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Bæredygtigt arktisk byggeri i det 21. århundrede

- Energirigtige vinduer

Statusrapport 2 til
VILLUM KANN RASMUSSEN FONDEN

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Energirigtige vinduer
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Jacob Birck Laustsen

Indhold

Forord

Dette er statusrapport 2 for projektet med titlen *Energirigtige vinduer* støttet af VILLUM KANN RASMUSSEN FONDEN.

Indledning

I projektets første del var der først og fremmest fokus på at vurdere mulighederne for at udvikle energimæssigt forbedrede vinduer til kolde klimaer. Der blev gennemført beregninger af energiforbruget i to forskellige enfamiliehuse i henholdsvis Grønland og Danmark med en række forskellige forslag til energirigtige vinduer. Ligeledes blev vinduernes energitilskud beregnet for Danmark og Grønland. Beregningerne viste, at det er muligt, at nå målsætningen om at udvikle vinduer med positivt energitilskud til arktisk klima. Dvs. at der i løbet af fyringssæsonen transmitteres mere solvarme ind gennem vinduerne, end der tabes ud gennem vinduerne som varmetab. Dette er beskrevet i paperet *Improved Windows for Cold Climates, bilag 3.*

De største energibesparelser i undersøgelserne blev opnået ved anvendelse af en ny vinduestype skitseret af BYG.DTU, som har en meget smal ramme/karm (2,5 cm) af glasfiberarmeret plast og en tre-lags rude med stor glasafstand. Fordelen ved vinduet er, at det meget smalle men dybe ramme/karmprofil giver plads til et meget stort rudeareal, som resulterer i en høj solenergitransmittans. Samtidig sikrer den tre-lags rudekonstruktion uden afstandsprofiler at vinduets varmetab minimeres.

Der er imidlertid behov for at undersøge hvordan forskellige lavemissionsbelægninger og flere lag glas påvirker sollystransmittansen og menneskers opfattelse af dagslyset. Endvidere er der behov for at udvikle en pålidelig beregningsmetode for bestemmelse af energimæssige egenskaber for vinduer med meget store hulrum i ruden.

Forskningsindhold

Projektets arbejdsområder

Siden sidste statusrapport har der bl.a. været arbejdet med følgende emner:

- Dagslysforsøg med forskellige rudeløsninger
- Vurdering af beregningsmetode til bestemmelse af energimæssige egenskaber for vinduer meget store hulrum i ruden

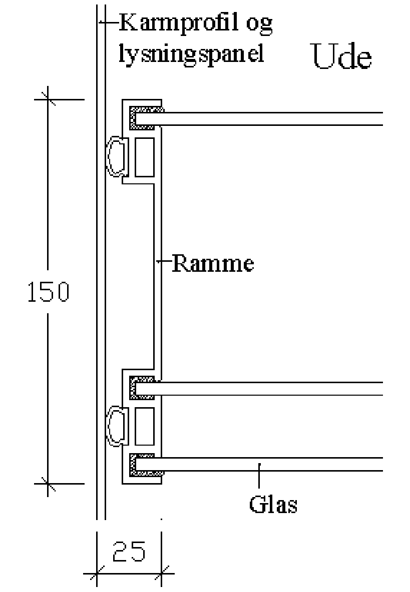
I det følgende beskrives arbejdet med de enkelte emner.

Dagslysforsøg med forskellige rudeløsninger.

De indledende undersøgelser viste, at de største energibesparelser blev opnået med et nyudviklet vindue med meget smal ramme/karm af glasfiberarmeret polyester og tre lag glas med 2 hårde lavemissionsbelægninger. Vinduet er vist i Figur 1. Karmen er meget dyb, således at den kan dække over stor isoleringstykkelse i muren, hvilket reducerer kuldebroer og flerdimensionale varmestrømme i samlingen mellem mur og vindue.

Pga. de store glasafstande vil en forseglet rude ikke være mulig pga. trykændringer ved temperaturvariationer i luft-gasblandingen. Derfor er hulrummene let ventilerede med udeluft, som ledes gennem filtre for at undgå snavs inde i ruden. En fordel ved dette er at afstandsskinner, som normalt giver anledning til kuldebroer helt undgås. Til gengæld betyder det også, at der ikke kan anvendes bløde lavemissionsbelægninger, da de kun kan anvendes i forseglede ruder da de ikke tåler fugt. Derfor anvendes i stedet to hårde lavemissionsbelægninger på overflader som vender mod hulrum.

Et minus ved anvendelse af lavemissionsbelægninger er, at de medfører at både den totale solenergitransmittans, g, og sollystransmittansen, τ, reduceres. Samtidig kan belægninger medføre en vis forvrængning af farvegengivelsen i rummet og når man ser gennem ruden. Pga. spektralfordelingen af transmittansen reducerer bløde belægninger g-værdien mere end hårde belægninger mens τ-værdien reduceres mere for hårde belægninger end for bløde.
Ruders sollystransmittans kan med stor nøjagtighed måles eller beregnes udfra kendskab til glassenes egenskaber, men der foreligger kun få praktiske undersøgelser af hvordan mennesker oplever dagslyset ved forskellige ruder. Da en af de primære årsager til at have vinduer i bygninger netop er, at sende dagslys ind i bygningen og give adgang til klart udsyn, var der derfor behov for at gennemføre en uddybende undersøgelse af forskellige ruders dagslysegenskaber med særlig fokus på betydningen af lavemissionsbelægninger.



Figur 1. Rammekarmkonstruktion udført i glasfiberarmeret plast og med plads til 3 lag glas.

For at vurdere hvordan lyset i praksis påvirkes ved anvendelse af forskellige ruder, er der gennemført et fuldskalaforsøg, hvor et testpanel har givet deres vurdering af fire forskellige ruder monteret i et forsøgshus på BYG.DTU. Ruderne er monteret i fire identiske sydvendte rum med samme indretning og vinduesstørrelser.

I undersøgelsen indgik følgende ruder:

- 2-lags almindelig termorude uden belægninger (lokale 5)
- 2-lags energirude med en blød lavemissionsbelægning (lokale 1)
- 3-lags energirude med 2 bløde lavemissionsbelægninger (lokale 2)
- 3-lags rude med 2 hårde lavemissionsbelægninger (lokale 3)

Figur 2. Forsøgshuset hvor de fire vinduer var monteret under forsøget. Solafskærmningerne var fjernet under forsøget.

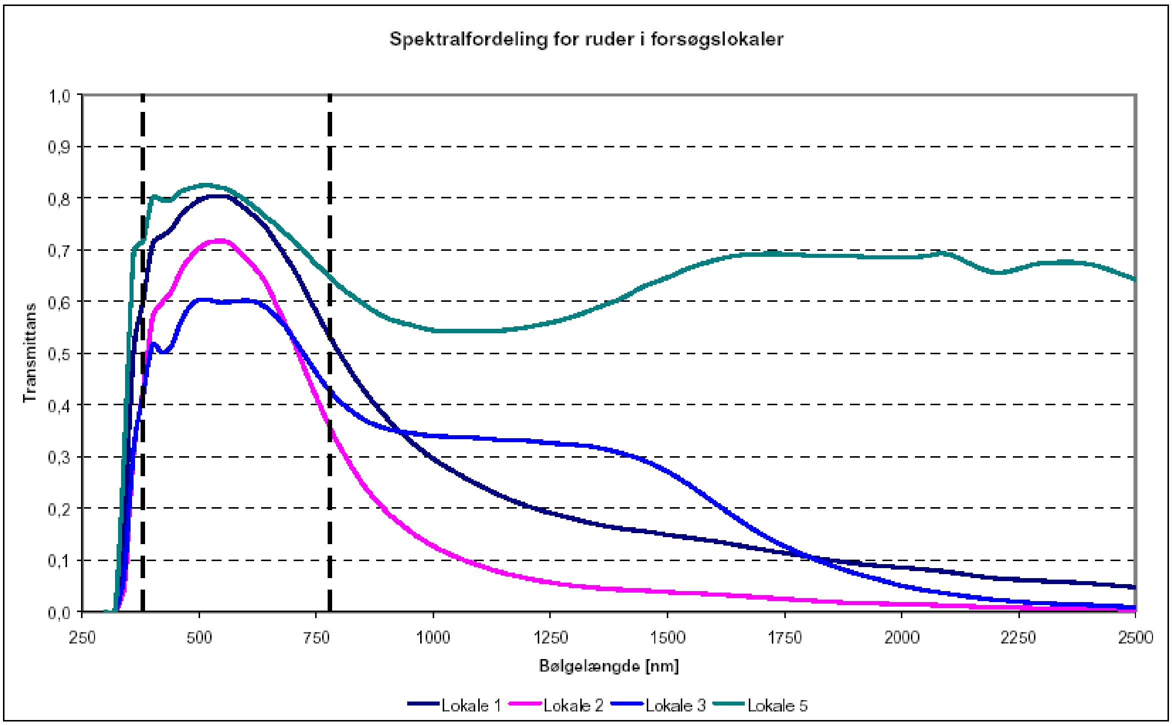
Vha. programmerne Glas 04 (*Pilkington,* 2003) og WIS (*TNO, 2004).* er der foretaget beregninger af termiske og optiske data for de fire forskellige rudetyper, som er vist i Tabel 1

Tabel 1 Beskrivelse af ruderne monteret i kontorlokalerne beregnet med programmet Glas 04.

