

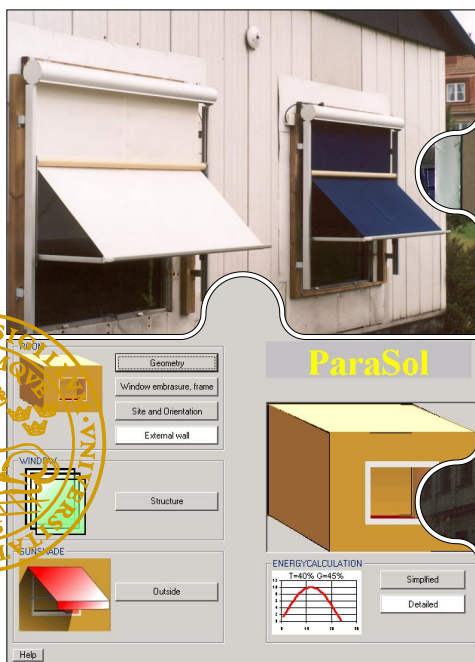
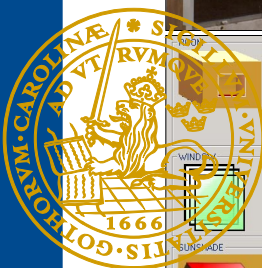
Solar Protection in Buildings

Editors

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Division of Energy and Building Design
Department of Construction and Architecture
Lund Institute of Technology
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Lund University

Lund University, with eight faculties and a number of research centres and specialized institutes, is the largest establishment for research and higher education in Scandinavia. The main part of the University is situated in the small city of Lund which has about 99 000 inhabitants. A number of departments for research and education are, however, located in Malmö. Lund University was founded in 1666 and has today a total staff of 5 530 employees and 28 000 students attending 60 degree programmes and 850 subject courses offered by 89 departments.

Department of Construction and Architecture

The Department of Construction & Architecture is part of Lund Institute of Technology, the technical faculty of Lund University. The main mission of the Department of Construction & Architecture is to pursue research and education on topics related to the built environment. Some of the topics of interest are: restoration and maintenance of buildings, construction management, design processes, construction, energy efficiency, climatization and design of ventilation and heating systems, demolition, disposal and re-use of building materials.

These topics are treated from both a Swedish and an international perspective and collaboration between actors from multidisciplinary fields of competence forms a particularly important aspect of research and education at the Department. The Department is divided into 7 sub-departments or divisions: Architectural Conservation & Restoration, Building Services, Building Science, Computer Aided Architectural Design, Construction Management, Energy & Building Design, and Housing Development & Management.

Division of Energy and Building Design

Reducing environmental effects of construction and facility management is a central aim of society. Minimising the energy use is an important aspect of this aim. The recently established division of Energy and Building Design belongs to the department of Construction and Architecture at the Lund Institute of Technology in Sweden. The division has a focus on research in the fields of energy use, passive and active solar design, daylight utilisation and shading of buildings. Effects and requirements of occupants on thermal and visual comfort are an essential part of this work. Energy and Building Design also develops guidelines and methods for the planning process.

Solar Protection in Buildings

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Key words

solar protection, solar shading, windows, buildings, energy need, heating, cooling, measurement, calorimetric, solar energy transmission, shading coefficient, calculation, design aid, solar simulator, user aspects, comfort, daylight

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Solar protection in buildings

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Abstract

Buildings with well functioning solar protection can cut the investment cost for cooling and ventilation installations, reduce energy use and create the conditions for good thermal and visual comfort. Since there is a lack of scientifically developed and comparable data available for the physical properties of solar protection devices, the research project *Solar protection in buildings*, described in this report, has been put in hand.

The aim is to determine, by measurements and calculations, the physical properties of different types of sunshades. Design aids for the construction industry must be developed and a standardised laboratory method should also be developed for measuring the physical properties of solar protection devices.

Measurements have been made and calculation models developed for external sunshades. A design tool, in the first place for external sunshades, is being developed and the first version was released in September 2000. A solar simulator has been constructed so that measurements on windows and sunshades may be made in a more standardised manner. Calculations have also been performed to study the effect of sunshades on energy use for heating and cooling, and a preliminary investigation has also been made with regard to user aspects and the effect on daylight in rooms when sunshades are used.

The results of this stage comprise values determined for the solar energy transmittance of external sunshades such as awnings, Italian awnings, external venetian blinds, horizontal slatted baffles, fabric screens, slatted blinds and solar control films. Calculation models for these types of sunshades have been developed and show good agreement with measurements. Calculations with the new sunshade models implemented in the energy balance program DEROB-LTH show that there is considerable potential for reducing energy needs where seasonally adapted solar shading is used. The results indicate that automatic regulation of sunshades which can however still be overridden by the users is the optimum solution.

It is planned that further work will comprise more measurements and development of calculation models for interpane and internal sunshades. In later versions, the design aid is to be complemented with interpane and internal sunshades. International standardisation work regarding measurements and calculation models should be speeded up. Daylight and thermal comfort are also important components, and there are plans to incorporate these.

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Foreword

We wish to extend our thanks to the following persons and organisations for their helpful cooperation in the solar protection project, and hope that this cooperation will continue.

We wish to thank the Swedish Solar Protection Association and especially Lennart Thern, the secretary of the Association, whose positive and involved attitude is a real asset. We also wish to thank the firm Persienn-Pågarna AB in Lund who helped us in purchasing and mounting the different sunshades which we studied, and gave us good advice.

Our thanks are also due to the Norwegian Solar Protection Association for their input, and to Ida Bryn for her assistance at the firm of consultants Erichsen & Horgen A/S in Oslo.

We are also grateful for the active and engaged cooperation of the reference group, which was completely altruistic since no finance was available for their assistance. The reference group consisted of Siv Averud / Ventilation, Climate and Environment Society, Solveig Larsen / Swedish Federation of Rental Property Owners, Mattias Klasson and Lennart Thern / Swedish Solar Protection Association, Conny Rolén / Swedish Council for Building Research, Anders Mærk and Kenneth Falck (previously Pål Rygg) / Norwegian Solar Protection Association, Bengt Lindström / Swedish Board of Housing, Building and Planning, Marie Hult / White Arkitekter and Ida Bryn / Erichsen and Horgen A/S. We hope that their assistance will continue in the future.

