Glazing and Sunshades

Strategies and Building Codes for Cold Climates

Marie-Claude Dubois

This research is funded by the Natural Sciences and Engineering Research Council of Canada (NSERC) and the “Fonds pour la formation des chercheurs et l’aide à la recherche (FCAR)”. 
Keywords

Shading devices; solar-protective glazing; awnings; energy use; heating; cooling; lighting; building codes; cold climates.
Foreword

This report contains the following articles:

I The Impact of the Design and Management of Seasonal Awnings on Energy Use in a Cold Climate

II Awnings and Solar-protective Glazing for Efficient Energy Use in Cold Climates

III The New Model National Energy Code of Canada for Buildings 1997: A Step Forward and One to Go

These articles are part of the thesis “Solar Control for Energy-efficient Buildings in Cold Climates” (Dubois, 1998a).

The first (I) article will be proposed for publication in a scientific journal before the end of 1998. The second article (II) has already been presented at an international conference and published in the conference proceedings (Dubois, 1998c). This article is a short version of the report “Solar-Protective Glazing for Cold Climates: A Parametric Study of Energy Use in Offices” (Dubois, 1998b). However, it contains a small comparison between the impact of awnings and solar-protective glazing on energy use, which is not included in the report. Finally, the last article (III) will be published in a non-scientific journal (The Canadian Architect) in the January 1999 issue under the theme “Green Buildings”. This study has been carried out apart from my main research activities. I decided to include it here because the subject was related to the main topic of my thesis.
Glazing and Sunshades
Contents

Keywords 2
Foreword 3
Contents 5
Acknowledgements 7
I The Impact of the Design and Management of Seasonal Awnings on Energy Use in a Cold Climate 9
II Awnings and Solar-protective Glazing for Efficient Energy Use in Cold Climates 25
References 39
Glazing and Sunshades
Many persons have been involved in one way or another in the work presented in this report. Two of them deserve special thanks: my supervisor, Maria Wall, and my colleague, Helena Bülow-Hüb. I thank Maria Wall for her positive attitude and dedication to our work and for meticulously reviewing these articles. I also thank Helena Bülow-Hüb who made several computer routines that facilitated the exchange of files from one simulation tool to the next. She also provided the scientific background for the calculation of the atmospheric data for Stockholm used in the first study (I) presented in this report.

The first (I) and second (II) articles are a result of a collaborative work within the Solar Shading Group at Lund University’s Department of Building Science. I thank Bertil Fredlund, Head of our Department, for making this project possible. I am also grateful to everyone in the Solar Shading Group, for fruitful discussions and for a good working climate. These studies would not have been possible without the hard work of Kurt Källblad and Hasse Kvist who developed the computer program that allowed simulations of energy use with shading devices. The work of Petter Wallentén and Håkan Håkansson with measurements has also indirectly contributed since it allowed the validation of the computer program developed.

The third (III) article was written after completion of an individual environmental project within the Institute for Environment and Energy Systems at Lund University. Bozze Wiman was the professor who encouraged me to pursue this study. I thank him for his useful comments throughout.

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Solar Glazing and Shades

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Lund, November 1998

Marie-Claude Dubois
I The Impact of the Design and Management of Seasonal Awnings on Energy Use in a Cold Climate
The impact of the design and management of seasonal awnings on energy use in a cold climate

Marie-Claude Dubois
Lund University, Department of Building Science, P.O. Box 118, SE-221 00 Lund, Sweden

Abstract

The impact of seasonal awnings on energy use for cooling and heating a single office located in Stockholm was studied. The awning’s management strategy, length, slope, horizontal overhang and colour were varied parametrically for a room with constant lighting and one with a dimming system for lights. The energy simulation program DEROB-LTH was used in conjunction with SUPERLITE and SUPERLINK for the daylighting/lighting simulations. DEROB-LTH calculates the impact of exterior shades of varying transmittance on both direct and diffuse radiation at each hour. The study showed that the management strategy and the length of the awning were the factors which had the most significant effect on space cooling and heating. The slope, the horizontal overhang and the colour only had a moderate impact on energy use. Overall, the use of daylighting did not lead to the adoption of different design and management solutions except for a single case. The study generally shows that large energy savings can be obtained with seasonal awnings provided that the management strategy and design are carefully controlled.

Keywords: Awnings; Cooling; Daylighting; Lighting; Heating; Cold climates; Simulation.

1. Introduction

Even in a cold country like Sweden, space cooling is required due to the high internal heat gains from equipment, lighting and occupants that prevail in certain types of buildings. There is also a growing tendency to use larger glazing areas in buildings partly since levels of thermal insulation through opaque elements tend to increase [1]. (This may also be a result of international architectural trends). The use of large glazing areas combined with high internal heat gains can result in overheating problems, which need to be corrected via artificial cooling. One way to reduce cooling loads is through the control of solar gains. This limits energy use in buildings, which is associated with important economic and (global) environmental issues.

Solar gains should not be reduced at the expense of the heating demand which is often dominant in cold countries. A surface perpendicular to the sun can receive a substantial amount of energy—up to 1000 W/m² at the surface of the earth [2]. This energy is a major source of “free” heat on a cold day and, also, a valuable source of “free” light year-round. An optimum strategy for cold climates must therefore be flexible i.e. allow a passive utilisation of solar gains during cold months and eliminate these gains during warm months while allowing natural light in the building at all times.

Tel.: +46 46 222 7347; fax: +46 46 222 4719; email: marie-claude.dubois@bl.hhs.se

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Earlier, the need to control solar gains has lead to the development of solar-protective glazing such as reflective and heat-absorbing (tinted) glass. While these glazings can considerably reduce space cooling, they have a detrimental impact on the heating demand since their properties are fixed. More promising avenues are the switchable or smart glazings that change their solar-optical properties as a function of environmental conditions or an applied electric current. However, most of these technologies are still at a research stage or are not yet widely used in buildings.

Conventional shading systems like awnings, venetian blinds, roller shades, etc., perhaps represent a more accessible technological approach to solar radiation control at the moment. These systems are already widely used in buildings and have some advantages (over solar protective glazing) that are worth mentioning:

1. most shading systems are moveable and can thus be used only when solar protection is needed;
2. it has been shown [3, 4, 5] that some systems, such as roller shades, can improve the window U-value under certain conditions;
3. some systems like awnings, overhangs and fins block direct radiation without completely eliminating the view to the outside;
4. most types of shades like venetian blinds, awnings, etc., block direct solar radiation whilst admitting diffuse and ground-reflected radiation which is highly desirable from the point of view of visual comfort;
5. shading systems allow occupant control. It has been shown [6] that this factor has positive impacts on human comfort.

While many studies of the impact of shading devices have been made in the past, most of them have only considered warm climates [7]. Another problem is that studies relating to cold climates have all shown that the use of shades—specifically exterior ones—resulted in higher annual energy use [8, 9, 10]. However, these studies have only considered fixed systems. It is rather obvious that a fixed exterior shade, which has a low shading coefficient, will increase annual energy use in a cold climate due to the loss of beneficial solar gains during the winter. Another problem is that most of the recent work has focused on venetian blinds [11, 12, 13] and that studies which included the impact of shades on daylight utilisation either related to warm climates and fixed systems [14, 15] or used a shading coefficient approach in the calculation method [16].

One study [17] indicated that seasonal (i.e. installed and removed once a year) awnings yield higher annual energy savings in cold climates than any type of solar protective glazing. This conclusion was reached even without optimum management and sizing of the awning. Nor was the impact of the shade on the daylighting utilisation potential considered in the study. These aspects are important to consider if an optimisation of our (material) resources versus energy savings is to be achieved. This will be the subject of the present paper.

This study analyses the impact of seasonal awnings on energy use for cooling and heating an office space located in Stockholm. The impact of the awning’s geometry, colour and management strategy on energy use is assessed for a room both with and without daylighting utilisation through computer simulation of the energy performance using the program DEROBILL. The daylighting/lighting simulations are achieved with SUPERLITE and SUPERLINK, which are part of the ADELINE 2.0 package. The study shows that the management strategy and the length of the awning are determinant factors affecting energy use. The slope, the horizontal overhang and the colour of the awning are less important. The study also suggests that daylighting utilisation does not lead to significantly different design and management solutions for the shades.