Placering	Type	Beskrivelse	Varmetransmissionskoefficient U [W/m²K]	Sollystransmittans τ_t [%]	Total solenergitransmittans g [%]	Farvegengivelsesindeks Ra
Lokale 1	2-lags	Optifloat Clear 4 mm Optitherm SN 4 mm (blød)	1,15	80	63	97
Lokale 2	3-lags	Optitherm SN 4 mm (blød) Optifloat Clear 4 mm Optitherm SN 4 mm (blød)	0,63	70	50	96
Lokale 3	3-lags	K Glass 4 mm (hård) Optifloat Clear 4 mm K Glass 4 mm (hård)	0,83	64	56	97
Lokale 5 (Reference)	2-lags	Alm. float 4 mm Alm. float 4 mm	2,63	82	76	98

Det fremgår af Tabel 1, at 2-lagsruderne har højere U-værdi og lavere g- og τ-værdier end 3-lagsruderne. Sammenlignes de to 3-lags ruder ses det, at ruden med hårde belægninger har bedste (højeste) g-værdi mens den med bløde belægninger har bedst τ-værdi. Ruden med hårde belægninger slipper altså mindst sollys ind.

Vha. programmet WIS er spektralfordelingen af transmittansen for de fire ruder beregnet og vist i Figur 3.



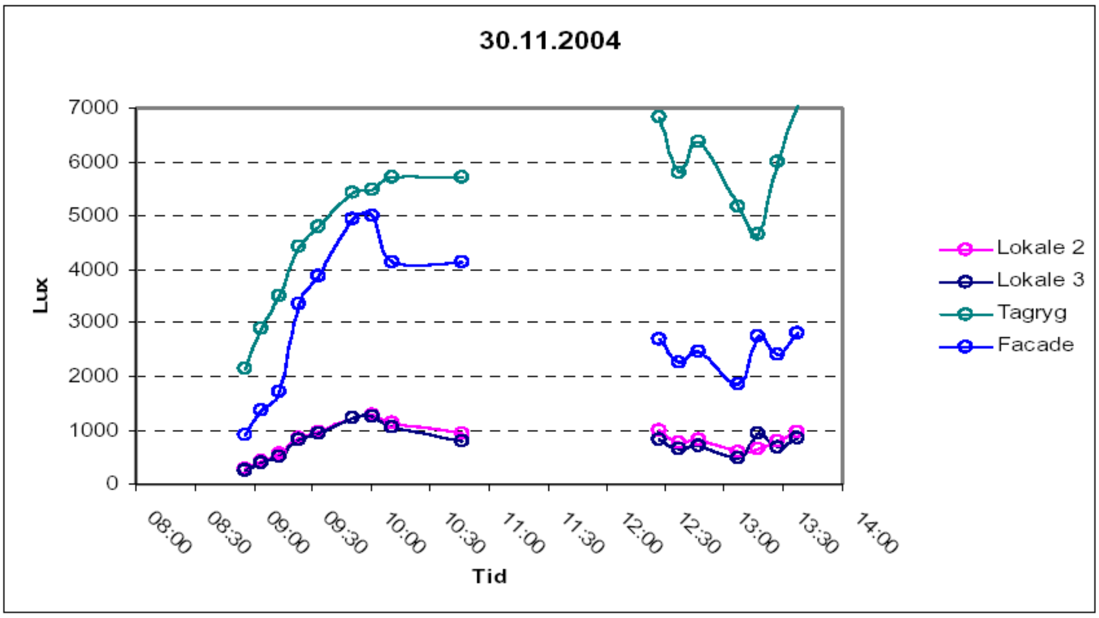
Figur 3. Spektralfordelingen for ruderne i de fire lokaler beregnet i WIS [xx].

Det fremgår af Figur 3, at der er stor forskel på spektralfordelingen af transmittansen for de fire ruder. Det ses også at kurven for ruderne i lokale 2 og 3 krydser hinanden, hvilket forklarer modsætningsforholdet mellem den totale solenergitransmittans og sollystransmittansen for de to ruder.

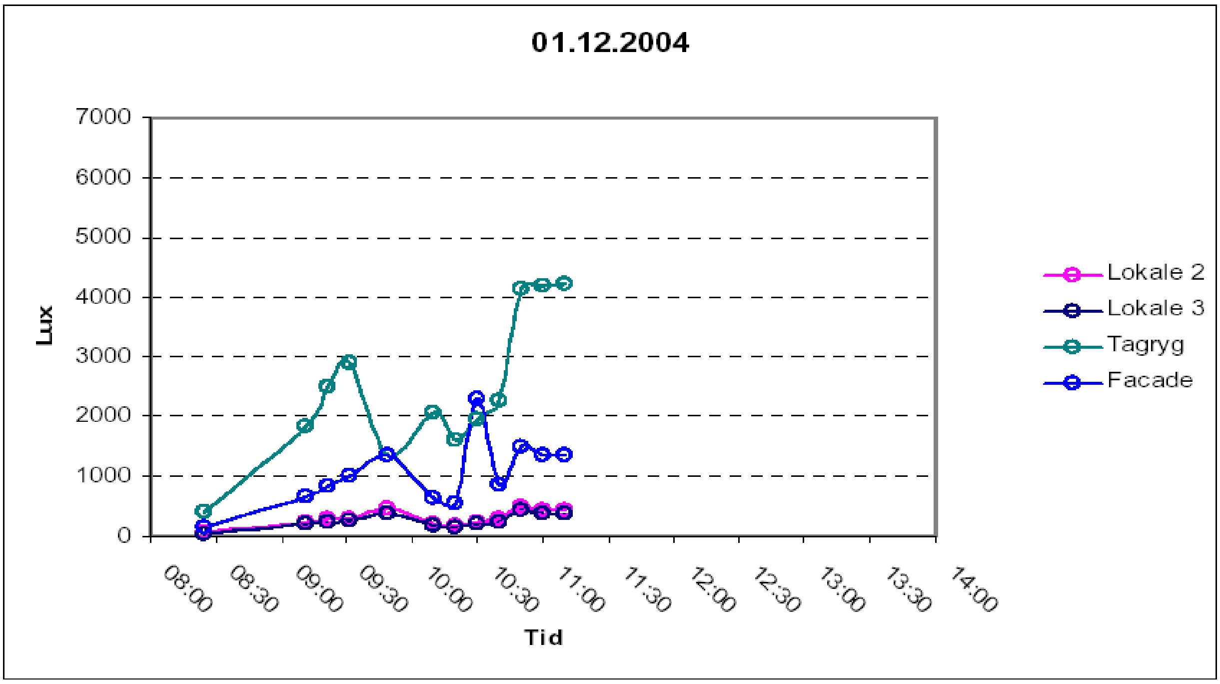
For at validere resultaterne beregnet I WIS er der foretaget målinger af spektralfordelingen af transmittansen for de to 2-lags ruder (lokale 1 og 5) i BYG.DTU's spektrofotometer. Resultaterne er vist i Bilag 1, hvoraf det fremgår, at der er god overensstemmelse mellem beregningerne og målingerne.

Dagslysforsøgene blev gennemført den 30/11 og den 1/12 2004, hvor det begge dage var overskyet. Derfor var lysniveauet udenfor lavt under forsøgene, hvilket er en fordel, da det netop er de kritiske tidspunkter med ringe dagslys, som er interessante. Der deltog 36 personer i forsøgene.

Samtidig med at forsøgene med testpersoner kørte blev lysniveauet målt i lokale 2 og 3 samt på taget af huset og på facaden. Måleresultaterne er vist i Figur 4 og Figur 5.



Figur 4. Lysniveauet målt under forsøget den 30/11 –2005. Kurverne er opdelt i to svarende til formiddag og eftermiddag.



Figur 5. Lysniveauet malt under forsøget den 1/12 2004.

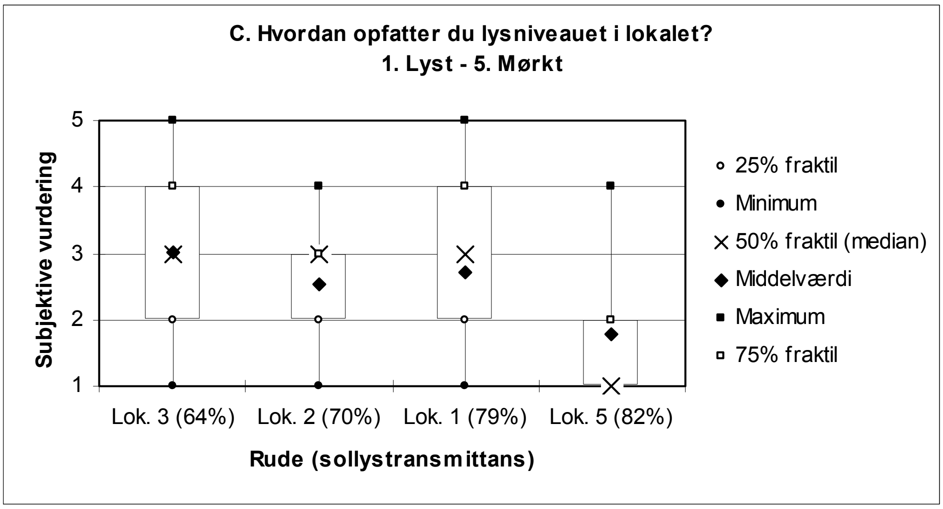
Af Figur 4 og Figur 5 fremgår det at lysniveauet i de to lokaler ligger ganske tæt. Der er dog en svag tendens til at der er mest lys i lokale 2 med vinduet med bløde belægninger.

