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A SIMPLE ENERGY RATING FOR SOLAR SHADING DEVICES

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Simpel energiklassifikation af solafskærmninger

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Forord

Det rapporterede arbejde er udført i forbindelse med projektet ”Køling 2002 – Solafskærmning”, J.nr. 7521/0049, med finansiering fra Energistyrelsen. Målet for arbejdet er at udvikle en metode til klassifikation af solafskærmninger udfra deres indflydelse på en bygnings energieffektivitet specielt med henblik på kontor- og institutionsbygninger i Danmark.

Resume

Når indflydelsen fra en solafskærmning på en bygnings energieffektivitet vurderes skal vurderingen altid foretages på baggrund af solafskærmningen i kombination med den benyttede rude.

En metode til klassifikation af vinduer med eller uden solafskærmning er udviklet på baggrund af deres evne til at reducere summen af de årlige energibehov til opvarmning og køling. Metoden benytter målte værdier for maximal og minimal total solenergitransmittans, g, for normalstråling der kan opnås med solafskærmningen. Ved at benytte Bsim2002 til at beregne de årlige energibehov til opvarmning og køling for et referencekontor er det vist at en pålidelig vurdering kan etableres ved brug af en andenordens regression for summen af de årlige energibehov til opvarmning og køling (midlet over fire facade orienteringer) på baggrund af de to målte parametre. Regressionsligningen giver en simpel metode til at definere en ”ABC” klassifikation for vinduer og variable solafskærmninger. Et antal eksempler er givet for at illustrere metoden.

Desuden findes at en variabel solafskærmning kan reducere det samlede opvarmnings- og kølebehov for referencekontoret med op til 25% sammenlignet med den bedste to-lags rude og med op til 33% sammenlignet med en traditionel to-lags rude.

De præcise numeriske resultater afhænger af forudsætningerne for simuleringerne herunder specielt definitionen af referencekontoret. Resultaterne må derfor på nuværende tidspunkt vurderes som værende foreløbige. Det er åbent til debat om modifikationer af referencekontoret er nødvendige for at få en bedre lighed med den gængse danske byggepraksis. Selvom dette kan indvirke på de numeriske resultater (og måske også indvirke på ydeevnen af de forskellige teknologier) vil metoden udviklet i dette arbejde stadig være anvendelig.

Metoden kan ikke benyttes for solafskærmninger hvor g ikke kan varieres af en styring men hvor g varierer som funktion af solens position f. eks. et fast udhæng eller typer af ruder med retningsbestemte egenskaber. Ikke desto mindre skulle det være muligt at udvide metoden til at dække disse systemer i videre studier.

A Simple Energy Rating for Solar Shading Devices

by

T.R. Nielsen, J.L.J. Rosenfeld and S. Svendsen

Foreword

The work reported here was carried out for the consultancy project “Køling 2002 – Solafskærming”, J.nr. 7521/0049, funded by the Danish Energy Agency. The objective of the work is to develop a method for rating solar shading devices according to their impact on the energy efficiency of a building, in particular office and institutional buildings in Denmark.

Summary

In considering the impact of a solar shading device on the energy efficiency of a building, it is always necessary to consider the shading device in combination with the glazing.

A method has been developed that allows windows with (and without) variable shading devices to be rated according to their ability to reduce the sum of annual heating and cooling loads of an office. The method requires the measurement at normal incidence of the maximum and minimum values of the total solar energy transmittance, g, that the shading system allows. Using Bsim2002 to calculate the annual heating and cooling loads for a reference office, it has been shown that a reliable order of merit can be established using a second order regression of the sum of the annual heating and cooling loads (averaged over four façade orientations) in terms of the two measured parameters. The regression equation provides a simple means to define an “ABC” rating scale for windows and variable solar shading devices. Some examples are given to illustrate the method.

It has further been shown that the use of a variable shading device can reduce the heating and cooling requirements for the reference office by up to 25% compared to the best unobstructed double glazing unit (DGU) and up to 33% compared to a float glass DGU.

The precise numerical results depend on the assumptions made in the simulations, especially the definition of the reference office. Therefore, they should at this stage be considered as preliminary. It is open to debate whether modifications are required to the reference office to reflect more closely current Danish building practices. Whilst this could affect the numerical results (and might also affect the relative performance of different technologies) the methodology developed in this work will remain applicable.

The method does not at present apply to shading systems for which g cannot be varied by a control system but for which g nevertheless varies with the position of the sun, for example fixed overhangs or some types of glazing systems with directional selectivity. However it should be possible to extend the method to such systems in future studies.

A Simple Energy Rating for Solar Shading Devices

1. Introduction

The aim of this study is to develop a simple method to rank solar shading devices according to their energy performance, i.e. the extent to which they can reduce cooling and heating loads in an office building. The study focuses on Denmark, where the climate is such that in many offices both heating and cooling are required during the year.

The problem is intrinsically complex because the shading device interacts with the glazing and will affect the energy flows in the room in several ways.

Most obviously, the total solar energy transmittance or g value of the window and shading device depends on the condition at any time of the shading device (for example to what extent the slats of a Venetian blind are rotated). This affects the solar heat gain and the effect this has on heating or cooling loads then depends on other variables, such as the thermal properties of the building and internal heat sources as well as the prevailing weather. The U value of the window may also vary depending on the condition of the shading device.

The condition of the shading device will also affect the intensity and distribution of daylight, which in turn may affect the electric lighting load, and hence the heating and cooling loads. Indeed, in practice shading devices are often adjusted to optimise the visual comfort in the room, rather than to save energy.

The energy savings realised in practice with a particular shading device will therefore depend on the building, on the use of the building (internal heat sources), on the climate and on the control strategy determining the operation of the shading device (which might simply be to let the occupants decide, or to optimise visual comfort, or to minimise HVAC loads or some combination of these).

It is clear, therefore that there is no way of ranking shading devices according to their energy performance in a general, absolute way. First, it is always necessary to consider the shading device in combination with the glazing. Second, in some situations system A will be better than system B; in others B will outperform A. Only detailed building simulations can determine the most appropriate device in a particular case.

To reduce the complexity of the problem the outline of the approach adopted in this study is as follows:

1. Use a reference office, with detailed specified thermal properties and internal heat gains from people, equipment and electric lighting.
2. Use a reference year's weather data.
3. Define two parameters to characterise the window and shading device. These are the maximum and minimum values of the total solar energy transmittance, g, that the system allows. For example, with a Venetian blind, g_{max} is the value of g when the blind is open or retracted; g_{min} is the value of g when the blind is closed.
4. Perform simulations using Bsim2002, with the office windows orientated East, West, North or South. A control strategy is used to set the value of g in the range g_{max} to g_{min} at each time step, so as to minimise the heating and cooling loads. The results of the simulations are the annual cooling and heating loads.
5. Carry out simulations with many pairs of g_{max} and g_{min}. None of these represents any particular shading device and window; they simply cover the full range of possibilities.

6. Carry out a two dimensional regression to predict the sum of the heating and cooling loads (averaged over the four orientations) as a function of g_{max} and g_{min}. This regression provides the basis of the energy rating system.