2. Some design considerations

Both the awning’s design and the management strategy (i.e. the period when the shade is used) have an impact on energy use. The awning design is mainly determined by the geometry and colour of the awning’s fabric. Erzien [18] observed that for shades like conventional awnings, the determination of the optimum awning geometry with respect to the solar position depended solely on the determination of the position of a single point “M” (Fig. 1). This point can be determined by the awning’s length (L), horizontal overhang (H) and slope (θ) with respect to the building facade. Note that some awnings also contain vertical parts. These types of systems were not included in this study.
Article I

2.1. Length

The awning’s length should be determined with respect to the sun’s lowest altitude during the cooling period. In practice, long awnings can provide complete shading of the window, especially around noon when the intensity of solar radiation is high. However, there is no need to extend the awning below the window sill since the sun is always above the horizon. While long awnings can provide adequate shading on the window, they may also block the view to the outside and reduce significantly the daylighting availability in the room. The impact of the length on energy use should be investigated in order to find the optimum length that will achieve a proper balance between solar shading, daylighting utilisation and the view to the outside.

2.2. Horizontal overhang

The horizontal overhang is the distance parallel to the building facade between the end of the glazing area and the end of the awning (see Fig. 1). A standard practice, in Sweden, is to have horizontal overhangs of about 10-15 cm on each side of the window. Also, in some cases, the design of the window makes it impossible for awnings to be larger than the width of the window, which means that complete shading is only provided around noon (for south orientated windows). Note that for other orientations than south, it is almost impossible to shade a whole window with sideless awnings, unless the horizontal overhang is extremely large. This problem was pointed out by other authors [19, 20]. The impact of the horizontal overhang on energy use needs to be investigated in order to verify whether current standard practice yields optimum energy savings and to find the optimum design which will achieve a proper balance between solar shading and daylighting utilisation. Note that the horizontal overhang has little effect on the view to the outside but can reduce daylighting availability in the room.

2.3. Slope

The slope is the angle between the awning and the building facade (see Fig. 1). With conventional awnings, an equivalent shade can be cast on the window during the same period of time with awnings of different slopes by adjusting the length and horizontal overhang. In general, steeper awnings are more economical as they require smaller dimensions. They may also be more effective for reduction of cooling loads since less diffuse and ground reflected radiation is admitted to the building. However, steep awnings reduce the solar radiation (and hence light) which is reflected from the back of the awning towards the interior of the room [21]. It can thus be speculated that the slope of the awning has some effect on both the cooling demand and the daylighting utilisation potential. The impact of the slope should be investigated in order to find an optimum design which will achieve a proper balance between solar shading from direct, diffuse and ground-reflected radiation and daylighting availability in the room.

2.4. Colour (solar-optical properties)

It is generally acknowledged that white shades have a lower shading coefficient, and are thus better shades, than dark ones [19]. While this is certainly true for opaque materials, results of measurements [22] with fabric i.e. translucent material indicate the contrary: dark fabrics are better shades than white ones. This is easily explained by the fact that the reflectance and transmittance of ordinary fabric material are roughly proportional: as the reflectance increases, so does the transmittance. A dark fabric, which absorbs most of the incident solar radiation, thus normally reflects and transmits less solar radiation than a white fabric.

Since dark shades reflect and transmit less solar radiation, the potential for daylight utilisation is lower with dark than with white shades. This may also have implications for visual comfort since less daylighting is admitted to the room when a dark awning is used. The impact of the colour and solar-optical properties of the shade (transmittance, reflectance) on energy use should be investigated in...
order to find an optimum solution which will achieve a proper balance between solar shading and daylighting utilisation.

2.5. Management

In cold climates, the cooling and heating seasons overlap each other i.e. during some months, both the heating and cooling systems are alternatively used. When the seasonal shade is installed so as to provide shading during all the cooling days of the year, a loss of beneficial solar gains occurs during many heating days in the spring and autumn. On the contrary, when the seasonal shade is only installed outside the heating season, no shading is provided on many cooling days during the spring and autumn. The impact of the management strategy should be studied, even for seasonal systems, in order to identify the optimum schedule which will achieve a proper balance between the cooling and the heating season.

3. Method

3.1. Office room

The impact of the awning geometry and management on energy use for cooling and heating an office room was studied. The room was a standard 2.9 m wide, 4.2 m deep and 2.7 m high (interior dimensions) rectangular space with one window (Fig. 2). The window consisted of a glazing area surrounded by a 0.1 m wide frame. The glazing area measured 1.8 m (width) by 1.3 m (height), covered 30% of the exterior wall area and was located 1.0 m from the floor. A recess of 0.1 m was assumed between the glazing and the frame.

The room was assumed to be surrounded by other rooms at the same temperature. Thus, the floor, ceiling and all the walls except the one facing the “exterior” were built as adiabatic surfaces (i.e. having no heat transfer) in the computer model (see Fig. 2). The exterior wall, which had a U-value of 0.25 W/m²K, was a standard construction with respect to normal Swedish building practice. The window was a double pane clear glass assembly with argon fill with a U-value of 2.65 W/m²K (centre-of-glass), a shading coefficient (SC) of 0.87 and a solar heat gain coefficient (SCHG) of 0.74.

Fig. 2. Office room.

The office room had constant infiltration (0.1 ach) and ventilation (10 L/s) rates and internal heat gains from one occupant (90 W), a computer and monitor (120 W) and energy efficient lighting (120 W). The internal heat gains (330 W) were applied during normal working hours (8-17), except at lunch time (12-13) when the occupant was assumed to be absent. The internal heat gains from lights were adjusted to lower levels for the cases with daylight utilisation. The lighting system had an efficacy of 50.75 lumens/W and thus provided 500 lux on the work surface at maximum power. Note that no internal heat loads were assumed during weekends.

The temperature set points were 20°C for heating during working hours (8-17) and 18°C outside working hours. During the cooling season, the temperature set points were 24°C during working hours (8-17) and 28°C the rest of the time.

The room was orientated towards the south for all cases and located in Stockholm, which is on the east coast of Sweden at latitude 59.35°N and longitude 18.07°E. The climatic year used for the simulations was 1988, which is considered a normal year. In 1988, the average temperature was 6.5°C and the total global solar radiation on a horizontal surface was 928.5 kWh/m² in the Swedish capital [23]. A free horizon with no obstruction (apart from the awnings) was assumed and the ground reflectance was 30%.

3.2. Awnings

Initially, an awning with an arbitrary slope (θ) of 30° and length (L) of 1.3 m was built in the computer model. The awning’s horizontal overhang was adjusted so that the glazing area would be completely shaded within a solid angle θ of 120° with respect to the glazing surface (Fig. 3). The glazing transmittance
drops dramatically beyond this angle, making it unnecessary to provide additional shading to the window. This initial awning provided complete shade of the glazing area during the cooling season within the 120° (horizontal) solid angle.

The management strategy, the awning’s length, horizontal overhang and slope as well as the colour (solar-optical properties) were then varied parametrically as illustrated in Fig. 4. Each set of simulations was performed for both a white and a dark blue awning. For the dark blue awning, the simulations were performed for both an office room with constant lighting and one with a continuous dimming system for lights.

3.2.1. Management

Keeping the base case geometry and colour constant, three management strategies were studied:

<table>
<thead>
<tr>
<th></th>
<th>April-November</th>
<th>May-September</th>
<th>June-September</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>long cooling</td>
<td>typical cooling</td>
<td>short cooling</td>
</tr>
<tr>
<td></td>
<td>season</td>
<td>season</td>
<td>season</td>
</tr>
</tbody>
</table>

The first strategy (April-Nov.) consisted of installing the awning on the first cooling day (April 4th) and removing it on the last cooling day (Nov. 11th) of the year. This strategy provided shade during the entire cooling season but also resulted in the loss of solar gains on many heating days in the spring and autumn. The second strategy (May-Sept.) consisted of installing the awning only during the typical cooling period i.e. from May 1st to September 30th. The third strategy (June-Sept.) consisted of installing the awning from the last (June 18th) to the first (Sept. 18th) heating day of the year. This strategy implies that many days which required cooling were not provided with shading. On the other hand, no shading was provided on any heating day.

3.2.2. Geometry: length, horizontal overhang and slope

Keeping all the base case parameters constant, the awning’s length was varied from 0 m (no awning) to 1.5 m. At 1.5 m, the awning shaded the window from all direct solar radiation coming from above the horizon within a 120° (horizontal) solid angle (Fig. 5a). The horizontal overhang was next varied from 0 to 1.13 m (base case). A horizontal overhang of 0 m means that the awning fits the glazing exactly (Fig. 5b). For this case, complete shading is only provided when the sun is directly in front of the window (around noon). The awning’s slope was next varied by 15° increments from 0° to 90°. The awning’s horizontal overhang and length were adjusted for each specific slope so that complete shading from direct radiation
Glazing and Sunshades

would be provided during the cooling season (May-Sept.), within the 120° solid angle. At 0°, the awning is similar to a screen and fits the window exactly blocking all incident direct and diffuse radiation. At 90°, the awning is similar to an overhang (Fig. 5c). Note that as the slope increases, the awning’s dimensions must be larger to provide the same shading from direct radiation during the same period and solid angle. Thus, awnings with steep slopes are more economical than awnings with shallow slopes. They also block more diffuse radiation and a bigger portion of the view to the outside.