Spørgeskemaet som blev anvendt til forsøgene er vist i Tabel 2.

Tabel 2. Spørgsmål stillet i spørgeskemaet.

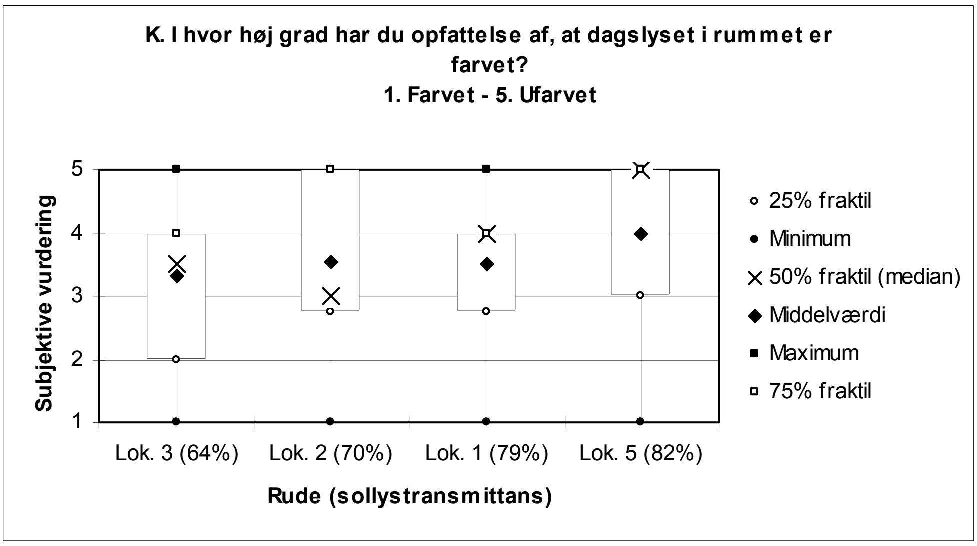
Spørgsmål		Bipolar skala (1-5)	
C.	Hvordan opfatter du lysniveauet i lokalet?	1	Lyst - Mørkt
D.	Hvordan vil du beskrive dagslyset i dette rum?	1 2 3 4	Koldt – Varmt Klart – Tonet Sløret – Skarpt Behageligt - Ubehageligt
E.	Hvor let er det for dig at læse teksten på papiret?	1 2	Vanskeligt – Let For mørkt – For lyst
F.	Hvordan vil du beskrive skyggerne på frugterne og omkring dem?	1 2	Slørede – Skarpe Hårde – Bløde
G.	Hvordan opfatter du detaljerne af frugterne?	1	Klare – Slørede
H.	Hvordan opfatter du farverne af frugterne?	1 2	Naturlige – Forandrede Farvede – Ufarvede
I.	Er der refleksioner eller spejlbilleder i computer-skærmen?	1	I høj grad – Ingen
J.	Hvordan opfatter du farverne af billedet på computerskærmen?	1 2 3 4	Varme – Kolde Naturlige – Kunstige Slørede – Klare Levende – Triste
K.	Har du opfattelse af, at dagslyset i rummet er farvet?	1	Farvet - Ufarvet
L.	Hvis du opfatter dagslyset som farvet, hvilken farve opfatter du?	1	Angiv farven (gerne som flere farver eller som to-farvet)
M.	Hvis du opfatter dagslyset som farvet, finder du da dagslysets farve som acceptabel?	1	Acceptabel – Uacceptabel
N.	Hvordan vil du beskrive vejret udenfor lige nu?	1 2 3	Overskyet – Skyfrit Klart (ingen dis) – Diset Smukt - Trist
O.	Hvordan vurderer du de omgivelser, du ser ud på?	1	Utiltalende – Tiltalende
P.	Hvordan er dit generelle indtryk af dagslyset udenfor lige nu?	1 2	Svagt – Stærkt Blændende – ikke blændende
Q.	Hvordan opfatter du farverne udenfor?	1 2 3 4 5	Varme- Kolde Slørede – Klare Naturlige – Unaturlige Levende – Triste Vellignende - Forandrede
R.	Hvordan har du oplevet temperaturen, mens du har opholdt dig i lokalet?	1	For varmt – For koldt
S.	Hvordan er dit helhedsindtryk af lyset i lokalet?	1	Acceptabelt - Uacceptabelt
T	Hvordan er dit helhedsindtryk af lokalet som arbejdsplads?	1	Dårligt – Godt
	Personlige spørgsmål		
p2	Hvad er dit køn?	1	Kvinde – Mand
p3	Hvad er din alder?	1	Alder:
p4	Har du normalt farvesyn?	1	Ja – Nej
p5	Bruger du kontaktlinser/briller?	1	Ja – Nej
p6	Hvis ja, er disse da farvede/tonede?	1	ja - Nej

I det følgende er nogle af de vigtigste svar fra spørgeundersøgelsen gengivet. I Figur 6 er vist svarene på hvordan testpersonerne vurderede lysniveauet i de fire lokaler.



Figur 6. Testpersonernes svar på spørgsmålet: Hvordan opfatter du lysniveauet i lokalet? Lyst – Mørkt.

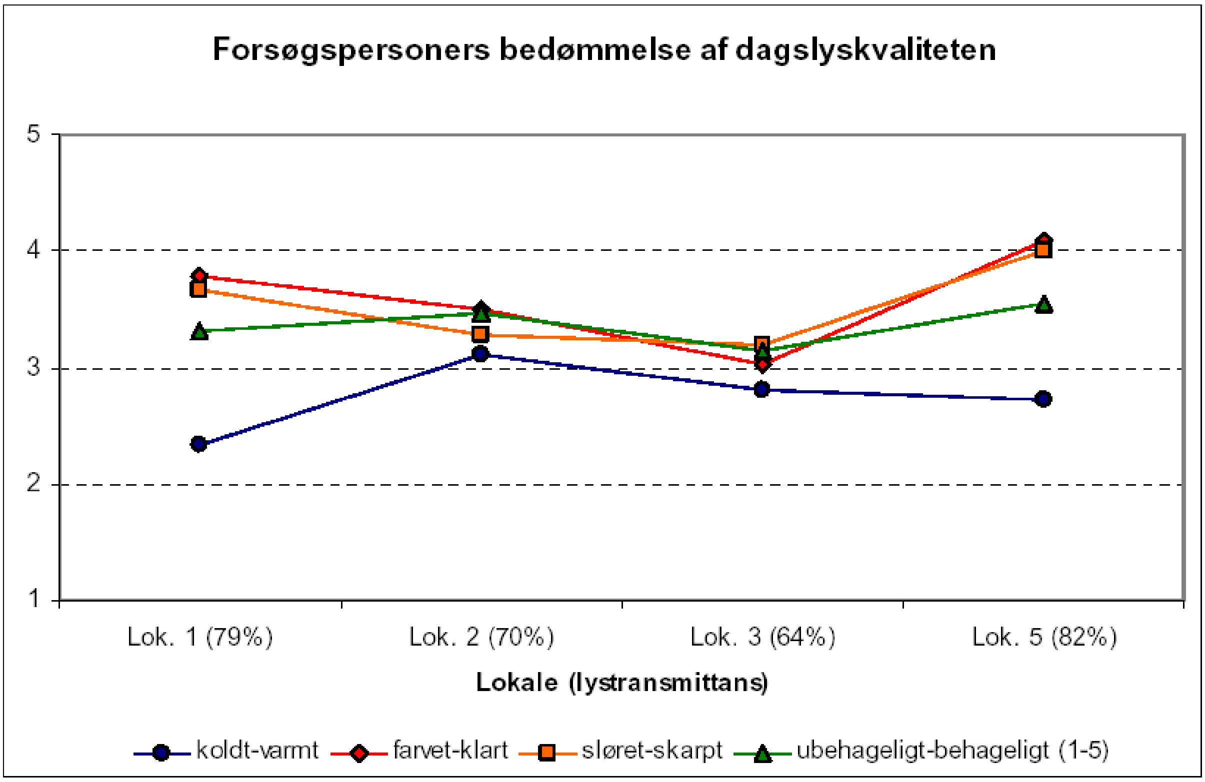
Det fremgår af Figur 6, at lokale 5 med 2-lags ruden uden belægninger opfattes som lysest, mens de tre andre vurdere næsten ens. Dog vurderes lokale tre med 3-lags ruden med to hårde belægninger marginalt mørkest. Det ses endvidere at lokale 1 med 2-lags rude med blød belægning vurderes en anelse mørkere end lokale 2 med 3-lags ruden med to bløde belægninger, på trods af at ruden i lokale 1 har væsentligt højere sollystransmittans end ruden i lokale 2. Dette kan indikere, at den praktiske menneskelige vurdering af lysgengivelsen ikke nødvendigvis svarer til den eksakte sollystransmittans.
I Figur 7 er testpersonernes svar på, om de opfatter dagslyset i lokalet som farvet vist.