Naturally, we also wish to express our special thanks to our financing organisations, Swedish Solar Protection Association, Norwegian Solar Protection Association, Lund University and, in particular, Swedish Council for Building Research and the Swedish National Energy Administration which has so far financed most of the project.

The researchers at Energy and Building Design and Building Science,
Lund University

1 Background

Maria Wall

Solar radiation is a valuable source of energy for buildings during the winter months and provides light all round the year. Solar energy can however also give rise to excessive temperatures in buildings, and may cause difficulties when the outside temperature is high. Excessive temperatures are often counteracted by means of cooling installations which contribute to increased total energy use in the building.

The use of solar protection instead of large cooling installations in e.g. offices, schools and hospitals may have the following effects:

- Lower investment costs for cooling and ventilation installations
- Lower running costs
- Reduced dependence on electric power
- Less use of Freon
- Lower depreciation costs
- Better work environment (no direct sunlight, less draught due to reduced ventilation, less noise, etc)
- Improved effectiveness of personnel owing to the better work environment

Development of windows with low U values and thus low energy losses made possible the use of large glazed surfaces in buildings without problems due to draughts or high heating costs. However, large glazed surfaces require solar protection. Otherwise there is a risk of excessive temperatures and/or large cooling requirements in summer.

The term solar protection is used here to denote awnings, roller blinds, horizontal slatted baffles, external venetian blinds, coated glass, etc. These may be placed on the inside, between panes or on the outside. During the design stage, it must be possible to judge comfort and energy needs for heating/cooling in order that a well functioning building may be designed. The larger the glazed surface, the greater is the risk that problems will arise. This is particularly so in the case of glazed spaces and atria (Wall, 1996). Some sunshades can also act as night-time insulation for

windows. The situation at present is that solar protection is seldom designed at the planning stage but is installed as an emergency measure when problems are first encountered, i.e. after the first summer when the building is in service.

Also, in Sweden the decisions made during the planning stage are traditionally of a fairly short term nature. Electricity for services is not included in the agreed rent for either offices, residential buildings or other premises. The building owner/landlord therefore has no incentive to choose energy efficient equipment if this is more expensive to buy. The final consumer (tenant) has no part in the decisions concerning investments. (Elmberg, Elmroth & Wannheden, 1996).

It is difficult to market and motivate the use of sunshades unless a sound assessment can be made of the effect of sunshades. The difficulty is that there is a lack of relevant and comparable data available regarding the amount of solar radiation that is transmitted through different types of sunshades and their function in combination with windows. Most makers and retailers of sunshades can only produce very rough estimated figures as to how much solar radiation will be screened – or no figures at all! In order that air conditioning installations in buildings may be designed correctly, it is obviously necessary to know what effect sunshades will have. There is also a lack of simple and reliable design aids for building services engineers and architects. The result is that the potential of effective solar protection is not considered in design. In turn, this results in the design and installation of unnecessarily large air conditioning plants, with high investment and running costs.

Since no data are available at present as to how effectively different sunshades provide protection against unwanted solar radiation, the research project *Solar protection in buildings* was started on 1 January 1997. It is time that the properties of sunshades were investigated. Knowledge of the thermal properties and effects of sunshades is at present very poor compared with those of e.g. windows. The object of this project is to change this.

The research project is based on cooperation between Lund University, the Swedish Solar Protection Association and the Norwegian Solar Protection Association. The Swedish and Norwegian associations represent firms engaged in solar protection products for buildings. Among the members there are both wholesalers, producers and retailers. Both associations have given economic support together with the Swedish Council for Building Research which has so far financed most of the project. At a later stage cooperation also commenced with the firm of consultants Erichsen & Horgen in Oslo.

This report describes the work so far performed in the project. Work on the project is far from finished. Thanks to new funding from the Swedish Council for Building Research and the Swedish National Energy Administration, the research is continuing from 2000 to 2002. Daylighting is now also included in the work. The collaboration with manufacturers is also continuing.

1.1 Potential savings

Use of electrical energy for the operation of buildings in the nonresidential sector constitutes a considerable proportion of the total use of electrical energy in Sweden. For 1993 it is estimated at approx. 19 TWh annually (BFR, 1995). This is very much of the same order as the electrical energy used to heat single family houses (incl. household electricity), 19.5 TWh annually in 1995 (Statistics Sweden, 1995).

The total use of electrical energy in the nonresidential sector is on average 120 kWh/m² annually excluding water heating (Nilson & Hjalmarsson, 1993). The breakdown of energy use is approximately as follows:

Lighting	30%
Office equipment	20%
Building services	30%
Others	20%

Electrical energy for building services is mainly used for ventilation, cooling plants and pumps. The energy for ventilation is the largest item. There are insufficient statistics for energy use in nonresidential premises, and it is therefore difficult to arrive at detailed breakdowns. According to an estimate made by the Swedish Board for Industrial and Technical Development (NUTEK), approx. 2.5 TWh annually is used for ventilation in nonresidential premises. In the *Energy Book* (BFR, 1995) use of electricity for ventilation is estimated at about 2 TWh annually.

There are however large variations between buildings. Under the assumption that electrical installations are effective, insolation into an office room over, on average, 8 hours may amount to as much as 2/3 of the total heat load (unwanted heat gain) in the office room. In this case no solar protection is used.

The function of air conditioning is to supply heat, remove excess heat and remove airborne pollutants. The air flow rates needed to remove excess heat are considerably larger than those required to achieve good air quality.

When the outside temperature approaches the indoor temperature, cooling machinery must also be used. It is well known that, owing to the large internal heat loads over a large proportion of the year, nonresidential premises in Sweden have a cooling requirement rather than a heating requirement. This excess heat must be removed by ventilation and/or cooling.

Since air conditioning plants are often designed on the basis of standardised internal heat loads for the highest possible loading, they are considerably overdesigned. The alternative of e.g. installing effective sunshading is not considered.

One good design principle is to reduce heat load by appropriate building design *in the first place*, i.e. consideration of window orientations, window sizes, the use of sunshades, control strategies for sunshades, etc. If these measures are not sufficient, an air conditioning plant is used as a supplement.