It should be emphasised that the ranking obtained applies only to the specific office and other assumptions made in the simulations. However, if these are sufficiently representative of practice in Denmark, the ranking should be useful in the initial stages of design.

2. Types of solar shading devices considered

The method adopted is applicable to the following types of systems:

- Unobstructed windows without a variable shading device. This includes all windows with coated or tinted glass provided that they are not subject to periodic shading by overhangs or other structures. For these systems g is fixed, and therefore in step 3 of the outline described above, $g = g_{max} = g_{min}$.
- Windows with a shading device that can be varied by a control system. This includes external, integrated and internal Venetian blinds, roller blinds, etc.

The method does not at present apply to shading systems for which g cannot be varied by a control system but for which g nevertheless varies with the position of the sun, for example fixed overhangs or some types of glazing systems with directional selectivity.

In the appendix examples are given of the types of shading devices currently used in Denmark, to which the method should be applicable.

3. Assumptions made in the simulations

The reference office

We have used the office originally defined in the European Commission Joule project REVIS [1, 2] and further refined in the International Energy Agency Solar Heating and Cooling (IEA SHC) programme Task 27 (Performance of solar facade components) [3, 4]. The same specifications will be used in the EC project SWIFT and for IEA SHC Task 25 (Solar assisted air conditioning of buildings) and Task 31 (Daylighting Buildings in the 21st century).

The office is in a middle-size office building with office modules aligned on two façades, separated by a central corridor, with staircase/service spaces at both ends of the building. It comprises 210 office modules, distributed over 7 floors and 2 orientations: 15 office modules per floor at each of the two orientations. Figure 1 shows the plan of one floor. The dimensions of the side, façade and rear walls of an office module are given in Figures 2 to 4. The corridor is 3.1 m wide.

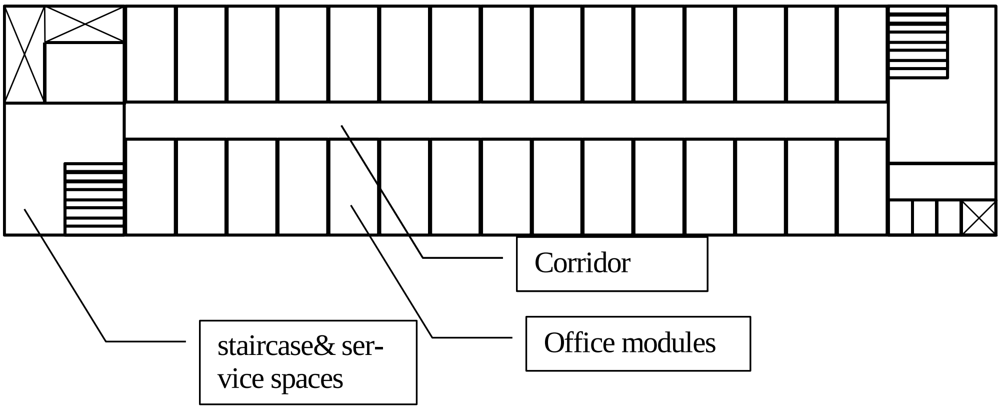

Figure 1. Plan of one floor of the reference office building.

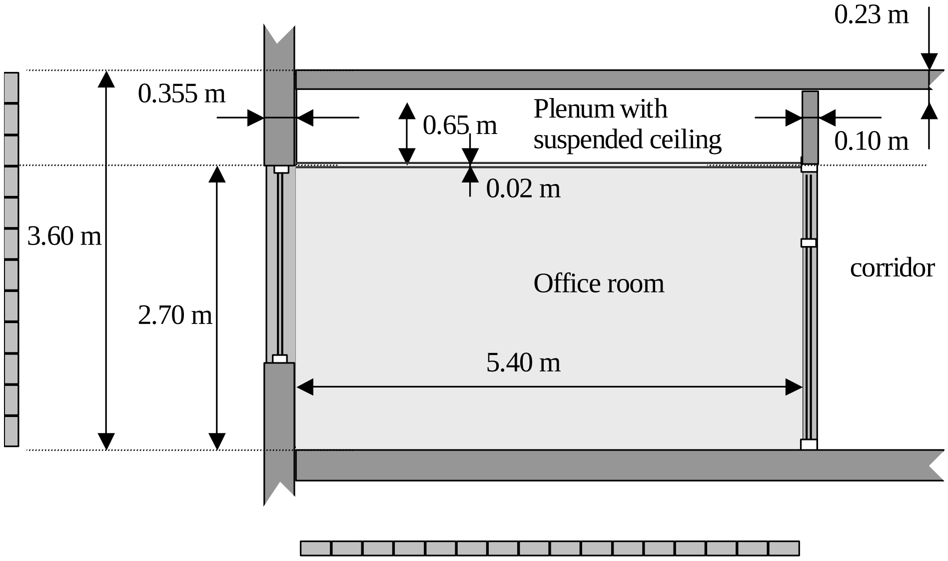

Figure 2. Sidewall of the reference office

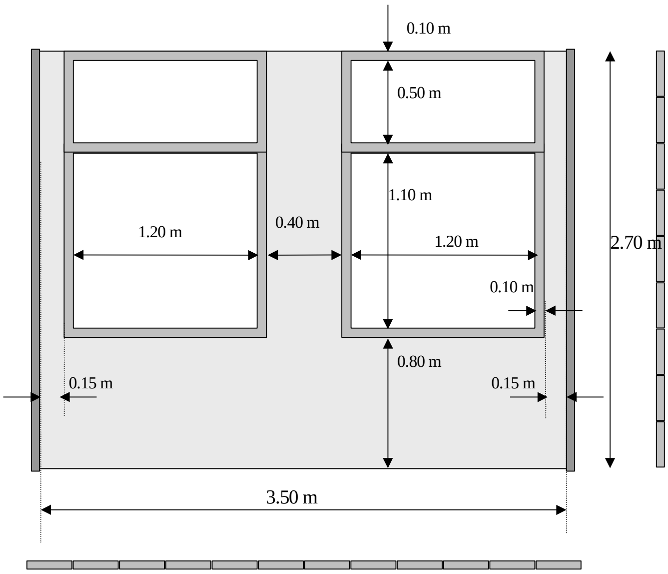

Figure 3. Façade wall of the reference office

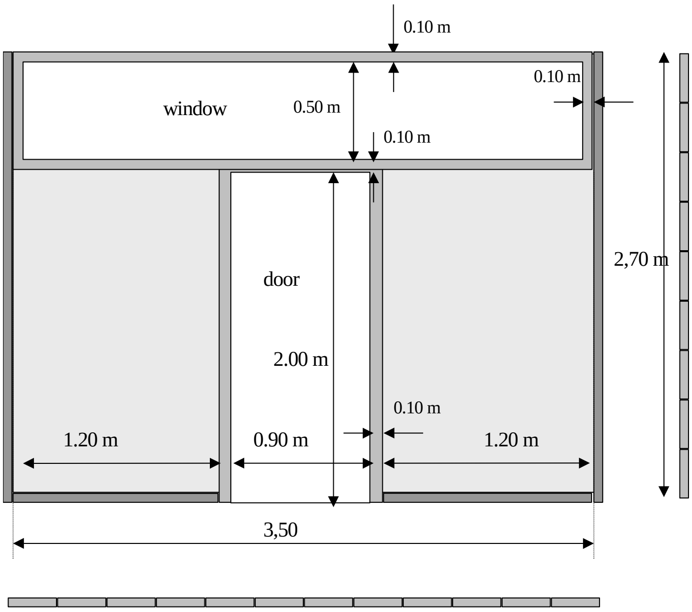

Figure 4. Rear wall of reference office, connecting to the corridor.