Figur 7. Testpersonernes svar på spørgsmålet: I hvor høj grad har du opfattelse af, at dagslyset i rummet er farvet? Farvet – Ufarvet.

Igen fremgår det, at ruden i lokale 5 skiller sig ud, idet det vurderes, at den farver lyset mindst, mens de tre andre ligger tæt.

I Figur 8 er testpersonernes svar på spørgsmål vedrørende lyskvaliteten i lokalerne vist.



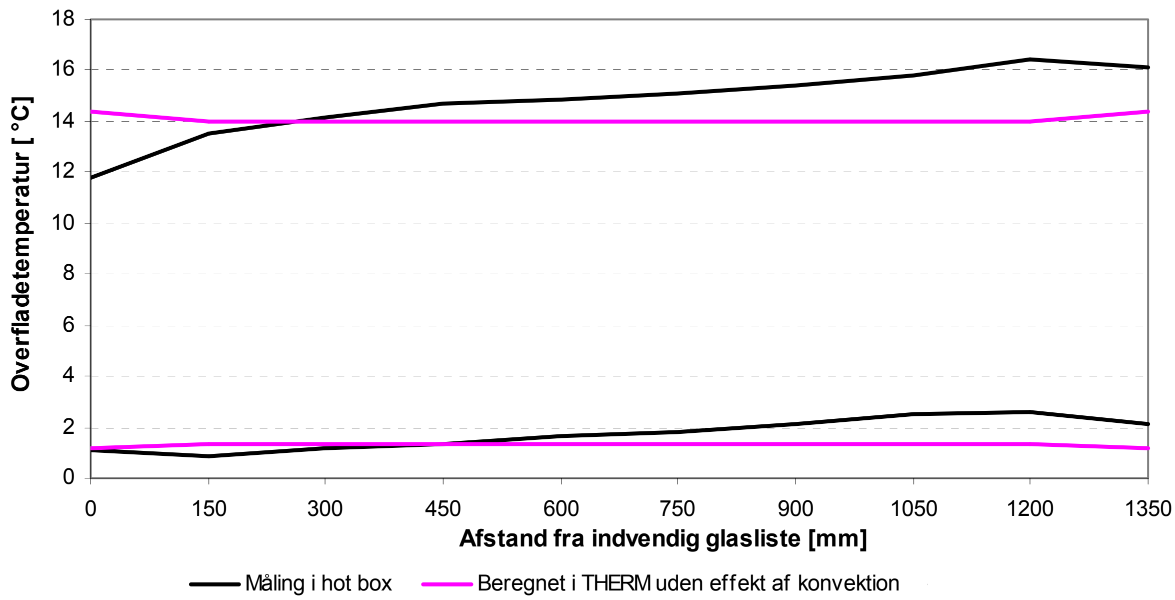
Figur 8. Subjektiv vurdering af spørgsmål D: Hvordan vil du beskrive dagslyset I dette rum? På en 5 punkts skala med 5 som mest positive og 1 som mest negative.

Den generelle tendens i besvarelserne var, at dagslysforholdene i lokalet med 3-lags ruden med bløde belægninger var en anelse bedre end i lokalet 3-lags ruden med hårde belægninger. Forskellene var dog så små, at det ikke entydigt kan konkluderes, at der er en væsentlig forskel dagslyskvaliteten for de to ruder. Samtidig skal det nævnes, at forsøgene blev foretaget på to vinterdage hvor det var overskyet. På en solskinsdag om sommeren hvor lysintensiteten udenfor er meget højere vil besvarelserne måske være anderledes. Der er derfor behov for at gennemføre et tilsvarende forsøg med testpersoner om sommeren hvor lysniveauet er højere.

Beregningsmetode til bestemmelse af energimæssige egenskaber for vinduer med stor glasafstand

Ved bestemmelse af vinduers varmetransmissionskoefficient, U, samt overfladetemperaturer anvendes normalt beregningsproceduren angivet i EN ISO10077-2 (*CEN, 2003)*. I denne metode erstattes hulrummet i ruden med et fast materiale med ækvivalent varmeledningsevne som resulterer i den aktuelle U-værdi for ruden. Dette betyder, at der ikke tages hensyn til hvordan konvektion i hulrummet påvirker temperaturfordelingen i ruden. Metoden giver rimelige resultater for ruder med lille glasafstand, men for ruder med stor glasafstand giver den misvisende resultater, idet den store glasafstand giver anledning til betydelig konvektion. Luftstrømningerne vil bl.a. bevirke at temperaturforholdene er forskellige i top og bund. Dette medvirker til, at de generelle forudsætninger om grænsebetingelser med konstante og ensartede overfladetemperaturer ikke gælder. Der var derfor behov for at undersøge forholdene nærmere ved at sammenligne målte og beregnede overfladetemperaturer.

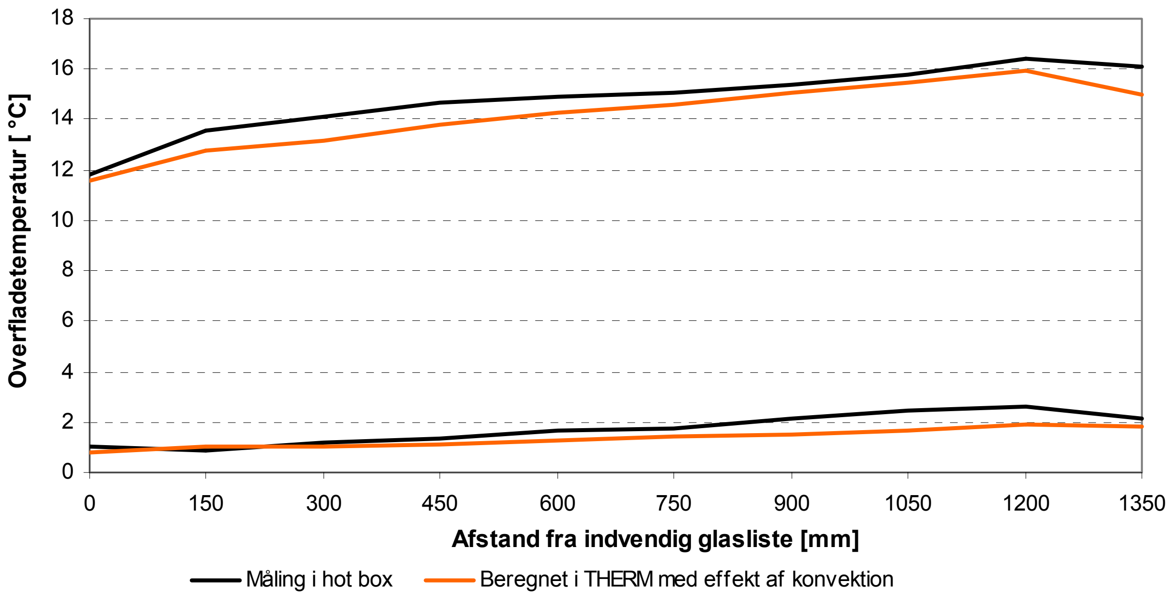
Der er således indledt en undersøgelse af hvor meget beregningsproceduren i EN ISO 10077-2 afviger fra de virkelige forhold, og om en mere detaljeret metode baseret på ISO 15099 giver mere pålidelige resultater. Der blev foretaget målinger af overfladetemperaturer på en simpel model af et vindue med stor glasafstand i BYG.DTU's guarded hot box. Vinduet blev opbygget af to lag glas med en glasafstand på 120 mm monteret direkte i polystyrenskum, som gjorde det ud for en ideel ramme/karm. Ruden, som er vist i Figur 11, målte 1350mm x 1100mm. Beregningerne er foretaget i programmet *Therm (LBNL 1, 2003)*, hvori der blev opbygget en model af vinduet i henhold til EN ISO 10077-2. I Figur 9 er de beregnede overfladetemperaturer vist sammen med de målte.



Figur 9. Overfladetemperaturer på rude med 120 mm hulrum hhv. målt i hot box og beregnet i henhold til EN ISO 10077-2.

Det ses, at der er nogen uoverensstemmelse mellem målingerne og beregningerne, hvilket primært skyldes, at den simple beregningsmetode ikke tager højde for effekten af lufttrømningerne i det store hulrum. Disse konventionsstrømninger medfører, at overfladetemperaturerne bliver højere i toppen af ruden, mens bunden afkøles. I modsætning hertil bliver temperaturfordelingen symmetrisk i top og bund for de simple beregninger (Figur 8).