To sum up, use of sunshades can result in both a not inconsiderable reduction in energy use and enhancement of comfort resulting in improved work environment. After all, it is not all offices that have cooling plants.

1.2 Previous work

Very little is known of the technical properties of different types of solar protection products and their effect on energy use and indoor climate. This is confirmed by a recent review of international literature performed at the department (Dubois, 1997). This holds in particular for the optical characteristics of these products but also for calculation methods and measuring procedures. There is therefore also insufficient knowledge of the effect that sunshades have on cooling requirement, heating requirement, comfort, etc.

Relevant work was done in Denmark and Sweden at an early date: Pleijel (1961), Petersen (1966), Isfält (1974). When this work was done, good measuring instruments were not available and computers were not so accessible as now. Only a small number of sunshades were studied, and it was therefore not possible to produce a good design aid. In recent years equipments for measurements on solar protection products were constructed at e.g. Lawrence Berkeley Laboratory (LBL) in USA. One project was carried out there by ASHRAE with an objective similar to this one, i.e. a standard procedure for the measurement and calculation of the performance of sunshades; see Klems and Warner (1992) and Klems et al (1996). Petter Wallentén, Building Science, has worked as guest

researcher at LBL under Stephen Selkowitz of the Windows and Daylighting Group in order to benefit from their experiences. In Europe, the University of Delft and the Fraunhofer Institute have performed similar studies.

Insolation can also be prevented by using special solar control glass, such as reflecting and coloured (heat absorbing) glass. Solar control glass has become popular in the past decades since it offers a relatively easy solution to the solar shading problem and can also be easily integrated into the building (Olgyay & Olgyay, 1957). In addition, solar control glass involves no additional installation or maintenance costs (Soebarto & Degelman, 1994). However, an appreciable drawback of solar control glass is that it reduces insolation during the winter months also. This may increase heating requirements and may often give rise to a higher annual energy need.

In cold climates, seasonal or otherwise controllable solar protection is therefore a more promising solution to the problem of excess temperatures in buildings, since this can be used only when there is a need to provide solar shading.

1.3 Benefits

Industrially, the project mainly concerns the construction industry with its technical consultants and architects and the managers of nonresidential buildings. The arguments in favour of well designed solar protection may be even more effective abroad than in a Nordic climate. Higher average outdoor temperatures, greater insolation and higher electricity prices all indicate this. There is therefore a very large market for solar protection products.

The ability to refer to scientifically produced data strengthens the competitiveness of Nordic companies. For the construction industry that is active in markets abroad, the Nordic building concept can be introduced as a low energy, environmentally friendly and less electricity-reliant product, while at the same time investment costs can be reduced if the cooling installation is replaced by solar protection. It is also valuable for Nordic companies to follow and influence, or even lead, international work on standardisation, e.g. within ISO.

In the end, the companies and industries which are affected by this problem are those which own and manage buildings, and the companies which perform activities in the premises. By a more effective use of solar protection, they can offer a better work environment while at the same time reducing running costs and capital charges.

For designers (engineers and architects), the results of the project mean that they can offer alternative and more environmental concepts in attaining the requirements specified by the clients for the indoor climate. This work also enhances the capability of the whole solar protection industry.

The aesthetic aspects which may be expected to be put forward when solar protection attains greater application may accelerate development, so that a wider range of products which can be adapted to our building traditions can be offered.

Finally, and this is very important, increased use of solar protection will produce a result that is of strategic importance for society, namely a reduction of reliance on electricity.

1.4 The goal of the project

The goal of the project as a whole is to determine the physical properties of different types of sunshades, to be used as input data in *calculation models* developed in the project. These models must be verified and developed into a *design tool* for consultants. In addition, a proposal for a *standardised laboratory method*, for measurement of the physical properties of sunshades, should be developed. There is no such method available at present, and this has also been realised in international standardisation work (ISO, CEN).

The design tool must be able to assess the effect of solar protection on cooling and heating requirements, and it must be constructed so that it can, at a later stage, be supplemented with the capability to judge thermal comfort and daylighting. *Training* should also be provided for those who work in the solar protection industry and building management, and for architects and engineers. It is also possible for this to be incorporated in the basic education of future architects and engineers.

1.5 Work done so far

This report describes the work done so far. Methods and equipment for measurements in a real climate have been produced. The solar transmittance of external sunshades in combination with windows has been measured, and measurements on interpane sunshades are at present in progress; see Chapter 2. A solar laboratory for measurement of solar transmittance for different angles of incidence for sunshades and/or windows has been developed; see Chapter 3. Development of calculation models and comparison of these with measurements is proceeding at the same time; see Chapter 4. The computer program DEROB-LTH developed at the department is complemented with these calculation models. Chapter 5 describes the generalised data produced so far for external types of sunshades. Measured data have been generalised by a large number of calculations with the program DEROB-LTH. The first version of a design tool has been made for external shadings, and this is described in Chapter 6. The effect of sunshades on energy use for an office room is described in Chapter 7 and in Chapter 8 a study on user aspects is presented. Finally, further work in the project is discussed.

1.6 Project organisation

A reference group is attached to the project and meets twice a year together with those engaged on the project at Lund University. This reference group is of very valuable assistance and acts as a sounding board for the project, and also ensures that the project is firmly established among the target groups.

The present composition of the reference group is as follows:

- 2 representatives of the Swedish Solar Protection Association:
Lennart Thern and Mattias Klasson
- 2 representatives of the Norwegian Solar Protection Association:
Anders Mærk and Kenneth Falck (the previous representative was Pål Rygg)
- 1 representative of the Swedish Council for Building Research:
Conny Rolén
- 1 representative of the Swedish Federation of Rental Property Owners:
Solveig Larsen

1 representative of the Swedish Ventilation, Climate and Environment Society:

Siv Averud

1 representative of architectural practices:

Marie Hult, White arkitekter AB

1 representative of the Swedish Board of Housing, Building and Planning:

Bengt Lindström, Building Department

1 representative of building services consultants:

Ida Bryn, Erichsen & Horgen A/S, Oslo.

