards EN ISO 10077-1 and 2 (CEN, 2003). Detailed calculations of U and Ψ were performed in the program Therm (LBNL (2003)). The net energy gain was determined for Danish climate and Greenlandic climate for zone and zone 2. In order to give a quick comparison of energy performance of the windows the net energy gain was determined for a standard size window. In Table 2 data and results for the examined windows are shown.

Table 2. Data for the examined windows. All windows measure the standard dimensions 1.23 m x 1.48 m.

	Glazing				Frame			Window 1.48 x 1.23 m		Net energy gain		
	Glazing	U_g	g	τ	Width	U_f	Ψ	U_{tot}	g_{tot}	E_{ref} Dk	E_{ref} Zone 1	E_{ref} Zone 2
Type		W/m^2K			m	W/m^2K	W/mK	W/m^2K		kWh/m^2	kWh/m^2	kWh/m^2
1	2 layers	1.28	0.63	0.66	0.1	1.3	0.128	1.61	0.46	-56	- 76	- 116
2	2 layers	1.17	0.63	0.79	0.1	1.37	0.047	1.34	0.46	-32	-26	-57
3	2 layers	1.15	0.67	0.80	0.054	1.33	0.034	1.27	0.58	-2	41	18
4	3 layers	0.93	0.58	0.65	0.025	1.49 *)	-	0.97	0.54	18	83	70
5	3 layers	0.93	0.58	0.65	0.025	1.49 *)	-	0.97 0.49**)	0.54 0.0**)	45		
6	1 + 2.	1.01	0.60	0.71	0.11	1.32	0.040	1.20	0.43	-23	-10	-36
7	3 layers	0.70	0.52	0.70	0.13	0.75	0.03	0.79	0.33	-6	16	0

*) Calculations of the thermal properties of glazings/windows with large cavities do not include a linear thermal transmittance, Ψ, because of the special method used (Jensen, C. (2001)). Any extra two dimensional heat losses due to the interaction between frame and glazing is included in the thermal transmittance, U, for the frame.

**) With shutters. Shutters are closed when it is dark. In Danish climate 63% of the degree hours in the heating season occur when it is dark. (Madsen. T.T. (2004)).

The calculations of the net energy gains show that the goal of developing windows for Nordic and arctic climates with positive net energy gain can be obtained with the proposed new windows. The window type 3, 4(5) and 7 have the largest net energy gains. Although window 7 has the lowest U-value window 3 and 4 have higher net energy gains, which indicate that increasing the g-value by reducing the frames width has a positive impact on the net energy gain because more solar energy is transmitted.

4. Simulations of energy consumption

In order to carry out a more detailed examination of the energy performance of the windows when mounted in a building, simulations of the energy consumption were performed in the program Bsim2002 (By & Byg (2002)). The simulation results were also used to evaluate the net energy gain method. The simulations were performed for the two houses shown in *Figure 2* with the different windows inserted. For house A calculations were carried out for Greenland (weather data zone 1 and zone 2) assuming heating season during the whole year. For house B calculations were carried out for Danish weather data (Copenhagen) assuming heating season from September 7. to May 6. Window 1 was not examined in house B. The results of the simulations for Greenland are shown in Table 3 and Figure 7 - Figure 8. The results for Denmark are shown in Table 4 and Figure 9.

Table 3. Energy consumption in house A, Greenland (Zones 1 and 2) with different windows.

Window			Zone 1			Zone 2		
Type	U_{tot} W/m^2K	g_{tot}	Heating kWh/year	Solar gain kWh/year	Venting kWh/year	Heating kWh/year	Solar gain kWh/year	Venting kWh/year
1	1.61	0.46	11427	3016	-247	14751	3324	-200
2	1.34	0.46	10744	3016	-275	13930	3324	-230
3	1.23	0.58	10024	3830	-558	13254	4107	-460
4	0.97	0.54	9488	3578	-498	12434	3956	-462
5	0.97– 0.49	0.54– 0.0	9294	3536	-498	12090	3896	-459
6	1.20	0.43	10455	2872	-252	13580	3166	-210
7	0.79	0.33	9830	2204	-136	12811	2426	-113

Heating: Energy consumption for space heating in the building.
Solar gain: Solar energy transmitted through the windows to the building, kWh.
Venting: Heat loss due to ventilation by opening windows and doors. Set point: 24 °C, kWh.

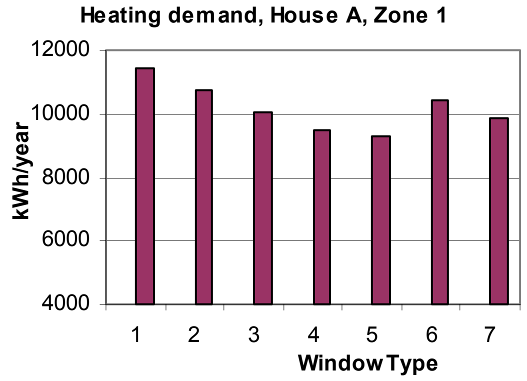


Figure 7. Heating demand for house A with different windows, Greenland, zone 1.