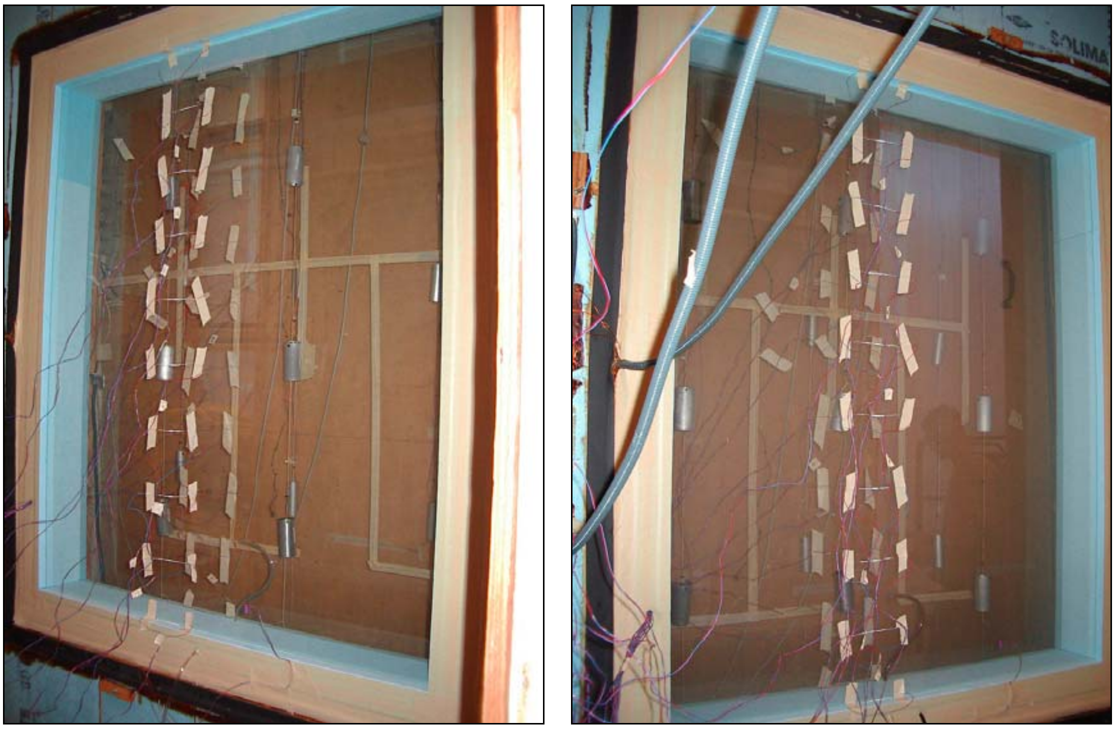
Vha. programmerne *Therm* og *Window* (*Therm LBNL 2, 2003)* er det muligt at opbygge en model af et vindue, hvor der i en finite element simulering tages hensyn til konvektionens påvirkning af temperaturfordelingen i rudens hulrum. Denne beregningsprocedure er baseret på ISO 15099 (*ISO, 2001)*. For at vurdere om denne beregningsmetode giver pålidelige resultater, er disse optegnet i Figur 10 sammen med de tilsvarende målte.



Figur 10. Temperaturfordeling over rude med glasafstand på 120 mm målt I hot box og beregnet I Therm under hensyntagen til effekten af konvektion.

Det fremgår af Figur 10, at de beregnede værdier generelt ligger lidt lavere end de målte, men at de følger samme mønster. Afvigelserne på knap 1 °C kan skyldes unøjagtighed ved måling af rumtemperaturen ved målingerne. Det kan altså konkluderes, at beregningsmetoden tager højde for konvektionen i hulrummet på en realistisk måde, og at den derfor er velegnet til termiske beregninger for ruder med store hulrum mellem glassene.

Der er dog behov for videre validering af beregningsmetoden ved sammenligninger med yderligere målinger i hot boxen. Endvidere vil det være interessant at undersøge hvordan konvektionsstrømningerne påvirker varmetransporten og temperaturfordelingen i en 3-lags rude, hvor luftstrømmene, som grænser op mod det midterste glaslag er modsatrettede.



Figur 11. Måling af overfladetemperaturer på rude med stor glasafstand opbygget i hot box.

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Improved Windows for Cold Climates, Laustsen, J. B., Svendsen S., Department of Civil Engineering, Technical University of Denmark, April 2005, Symposium on Energy Efficient Building in Sisimiut, April 2005.

Artikler og papers under udarbejdelse:
The Effect of Soft and Hard Low Emittance Coatings on the Light Transmittance of Glazings. Laustsen, J. B., Svendsen S., Department of Civil Engineering, Technical University of Denmark.

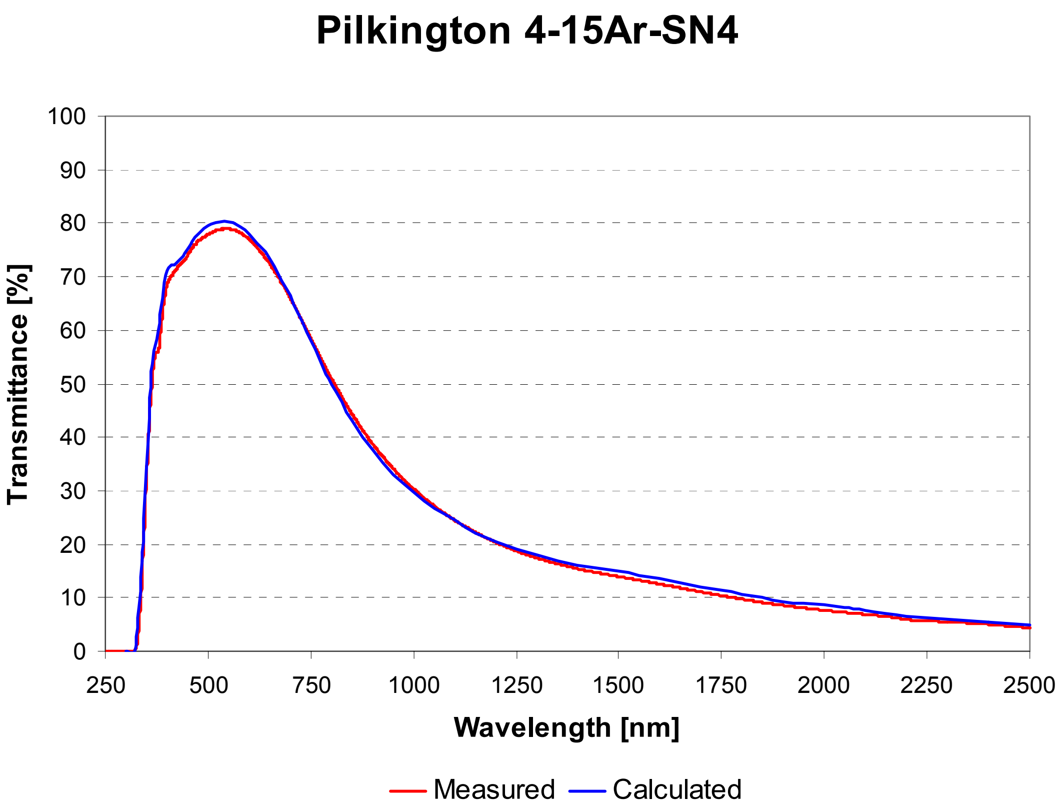
Modelling the Energy Performance of Windows With Large Air Gaps. Laustsen, J. B., Svendsen S., Department of Civil Engineering, Technical University of Denmark.

Præsentationer

Energy-efficient building, Improved Windows for Cold Climates. Svendsen S., Laustsen, J. B., Department of Civil Engineering, Technical University of Denmark, April 2005, Symposium on Energy Efficient Building in Sisimiut, April 2005.

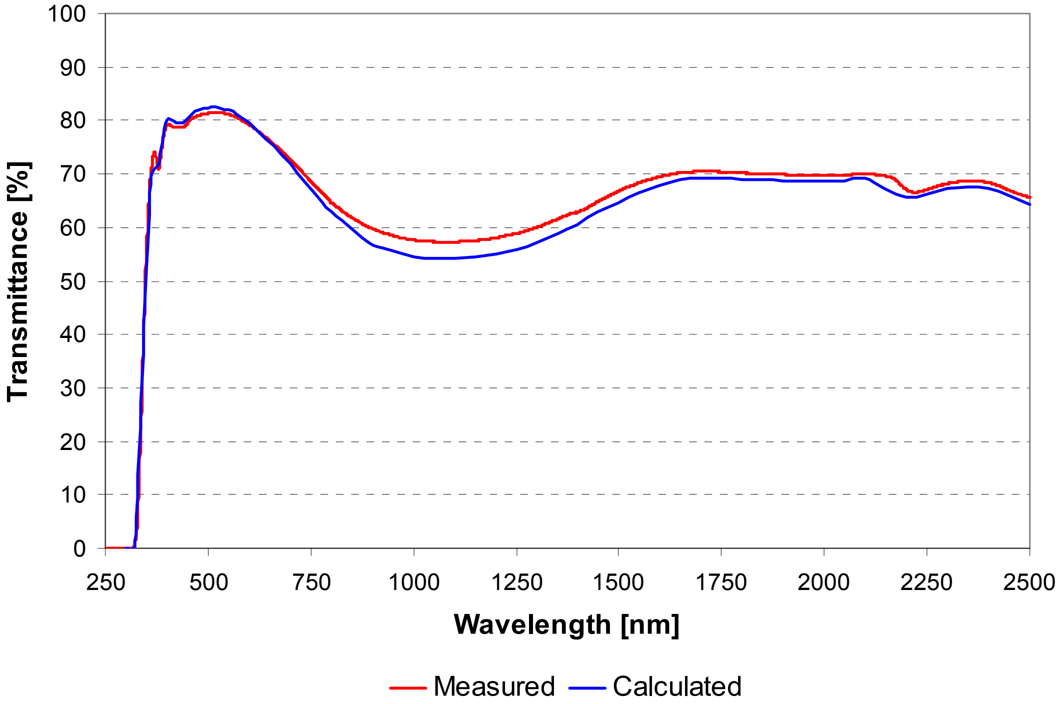
Regnskab. Se bilag 2

Bilag 1. **Spektralfordeling af transmittansen for to 2-lags ruder (lokale 1 og 5) beregnet i WIS og målt i BYG.DTU's spektrofotometer Varian Cary 5E.**