![Diagram](image.png)

Length  Horizontal overhang  Slope

Fig. 5. Variation of the a) length, b) horizontal overhang and c) slope.

3.2.3. Colour

Keeping the base case geometry (length, horizontal overhang and slope) and management strategy constant, the awning’s colour was varied from dark blue to white. This implied the variation of the solar-optical properties of the fabric material, namely, the transmittance (T), reflectance (R) and absorptance (A). The data for most fabrics was chosen from a manufacturer’s data [24] and laboratory measurements [25] at normal incidence (Table 1). Two “theoretical” fabrics with properties that had no relation to those of ordinary fabric material were added to the study. The theoretical fabrics had a low transmittance and a high reflectance and vice versa. This made it possible to distinguish, during analysis of the results, between the impact of the transmittance and reflectance on energy use.

<table>
<thead>
<tr>
<th>Colour</th>
<th>T (%)</th>
<th>R (%)</th>
<th>A (%)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark blue</td>
<td>1</td>
<td>14</td>
<td>85</td>
<td>3</td>
</tr>
<tr>
<td>Dark green</td>
<td>3</td>
<td>7</td>
<td>90</td>
<td>1</td>
</tr>
<tr>
<td>Theoretical 1</td>
<td>4</td>
<td>65</td>
<td>31</td>
<td>3</td>
</tr>
<tr>
<td>Theoretical 2</td>
<td>21</td>
<td>14</td>
<td>65</td>
<td>3</td>
</tr>
<tr>
<td>Light grey</td>
<td>7</td>
<td>42</td>
<td>51</td>
<td>1</td>
</tr>
<tr>
<td>Medium grey</td>
<td>8</td>
<td>33</td>
<td>59</td>
<td>1</td>
</tr>
<tr>
<td>Dark red</td>
<td>13</td>
<td>42</td>
<td>45</td>
<td>1</td>
</tr>
<tr>
<td>Bright yellow</td>
<td>19</td>
<td>61</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Theoretical 2</td>
<td>21</td>
<td>14</td>
<td>65</td>
<td>3</td>
</tr>
<tr>
<td>White</td>
<td>23</td>
<td>67</td>
<td>10</td>
<td>2</td>
</tr>
</tbody>
</table>

1 = manufacturer’s data; 2 = laboratory measurements; 3 = theoretical fabric (not real); * same on front and back.

3.3. Simulation tools

3.3.1. DEROB-LTH

The simulation of the energy demand for space heating and cooling was performed with the program DEROB-LTH. DEROB, which is an acronym for "Dynamic Energy Response of Buildings", was originally developed at the University of Texas at Austin [26]. The program was later improved and ported to a Microsoft Windows (95, NT) environment at the Department of Building Science, Lund University, Sweden [27]. One special feature of this program is that it considers solar-angle dependent optical properties of single as well as multiple glazing assemblies in the dynamic calculations. Those properties are either calculated by the program based on the Fresnel formalism or directly entered by the user as angle-dependent triplets (transmittance, reflectance front and back) in a glass library. In this study, the latter input technique was used and angular-dependent properties were calculated with the program WINDOW 4.1 [28] based on a manufacturer’s measurements for normal incidence [29].

Another special feature of DEROB-LTH is that it calculates the impact of exterior shades of various optical properties (transmittance, absorptance) on both direct and diffuse solar radiation incident on the windows. (Thus opaque as well as translucent shades can be modelled). One assumption of the shading algorithm is that all incident radiation on the shade is absorbed, transmitted or reflected as pure diffuse radiation. Details of the shading and window
algorithms used in DEROB-LTH can be found in [30].

The window and shading algorithms have been validated experimentally for sunny days [31]. It was found that the program predicts the hourly transmitted solar radiation through double pane clear glass very accurately. The agreement between the hourly transmitted solar radiation values was satisfactory for the window equipped with a dark and a white awning. Discrepancies between calculated and measured values were mainly attributed to geometrical differences between the computer model and the real building.

One main limit of DEROB-LTH is that it calculates the solar position for only one day in the middle of each month. The solar radiation intensity is, however, treated on an hourly basis. Another major limit of the program is that it can only model fixed shading systems. In this study, results for seasonal awnings were obtained by mixing the results for one whole year simulation with the bare window case and one whole year simulation with an awning in place all year. This operation was done on a calculation spreadsheet and the impact of the awning on the indoor temperature for the days following the installation and removal of the awning was neglected. Note that the program is currently in development to include the calculation of the solar position for each hour of the year and the possibility to model dynamic shading systems.

3.3.2. SUPERLITE and SUPERLINK

The daylighting and lighting calculations were performed with the programs SUPERLITE and SUPERLINK included in the ADELINE-2.0 package [32]. SUPERLITE predicts hourly illuminance values on a virtual working surface (0.8 m from the floor, in this case) for a whole year based on the three CIE standard skies. SUPERLINK uses the results of the daylighting calculations performed by SUPERLITE and SSP (Sunshine Probability) factors derived from climatic and atmospheric data for the determination of the hourly daylighting utilisation potential. In this study, a continuous dimming system with four sensors located around the centre of the room was assumed. The maximum electric lighting load for this system was 120 W. The hourly electrical load (thus heat gain) was calculated from the SUPERLINK output to represent a ratio of the luminous flux versus electrical power typical of a real lighting system (Fig. 6). This hourly load from lights was subsequently added to the internal heat gains from the occupant and the computer and monitor set. This new internal load file was entered in DEROB-LTH for the calculation of the hourly space heating and cooling demand. For cases where no daylighting utilisation was assumed, an internal load file with a constant lighting load (120 W) was used as described in section (3.1).

![Graph](image)

**Fig. 6:** Luminous flux (%) as a function of the electrical power (%).

SUPERLITE has been validated experimentally and it was shown that it predicted internal illuminance levels satisfactorily in simple rooms [33]. It should be noted, however, that one study has shown that the program generally overpredicts illuminance values in complex spaces [34].

One major limitation of SUPERLITE is that external obstructions can only be opaque. Thus, the white awning, which has a transmittance of 23% could not be modelled accurately with this program.

4. Results and discussion

4.1. Impact of the management strategy

The first experiment consisted of installing the base case awning according to three schedules: a long (April-Nov.), a typical (May-Sept.), and a short (June-Sept.) cooling season. The results indicated that the management strategy was a significant factor affecting energy use for heating and cooling the space. For seasonal awnings, the best strategy consisted of installing the awning during the typical cooling period i.e. from May 1st to September 30th, regardless of the awning’s colour and lighting strategy. The annual energy use for the white awning
and each management strategy studied is illustrated in Fig. 7. The energy use for a room without solar protection (no awning) and the case with a fixed awning (all year) is also presented for comparison. In these figures, heating and cooling loads are added in a 1:1 ratio i.e., it is assumed that the same amount of energy is used to produce 1 kWh of heat or 1 kWh of cooling.

![Graph showing annual energy use (kWh/m²-year) as a function of the management strategy for a white awning with constant lighting.](image1)

Fig. 7: Annual energy use (kWh/m²-year) as a function of the management strategy for a white awning with constant lighting. The awning geometry and colour are identical for each management strategy presented.

The results show that the lowest annual energy use was obtained with the typical cooling season strategy (May–Sept.). This strategy resulted in a reduction in cooling loads of 20.4 kWh/m²·year (75%) and a small increase in annual heating loads of 4.4 kWh/m²·year (4%) compared with a case with no solar protection (no awning). The results also show that the short cooling season (June–Sept.) resulted in less annual energy use than the long cooling season (April–Nov.). The short cooling season yielded reductions in cooling of only 13.8 kWh/m²·year (51%) but trends for heating loads (increase of 5.1 kWh/m²·year, 5%) were similar to the typical cooling season. The long cooling season strategy yielded a reduction in annual energy use due to large reductions in cooling loads (21.5 kWh/m²·year, 79%). However, this solution caused a significant increase in heating loads (17.7 kWh/m²·year, 17%) and was the worst solution amongst the 3 management strategies studied. Finally, the results show that although a fixed awning (all year) reduced cooling loads significantly (21.5 kWh/m²·year, 79%), it yielded the largest increase in annual energy use due to much larger heating loads (31.0 kWh/m²·year, 30%) than for a case where no solar protection was used.