The following are taking part in the project from Lund University:

Building Science

Bertil Fredlund, Professor (until October 2000)

Petter Wallentén, MSc, Physicist, PhD (until February 2000)

Håkan Håkansson, MSc, Civil Engineer, PhD

Kurt Källblad, PhD, Senior researcher (retired since February 2001)

Energy and Building Design

Björn Karlsson, Professor, since April 2000

Maria Wall, Architect, PhD, Assistant professor

Hasse Kvist, BSc, Mathematician, Research scientist

Marie-Claude Dubois, MSc Architect, Research scientist

Helena Bülow-Hübe, MSc, Civil Engineer, Research scientist

Urban Lundh, BSc

Bengt Hellström, MSc, Mechanical Engineer, Research scientist (since March 2001)

1.7 Links with other research projects

The Division of Energy and Building Design participates in the international research project Task 23, *The optimization of solar energy use in large buildings* within *International Energy Agency (IEA), Solar Heating and Cooling Programme*. The aim of Task 23 is to develop methods and tools for the improvement of the design process so that well functioning buildings are achieved, with special emphasis on optimum solar energy use, daylighting, comfort, low energy need, energy efficiency, sustainability and costs. Task 23 concentrates on large buildings such as offices and schools. System solutions shall make for good energy management,

utilisation of daylight and both passive and active solar utilisation, without the systems becoming too complex. These types of buildings which have the aim of a high degree of solar utilisation and low energy use mostly have large glazed surfaces, which means that a well thought-out design of solar protection and control strategy is essential. There is therefore a natural coupling between this international project and the Swedish/Norwegian solar protection project. Task 23 began in 1997 and will finish in 2002, and its timing is also in good agreement with the solar protection project.

Energy and Building Design is also taking part in the project *Buildings without heating systems*, under which terrace houses of extremely low energy use, without separate heating systems, shall be built in Göteborg and Malmö. This project is a collaborative effort between the architectural practice EFEM Arkitektkontor and the Swedish Testing and Research Institute (SP). The project also forms part of an EU project within the THERMIE programme. The terrace houses to be built within the project have a very short heating season, with the risk of very high excess temperatures in the spring and autumn unless solar protection is applied in combination with window opening. During the spring and autumn the sun has a relatively low altitude, which means that the usual roof overhangs that are useful during the summer are not sufficient to shade the windows. Traditionally, insolation in the spring and autumn is utilised to reduce heating requirements in buildings of more normal insulation, but in these low energy buildings temperatures will in most cases become excessively high.

A Norwegian research project, *Solar shading as an environmental measure*, has also recently commenced as a complement to the solar protection project described in this report. The Norwegian project is conducted by the firm of consultants Erichsen & Horgen A/S, with Ida Bryn as contact person. The Norwegian project commenced at the beginning of 1999 and was finished at the end of 1999.

2 Measurement of the properties of sunshades in a real climate

Petter Wallentén and Håkan Håkansson

2.1 Introduction

There is a lack of relevant data available at present as to how well sunshades protect buildings against unwanted insolation. Most retailers and producers of sunshades provide very rough estimated figures. The makers of screens which all conform to ASHRAE Standard 74-1988 are one exception. This standard provides information on solar transmittance of mainly perpendicular incidence and is valid for sunshades where geometry need not be considered. In order to remedy these gaps in knowledge, in this project the properties of sunshades are measured in a real climate.

The results relate to measurements on

- two awnings
- two external venetian blinds
- two Italian awnings
- one horizontal slatted baffle
- three fabric screens
- two roller shutters
- two solar control films

The awnings were the same type, but one had a light colour and the other a dark fabric. The external venetian blinds were silver coloured with slats 50 and 80 mm wide. The Italian awnings were tested with the same fabrics as the awnings. Both types of awning were tested in two positions, fully and partially extended. The external blinds were also tested in two positions, fully lowered with horizontal slats and fully lowered with slats at 45° to the window.

2.2 Method

In the first stage a double hot box arrangement was used. Two well insulated boxes were placed in a room at about 20°C. On one side the boxes had a double glazed unit (4 mm – 12 mm – 4 mm, clear glass) of 1.17 m × 1.17 m size which was in contact with the sun and the outdoor climate through a hole in the wall of the building. The windows in the boxes faced south. The way the boxes were mounted in the facade is shown in Figure 2.1. The measuring system is illustrated schematically in Figure 2.2.



Figure 2.1 Boxes with sunshade.

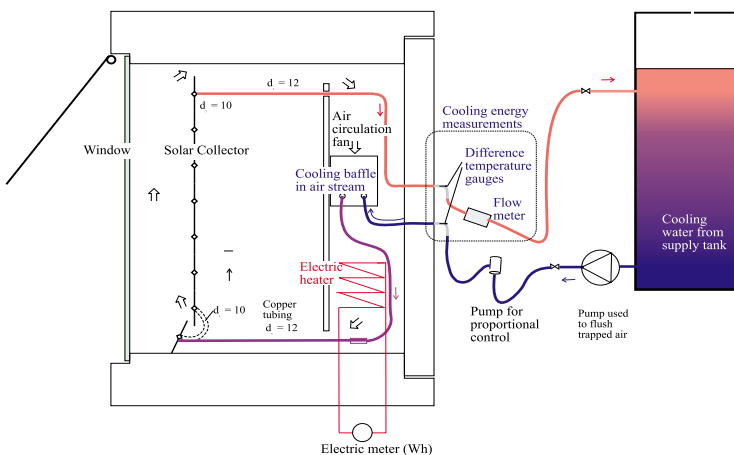


Figure 2.2 Hot box and measuring system.