Optifloat Clear 4 mm Glazing cavity 15 mm Optitherm SN 4 mm			
	Solar direct transmittance, τ_e [%]	**Light transmit-tance,** τ_v [%]	**UV trans-mittance,** τ_{UV} [%]
Measured at DTU (Varian Cary 5E spectrophotometer)	53	78	29
Database in WIS (www.WinDat.org)	53	79	32

Pilkington 4-15Ar-4



Optifloat Clear 4 mm Glazing cavity 15 mm Optifloat Clear 4 mm			
	Solar direct transmittance, τ_e [%]	**Light transmit-tance, τ_v** [%]	**UV transmit-tance, τ_{UV}** [%]
Measured at DTU (Varian Cary 5E spectrophotometer)	70	80	44
Database in WIS (www.WinDat.org)	69	81	44

Bilag 2: Regnskab

Projekt: Energirigtige vinduer

BYG•DTU
Brovej 118, 2800 Kgs. Lyngby

Projektnummer: 25501
Projektleder: Svend Svendsen
Finansiering: Villum Kann Rasmussen Fonden
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	Realiseret total	Rev. budget
Indtægter:		
VKR. fonden	1.020.000,00	1.520.000,00
Indtægter i alt	1.020.000,00	1.520.000,00
Udgifter:		
Forskertimer	497.735,82	1.307.000,00
Teknisk/administrativ bistand	31.261,00	153.000,00
Rejser	797,50	20.000,00
Drift og materialer	21.773,24	40.000,00
Øvrige		
Udgifter i alt	551.567,56	1.520.000,00
Projektsaldo i alt	468.432,44	0,00

Kgs. Lyngby d. 13. maj 2005

Michael Berthelsen
Administrationschef

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Improved Windows for Cold Climates

Jacob Birck Laustsen, Assistant research Professor
Technical University of Denmark;
jbl@byg.dtu.dk www.byg.dtu.dk

Svend Svendsen, Professor,
Technical University of Denmark;
ss@byg.dtu.dk www.byg.dtu.dk

KEYWORDS: ***Windows, Energy performance, Heat transfer, Solar gain, Net energy gain***

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.

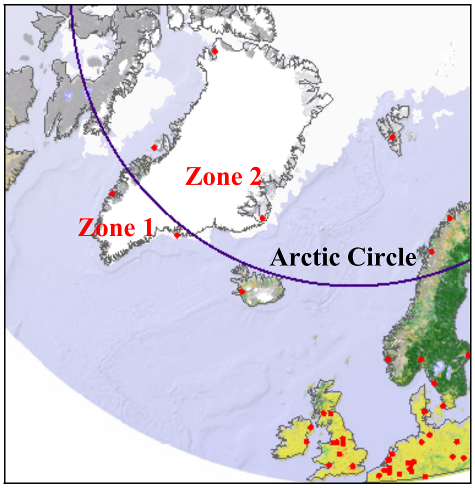
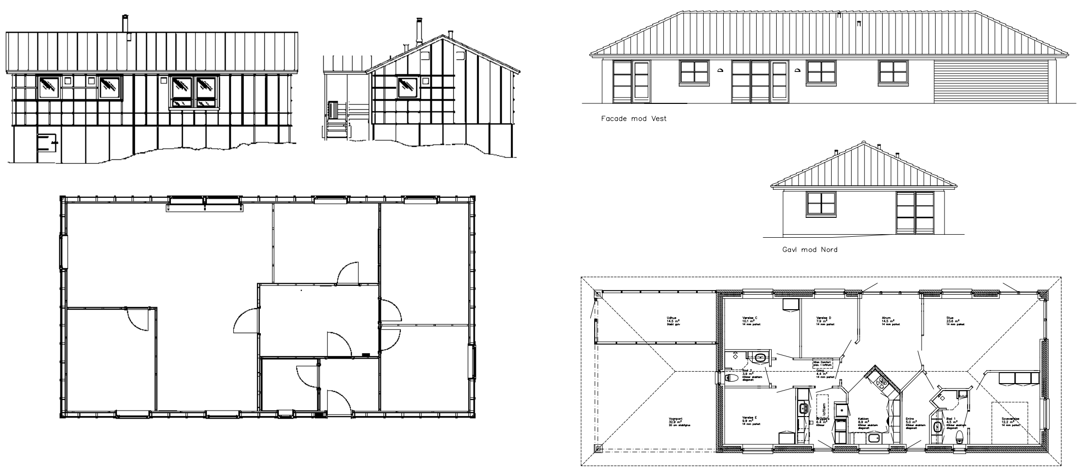


Figure 1.: Climate zones in Greenland. Zone 1 south of the Arctic Circle and zone 2 north of the Arctic Circle (Kragh, J. (2005))

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.

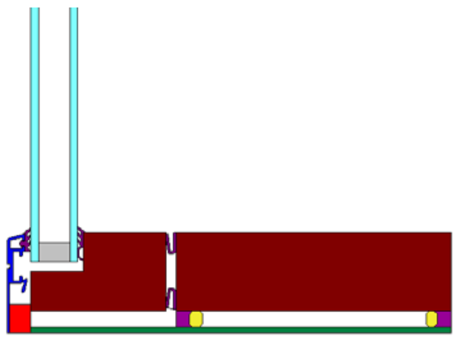


Figure 3. Type 3. Slim frame profile (5 cm) made from wood covered with aluminium.

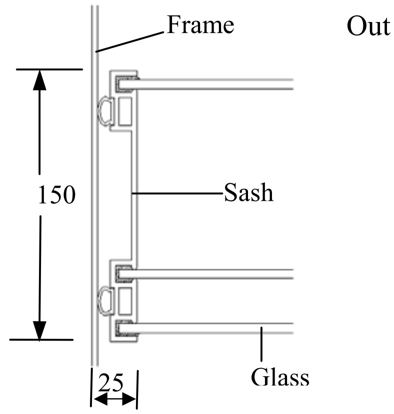


Figure 4. Type 4. Frame profile made from fibre glass reinforced polyester with three layers of glass.

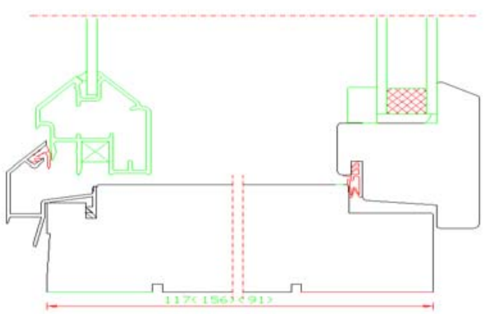


Figure 5. Type 6. Finnish window, 1+2 glazing. Frame made from wood and aluminium

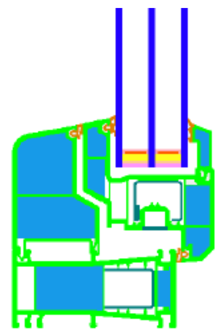


Figure 6. Type 7. PVC frame profile with PU foam in the cavities. Triple glazing unit. (Passivhaus.de.)

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.

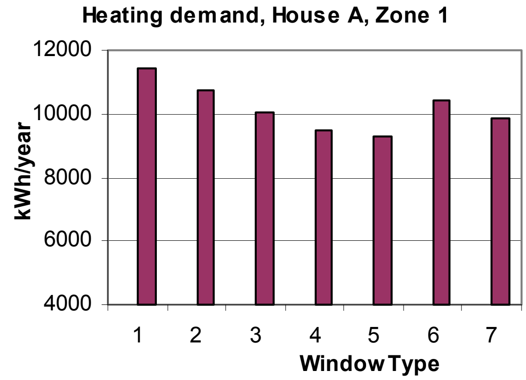


Figure 7. Heating demand for house A with different windows, Greenland, zone 1.

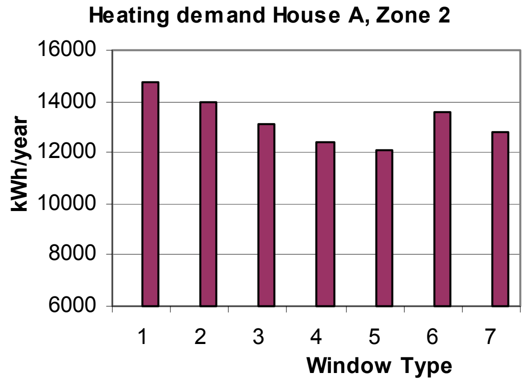


Figure 8 Heating demand for house A with different windows, Greenland, zone 2.

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

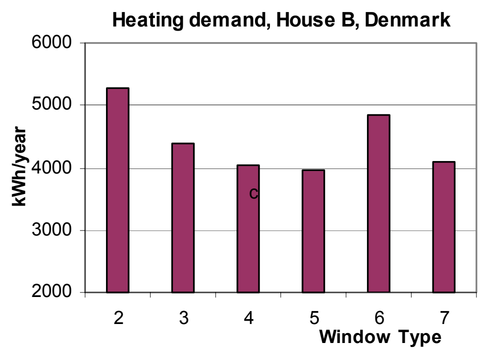


Figure 9. Heating demand for house B with different windows, Denmark

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.