The construction of each wall is specified with material properties based on the CEN standard [5], except for the thermal conductivity of thermal insulation layers for which [5] gives ‘safe’ (high) values; for these values are specified that are representative of certified products. Details can be found in [3, 4]; by way of illustration, the specification of the construction of an intermediate floor is given in Table 1. With surface resistances of 0.10 m^{2}KW^{-1} on each side, the corresponding U-value is 1.224 Wm^{-2}K^{-1}.

Layer, from top to bottom	Thickness m	Thermal conductivity Wm^{-1}K^{-1}	Thermal resistance m^{2}KW^{-1}	Specific mass kgm^{-3}	Specific heat capacity Jkg^{-1}K^{-1}
Carpet	0.010	0.100	0.100	200	1400
Cement floor	0.020	0.900	0.022	1800	1100
Concrete slab	0.200	1.600	0.125	2200	1070
Cavity/plenum	0.650	-	0.170	1.23	1000
Suspended ceiling (particle board)	0.020	0.100	0.200	300	1700
Total	0.900	-	0.617	-	-

Table 1. Specification of an intermediate floor [3].

The specification in [3] also defines the solar and thermal radiation properties of all the surfaces (needed to model radiative heat exchange) as well as other parameters such as air infiltration rates.

For the Bsim2002 simulations, the model contains two of the office modules (one in each of the orientations of the building façades) and the part of the corridor between them, situated in the middle of an intermediate floor. This avoids the need to take account of the roof, ground floor and service spaces. The model contains three thermal zones (the two offices and the corridor), as shown in Figure 5. It is assumed that the modeled office rooms and corridor space have rooms similar to themselves at the boundaries where the model is cut off. In Bsim2002 all rooms must be closed with constructions on all sides. It is therefore necessary to apply a construction to the otherwise open sides of the corridor. For this purpose a thin construction of insulation material is used. Previous studies [6] showed that the heating and cooling loads and temperatures in the modeled spaces were insensitive to the precise thermal properties used for this boundary.

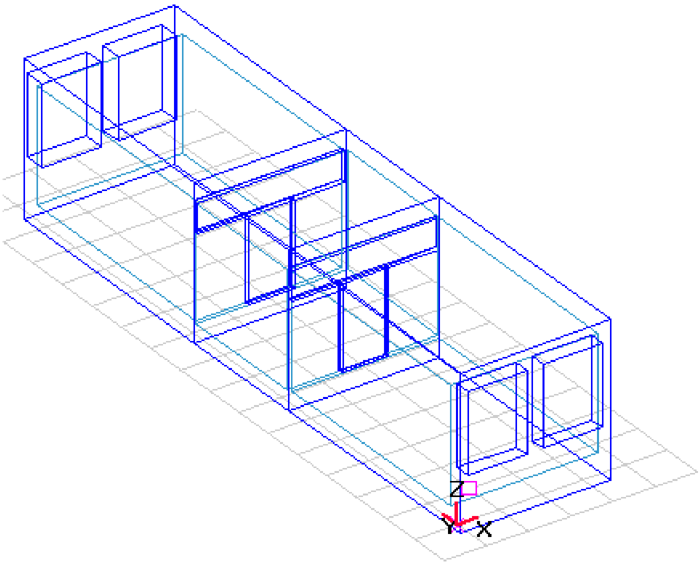

Figure 5. Two reference offices and communicating section of the corridor modelled in Bsim2002.

Internal heat gains

In [3] a detailed hour – by – hour specification is given of the room occupancy, incidental heat gains and electric lighting. Working hours are taken to be 08.00 to 18.00 for 5 days per week. No account is taken of public holidays.

In outline, it is assumed that 1.5 persons use each office. The occupancy profile leads to an average occupancy during working hours of about 1.28 persons, based on 8 working hours per person. The heat dissipation is 70W per person.

Incidental heat gains from equipment in each office are assumed to be 18W continuously (24 hours, 7 days per week) plus 172.5W during working hours.

The specified electric lighting schedule leads to an average heat gain of 89.8 W in each office and 5W per m^2 floor area in the corridor during working hours.

Set points for cooling and heating

To ensure that the simulations will show up differences in performance of different shading devices, it is necessary to choose conditions such that the solar heat gain, if uncontrolled, would make the dominant contribution to the cooling load. Preliminary simulations showed that this could be achieved for the reference office by choosing 24°C as the set point for the onset of cooling during working hours. Outside working hours the set point for cooling is 28°C [3]. The heating set point is 20°C during working hours and 16°C at other times [3].

The control strategy for the shading device

The control strategy adopted is that at each time step g is adjusted within the range between g_{max} and g_{min} to minimise the heating and cooling load. Thus, at each time step in the simulation, if cooling is not required, g is set to g_{max}. If cooling would be required with $g = g_{max}$, g is reduced to the point at which the cooling load is zero, unless g_{min} is reached, when some cooling may still be required. This strategy ensures that the shading device is as open to daylight as possible subject to the requirement to minimise the cooling load. In this way, the effect on the electric lighting load is reduced. In any case, the electric lighting schedule specified in the reference office was maintained throughout.

Weather data

We used the Danish Design Reference Year [7]. This provides an hourly series of weather data typical of long – term average conditions in Denmark (Copenhagen).

Other assumptions

At present Bsim2002 does not allow varying U together with g in a simulation in which the indoor temperature is the control parameter. A U value of 1.5 $Wm^{-2}K^{-1}$ for the windows is assumed in all the simulations. In practice, the U value of a particular window may be different, and that will affect the heating and cooling loads. Furthermore, some shading devices may reduce the window’s U value when they are closed. However, with the adopted control strategy the blinds are only closed during periods requiring cooling, and it is expected that this will usually be during the summer, when the temperature difference across the window is small. Thus we expect that the effect of varying U value on the thermal heat flows would be small. It may nevertheless be of interest to explore this in future work.

The values of g_{max} and g_{min} are those at normal incidence. Bsim2002 includes an angle of incidence modifier to adjust g according to the angle of incidence of the light.