4.2. Impact of the length

One series of simulations consisted of varying the length of the awning from 0 to 1.5 m, keeping the base case slope (30°), horizontal overhang (1.13 m) and management strategy (May–Sept.) constant. At 1.5 m, the awning is drawn down to the level of the window sill and shades all direct radiation coming from above the horizon (within a 120° solid angle). At 0 m, there is no awning at all. Note that in reality, an awning cannot be fully drawn up within the wall since there is a holder for the roll of fabric which protrudes from the wall by about 0.1–0.15 m.

The results indicated that the length of the awning had a significant impact on cooling loads but that beyond a certain length (in this case, 0.975 m), negligible additional energy savings were obtained. The incremental annual energy use for cooling and heating the space is presented in Fig. 8. In this figure it is assumed that the same amount of energy is used to produce 1 kWh of heat or 1 kWh of cooling.

![Graph showing incremental annual energy use (kWh/m²-year) as a function of the awning’s length.](image2)

Fig. 8. Incremental annual energy use (kWh/m²-year) as a function of the awning’s length. The slope is 30° and the horizontal overhang is 1.13 m. The awning is installed during the typical cooling season (May–Sept.). The electricity savings for lights are not included.

The results show that increasing the awning’s length from 0 to 0.975 m reduced cooling loads by 17.1 kWh/m²·year (73%) for the white awning, by 19.1 kWh/m²·year (81%) for the blue awning, and by 13.5 kWh/m²·year (68%), for the blue awning with daylight utilisation. Beyond 0.975 m, the impact of the length on both cooling and heating loads was negligible. The white awning yielded higher cooling loads than the blue awning and the lowest cooling load was obtained with the blue awning with daylight utilisation. The incremental heating loads as a function of the awning’s length are also shown in Fig. 8. This
shows that the length had a smaller effect on the heating demand than on the cooling demand. This is mainly because both heating and cooling loads presented in this figure are for the whole year. Thus, the impact of the length on heating loads only includes a few days between May 1st and September 30th when heating is required and the awning is in place. Despite this fact, note that increasing the awning’s length from 0 to 1.5 m caused an increase in heating by around 10 kWh/m²/year (7%) for the daylight office and by around 5-8 kWh/m²/year (4-5%) for the blue and white awnings with constant lighting. The heating load was the highest with daylighting utilisation, especially for long awnings. However, the curves presented in Fig. 8 do not include electricity savings for lights.

The results show that the awning’s length is an important factor affecting the cooling (and heating) loads. This is mainly because the length determines which portion of the window is shaded during most of the hours when the solar radiation intensity is high (around noon). The results indicate, however, that the awning’s length need not extend beyond a certain limit (around 0.9 m in this case). Note that at 0.9 m, complete shading of the window is provided for solar altitudes above ~50°. This condition is not around noon for all the months when cooling is required except September.

4.3. Impact of the horizontal overhang

One experiment consisted of varying the horizontal overhang from 0 to 1.13 m keeping the base case slope (30°), length (1.3 m) and management strategy (May-Sept.) constant. The results showed that the effect of the horizontal overhang on energy use was generally moderate. The incremental annual energy use for cooling and heating is presented in Fig. 9. In this figure it is assumed that the same amount of energy is used to produce 1 kWh of heat or 1 kWh of cooling.

Fig. 9 shows that the horizontal overhang reduced cooling by at most 1.5 kWh/m²/year (21%) for the white awning, by at most 1.0 kWh/m²/year (21%) for the blue awning and by at most 0.5 kWh/m²/year (22%) for the blue awning with daylight utilisation. Most of the impact of the horizontal overhang on energy use was between 0 and 0.15 m. Beyond 0.15 m, the horizontal overhang had virtually no effect on the cooling (and heating) demand. The impact of the horizontal overhang on cooling loads was about the same regardless of the awning’s colour and lighting system. The white awning resulted in the highest cooling demand while the blue awning with daylighting utilisation yielded the lowest annual cooling load. Note that the impact of the horizontal overhang on the annual cooling demand was of the same magnitude (1.4-2.2 kWh/m²/year) in absolute value as the impact of the horizontal overhang on the annual cooling demand in spite of the fact that the awning covered the window only on a few heating days between May 1st and September 30th. The heating demand was higher with daylighting utilisation but the values presented in Fig. 9 do not include electricity savings for lights.

Fig. 9. Incremental annual energy use (kWh/m²/year) as a function of the horizontal overhang. The slope is 30° and the length is 1.3 m. The awning is installed during the typical cooling season (May-Sept.). The electricity savings for lights are not included.

4.4. Impact of the slope

One series of simulations consisted of varying the slope from 0° (like a screen) to 90° (like an overhang). The length and width of the awning were adjusted for each slope so that the shading from direct radiation would be equivalent for each case. The results generally showed that the cooling load increased and the heating load decreased as the slope increased. However, the impact of the slope was overall moderate. Results for this series of simulations are presented in Fig. 10. As in other figures, this figure assumes that the same amount of energy is used to produce 1 kWh of heat or 1 kWh of cooling.

The results indicate that the slope increased the cooling load by at most 3.9 kWh/m²/year (7%) for the white awning, by at most 2.5 kWh/m²/year (88%) for the blue awning and by at most 1.3 kWh/m²/year (90%) for the blue awning with daylight utilisation. The impact of the slope on the heating demand was approximately of the same magnitude in absolute value i.e. at most 3.6 kWh/m²/year but relatively small
Glazing and Sunshades

(at most 3%) compared with the total annual heating demand.

![Incremental annual energy use (kWh/m²/year) as a function of the slope. The awning's width and length are adjusted so that the shadow cast on the glazing area is equivalent for each case. The awning is installed during the typical cooling season (May-Sept.). Electrical energy savings for lights are not included.](image)

The results show that the screen (0°) yielded the lowest annual cooling load for both the blue and the white awning with constant lighting. This is mainly because steeper slopes result in less diffuse and ground reflected radiation reaching the glazing surface. There is also less solar radiation reflected from the back of the awning to the interior of the room with steeper awnings. However, for the awning with daylight utilisation, the screen (0°) yielded a higher cooling load than all other slopes except for the 90° awning. The screen blocked all incident solar radiation and light; lights could thus never be dimmed and the resulting cooling demand was similar to that for the blue awning with constant lighting.

4.5. Impact of the colour

The colour was next varied from dark blue (T = 1%) to white (T = 23%) keeping the base case geometry and management strategy constant. No simulation with daylighting utilisation was performed for this parameter since the daylighting simulation program used can only model opaque exterior obstructions.

The results for this series of simulations generally showed that the colour had a relatively moderate effect both on the cooling and heating loads. Most importantly, the results showed that the energy use was primarily dependent on the transmittance of the fabric material and negligibly dependent on the reflectance. The incremental energy use for cooling and heating is plotted as a function of the transmittance in Fig. 11. As for other figures presented in this article, it is assumed that the same amount of energy is used to produce 1 kWh of heat or 1 kWh of cooling.

![Incremental annual energy use (kWh/m²/year) as a function of the transmittance. The awning’s geometry is as for the base case and the awning is installed during the typical cooling season (May-Sept.).](image)

$$T_r = T + 0.05 R \quad \%$$

where

- $T$ = Transmittance of the awning’s fabric
- $R$ = Reflectance of the awning’s fabric (on the back)

4.6. Relative impact of each parameter

This study consisted of varying several parameters related to the management strategy, the geometry (length, horizontal overhang and slope) and the colour (or solar-optical properties) of a conventional awning. The results of the study generally suggest that the management strategy and the length of the awning are the most important parameters having a significant impact on energy use. The awning’s slope, colour and horizontal overhang affected energy use moderately compared with the management strategy and length. Fig. 12 illustrates the annual energy savings (for cooling) and corresponding additional annual energy use (for heating) achieved by varying each parameter for the blue awning with and without daylighting.
utilisation. For the management strategy, the difference shown in Fig. 12 is between the best and the worst strategy amongst the three strategies tested (see Fig. 4). For the length, the difference shown in Fig. 12 is between a fully drawn up awning (L = 1.5 m) and a fully extended awning (L = 1.5 m). For the other parameters, the differences shown in Fig. 12 are between the best and the worst design solutions tested (see Fig. 4). These figures do not include electricity savings for lights and they assume that the same amount of energy is used to produce 1 kWh of heat or 1 kWh of cooling.