7. References

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Bilag 4. Overheads til præsentationen ”Improved Windows for Cold Climates”.

Energy-Efficient Building, Symposium in Sisimiut, Greenland, April 12-14 2005.

Energy-efficient building

Improved Windows for Cold Climates

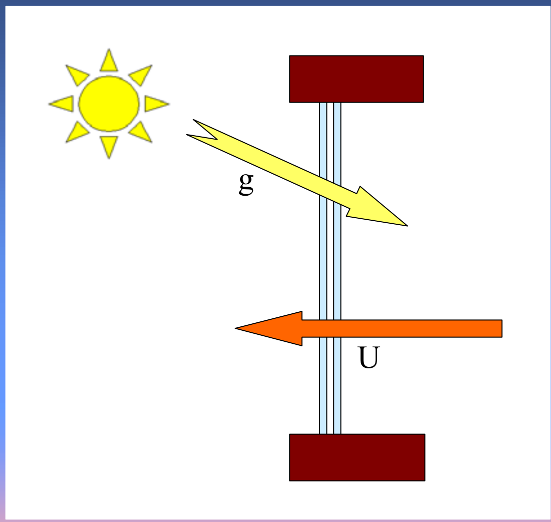
Professor Svend Svendsen
Technical University of Denmark

April 12th – 14th 2005 · Symposium in Sisimiut

Aim of research project

Investigation of
possibilities for developing
windows
with improved energy performance
for cold climates.

Net Energy Gain



The Net Energy Gain

$$E = I \cdot g \quad - \quad U \cdot G$$

E	Net energy gain	[kWh/m^2]
I	Solar radiation	[kWh/m^2]
g	Total solar energy transmittance	
U	Thermal transmittance	[W/m^{2}K]
G	Degree hours	[kKh]

Net Energy Gain

Based on reference house

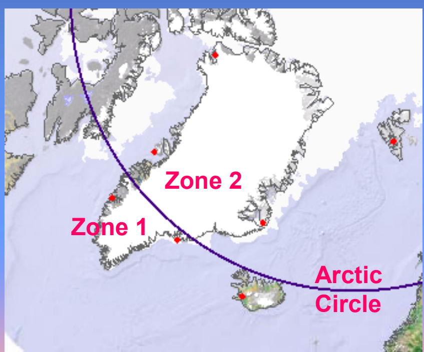
Window distribution:

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

Climate of Greenland

Divided into two zones:

- Zone 1 South of the Arctic Circle
- Zone 2 North of the Arctic Circle



$E_{GI\_1} = 490\ g - 186\ U$

$E_{GI\_2} = 532\ g - 223\ U$

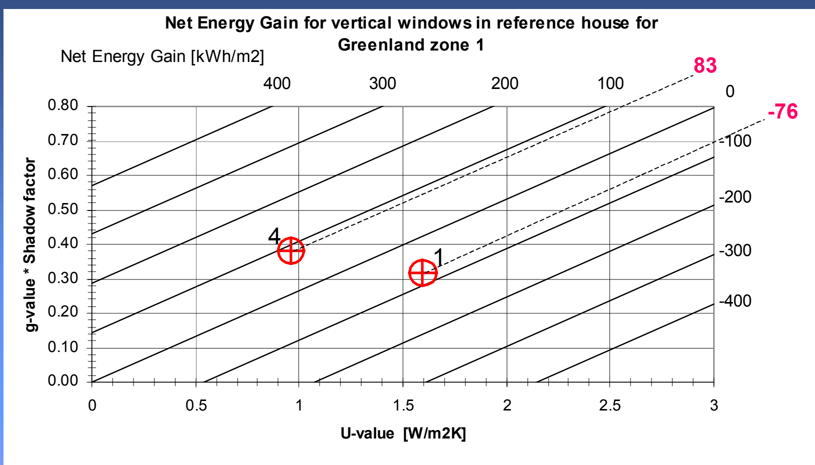
Danish Climate

Heating season:
24 September to 13 May

Shadow factor of 0.7

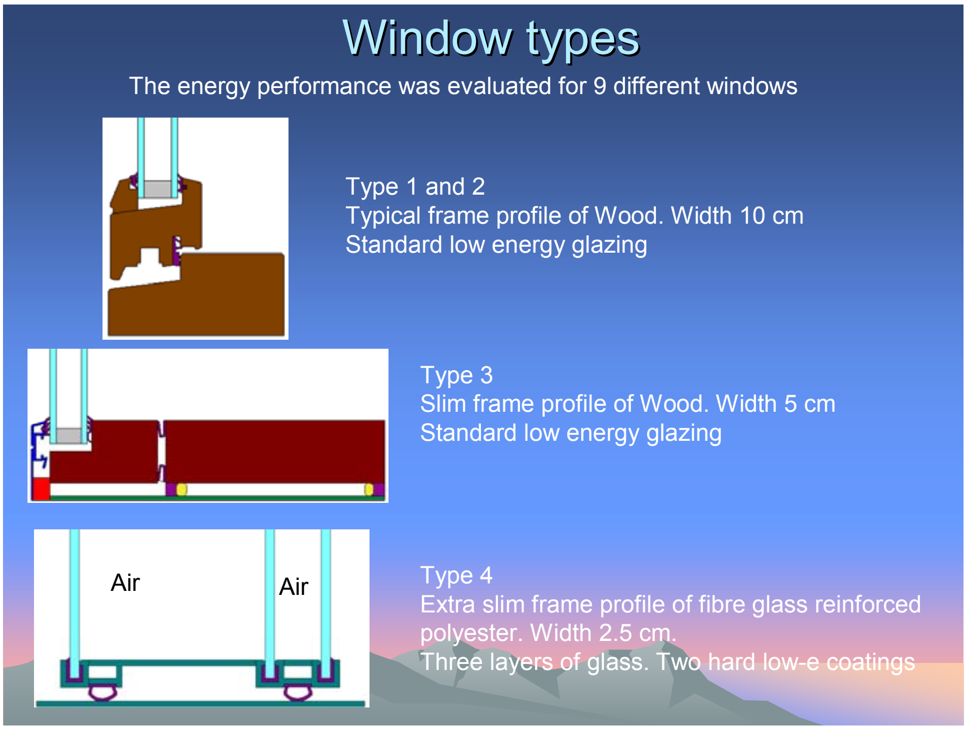
Net Energy gain:
E_{Dk} = 196 g – 90 U [kWh/m^2]

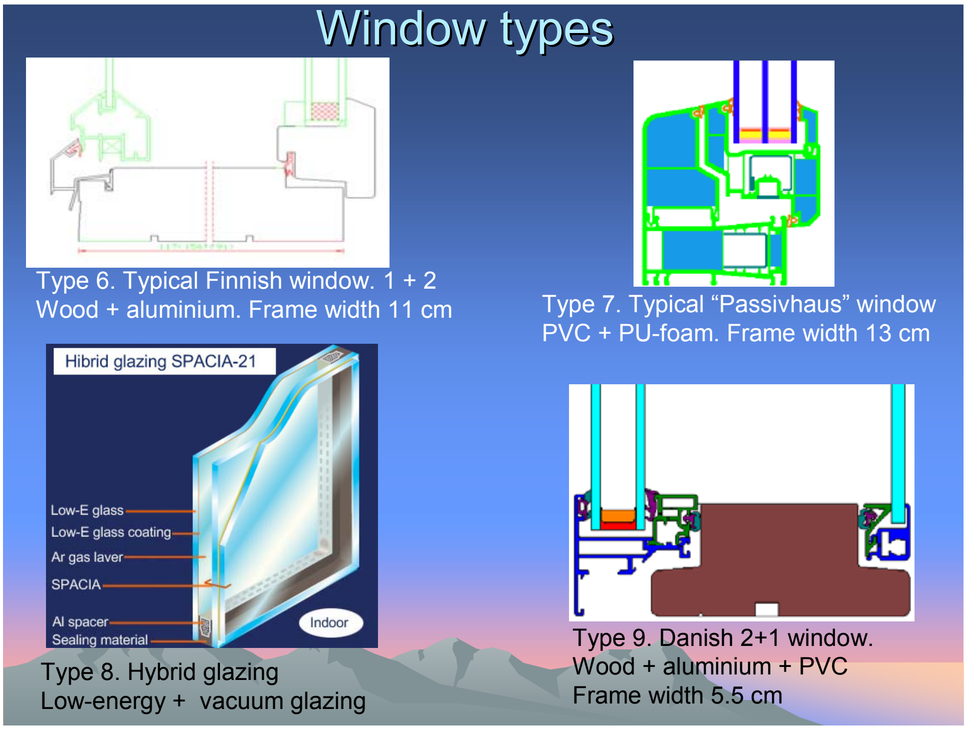
Net Energy Gain Diagram



The g-value is multiplied by the shadow factor of 0.7 before it is used in the diagram

Window type 1	U = 1.61 W/m^{2}K	g=0.46	E = -76 kWh/m^2
Window type 4	U = 0.97 W/m^{2}K	g=0.54	E = 83 kWh/m^2