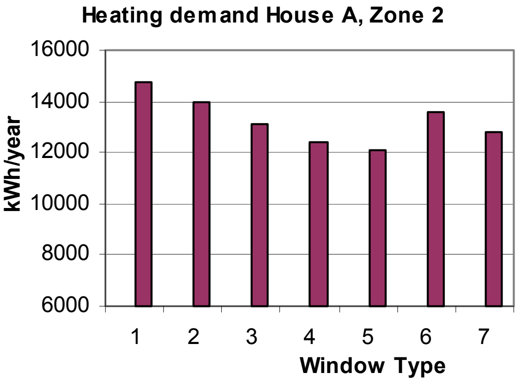


Figure 8 Heating demand for house A with different windows, Greenland, zone 2.

Table 4. Energy consumption for house B (Denmark) with different windows.

Type	U_{tot} W/m^{2}K	g_{tot}	Heating kWh/year	Solar gain kWh/ year	Venting kWh/ year
2	1.34	0.46	5274	1891	-136
3	1.23	0.58	4401	2705	-423
4	0.97	0.54	4032	2373	-344
5	0.97 – 0.49	0.54 – 0.0	3949	2349	-353
6	1.20	0.43	4836	1901	-162
7	0.79	0.33	4093	1582	-131

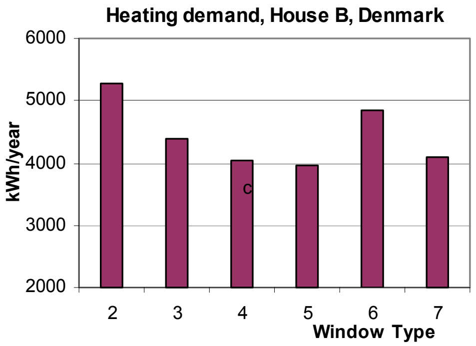


Figure 9. Heating demand for house B with different windows, Denmark

It appears from the calculations that considerable energy savings can be achieved by improving the existing windows (types 1 and 2).

Type 3, which is based on quite simple improvements (slim frame and the best DGU on the Danish market) saves between 12-17% of the energy consumption.

Type 4 reduces the energy consumption by 17-24%. The advantage of this window is the large glazing area due to the extremely narrow frame profile in combination with the low U-værdi.

Type 5 (= type 4 + shutter) results in savings of 19-25% due to the further reduced U-value during night time when the shutters are closed.

Type 6 only saves about 8% of the heating demand. However, it is expected that reducing the frame width and applying hard low-e coating on the outermost glass pane can improve the energy performance of this window type. Furthermore, a thermal break in the aluminium sash will reduce the U-value.

Type 7 results in energy savings of 14-22% due to the very low U-value of both the frame profile and the glazing. However, the wide frame profile and the three layers of glass with two low-e coatings have the effect that the total solar energy transmittance is only 0.33 for which reason the window does not exploit the solar gain to optimum effect.

The results show that the largest energy savings are obtained using the window types 4, 5 and 7. By developing hybrid solutions that combine type 7´s very low U-values of both frame and glazing with the slim frame construction in type 4, which increases the g-value, it will be possible to obtain even higher net energy gain. It appears that the windows type 3 and 4/5 that have high g-values due to large glazing areas provide a large solar gain, which is good for the energy balance, but this can also result in overheating problems in warm periods with sunny days. Therefore, the demand for venting is higher for these windows. Applying solar shading devices can solve most of these problems.

5. Comparison of the net energy gain and the building simulations

By comparing Table 2, Table 3 and Table 4, it appears that using the net energy gain or the building simulations for evaluating the energy performance of the windows gives almost the same overall results. The larger net energy gain, the lower energy consumption for heating. The BSim simulations show that there are minor venting heat losses for all the windows during the heating season. The venting heat loss is less than 10 % of the solar gain for type 1, 2 and 6, 7 and less than 15 % for the windows with highest g-values type 3, 4, and 5. Furthermore the heating load is typically between 2 and 3 times larger than the solar gain. This means that, for domestic buildings, almost all the solar gain is utilized for space heating and a change in the net energy gain will have almost full effect on the heating load of the building. Hence, the energy savings for space heating can be estimated as the change in the net energy gain, which is therefore useful for an initial evaluation of the energy performance of windows for domestic houses.

6. Conclusion

Based on the calculations of the net energy gain and the heating consumption of seven different windows it is concluded that there are good possibilities for developing windows with improved energy performance for cold and arctic climates. The windows type 3,4,5 and 7 result in the highest net energy gains and the lowest energy consumptions in the houses.

For type 7 the good result is due to the very low thermal transmittance. An unfortunate effect of the combination of the wide frame profile and the three-layer glazing is that the total solar energy transmittance is quite low resulting in a low solar gain. The good results for window type 3,4 and 5 show that the g-value has a significant influence on the energy performance. A simple and efficient way to improve the g-value is by increasing the glazing area by reducing the frame width. In the new developed window type 4 this is implemented with a frame width of only 25 mm and still keeping a low U-value. The 3- layer glazing with large gaps ensures that use of edge constructions that normally results in a thermal bridge can be avoided. Since the windows with low U-value and high g-value result in positive net energy gain they will contribute to the space heating of the houses. During periods with sunny days the high solar gain can cause overheating problems. Therefore there is a need for developing windows with integrated solar shading devices.

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