4.7. Impact of daylighting utilisation

In this study, the impact of the design and management of awnings on space cooling (and heating) was analysed for a blue and a white awning with a constant lighting system and for a blue awning with a continuous dimming system for lights. The annual energy use for cooling and heating the space was presented without the inclusion of the electricity savings for lights. This approach was preferred because different sources of energy may be used for heating, lighting and cooling a real building (e.g. gas for heating, district cooling and electrical lighting). Thus, aggregating the energy savings for different end-uses may lead to erroneous conclusions. The annual electricity savings for lights achieved due to daylighting utilisation are presented in Table 2 instead. This table shows that daylighting utilisation yielded almost constant electricity savings of around 11 kWh/m²/year for all cases. The only exception was the 0° slope (similar to an opaque screen) awning where no daylighting utilisation was possible during the whole cooling season.

Table 2
Annual electricity savings (kWh/m²/year) for lights with a continuous dimming system and different shading strategies.

<table>
<thead>
<tr>
<th>Management</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
</tr>
</thead>
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<tr>
<td>Fixed awning</td>
<td>11.6</td>
<td>11.6</td>
<td>11.1</td>
<td>11.1</td>
<td>11.4</td>
</tr>
<tr>
<td>Non-adjustable</td>
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<td>11.6</td>
<td>11.5</td>
<td>11.5</td>
<td>11.4</td>
</tr>
<tr>
<td>Adjustable</td>
<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
</tr>
</tbody>
</table>

Length (m) | 0   | 0.15 | 0.65 | 0.95 | 1.3   | 1.5   |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<tr>
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<td>11.6</td>
<td>11.5</td>
<td>11.5</td>
<td>11.4</td>
<td>11.4</td>
</tr>
<tr>
<td>0.15</td>
<td>11.6</td>
<td>11.5</td>
<td>11.5</td>
<td>11.5</td>
<td>11.4</td>
<td>11.4</td>
</tr>
<tr>
<td>0.65</td>
<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
</tr>
<tr>
<td>0.95</td>
<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
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<td>11.4</td>
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<tr>
<td>1.5</td>
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<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
</tr>
</tbody>
</table>

Horizontal overhang (m) | 0   | 0.15 | 0.45 | 0.60 | 0.75  | 1.00  |
<table>
<thead>
<tr>
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<td>11.4</td>
<td>11.4</td>
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<td>11.4</td>
</tr>
<tr>
<td>0.15</td>
<td>11.4</td>
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<td>11.4</td>
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<tr>
<td>0.45</td>
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<td>0.60</td>
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<td>11.4</td>
<td>11.4</td>
</tr>
<tr>
<td>1.00</td>
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<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
</tr>
</tbody>
</table>

Slope (%) | 0   | 15  | 45  | 60  | 75   | 90   |
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
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<td>11.5</td>
<td>11.4</td>
<td>11.2</td>
<td>11.2</td>
<td>11.1</td>
<td>11.2</td>
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<td>11.4</td>
<td>11.2</td>
<td>11.2</td>
<td>11.1</td>
<td>11.2</td>
</tr>
<tr>
<td>45</td>
<td>11.5</td>
<td>11.4</td>
<td>11.2</td>
<td>11.2</td>
<td>11.1</td>
<td>11.2</td>
</tr>
<tr>
<td>60</td>
<td>11.5</td>
<td>11.4</td>
<td>11.2</td>
<td>11.2</td>
<td>11.1</td>
<td>11.2</td>
</tr>
<tr>
<td>75</td>
<td>11.5</td>
<td>11.4</td>
<td>11.2</td>
<td>11.2</td>
<td>11.1</td>
<td>11.2</td>
</tr>
<tr>
<td>90</td>
<td>11.5</td>
<td>11.4</td>
<td>11.2</td>
<td>11.2</td>
<td>11.1</td>
<td>11.2</td>
</tr>
</tbody>
</table>

The results presented in Table 2 are somewhat surprising. It seems that lights were dimmed in approximately the same way regardless of the awning's geometry. One possible explanation for this is that there was sufficient (diffuse) daylighting in the space most of the time during the summer. Thus, the electrical power (thus the heat output) was almost always about 33% of the maximum power (120 W).
Glazing and Sunshades

(see Fig. 6). Another explanation for the results obtained is that the position of the sensors (in the centre of the room) might not have allowed the detection of light patches close to the window (due to the high summer sun). Thus, the effect of the direct sun on the artificial lighting levels might have been underestimated for many cases. Finally, it should be mentioned that while the awning was only installed during the cooling season, the dimming system functioned year-round. The savings shown in Table 2 are for the whole year. This factor certainly contributes to even out the results. However, the results should be interpreted with caution especially since it has been shown [34] that SUPERLITE generally overpredicts illumination levels in complex spaces. The results of the lighting calculation should thus be validated against other model predictions or laboratory measurements.

In general, however, Table 2 explains the results discussed in the previous sections: daylight utilisation did not yield very different design solutions compared with the fixed lighting cases. For example, the cooling demand varied in a similar way as a function of the length and the horizontal overhang with or without daylighting utilisation (see Fig. 8, 9). This is also due to the fact that the lighting system used was rather energy-efficient (10 W/m²) with a relatively high efficacy (50.75 lumen/W) and thus produced a relatively low heat gain in the space even at maximum power. The effect of the dimming system on the cooling load was thus overall moderate.

5. Conclusions

This study consisted of varying the management strategy, the geometry and the colour of a conventional awning and analysing the impact of each change on the energy use for cooling and heating an office room with and without daylighting utilisation. The results of the study primarily show that the management strategy is an important parameter to control for achieving an optimum performance of a shading system. Since large differences were obtained with seasonal awnings, it can be speculated that the performance of dynamic systems is much higher than that of seasonal systems. This suggests that research and development efforts should primarily focus on developing and improving dynamic shading systems so that an accurate and rapid response to environmental conditions is made possible. Technical failures associated with these systems should be solved. Meanwhile, the results of this study show that some significant energy savings can be achieved with simple seasonal shades which represent a lesser technical challenge.

The results also suggest that the length is a significant factor in affecting cooling loads mainly because it determines which portion of the window is shaded at hours when the solar radiation intensity is highest (i.e. around noon). The study showed, however, that beyond a certain length, little additional savings in cooling were obtained. This is mainly because the high cooling period (around noon and mainly during June, July and August) corresponds to the period when the sun’s altitude is highest. Shorter awnings provide appropriate shading during this period. This result has some positive implications: since the awning only covers the upper portion of the window, a large portion at the bottom remains free and allows a view to the outside for the (seated) occupant.

The study generally indicated that the horizontal overhang, the slope and the colour of the awning only had a moderate effect on the cooling (and heating) demand. Most of the effect of the horizontal overhang was between 0 (glazing width) and 0.15 m. Thus, while awnings should be wider than the glazing width, there is no need for very large awnings. The current practice, which consists of having a horizontal overhang of 0.10-0.15 m on each side of the window, appears to be an energy-efficient and economical solution.

Increasing the slope of the awning contributed to increases in the cooling demand for both the daylit and non-daylit office room. Only the 0° slope case (similar to a screen) was an exception to this general observation mainly because there was no potential for daylighting utilisation in that case. Since shallow slopes require larger dimensions than steeper awnings to cast the same shade from the (direct) sun, it is recommended that steeper slopes should be employed because they are more economical and more energy-efficient. Steeper awnings might also be less sensitive to wind effects.

Varying the awning’s colour (and thus solar-optical properties) indicated that the energy use varied roughly as a function of the fabric transmittance. The reflectance (on the back of the awning) only had a secondary effect on the energy use. Thus, dark awnings yielded a lower cooling demand than pale ones mainly because dark fabrics have a lower transmittance than pale fabrics.

Finally, one important finding was that the use of a dimming system for lights did not suggest very
different design solutions and management strategies. An analysis of the electrical savings for lights for each awning studied showed that the savings were almost equal (i.e. 11 kWh/m²/year) for all cases. While this may be due to a few factors inherent to the lighting system assumed (position of sensors, high efficiency, etc.), the results should be interpreted with caution. A study [34] showed that the simulation program used can overpredict the illuminance levels in the case of complex spaces. The results obtained with the daylighting simulations should thus be validated experimentally or with the help of other daylighting models.

The results of this study were obtained solely via energy and daylighting/lighting simulations. As in any simulation, a series of assumptions are involved and results should be interpreted bearing the assumptions involved in mind. Validation with measurements or inter-model comparisons are suggested.

Also, it should be noted that the lighting strategy assumed in this study was based on illuminance levels at the work surface. Recent research [35] suggests that the visual comfort is dependent both on the brightness of the walls (especially behind the computer screen) and the visual interest (variation of light and shade) in the room. Thus, the initial conditions assumed in this study for providing appropriate artificial lighting levels may not yield an optimal visual comfort in a real environment.

Finally, it should be mentioned that the study was only made for one orientation (south) and one climate (Stockholm). Research is needed to establish guidelines applicable to many more climates and orientations. Studies of visual and thermal comfort as a function of the shading system and management strategy should also complement this study.