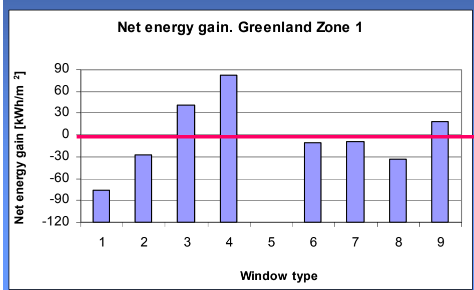

Window types
The energy performance was evaluated for 9 different windows
Type 1 and 2
Typical frame profile of Wood. Width 10 cm
Standard low energy glazing
Type 3
Slim frame profile of Wood. Width 5 cm
Standard low energy glazing
Air
Air
Type 4
Extra slim frame profile of fibre glass reinforced polyester. Width 2.5 cm.
Three layers of glass. Two hard low-e coatings

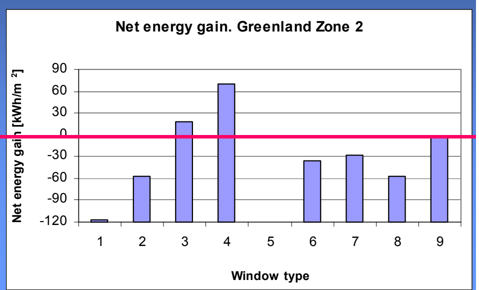

Window types
Type 6. Typical Finnish window. 1 + 2
Wood + aluminium. Frame width 11 cm
Type 7. Typical “Passivhaus” window
PVC + PU-foam. Frame width 13 cm
Hibrid glazing SPACIA-21
Low-E glass
Low-E glass coating
Ar gas layer
SPACIA
Al spacer
Sealing material
Indoor
Type 8. Hybrid glazing
Low-energy + vacuum glazing
Type 9. Danish 2+1 window.
Wood + aluminium + PVC
Frame width 5.5 cm

Results

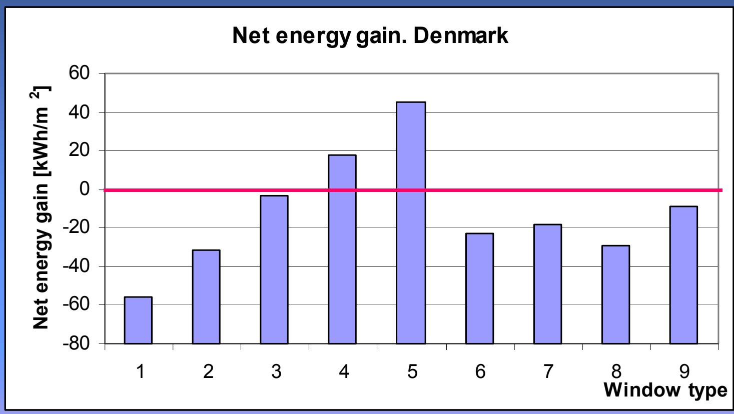
	Glazing		Frame			Window 1.48 x 1.23 m		Net energy gain		
	U_g	g	Width	U_f	Ψ	U_{tot}	g_{tot}	E_{ref} Dk	E_{ref} Zone 1	E_{ref} Zone 2
Type	W/m²K		m	W/m²K	W/mK	W/m²K		kWh/m²	kWh/m²	kWh/m²
1	1.28	0.63	0.10	1.30	0.128	1.61	0.46	**-56**	**- 76**	**- 116**
2	1.17	0.63	0.10	1.37	0.047	1.34	0.46	**-32**	**-26**	**-57**
3	1.15	0.67	0.054	1.33	0.034	1.27	0.58	**-2**	**41**	**18**
4	0.93	0.58	0.025	1.49 *)	-	0.97	0.54	**18**	**83**	**70**
5	0.93	0.58	0.025	1.49 *)	-	0.97 0.49**)	0.54 0.0**)	**45**		
6	1.01	0.60	0.11	1.32	0.040	1.20	0.43	**-23**	**-10**	**-36**
7	0.70	0.52	0.13	0.75	0.030	0.79	0.33	**-6**	**16**	**0**
8	0.70	0.43	0.10	1.30	0.05 ***)	0.99	0.31	**-39**	**-33**	**-57**
9	0.72	0.51	0.055	2.71	-	1.03	0.43	**-9**	**18**	**-2**

Net energy gain in Greenland



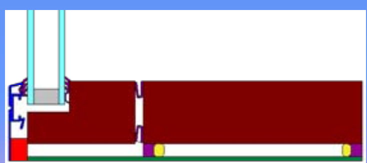


Net energy gain in Denmark



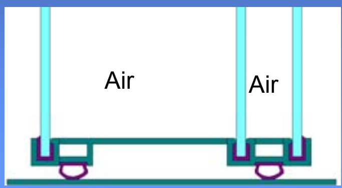
Window With Positive Net Energy Gain Type 3

- Energy glazing with low iron glass
- Warm edge
- Slim frame of wood



- Low heat loss
- High solar gain
- Positive net energy gain

Window With Positive Net Energy Gain
Type 4

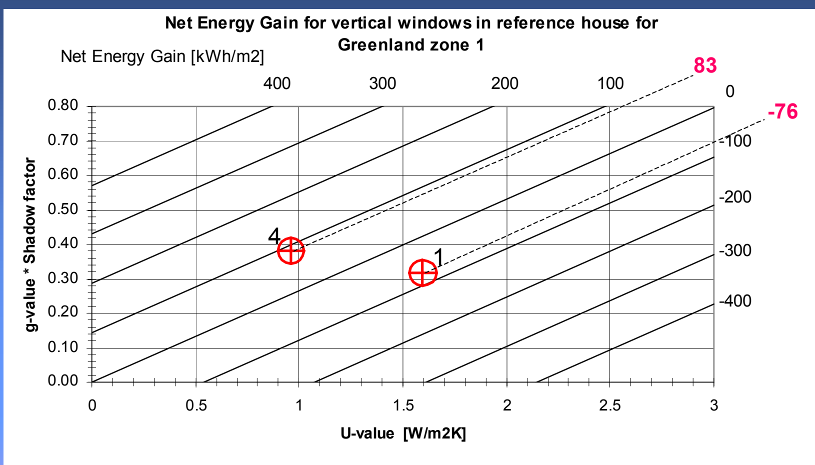


Extra slim frame profile of 2.5 cm.
Fibre glass reinforced polyester.
Three layers of glass.
Two hard low-e coatings
Air gabs sealed but micro ventilated
Air pressure neutralized through tubes with filters to outside

Non-sealed air gabs in glazing → longer service life

Large air gaps → integration of solar shading in glazing

Net Energy Gain Diagram



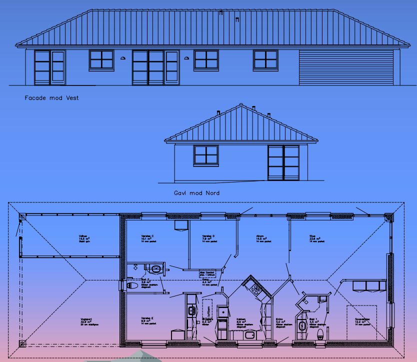
The g-value is multiplied by the shadow factor of 0.7 before it is used in the diagram

Window type 1	U = 1.61 W/m²K	g=0.46	E = -76 kWh/m²
Window type 4	U = 0.97 W/m²K	g=0.54	E = 83 kWh/m²

Simulations in BSim 2002

Energy consumption for heating and ventilation were determined for the windows used in typical houses in Greenland and Denmark

House A: (Arctic climate, Greenland)
Illorput



House B: (Danish climate)
Snekkersten

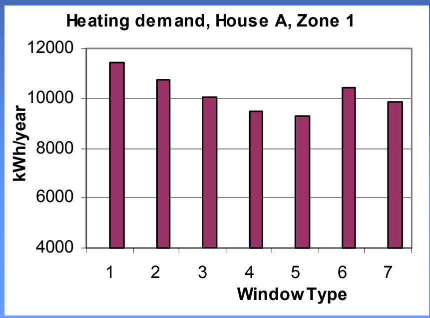
Energy consumption in Greenland

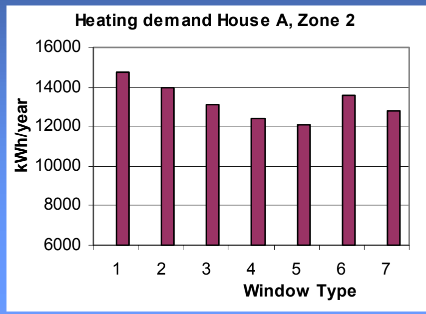
Based on heating of building with the window types

Building simulations performed in BSim 2002

Window			Zone 1			Zone 2		
Type	U_{tot} W/m^{2}K	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

Energy consumption in Greenland

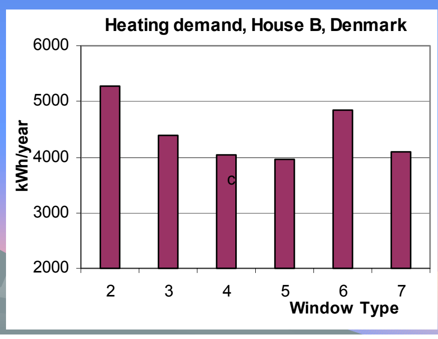




Energy consumption Denmark

Building simulations performend in BSim 2002

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



Conclusion

- It is possible to develop windows with positive net energy gain in cold climates
- Improvements of existing window types
- Further improvements possible based on new window types