4. Results

Simulations were carried out for a series of pairs of g_{max} and g_{min}. The chosen values do not represent any specific window or shading device; they simply cover the full range of possibilities. In principle g_{max} can have a value between 0 and 1, although in practice, it is usually between about 0.2 and 0.8. For a given g_{max}, g_{min} can be between g_{max} and zero. A window without a variable shading device would have a fixed g, $g = g_{min} = g_{max}$, with g depending on the properties of the glazing. An external variable blind could be expected to have g_{min} close to zero, an integrated Venetian blind might have g_{min} in the range 0.1 to 0.3, depending on the properties of the glazing. For an internal blind, g_{min} will not generally be much less than g_{max}, unless the blind is highly reflecting on the side facing the window.

The resultant annual cooling and heating loads, expressed as kWh per m^2 of glazing obtained for the reference office and other assumptions described in section 3 are shown in Table 2, for windows facing north, south, east and west respectively.

Although both g_{max} and g_{min} influence the heating and cooling loads, the main factor determining the cooling loads is the value of g_{min}. This can be seen in Figure 6, where the cooling loads shown in Table 2 are plotted against g_{min}. Points with different g_{max} at the same g_{min} (for example at g_{min} = 0.2) are only slightly separated, showing that g_{max} has only a minor effect on the cooling load. This is the result of the control strategy adopted in the simulations. As explained in section 3.4, when cooling would be required, g is set at a value less than g_{max}, and cooling only occurs when g_{min} is reached. The cooling loads calculated for south, east and west facing windows are very similar, but for north facing windows the cooling loads are considerably lower, because the solar gains are much reduced.

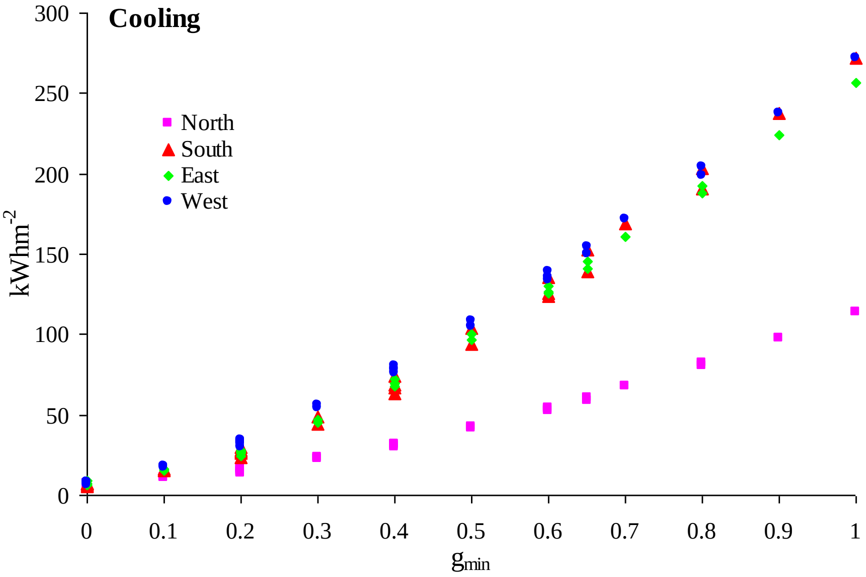

Figure 6. Plot of annual cooling loads against g_{min}, for the four window orientations. Data from Table 2.

In contrast, as shown in Figure 7, the heating loads are predominantly determined by g_{max}. This is because, during the heating season, the control strategy will generally set g to g_{max} to maximise the solar heat gains. However, there is a marked secondary correlation with g_{min}. This is caused by the dynamic nature of the simulation. Even during the heating season, there will be times when g is reduced below g_{max} to avoid cooling and this effectively reduces the solar heat gains stored in the building and hence causes an increase in the heating load. The heating loads for north, east and west facing windows are similar; those for south facing windows are somewhat lower.

g_{max}	g_{min}	North		South		East		West	
		Cooling kWhm^{-2}	Heating kWhm^{-2}	Cooling kWhm^{-2}	Heating kWhm^{-2}	Cooling kWhm^{-2}	Heating kWhm^{-2}	Cooling kWhm^{-2}	Heating kWhm^{-2}
1	1	113.8	189.8	271.6	138.0	256.3	202.9	272.1	202.9
1	0.9	97.4	195.3	238.0	143.2	224.5	204.2	237.8	204.2
1	0.8	82.0	200.5	203.4	148.4	192.4	205.5	204.4	205.7
1	0.7	67.4	205.2	169.3	153.4	160.7	206.3	171.4	206.8
1	0.65	60.7	207.6	152.6	155.7	145.1	206.8	154.9	207.3
1	0.6	54.2	209.6	135.9	157.8	129.7	207.0	139.3	207.8
1	0.5	42.2	213.3	103.9	161.5	100.0	207.6	108.9	208.9
1	0.4	32.0	215.6	74.5	163.8	71.9	208.3	80.7	209.6
1	0.3	23.2	217.2	49.2	165.4	46.9	208.9	56.3	210.7
1	0.2	16.1	218.2	29.9	166.9	28.1	209.1	34.6	211.2
1	0.1	11.2	218.8	16.4	167.7	15.9	209.6	18.5	211.5
1	0	7.6	219.5	7.6	168.8	9.1	209.9	8.3	212.0
0.8	0.8	80.2	215.4	190.4	161.5	188.3	220.6	198.7	221.1
0.8	0.6	53.1	224.0	125.8	170.6	126.6	221.9	135.2	223.2
0.8	0.4	31.3	230.5	68.2	177.1	69.8	223.2	78.4	225.3
0.8	0.2	15.9	233.6	27.6	180.7	27.1	224.2	33.3	226.8
0.8	0	7.3	235.7	7.3	183.3	8.6	224.5	8.1	227.3
0.65	0.65	58.9	234.4	139.3	180.2	141.1	234.4	149.7	234.9
0.65	0.6	52.6	236.2	123.7	182.3	126.0	234.6	134.1	235.7
0.65	0.5	41.1	240.1	94.0	186.2	96.9	235.2	104.4	236.5
0.65	0.4	31.0	243.2	66.9	189.3	69.3	235.9	77.9	237.5
0.65	0.3	22.4	245.1	44.5	191.4	45.1	236.5	53.9	238.5
0.65	0.2	15.6	246.4	27.1	193.0	26.8	236.7	32.8	239.1
0.65	0.1	10.4	247.9	15.1	194.8	15.1	236.7	17.4	239.6
0.65	0	7.0	249.0	7.0	196.1	8.6	237.0	7.8	240.1
0.4	0.4	30.2	270.3	63.5	219.8	67.4	260.9	76.3	263.3
0.4	0.2	14.8	273.7	25.8	224.0	26.0	262.0	31.5	265.1
0.4	0	6.3	275.5	6.5	225.5	7.6	262.5	7.0	266.1
0.2	0.2	13.8	302.3	23.7	266.4	24.5	289.8	29.7	292.2
0.2	0	5.5	304.2	5.5	268.0	6.8	290.6	6.3	293.8

0	0	3.6	336.5	3.9	334.4	3.9	335.7	3.9	335.2

Table 2. Calculated annual cooling and heating loads per m^2 of glazing for the four orientations, for chosen pairs of g_{max} and g_{min}.