Acknowledgements

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References


Glazing and Sunshades


II Awnings and Solar-protective Glazing for Efficient Energy Use in Cold Climates
Glazing and Sunshades
AWNINGS AND SOLAR-PROTECTIVE GLAZING
FOR EFFICIENT ENERGY USE IN COLD CLIMATES

Marie-Claude Dubois, M. Arch.
Lund University, Lund Institute of Technology, Dept. of Building Science
PO Box 118, S-221 00 Lund, Sweden. Fax: +46 46 222 47 19. E-mail: marie-claude.dubois@kbl.lth.se

ABSTRACT
Annual energy use for heating and cooling of a single-occupant office room located in Lund (Sweden) was analysed for eight solar-protective glazing options and one shading system. Various glazing-to-wall area ratios (GWAR) and orientations were studied. The energy performance was assessed through computer simulations with the program DEROB-LTH recently supplemented with improved algorithms for windows and exterior shading systems. The study showed that the most energy-efficient glazing option was orientation-dependent: south and north orientations required higher solar transmittance or GWAR than east and west, assuming similar coefficients of performance (COP) for heating and cooling systems and equivalent thermal losses among all cases. The study also demonstrated that a removable awning coupled with clear glazing performed better in terms of annual energy use than all solar-protective glazing options tested. However, it was also demonstrated that the fixed awning resulted in higher annual energy use compared with solar-protective glazing for all orientations. This study generally shows that glazing and shading strategies should be flexible in cold climates and allow the use of solar gains during the heating season while limiting these gains during the cooling season. Removable or dynamic shading systems offer larger potential energy savings than fixed systems or solar-protective glazing.

1 INTRODUCTION
In spite of developments in the area of switchable glazing technologies, there is still an interest to study shading devices and their impact on building energy use because shading systems represent a great retrofit opportunity at relatively low investment costs. In addition, most shading devices have the advantage over low solar transmittance or electrochromic glazing to leave the view to the exterior almost unchanged even when direct solar radiation is completely blocked. Shading can also provide additional insulation to the windowpanes. Most importantly, shading systems are already commonly used in buildings, even in cold climates, because they allow the control of solar gains, daylighting levels and privacy. Thus, the impact of shading systems on energy use in buildings must be assessed to develop energy-efficient strategies, to identify bad shading practices yielding a waste of energy and to compare the energy savings accomplished with shading systems with the ones obtained with advanced glazing technologies available today.

Studies of the impact of shading on annual energy use have shown that shading reduces cooling loads substantially, thus reducing annual energy use in a building. However, most of these studies have been aimed at warm climates [3]. Little work has been done to assess the impact of shading devices on annual energy use in heating-dominated climates. One study [5] showed that exterior shading devices and absorbing glass are net energy losers in heating-dominated climates and that interior devices perform better than exterior fixed devices because they shade the entire window while providing additional insulation to the windowpanes. Another study [14] demonstrated that window films provide no savings at all in heating-dominated climates. A third study [13] showed that an energy-efficient shading strategy is climate dependent: in cooling-dominated climates, lower annual energy use is obtained with lower shading coefficients.
Glazing and Sunshades

(better shade) while heating-dominated climates require higher shading coefficients. However, these studies were achieved through computer simulations using a shading coefficient based approach. This approach is no longer valid with dynamic energy calculation models. For energy analyses including hourly building performance calculations, angular dependent values of the solar heat gain coefficient should be used instead [8, 10].

In this research, the impact of one awning and of solar-protective (reflective, absorbing) and low-emissivity coated glazing on heating and cooling loads is analysed for one office room located in Lund (southern Sweden). Eight glazing options and three shading strategies are studied. The glazing-to-wall area ratio (GWAR) is varied 0-70% and the office room is alternatively orientated N, NE, E, SE, S, SW, W and NW.

2 METHOD

2.1 Computer simulations

2.1.1 Energy performance

The building energy performance was assessed with the dynamic program DEROB-LTH developed at the University of Texas [2]. This program has been constantly improved at Lund University’s Department of Building Science, Lund, Sweden. It runs on a PC in the MS Windows environment [6]. The program was recently provided with an improved window module that treats the window in the same way, generally, as the program WINDOW 4.1 [1]. DEROB-LTH was also recently supplemented with an algorithm that calculates the effect of exterior shades like awnings on direct and diffuse solar radiation at each hour interval. This new algorithm assumes that all direct and diffuse radiation reaching the exterior shade is either reflected or transmitted as pure diffuse radiation [7].

2.1.2 Windows thermal-optical properties

The program WINDOW 4.1 was used to calculate the windows' thermal and optical properties (at 10° increments). The solar angle dependent optical properties were calculated from a manufacturer’s measurements for normal incidence. WINDOW 4.1 gives accurate angular properties for homogeneous glasses (uncoated) by applying Fresnel equations and Snell’s law. This procedure is valid for most clear, low-iron and absorbing glasses but may induce inaccuracies for coated glazing as in the case of reflective and low-emissivity coated glass tested in this study [4]. A recent study [11], however, indicates that these inaccuracies are within a few percent.

2.2 Constant parameters

2.2.1 Office module

The office module was a 4.2 m deep, 2.9 m wide and 2.7 m high (floor to ceiling) single-occupant room (Fig. 1). The room was constructed according to ordinary building practices for commercial offices in Sweden. Heat transfer through the room’s walls, floor and ceiling were, however, selectively constrained in order to isolate the energy effects due to the window and/or shade system solar properties. The room’s floor, ceiling and all walls except the wall facing the “exterior” were thus wrapped in a thick insulation layer to make all walls adiabatic (i.e. having no heat transfer). The insulation thickness in the wall facing the “exterior” (surrounding the window) was adjusted to yield equivalent thermal losses through the window-wall system for all cases studied. This procedure made it possible to compare windows with different thermal properties (U-value).

![Diagram of Office Module](image)

**Figure 1:** Office module.

2.2.2 Internal loads, heating and cooling thermostat settings, ventilation and infiltration rates

The internal loads in the office room consisted of the heat generated by the occupant (90 W), a computer and monitor (120 W) and energy-efficient lighting (120 W). No daylighting utilisation (dimming system) was assumed. The thermostat settings for heating were 20°C during working hours (8-17), with a night setback temperature of 16°C. For cooling, the thermostat settings were 24°C (8-17), with a night setback of 28°C. The ventilation rate was 10 l/s and the infiltration was 0.1 ach. No heat recovery of exhaust air was assumed.

2.2.3 Climate

The office room was located in Lund in the south of Sweden (latitude 55.72 N). The climate file used was for 1988, which is considered a normal year [13]. During that year, the average annual temperature was 8.2°C; the average minimum temperature was 0.4°C and the average maximum temperature was 16.7 °C. The average global
solar radiation was 108 Wm\(^{-2}\) on a horizontal surface and 85 Wm\(^{-2}\) on a vertical surface (south) [15].

2.3 Variables

2.3.1 Glazing types

The glazing types were chosen to represent a wide range of solar transmittance values. The glazing options studied are presented in Table 1 below.

<table>
<thead>
<tr>
<th>Glazing types</th>
<th>SC(^1)</th>
<th>T(_{sol}) (%)</th>
<th>U-value(_{tot}) (Wm(^{-2})K(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>D: reflective bronze*</td>
<td>0.16</td>
<td>5</td>
</tr>
<tr>
<td>B</td>
<td>D: reflective blue</td>
<td>0.32</td>
<td>18</td>
</tr>
<tr>
<td>C</td>
<td>T: reflective</td>
<td>0.44</td>
<td>30</td>
</tr>
<tr>
<td>D</td>
<td>T: absorbing blue</td>
<td>0.48</td>
<td>31</td>
</tr>
<tr>
<td>E</td>
<td>T: absorbing blue*</td>
<td>0.56</td>
<td>38</td>
</tr>
<tr>
<td>F</td>
<td>T: low-reflectivity*</td>
<td>0.60</td>
<td>41</td>
</tr>
<tr>
<td>G</td>
<td>T: clear</td>
<td>0.76</td>
<td>56</td>
</tr>
<tr>
<td>H</td>
<td>D: clear*</td>
<td>0.86</td>
<td>68</td>
</tr>
</tbody>
</table>

\(D = \) double pane; \(T = \) triple pane

* with argon (others are with air)

2.3.2 Shading system

A dark blue awning with absorptance 67% and transmittance 7% was designed so that it would block all direct solar radiation on the south façade during the cooling season (May–September) (Fig. 1). The same awning was applied to all other façades in spite of different sun angles because it is practically impossible to shade the whole window with the type of awning used on east, west and north façades. This problem, which shows that shading systems should be chosen according to orientation, was pointed out by numerous authors [9, 12].