The boxes are heated electrically and cooled with water that passes through a cooling unit and a Teknoterm solar collector placed immediately behind the window. A fan of approx. 70 W in each box ensures that air circulates. Most of the solar energy transmitted through the window is absorbed by the solar collector and a smaller proportion by the air and the walls of the box, and is then passed to the cooling exchanger. For the primary solar transmittance, thermal conduction through the window is calculated from the temperatures on the outside and inside of the window. For the total solar transmission, the temperatures inside and outside the box, multiplied by the dark U-value of the window, are used. The heat balance for the box is

$$Q_{cool} + Q_{window} + Q_{room} - Q_{el,heat} + Q_{capacity} = Q_{sun} \quad (2.1)$$

measured cooling energy	measured and calculated heat transfer through window	measured and calculated heat transfer from box to room	measured electric heat	heat capacity	transmitted solar energy
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During the night when there is no sun, the right hand term is equal to zero. This is used to calibrate the boxes. The equation is used to calculate Q_{sun} which is the total solar energy transmitted through sunshade and window. The total solar transmittance of the system is denoted g_{system} . g_{system} is calculated by dividing Q_{sun} by the product of global solar radiation on the window, I_G , and the area of the window, A_w .

$$g_{system} = \frac{Q_{sun}}{I_G \cdot A_w}$$

Depending on how Q_{window} is calculated, g_{system} will be equal to the total solar energy transmittance (including secondary heat transfer), usually denoted as g , or to the primary transmittance plus the energy absorbed in the inside pane, here denoted τ_{system} . Obviously, total transmittance is slightly larger than primary transmittance. Unless otherwise stated, the figures quoted in this chapter refer to total transmittance.

The solar transmittance for a certain sunshade can be calculated in different ways. The simplest way is to assume that the total transmittance is the product of the transmittance for the different parts of the system:

$$g_{system} = g_{sunshade} \cdot g_{window}$$

or

$$g_{\text{sunshade}} = \frac{g_{\text{system}}}{g_{\text{window}}} \approx \text{“shading coefficient”}$$

If the window is double glazed, g_{sunshade} is the same as the *shading coefficient* which is sometimes used in connection with sunshades. The U-value of a double glazed window is approx. $3 \text{ W/m}^2\text{°C}$. In the measurements described here, the double glazed window used had a U-value of approx. $3.5 \text{ W/m}^2\text{°C}$ because the fan on the inside reduced the surface resistance between the glass and the air. Because of the fan, the total solar transmittance is slightly higher than what is actually meant by the shading coefficient.

It is somewhat inappropriate to use the term “transmittance of sunshade” for g_{sunshade} because reflections between sunshade and outer pane and reflections between the facade and sunshade are included in this value. The value of g_{sunshade} will thus depend on the properties of the glass and the facade. However, this way of calculating g_{sunshade} removes the effects of geometric factors which are the same for measurements with and without sunshades: window embrasure, fixings, etc. For these reasons g_{sunshade} is a value of practical utility which is presumably adequate in most cases except where an outer pane of high or low reflecting properties is used in combination with a facade that is very different from that used in the measurements.

The transmittance of the window, g_{window} , can be either measured or calculated. It is easiest to use one box to measure the transmittance of the sunshade and the other to measure simultaneously the transmittance of only the window. This is particularly advantageous when there is cloud or haze which makes the solar radiation vary at random. All the results set out below are based on 5 minute means which have been smoothed with a moving average over 50 minutes. In all cases, the global solar radiation on the facade was greater than 100 W/m^2 . The facade on which the sunshade was mounted was painted in a light colour, with a reflectance of approx. 50%.

2.3 Calibration

Calibration was performed by applying linear regression according to the method of least squares to values measured when the solar energy was equal to zero. The right hand side of Equation (2.1) is then equal to zero, and the assumed parameters can be used to minimise the error. The full equation for the heat balance in the box is

$$Q_{cool} + Q_{window}(K_w, A_w, T_1, T_2) + K_r \cdot \Delta T_r - Q_{el.heat} + K_{air} \cdot Q_{air}^k (\delta T_{air}, \delta t) + K_{surfaces} \cdot Q_{surfaces}^k (\delta T_{surfaces}, \delta t) = Q_{sun} \quad (2.2)$$

where

Q_{cool}	measured cooling energy	(W)
K_w	free parameter for heat loss through the window	(-), (W/m ² °C)
A_w	area of window	(m ²)
T_1	temperature of inner pane or of air in the box	(°C)
T_2	temperature of outer pane or of outside air	(°C)
Q_{window}	calculated heat loss through window pane	(W)
K_r	free parameter for heat loss through the walls of the box	(W/°C)
ΔT_r	difference between temperature of air in box and inside air	(°C)
$Q_{el.heat}$	electric heat supplied plus fan energy	(W)
K_{air}	free parameter for heat capacity at air node	(Ws ^{1/2} /°C)
δt	time step	(s)
δT_{air}	temperature change at air node in the box	(°C)
Q_{air}^k	input to heat capacity at air node in the box	(W)
$K_{surfaces}$	free parameter for heat capacity at inside surfaces of the box	(Ws ^{1/2} /°C)
$\delta T_{surfaces}$	change in surface temperatures in the box	(°C)
$Q_{surfaces}^k$	input to heat capacity at surface nodes in the box	(W)

The parameters to which the curve is fitted are K_w , K_r , K_{air} and $K_{surfaces}$.

2.3.1 Heat loss through window

The heat losses through the window: $Q_{window}(K_w, A_w, T_1, T_2)$ can be calculated in two ways. Either by using the temperature sensors on the glass surfaces and the formulae for heat losses across the gaps as in Equation (2.4), or by using the temperatures of the air in the box and of the outside air, and a constant. In this case,

$$Q_{window} = K_w^1 \cdot A_w \cdot (T_2 - T_1) \quad (\text{W}) \quad (2.3)$$

where

K_w^1	U-value	(W/m ² °C)
T_1	temperature of outside air	(°C)
T_2	temperature of air in the box	(°C)

If the glass temperature is instead used, the calculation is more complicated. Heat losses through the panes of glass can then be expressed as

$$Q_{window} = A_w K_w^2 (h_c^{2-1} + h_r^{2-1}) (T_2 - T_1) \quad (\text{W}) \quad (2.4)$$

where

K_w^2	dimensionless factor	(-)
h_c^{2-1}	convective/conductive coefficient for heat transfer between the panes of glass	(W/m ² °C)
h_r^{2-1}	long wave radiation coefficient for heat transfer between the panes of glass	(W/m ² °C)
T_2	temperature of inner pane	(°C)
T_1	temperature of outer pane	(°C)