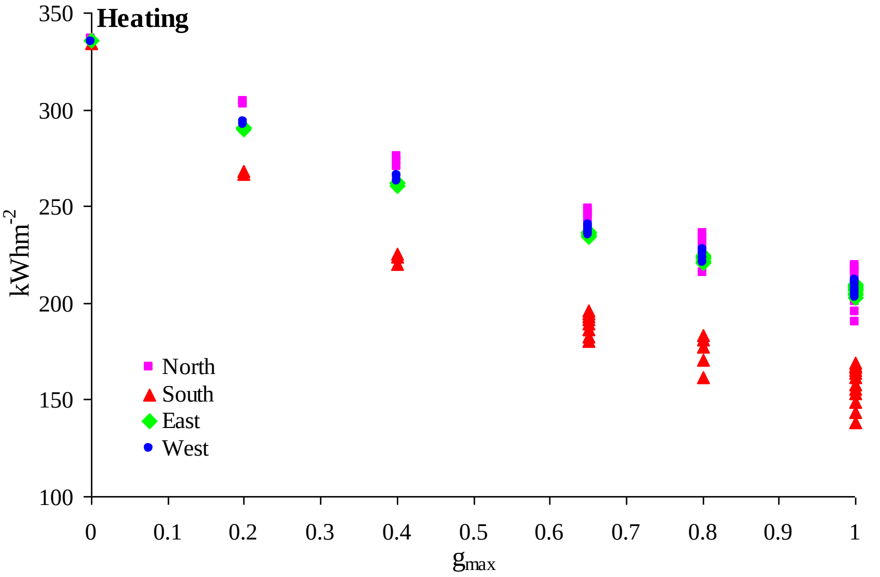

Figure 7. Plot of annual heating loads against g_{max}, for the four window orientations. Data from Table 2.

The effect of removing solar heat gains entirely is demonstrated by the (hypothetical) case, $g_{max} = g_{min} = 0$. As can be seen from Table 2, the cooling load for this case is almost zero. This confirms that for the chosen reference office, internal heat gain schedule and cooling set point of 24°C, solar heat gain is the dominant factor causing the need for cooling. These are therefore the conditions under which the use of variable shading devices will show the greatest energy savings and under which the performance of different devices can best be demonstrated.

It would be possible to carry out regressions for the cooling and heating loads separately for each orientation. However, since the aim is to produce a single energy rating system (rather than separate ones for different orientations), we first average over the four orientations. Figure 8 and 9 show plots similar to Figures 6 and 7, for the loads averaged over the four orientations.

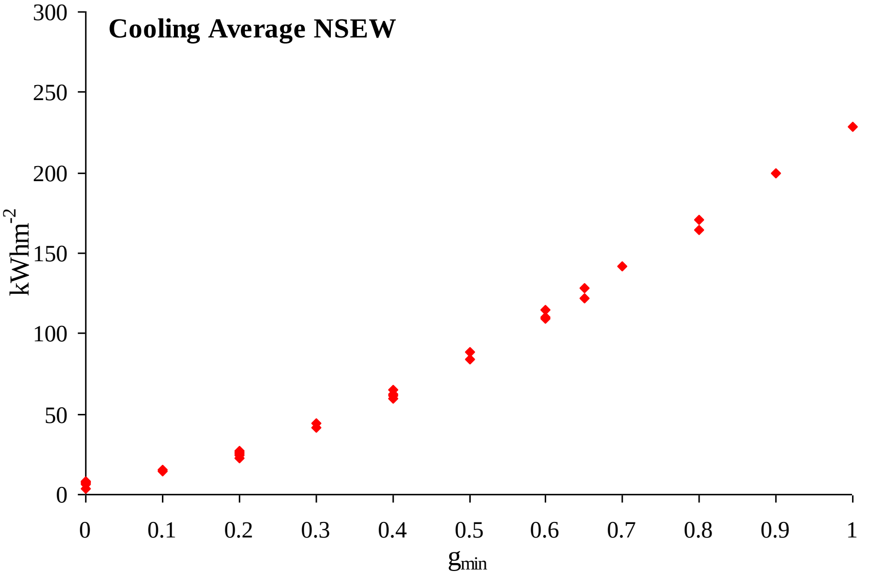

Figure 8. Plot of annual cooling loads against g_{min}, averaged over the four window orientations. Data from Table 2.

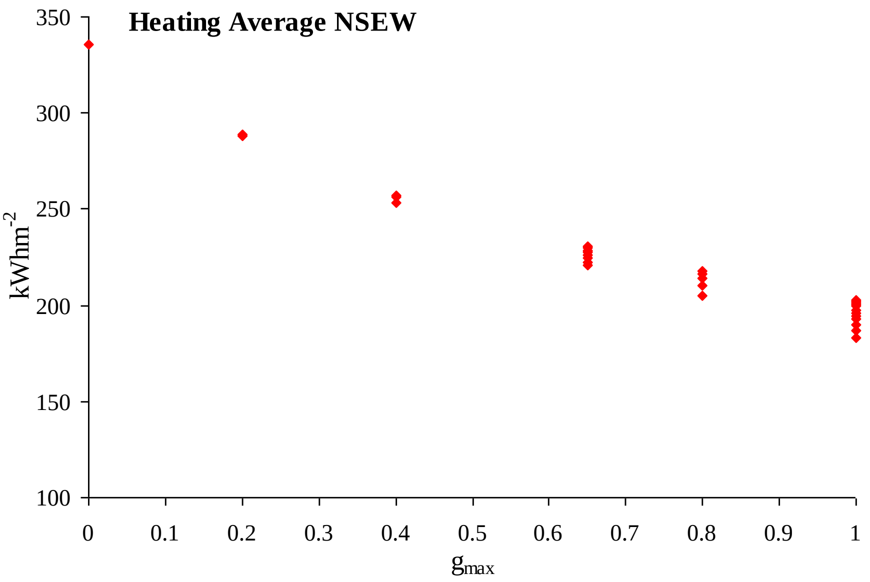

Figure 9. Plot of annual heating loads against g_{max}, averaged over the four window orientations. Data from Table 2.

To obtain an energy rating system in terms of the two parameters defining a window and variable shading device, we sum the average heating and cooling loads for each chosen pair of g_{max} and g_{min} and carry out two dimensional regressions to predict the total load, E, as a function of g_{max} and g_{min}. Thus for a linear regression we find the best fit coefficients a_0 to a_2 in

$$E = a_0 + a_1 g_{max} + a_2 g_{min} \tag{1}$$

For a second order regression, there are six coefficients:

$$E = a_0 + a_1 g_{max} + a_2 g_{min} + a_3 g_{max}^2 + a_4 g_{min}^2 + a_5 g_{max} g_{min} \tag{2}$$

The results of the regressions are shown in Figure 10. The red crosses show the predictions of the linear regression. The blue diamonds show the loads predicted by the second order regression. For a perfect prediction, the points would fall on the dotted line. As can be seen in Figure 10, the linear regression does not always preserve the ranking, and will therefore mislead in some cases. The second order regression does preserve the ranking and is therefore preferable. A third order regression offered no significant improvement over the second order regression.