Three shading strategies were used: a fixed awning, an awning installed only during the cooling season (May–October 30), and a “dynamic” awning. The “dynamic” awning was drawn up completely on heating days and fully extended to its lowest point on cooling days. DEROB-LTH does not yet allow the modelling of a dynamic awning so annual energy use for this case was calculated separately on a calculation spreadsheet.

2.3.3 Other variables

The other variables were the orientation and the glazing-to-wall area ratio (GWAR). The orientation was varied by 45° increments (N, NE, E, SE, S, SW, W and NW) and the GWAR was varied from 0 to 70% as shown on Figure 2.

![Figure 2: Glazing-to-wall area ratios (GWAR).](image)

2.4 Simulation scheme

Three series of simulations were performed. In the first series (Fig. 3, top), the glazing type and orientation were varied for 30% GWAR. In the second series (Fig. 3, middle), the GWAR was varied for north, east and south orientations and for five glazing types. In the third series, the awning was added to the glazing type H for 30% GWAR on north, east and south façades. Three shading strategies were tested (Fig. 3, bottom).

![Figure 3: Simulation scheme.](image)

\(^1\) SC = Shading coefficient = ratio of the solar heat gain coefficient of a glazing system for a particular angle of incidence and incident solar spectrum to that for clear, single pane glass (standard reference glazing with T\(_{sol}\) = 0.86 at normal incidence) with the same angle and spectral distribution.
3 RESULTS AND DISCUSSION

3.1 Variation of the glazing type and orientation

In the first series of simulations, energy use was analysed for the office room with 30% GWAR, for eight glazing types and eight orientations. Results showed that low solar transmittance glazing (type A) yielded the lowest annual cooling load and the highest annual heating load. High transmittance glazing (types G, H) exhibited opposite trends. Results also indicate that the south facing room had the lowest annual heating load while the north facing room had the highest. For cooling, the southeast orientation yielded the highest annual cooling load while north yielded the lowest. East and west orientations yielded similar loads both for heating and cooling.

In absolute values, heating was more affected by a change in orientation than cooling. This is clearly shown in Figure 4: the maximal reduction in heating load due to a change in orientation was about 23 kWh/m²yr while it was only 15 kWh/m²yr for cooling. In percent, however, cooling was reduced by up to 58% while heating was reduced by up to 23%. The absolute maximal reduction in heating load due to a change in glazing type was about 29 kWh/m²yr while, for cooling, it was about 22 kWh/m²yr. In percent, cooling was reduced by at most 86% while heating was reduced by at most 27%. The glazing type was thus a more significant factor affecting energy use than the orientation, especially with respect to cooling loads.

![Figure 4: Incremental annual energy use (kWh/m²yr) for eight glazing types and eight orientations, GWAR = 30%, in Lund.](image)

Assuming that the heating and cooling systems had a similar COP and that energy distribution systems required the same amount of energy both for heating and cooling, heating and cooling loads were added up for the analysis of annual energy use as a function of orientation and glazing type. As shown in Figure 5, the optimal glazing strategy was orientation-dependent: on south and north façades, higher transmittance glazing (types F, G, H) yielded lower annual energy use while on east and west façades, average transmittance glazing (types C, D) performed better. Surprisingly, the low-emissivity coated glazing (type F) always yielded the lowest annual energy use for all orientations while the low solar transmittance glazing (type A) almost always yielded the highest annual energy use. Note that since thermal losses are constant for all cases, the performance of the low-emissivity coated glazing cannot be attributed to its thermal behaviour.

![Figure 5: Annual energy use (kWh/m²yr) for eight glazing types and eight orientations, GWAR = 30%, in Lund.](image)

3.2 Variation of the GWAR, glazing type and orientation

In the second series of simulations, the GWAR was varied for three orientations and five glazing types. Results of these simulations indicate that the cooling load increased with increasing solar aperture² (SA). The opposite trend was observed for heating loads (Fig. 6). In general, the south orientation was more affected by a change in SA than other orientations. A significant feature of Figure 6 is that for east and south orientations, the cooling load increased in a similar way with an increase in SA. For south, however, the heating load decreased much more with increasing SA than for east. In other words, for the east orientation, increasing the SA (SC or GWAR) yielded increases in cooling loads larger than the reductions in heating load. This was especially true for SA larger than 0.3.

Assuming, again, equivalent COP for heating and cooling systems, annual energy use was analysed as a function of SA. It was found that for south, the annual energy use was minimised at SA around 0.2 while for east, annual energy use was minimised at lower SA e.g., approximately 0.12. This means that, for the south orientation, high solar transmittance glazing (type H) yielded minimal annual energy use with GWAR around 20% while glazing type F was optimal with GWAR around 30% and glazing types C

¹ The solar aperture is the product of the SC (shading coefficient) and the GWAR
and D were optimal with GWAR around 40%. On the east façade, high solar transmittance glazing (type H) yielded lower annual energy use with GWAR around 15% while average transmittance glazing (types C, D) and glazing type F yielded lower annual energy use with GWAR around 20-30%. For the north orientation, the flat horizontal curve shown in Figure 7 indicates that the impact of the SC or GWAR on annual energy use was small. In general, the results show that annual energy use was minimised at lower GWAR or SC on east (and west) façades than on the south façade.

![Graph showing energy use vs solar aperture for different orientations.](image)

**Figure 6:** Incremental annual energy use (kWh/m²·yr) as a function of solar aperture for three orientations, in Lund.

![Graph showing energy use vs solar aperture for different orientations.](image)

**Figure 7:** Annual energy use (kWh/m²·yr) as a function of solar aperture for three orientations, in Lund.

### 3.3 Introduction of a shading system

In the last series of simulations, an awning was added to the high solar transmittance glazing (type H) with 30% GWAR for three orientations and three shading strategies. Results of these simulations indicate that the fixed awning resulted in increased annual energy use due to increased heating loads for all orientations (Fig. 8). These results agree with results found by Huhn et al. [5] and Treado et al. [13, 14].

![Graph showing energy use vs shading option for different orientations.](image)

**Figure 8:** Annual energy use (kWh/m²·yr) as a function of glazing-shading option for a) north, b) east, c) south and GWAR = 30%, in Lund (Awn 1 = fixed; Awn 2 = seasonal, Awn 3 = dynamic).

The study also showed that the seasonal and “dynamic” awnings reduced the annual energy use significantly, especially on the south façade. The seasonal awning reduced the cooling load by 18.8 kWh/m²·yr (6%) and increased heating loads by 4.8 kWh/m²·yr (6%), decreasing annual energy use by 13.9 kWh/m²·yr (14%) compared with the clear glazing option (type H), which was one of the best glazing strategies for the south façade. The “dynamic” awning performed even better with an annual
energy use reduction of 19.8 kWhm⁻²yr⁻¹ (20%) compared with the clear glazing (type H).

For north and east orientations, the seasonal and "dynamic" awnings also resulted in lower annual energy use although savings were smaller than for south. Even on the north façade, the seasonal awning resulted in annual energy savings compared with all solar-protective glazing options tested. Since this façade is in the shade most of the time, the savings achieved can be attributed to the reduction in diffuse solar radiation reaching the window.

4 CONCLUSIONS

In this study, optimal transmittance properties for glazing in a heating-dominated city were identified by varying the glazing type, the GWAR and the orientation. One significant finding is that the most energy-efficient glazing option is orientation-dependent: south and north façades require higher solar transmittance or higher SA (GWAR or SC) than east and west façades. This conclusion is drawn assuming equivalent COP for cooling and heating systems and constant thermal losses among all cases. Another important finding is that a high solar transmittance glazing combined with a removable awning, either on a seasonal or on a daily basis, results in lower annual energy use than all solar-protective glazing options tested for any orientation, including north. These results are promising since the impact of the glazing-shading strategy on electricity use for lighting was not assessed. The potential to replace artificial lighting by daylighting is much higher with high than with low solar transmittance glazing. The clear glazing plus removable awning option may thus result in much larger overall energy savings than those reported here.

Although a detailed calculation method was used to obtain heating and cooling loads, the window module and shading algorithm recently implemented in DEROB-LTH have not been fully validated yet. Measurement work is on the way at Lund University’s Department of Building Science for validation of the computer program. Future plans also include the implementation of dynamic algorithms for other types of shading devices like venetian blinds, roller shades, screens, etc. These algorithms will allow an extended study of energy patterns with different kinds of shading systems in cold climates.