The convective heat transfer is calculated according to the formulae given by ElSherbiny et al (1982):

$$\text{Ra} = \frac{g_n (T_2 - T_1) D^3 \beta}{\nu_{air} a_{air}}$$

$$\text{Nu}_1 = 0.0605 \text{ Ra}^{1/3}$$

$$\text{Nu}_2 = 0.242 (\text{Ra} \cdot D/H)^{0.272}$$

$$\text{Nu}_3 = \left\{ 1 + \left[0.104 \text{Ra}^{0.293} / \left(1 + (6310/\text{Ra})^{1.36} \right) \right]^3 \right\}^{1/3} \quad (2.5)$$

$$\text{Nu} = \max[\text{Nu}_1, \text{Nu}_2, \text{Nu}_3]$$

$$h_c^{2-1} = \frac{\lambda_{air} \text{Nu}}{D} \quad (\text{W/m}^2\text{°C}) \quad (2.6)$$

where

g_n	gravitational constant	(m/s ²)
λ_{air}	thermal conductivity of air	(W/m°C)
ν_{air}	kinematic viscosity of air	(m ² /s)
β_{air}	coefficient of thermal expansion (1/T)	(K ⁻¹)
a_{air}	thermal diffusivity of air [$\lambda/(\rho c)$]	(m ² /s)
D	distance between panes of glass	(m)
H	height of window	(m)

Nu	Nusselt number	(-)
Ra	Rayleigh number	(-)

The coefficient for the exchange of long wave radiation between the panes is calculated as

$$h_r^{2-1} = \varepsilon_{eff} \sigma (T_1^2 + T_2^2) (T_1 + T_2) \quad (\text{W/m}^2\text{°C}) \quad T \text{ in Kelvin}$$

$$\varepsilon_{eff} = \frac{1}{1/\varepsilon_1 + 1/\varepsilon_2 - 1} \quad (2.7)$$

where

σ	Stefan-Boltzmann constant ($5.67 \cdot 10^{-8}$)	(W/m ² K ⁴)
ε	emissivity	(-)

The emissivity of glass was assumed to be 0.837.

2.3.2 Power input to heat capacity

The mass in the box consists of the installed cooling system and the walls of the box. Two different capacity nodes are used: an air node behind the solar collector panel and a mean for the wall surfaces in the box. The analytical solution for stepwise change in an infinite panel is used as the model for the power input to these nodes, see e.g. Carslaw & Jaeger, (1959).

$$T(x,t) = T_0 + (T_s - T_0) \cdot \text{erfc}(x/\sqrt{4at}) \quad (\text{°C}) \quad (2.8)$$

where

x	distance into the panel	(m)
T_s	new temperature at time $t=0$ at the surface	(°C)
T_0	start temperature	(°C)

$$\text{erfc}(x) \text{ complementary error function} = \frac{2}{\sqrt{\pi}} \int_x^\infty e^{-s^2} ds$$

The total accumulated energy $e(t)$ from $t = 0$ to t can be calculated from Equation (2.8).

$$e(t) = \frac{\lambda(T_s - T_0)}{\sqrt{\pi a}} \cdot 2\sqrt{t} \quad (\text{Ws/m}^2)$$

The mean power input is then

$$q(t) = \frac{2\lambda}{\sqrt{\pi a}} \cdot \frac{T_s - T_0}{\sqrt{t}} \quad (\text{W/m}^2) \quad (2.9)$$

The power input to the air and surface node is therefore calculated as

$$Q_{air}^k = 1000 K_{air} \frac{\delta T_{air}}{\sqrt{\delta t}} \quad (\text{W}) \quad (2.10)$$

$$Q_{surfaces}^k = 1000 K_{surfaces} \frac{\delta T_{surfaces}}{\sqrt{\delta t}} \quad (\text{W}) \quad (2.11)$$

with

$$K = A \frac{2}{1000} \sqrt{\lambda \pi \rho c} \quad (\text{Ws}^{1/2}/\text{K})$$

If $A = 1 \text{ m}^2$, the value of K for some materials is

Copper	$K = 42$
Wood	$K = 1.47$

2.3.3 Linear regression

The free parameters have been fitted with respect to 4000 values measured from 1 January to 2 September 1998. The values used were the night-time readings when it is known that $Q_{sun} = 0$. The equation used was

$$\begin{aligned} Q_{el.heat} - Q_{cool} = & Q_{window}(K_w A_w T_1, T_2) + \\ & + K_r \cdot \Delta T_r + K_{air} \cdot Q_{air}^k(\delta T_{air}, \delta t) + \\ & + K_{surfaces} \cdot Q_{surfaces}^k(\delta T_{surfaces}, \delta t) \end{aligned} \quad (\text{W}) \quad (2.12)$$

which was the condition applied for curve fitting. The measured values had been calculated as 50 minute moving averages calculated every 25 minutes. After this the effect of any outliers was reduced by gradually removing, in steps of 2% of the material, the values that had the worst fit. This reduction was carried on until the difference between two calculations of the parameters was less than 5%. On the basis of these calculations the following results were obtained.

Table 2.1

Box 1					
	Fitting error(W)	K_w^2 (-)	K_r (W/°C)	K_{air} (Ws ^{1/2} /K)	$K_{surfaces}$ (Ws ^{1/2} /K)
Value		1.199	3.427	1.888	0.308
σ	2.045	0.0006	0.032	0.106	0.148
$\sigma(\%)$	3.25	0.071	0.95	5.6	48.0
K_w^1 (W/m ² °C)					
Value		3.520			
σ	4.269	0.0050			
$\sigma(\%)$	8.2	0.14			
Box 2					
	Fitting error(W)	K_w^2 (-)	K_r (W/°C)	K_{air} (Ws ^{1/2} /K)	$K_{surfaces}$ (Ws ^{1/2} /K)
Value		1.192	2.440	1.877	0.8176
σ	1.922	0.0009	0.033	0.088	0.230
$\sigma(\%)$	2.6	0.072	1.3	4.7	24.0
K_w^1 (W/m ² °C)					
Value		3.595			
σ	4.626	0.0052			
$\sigma(\%)$	8.4	0.14			

When K_w^1 was being fitted, all the other parameters were regarded as fixed. This was done because K_w^1 is a difficult parameter to measure since it is affected by wind conditions on the outside. As will be seen from the table, the estimated standard deviations for K_w^1 , K_w^2 and K_r are very low. The estimated standard deviations for K_{air} and $K_{surfaces}$ are much higher. $K_{surfaces}$ in particular has a very high standard deviation, and it is debatable whether this parameter should be used. In spite of this, $K_{surfaces}$ has been used in the results presented, as it is found that it has little influence on the final result. The fitting error is about 2 W when K_w^2 is used, and 5 W when K_w^1 is used.