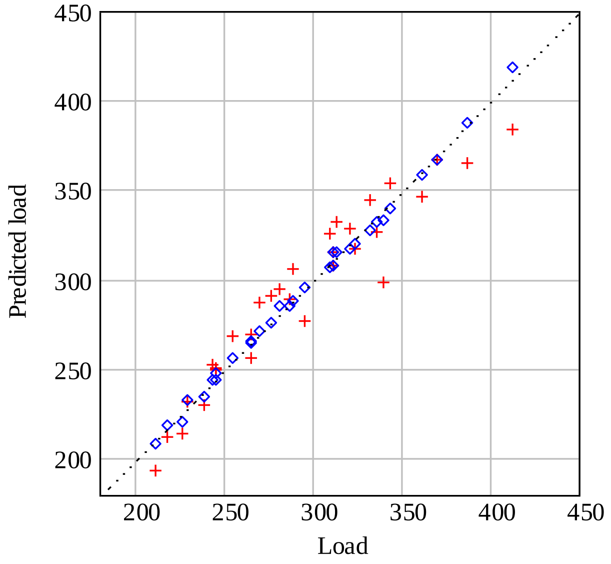

Figure 10. Prediction by first and second order regressions of the sum of annual heating and cooling loads, averaged over the four orientations. Red crosses, linear regression; blue diamonds, second order predictions.

It is of interest to consider windows with coated glazings but no variable shading device, i.e. cases when $g = g_{max} = g_{min}$. This is illustrated in Figure 11. Here the predicted annual load is plotted against the fixed value of g. The brown squares are the loads calculated by the simulations (selected data from Table 2). The red line is the prediction of the linear regression; the blue line is that of the second order regression. The former suggests that the minimum is reached for g = 0, i.e. with no windows at all. The second order regression indicates that the best choice of g is about 0.3. Co-incidentally, this is the value of g for a double-glazing unit incorporating the latest solar control coatings (this will no doubt please the glass manufacturers). It should, however, be stressed that the optimum value of g found here applies to the reference office, its internal heat gain schedule and chosen cooling set point. For smaller internal heat gains or a higher cooling set point, the minimum would be expected to move to higher g, as less cooling would be required, and the heating load could be further reduced with a higher g value.

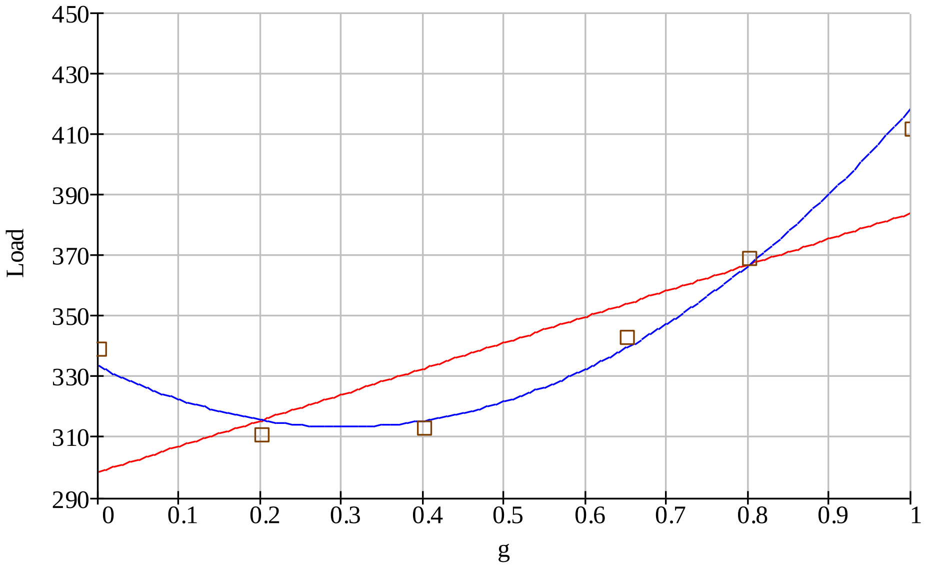

Figure 11. Sum of annual cooling and heating loads, averaged over the four orientations, for $g_{max} = g_{min}$. Brown squares, results of simulations; red line, prediction with linear regression; blue line, prediction with second order regression.

For windows with a variable shading device, Figure 12 shows the results obtained for g_{min} = 0.4, 0.2 and 0, as a function of g_{max} (recall that $g_{max} \geq g_{min}$, so that the results for g_{min} = 0.4, 0.2 start at g_{max} = 0.4, 0.2 respectively). As before, the brown squares are the results of the simulations, the red lines are the predictions with the linear regression and the blue lines those with the second order regression. The Figure shows that for a given g_{min} the largest value of g_{max} is best, and that the lower g_{min}, the lower the sum of heating and cooling loads. Thus, a variable shading device will perform best with a float glass or low e coated glass glazing, and the wider the range of g available, the better. This result contrasts with the one found for windows without a variable shading device (fixed g, Figure 11) and shows the importance of considering the glazing and shading device together when designing a building. For example, an initial decision to use only coated glazing (hence optimally choosing solar control glazing with $g_{min} = g_{max} = 0.3$), followed later by a retrofit of variable blinds would at best reduce the load from about 310 to 280 kWhm^{-2}, whereas an initial design combining the variable blind with low e coated glazing (g_{max} = 0.7, say), could reduce the load to 230 kWhm^{-2}.

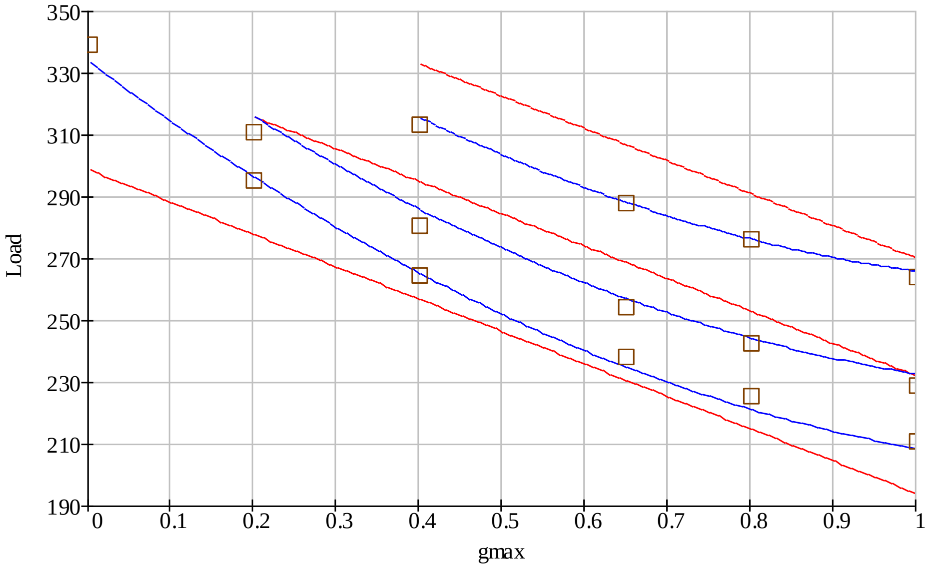

Figure 12. Sum of annual cooling and heating loads, averaged over the four orientations, as a function of g_{max}. From top of Figure, results for g_{min} = 0.4, 0.2 and 0. Brown squares, results of simulations. Red lines, prediction with linear regression. Blue lines, prediction with second order regression.