REFERENCES


A Step Forward and One to Go.
Glazing and Sunshades
The New Model National Energy Code of Canada for Buildings 1997: A Step Forward and One to Go

by Marie-Claude Dubois

The new Model National Energy Code of Canada for Buildings 1997 has been greatly improved thanks to the switch towards a performance-oriented approach. Some improvements remain, however, such as a better definition of the fenestration thermal performance as a function of glazing optical properties, fenestration design and orientation.

A Step Forward

Two new model national codes aimed at controlling energy use in buildings and houses have recently been released by the NRC. The new codes, which together comprise some 439 pages, are, as Koroluk (1994) puts it, "more performance-oriented than any of the other model Canadian Codes, including the National Building Code and the National Fire Code". A more performance-oriented approach has been taken in order to "encourage greater innovation in design and construction as a means of reducing costs in a highly competitive economic environment" (Thomas, 1996).

The new codes offer three possible compliance paths: prescriptive, trade-offs and performance. In the prescriptive path, minimum thermal characteristics for envelope elements are dictated and energy-conservation measures can be stated as specific instructions. This approach—the simplest—was the one traditionally used in Canadian building codes. Trade-offs, on the other hand, allow the designer to reduce thermal resistance in one portion of the envelope, provided that the resistance in other areas is increased so that the overall energy use for the building is not increased. As Haysom (1994) explains, "this path is meant to be an easy way to make small adjustments to the characteristics of the building envelope without having to go the full performance route". In the performance route, the finished structure or system must be as energy-efficient as that required by corresponding prescriptive codes. In other words, instead of telling the designer how to do something, performance codes state the objectives that must be met, leaving the design professional to make the decisions about how to achieve the performance.

Other good points. Apart from this long-awaited switch towards a performance approach, the new codes now possess requirements that are both region- and fuel-sensitive. For this purpose, the country has been divided up into 34 regions and the life-cycle cost analyses on which requirements are based have been drawn up with reference to regional climate, and regional construction and fuel costs, thereby ensuring that code users can make energy choices based upon their local conditions.

The new codes are also very complete and cover most of the end-uses and energy-related characteristics of buildings: envelope, lighting, heating, ventilating and air-conditioning systems, service water heating systems and electrical power. Each of these sections are moreover

1 Marie-Claude Dubois, B. Arch., M. Arch. is working within the Solar Shading Group at Lund University's Department of Building Science, Lund, Sweden. Her research is funded by the Natural Sciences and Engineering Research Council of Canada (NSERC) and "Fonds pour la formation des chercheurs et l'aide à la recherche (FCAR)".
supplemented with a set of definitions at the beginning, guides, tables, conversion factors, and a very useful commentary section at the end, which truly makes the designer's life easier.

Finally worth mentioning is the introduction of an "environmental multiplier", which can be applied to energy costs to "reflect the fact that current market energy costs do not necessarily reflect the full impact of the use of energy on the environment (e.g., carbon dioxide emissions from the burning of oil or natural gas)" (NRC, 1997). Although this multiplier has only been taken into consideration by one province (Manitoba) in the 1997 edition, it is an encouraging step towards more environmentally-based (and not solely economically-based) energy codes for buildings.

**Impressive Process.** The Canadian building codes are a result of an impressive consultative process involving standing committees from the Canadian Commission on Building and Fire Codes (CCBFC) that rely on topic and task groups for advice of special interest. Members of these groups are drawn from all sectors of the construction industry over the whole country and the code drafting process has one of the most extensive public review procedures in the world (NRC, 1998). Owing to the fact that this extensive (and surely expensive), nation-wide process takes place about every five years, the codes have now reached a level of excellence and completeness hardly attained before.

Bearing in mind the excellence of the new codes, one is now entitled to ask "how can the next energy codes for buildings be improved in Canada?" or "which aspects of the codes need further developments?" The following is an attempt to provide part of the answer to these questions, at least regarding the requirements for the building envelope.

**Steps to Go**

Some of the most obvious flaws of the new codes are related to fenestration performance. Although prescriptions regarding the thermal transmittance (U-value) of windows are given according to a range of fenestration-to-wall area ratios (FWAR) for fixed and operable windows, there are no considerations of orientation. It is, however, of common knowledge that north-orientated windows usually yield a higher heating and a lower cooling load than south-orientated ones. Thus, exactly the same window with the same FWAR will result in different annual energy use totals on different facades. In view of this, prescriptions for windows should be more severe on north facades.

Another flaw is that no consideration is given to the glazing optical properties or solar heat gain coefficient (SHGC)\(^2\) although it is generally acknowledged that a glazing with a lower SHGC, like reflective or tinted glass, yields higher heating but lower cooling loads which often results in higher annual energy use in heating-dominated climates like Canada. This means that two glazings with similar thermal properties (U-values) can yield very different annual energy use trends for the same building and location. Reflecting this fact, requirements should vary as a function of the glazing SHGC.

**Impact on energy use.** In order to illustrate the impact of these flaws on energy use, the results of a small study carried out at Lund University's Department of Building Science (Sweden) are presented. The study consisted of assessing the energy performance of a standard office room (Fig. 1) located in Montreal using dynamic computer simulations. The

\(^2\) The SHGC is mainly determined by the glazing solar-optical properties. It is defined by ASHRAE (1997) as the fraction of incident irradiance (solar radiation falling on the glazing) that becomes heat gain in the space, it thus includes both the directly transmitted portion, and the absorbed and re-emitted portion of solar radiation.
room’s orientation and the fenestration’s SHGC, U-value and FWAR were alternatively varied and the impact these changes on annual energy use was determined.

Figure 1: Office room for the base case

As shown by the results (Fig. 2), a simple change in orientation from south to north (Case #2) yielded an increase of 61 kWh/m²/year (80%) in heating and a reduction of 16 kWh/m²/year (50%) in cooling, resulting in 46 kWh/m² (40%) higher energy use, annually3. Reducing the fenestration SHGC (from 0.66 to 0.38), keeping the same U-value as for the base case, (Case #3) increased annual energy use by 14 kWh/m²/year (10%). The heating loads were increased by 25 kWh/m²/year (30%) and the cooling loads were reduced by 11 kWh/m²/year (30%). Doubling the fenestration U-value (Case #4), keeping the same SHGC as for the base case, increased heating by 40 kWh/m²/year (60%) without significantly affecting cooling loads. The effect on annual energy use was an increase of 38 kWh/m²/year (40%) i.e. almost the same as a change in orientation (Case #2). Doubling the FWAR (Case #5) reduced heating loads significantly (25 kWh/m²/year i.e. by 40%) but almost tripled cooling loads resulting in an annual increase in energy use of 32 kWh/m² (30%).

Figure 2: Annual energy use (kWh/m²/year) for five cases

3 Here, the annual energy use is the sum of the space load for heating and cooling in a 1:1 ratio. No account is taken of the energy systems used or energy costs.
Glazing and Sunshades

The results thus indicate that parameters such as the orientation, the FWAR and the glazing type can have moderate to large impacts on annual energy use (up to 40%). Especially, the study shows that the impact of a change in orientation from south to north or a change in FWAR from 32 to 64% can be as large as doubling the fenestration U-value. The impact of lowering the SHGC was smaller but still significant, especially if heating and cooling loads are considered individually (+30%/-30%).

Some conclusions. The results of this study suggest that requirements that only consider the thermal transmittance of windows are vague because a wide range of annual energy use totals can be obtained depending on the glazing type selected, the orientation and the FWAR. This implies that, using a performance approach, a building with almost any properties can be designed—with the new MNECB 1997 in hand—since a wide range of energy use totals can be obtained following the prescriptive path by playing around with the fenestration properties, design and orientation. In the code it is argued that an "attempt to account for the solar heat gain coefficient resulted, in nearly all cases, in a penalty for tinted glazing (...). Since it is generally accepted that a lower solar heat gain coefficient has benefits such as system size reductions and comfort improvements, such a penalty for tinted glazing was not considered appropriate" (NRC, 1997, p. 59). While this is certainly true, it does not explain why the orientation—a factor which has a dramatic impact on energy use as demonstrated here—is not considered in the new MNECB. Note that other national codes, such as the Swedish building code (Boverket, 1997) for instance, give credits (or penalties) for the window U-value as a function of orientation.

Finally, it should be mentioned that there are other solutions (than tinted or reflective glazing) to overheating problems such as seasonal or dynamic shading devices, for example. Some advanced glazing technologies like smart (switchable) windows will soon be, or are already, commercially available. Provided that the technical problems connected with these technologies are solved, they promise to offer a much better performance in cold and temperate climates than tinted and reflective glass since they will allow a passive utilisation of solar radiation in the winter while offering solar protection when needed. These technological advancements will definitely generate the need for more precise requirements for the optical properties, shading, and orientation of windows in the next Canadian building code for energy.

References


References