2.4 Windows

Figure 2.3 shows measurements of the primary transmittance of windows plus the energy absorbed in the inner pane (τ_{system}) for both boxes. Ideally, the two curves should fully coincide. In the figure, transmittance for the different windows differs by less than 3% between 9.00 and 15.00 hours. With reference to Figure 2.3 and other analyses of the uncertainty in measurements, the relative accuracy in measuring transmittance is estimated at approx. 5%, but not less than $\pm 1\%$ in transmittance. That is to say, the measured transmittance for a window is e.g. $50 \pm 2.5\%$, or with an awning $10 \pm 1\%$.

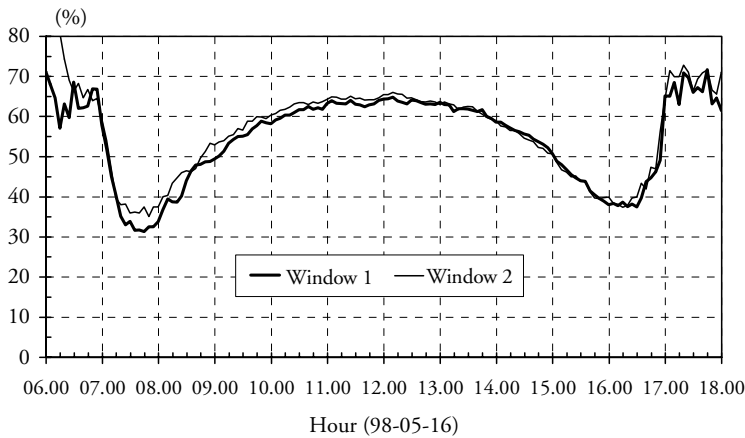


Figure 2.3 Measurement of transmittance through windows in box 1 and box 2. Southerly orientation. No awning. Primary transmittance of window (τ_{system}).

The reason for the shape of the curve is that in the early morning and evening it is mainly diffuse sunshine that falls on the window. The transmittance for diffuse light is approx. 65% and this light is not affected a lot by the window embrasure and fixings. During the morning and afternoon the sun strikes the window at a very acute angle which produces low transmittance: 35%. At noon the sun is at the smallest angle to the window and transmittance is high, 65%. Even without awnings the window is shaded by the embrasure. Because of this the measurements yield a lower value than the theoretical figure for the window unit itself.

2.5 Awnings

The results relate to measurements on two awnings: one with a light (beige, NCS 0502-Y) fabric and the other a dark (dark blue, NCS 7030-R70B) fabric. The fabrics were spin bath dyed 100% acrylic fibre with 30-31 threads/cm in the warp and 14.5-15 threads/cm in the weft, weight 290-300 g/m². The awnings were tested in two positions, fully extended as far as the awning permitted, Figure 2.4, and partially extended so that the awning just shaded the window from direct sun, Figure 2.5. In all cases the pelmet (valance) of the awning had been removed to permit more uniform measurements. If a pelmet is used, it is reasonable to expect that transmittance will be further reduced. The tests described cover the period 24 May 1997 – 30 June 1997. The way the transmittance for the awning fabric varies with the angle of incidence of solar radiation was not studied in this first stage.

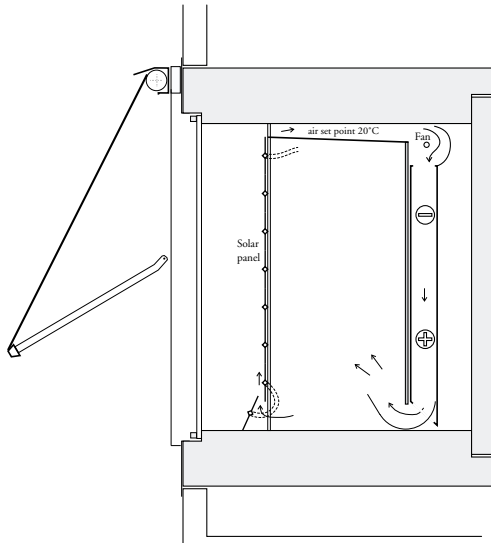


Figure 2.4 Fully extended awning.

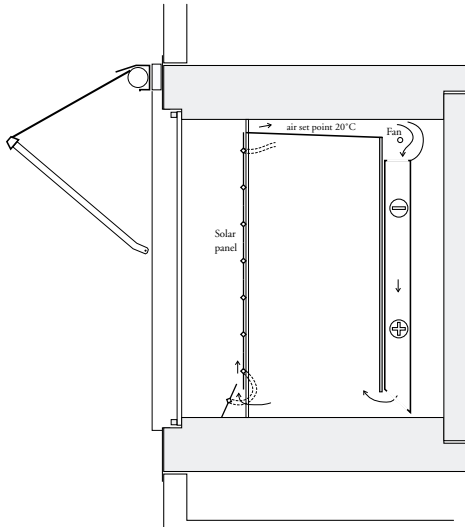


Figure 2.5 Box with awning partially extended. This means that the awning just shades the southerly window from direct sun at noon.

2.5.1 Fully extended awnings

Figure 2.6 illustrates measurement of the total system transmittance, g_{system} , for windows and fully extended awnings. As expected, the awning provides most shade in the middle of the day. During the morning and afternoon the awning does not shade the whole window. The minimum solar energy transmitted through the system is 12% with the dark awning and 26% with the light awning.

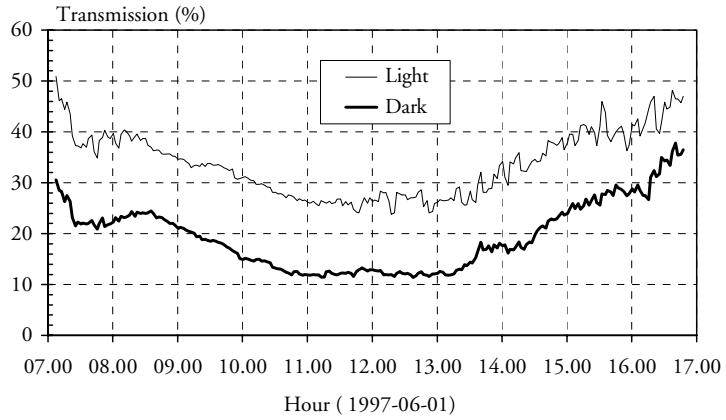


Figure 2.6 Total transmittance for the window system in combination with awning (g_{system}). The awning is fully extended, see Figure 2.4. Southerly orientation.