A comparison of Figures 11 and 12 further reveals that a window with variable shading device will generally outperform a window with a fixed g. The best that can be achieved with the latter is an annual load of about 310 kWhm^{-2}, whereas with a variable shading device this can be reduced to about 230 kWhm^{-2} (taking 0.7 as the maximum practical value for g_{max}). Thus the potential for energy savings through the use of variable shading devices is considerable, up to 25% compared to the best fixed – g window. Of course, the precise numbers refer only to the reference office and the other assumptions used in the simulations. To the extent that these are typical of office buildings in Denmark, however, this is a very significant result emerging from this study.

The best fit coefficients for the regressions given by equations (1) and (2) are shown in Table 3. Also shown are the standard deviation of the predictions from the simulation results and the correlation coefficient, which is a measure of the goodness of the fit. It is strongly recommended that the second order regression be used as the basis of a performance rating system.

Coefficient	Variable	Linear regression	2nd order regression
a_0	constant	298.40	333.60

a_1	g_{max}	-104.71	-202.74
a_2	g_{min}	190.45	70.22
a_3	g_{max}^2	-	77.49
a_4	g_{min}^2	-	112.10
a_5	$g_{max} \cdot g_{min}$	-	28.28
Standard deviation		14.89	3.15
Correlation coefficient		0.957	0.998

Table 3. Best fit coefficients for the linear and second order regressions of the sum of the annual cooling and heating loads (in kWh per m^2 of glazing), averaged over the four orientations.

5. Energy rating systems

To use the results of this study to rate the energy performance of specific windows and variable shading devices, it will be necessary to measure or calculate g_{max} and g_{min} (at normal incidence) for the system in question. Specialised equipment, such as the illuminated hot box available at DTU, is required and the measurement is onerous (expensive). Typically, the uncertainty in the measurements is about ± 5% [8]. The methods for calculating g are at present only available for some shading devices, for example horizontal Venetian blinds and roller blinds. However, the measurements required are the optical properties of the individual components making up the system, which is generally less onerous. The accuracy of the models is similar to the measurements. Given g_{max} and g_{min}, the second order regression should be used to calculate E from equation (2).

Two possible rating systems then suggest themselves. The first is to use the value of E directly, giving a continuous scale. The other is to divide the range of possible values into bands, labelled A to D, say. The practical range for E is from about 220 to about 360. Systems for which E is calculated to be ≤ 265 would be placed in class A, those with E in the range $265 < E \leq 290$ in class B, those with $290 < E \leq 325$ in class C and those with $E > 325$ in class D. The latter classification is preferable, as it compensates for the uncertainties in the two parameters (except, inevitably, at the boundaries of the classes) and avoids spurious claims of superiority based on obtaining a slightly lower value than rival systems (advertisers rarely include uncertainty bands in their claims). The number of classes and their bounds proposed here are provisional. A more detailed examination is required to establish a rating scale that clearly groups together systems that belong in the same family.

Some examples of energy rating

To illustrate the energy rating method, in Table 4 are presented some results for various generic systems. The double – glazing units (DGU) all have a 6 mm outer glazing and a 4 mm inner glazing. The values of g_{max} and g_{min} are taken from the references indicated in the Table.

Window and shading system	g_{max}	g_{min}	E from Equation (2) and Table 3	Class (proposed)
Inner glazing K glass™ DGU [10]	0.69	0.69	346	D
Outer glazing K glass™ DGU [10]	0.64	0.64	338	D
Outer glazing Suncool HP™ DGU [10]	0.44	0.44	318	C
Outer glazing Cool lite™ DGU [11]	0.29	0.29	314	C

Internal low reflectance film with float glass DGU [12]	0.76	0.73	351	D
Internal high reflectance film with float glass DGU [12, 13]	0.76	0.38	275	B
Internal high reflectance film with solar control DGU [12]	0.35	0.23	297	C
Integrated Venetian blind in low e DGU [9]	0.65	0.20	257	A
Integrated Venetian blind in solar control DGU [11]	0.29	0.11	291	B
External Venetian blind with low e DGU (hypothetical)	0.69	0.05	235	A
External Venetian blind with solar control DGU (hypothetical)	0.35	0.05	276	B

Table 4. Some examples of the Energy rating of windows and shading systems.

6. Conclusions

A method has been developed that allows windows with (and without) variable shading devices to be rated according to their ability to reduce the sum of annual heating and cooling loads of an office. The method requires the measurement at normal incidence of the maximum and minimum values of the total solar energy transmittance that the shading system allows. Using Bsim2002 to calculate the annual heating and cooling loads for a reference office, it has been shown that a reliable order of merit can be established using a second order regression of the sum of the annual heating and cooling loads (averaged over four façade orientations) in terms of the two parameters, g_{max} and g_{min}.

It has further been shown that the use of a variable shading device can reduce the heating and cooling requirements for the reference office by up to 25% compared to the best unobstructed DGU and up to 32% compared to a low e glass DGU.

The method does not at present apply to shading systems for which g cannot be varied by a control system but for which g nevertheless varies with the position of the sun, for example fixed overhangs or some types of glazing systems with directional selectivity. However it should be possible to extend the method to such systems in future studies.

The numerical results apply only to the reference office and the other assumptions used in the simulations, detailed in section 3. Further work is required to establish the sensitivity of the ranking to these assumptions. It is also open to debate whether some other definition of a reference office might be more typical of current building practice in Denmark (for example larger windows or all glass façade). Although this might produce different rankings, the methodology developed here is generally applicable.

The performance of shading systems depends strongly on the conditions under which they are used and for optimal selection, it would always be recommended to carry out simulations for the specific building at the design stage. Nevertheless, in so far as the reference office is representative of some office buildings in Denmark, the ranking method could be used for a preliminary sorting. It could also be used to answer questions such as “If system A rather than B is chosen (because it is cheaper, or looks nicer) what is the penalty paid in terms of heating and cooling?”

7. References

[1] van Dijk, H.A.L., The European Project Revis, Daylighting Products With Redirecting Visual Properties. In *Proceedings of NorthSun Conference 2001*, 6 – 8 May 2001, Leiden, Netherlands. Available on CD from Stichting Duurzame Energieconferenties, Deventer, the Netherlands or on line at http://www.northsun.org/.

[2] van Dijk, H.A.L., *Daylighting Products With Redirecting Visual Properties*. Coordinator's publishable final report. European Commission JOULE Programme, Project REVIS. TNO Building and Construction Research, P.O. box 49, NL 2600 AA Delft, The Netherlands.

[3] van Dijk, H.A.L., *Reference office for thermal, solar and lighting calculations*. IEA SHC Task27, Performance of solar facade components. Document IEA27-r-a-2-TNO-Sept.2001-Ref.office_v-1.0.doc. TNO Building and Construction Research, P.O. box 49, NL 2600 AA Delft, The Netherlands.

[4] van Dijk, H.A.L., *Draft Addendum to Reference office for thermal, solar and lighting calculations*. IEA SHC Task27, Performance of solar facade components. Document IEA27-r-a-2add-TNO-April 2002-Ref.office_v-1.0-addendum.doc. TNO Building and Construction Research, P.O. box 49, NL 2600 AA Delft, The Netherlands.

[5] EN 12524:2000. Building materials and products – Hygrothermal properties – tabulated design values. Comité Européen de Normalisation, Brussels, Belgium.

[6] Nielsen, T.R., *Simulation results for reference office*. IEA SHC Task27, Performance of solar facade components. Document r-a-DTU-TRN-Simulation results for reference office 2-2002.doc. Byg DTU, Building 118, DK-2800, Kgs. Lyngby, Denmark.

[7] Jensen, M.J. & Lund, H. (1995) *Design Reference Year, DRY- Et nyt dansk referenceår*, Meddelelse, Nr. 281, Thermal Insulation Laboratory, Technical University of Denmark, ISSN 1395-0266.

[8] Platzer, J.W., The Altset Project Measurement Of Angular Properties For Complex Glazings. In *Proceedings of Eurosun 2000*, 19 – 22 June, Copenhagen, Denmark. Available on CD from Esbensen, Vesterbrogade 124 b, 1620 Copenhagen, Denmark.

[9] Rosenfeld, J.L.J., Platzer, W.J., van Dijk, H. and Maccari A., Modelling the optical and thermal properties of advanced glazing, Overview of recent developments. In *Proceedings of Eurosun 2000*, 19 – 22 June, Copenhagen, Denmark. Available on CD from Esbensen A/S, Vesterbrogade 124 b, 1620 Copenhagen, Denmark.

[10] Data obtained using Glas98.dk, 2001 version. Pilkington Danmark A/S. K glass and Suncool HP are trademarks of Pilkington.

[11] Rosenfeld, J.L.J., *Double Glazing with Integral Venetian Blind*. Sagsrapport BYG·DTU SR 02-24 (2002). [Confidential, restricted circulation. Apply to authors]. Cool-lite is a trademark of St Gobain.

[12] Rosenfeld, J.L.J., *Optical properties of four Sun-flex solar control blinds*. Sagsrapport BYG·DTU SR-02-15 (2002).

[13] Rosenfeld, J.L.J., Optical properties of some solar control blinds. In *Proceedings of Eurosun 2002*, June 23 – 26 2002 Bologna, Italy. Available on CD from ISES Italia, Via Tommaso Grossi 6, 00184 Rome, Italy.

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Appendix

Solar shading devices in Denmark

By

Marianne Hornuff and Helle Rasmussen

This appendix contains a short description of types of solar shading devices that are used in commercial and office buildings in Denmark. At the end of the appendix there are some examples of their usage.

It should be noted that this is not a complete survey of all the manufacturers or solar shading devices used in Denmark.

Types of solar shading devices

Below a list is given of the solar shading devices, which are most commonly used in Denmark. The list is divided into three categories: external, integrated and internal.

External shading devices

- Awnings
- Screen
- Awning/blind (Markisolet in Danish)
- Horizontal lamellae (fixed)
- Vertical lamellae (fixed) (can be up to 840 mm wide)
- Venetian blind
- Overhang/ Sunshades

Integrated shading devices or built-in shading devices

- Horizontal Venetian blind
- Screen
- Film

Internal

- Film
- Blind
- Vertical Venetian Blind (lamelgardiner in Danish)
- Horizontal Venetian blind
- Concertina blind (Plisségardin in Danish)
- Curtain
- Light shelf

In Denmark the internal shading devices are traditionally the most commonly used in commercial and office buildings, however, the new trend is to use external solar shading devices due to the better protection against solar heat gains. Especially, the new sunshades of glass lamellae are popular.

Examples of the usage of solar shading devices in Denmark

Below is a list of relatively new commercial and office buildings in Denmark, where solar shading devices are used. Below the Table the different types of solar shading devices are illustrated. We acknowledge permission from the manufacturers to reproduce those photographs taken from company web sites. The authors took the remaining photographs.

Building (location)	Types of solar shading devices	Manufacturer
External		
Unibank (Copenhagen)	Glass lamellae and internal screens (not on the same windows)	-
Denmark's Radio (Copenhagen)	Vertical lamellae	Dasolas
Nokia (Copenhagen)	Vertical lamellae	Dasolas
Politiken (Erritsø)	Vertical lamellae	Dasolas
Haribo	Sunshade	Dasolas
Statoil (Copenhagen)	Horizontal wooden lamellae (cedar)	Dasolas
Holbergskolen (Copenhagen)	Horizontal wooden lamellae (cedar)	Dasolas
Tiscali (Nordhavn)	Vertical lamellae	-
Kromann Reumert (Nordhavn)	Horizontal lamellae	-
Statoil (Copenhagen)	Glass lamellae	Jyllands Markisefabrik
Computer Associates, Holte	Awning/blind (Markisolet)	Blendex
Tschudi & Eitzen A/S, Gentofte	Awning/blind (Markisolet)	Jyllands Markisefabrik
Novo Nordisk (Kalundborg)	Glass lamellae	-
Neurosearch, Ballerup	Horizontal alu lamellae	Blendex
IMB, Allerød	External Venetian blind	Blendex
DANICA, Lyngby	External Venetian blind	Blendex
KOE, Kolding	Overhang	Dasolas
Integrated		
Roskilde Amtssygehus	Integrated Venetian blind	Hagen
Roskilde Universitets Center	Integrated Venetian blind	Hagen
Internal		
Philips	Screen	-
Nykredit	Screen	-
NNC head office (Copenhagen)	Blind (Screen)	-

External Screen
Blendex

External Screen
Acrimo

Vertical lamellae
Danmarks Radio, Copenhagen
Dasolas

Awning/blind (Markisolet)
Computer Associates, Holte
Blendex

Horizontal aluminium lamellae
Neurosearch, Ballerup
Blendex

Horizontal glass lamellae
(Tuborg Havn)

External Venetian blind
IBM, Allerød
Blendex

External Venetian blind
DANICA, Lyngby
Blendex

Overhang
KOE, Kolding
Dasolas

Sunshade

Acrimo

Integrated Venetian blind

Luxalon

Integrated Venetian blind
Roskilde Amtssygehus, Roskilde
Hagen

Internal blind (screen)
Arcimo

Internal blind (screen)
Luxalon

Internal Venetian blind
Luxalon

Concertina blind (Plisségardin)
Acrimo

Internal vertical lamella curtain
Arcimo

Internal vertical lamella curtain
Luxalon

Internal film
Sun-Flex

Internal film
Sun-Flex