Figure 2.7 shows the transmittance for the awning, $g_{sunshade}$ for fully extended awnings. The curves had been measured on different days: 6.6.1997 and 7.6.1997. Conditions on these two days were however essentially the same, strong direct and weak diffuse solar radiation.

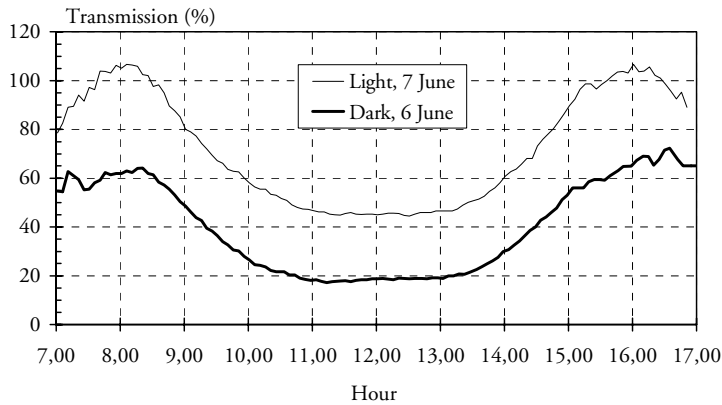


Figure 2.7 Total transmittance for the awning, $g_{sunshade}$ for fully extended awning. Southerly orientation.

The light awning transmits 2.5 times as much solar energy as the dark one, 45% against 18%. The difference is especially large in the early morning and evening when the light awning transmits over 100% in spite of being fully extended. The explanation may be that the fact that

the awning increases the sunlit area is more important than that the awning shades the window. Also, light from the facade may be reflected onto the underside of the awning and reflected further to the window.

2.5.2 Partially extended awnings

Figure 2.8 illustrates measurement of the total system transmittance, g_{system} , for windows with partially extended awnings, i.e. the awning just shades the window. The day when the measurements were made was not cloudless and the diffuse component of solar radiation was therefore at times strong, particularly during the morning and between 15.00 and 16.00 in the afternoon. Around noon, however, direct solar radiation was absolutely predominant. Because of diffuse radiation, transmittance increases: the awning shades diffuse solar radiation only partially, and diffuse solar radiation is not shaded by window embrasure and fixings.

The minimum solar energy transmitted through the system is 18% with the dark awning and 23% with the light one. The small difference between fully and partially extended awning is worth noting – refer to Figure 2.6. The explanation may be, according to the comment to Figure 2.7, that the fact that the awning increases the total sunlit area is as important as that the awning shades the window. Another point worth noting is that the difference in transmittance between light and dark awning is naturally less when the awning is only partially extended.

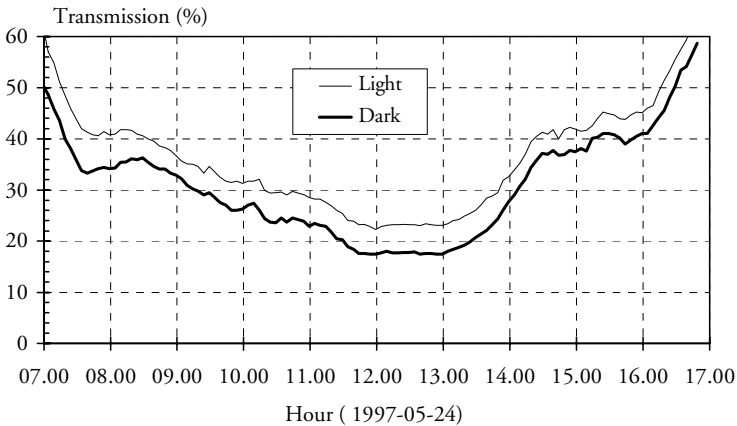


Figure 2.8 *Total system transmittance, g_{system} , for window in combination with partially extended awnings, when the awnings just shade the window. Southerly orientation. The day when the measurements were made was cloudy in the early morning and afternoon.*

Figure 2.9 shows transmittance for the awning, g_{sunshade} for the partially extended awning. The curves were measured on different days: 18.6.1997 and 30.6.1997. Conditions on these days were essentially the same.

The difference between the light and dark awning is much less in this case than when the awning is fully extended, see Figure 2.7. The light awning transmits 40% of solar radiation and the dark one at least 30%. The light awning therefore transmits approx. 30% more solar radiation than the dark one in the middle of the day. As before, in the early morning and during the afternoon the light awning transmits an extremely high amount of solar energy, even more than 100% in some cases. This suggests that the light awning acts as a solar collector on these occasions.

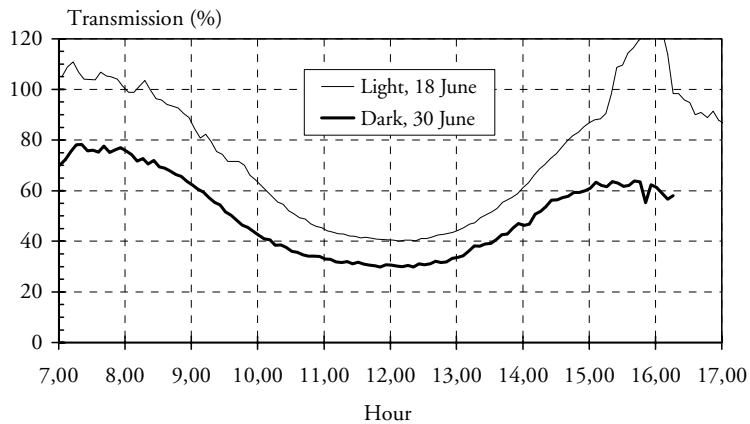


Figure 2.9 Total transmittance for awning, g_{sunshade} for partially extended awnings. Southerly orientation. The curves are measured on different days: 18.6.1997 and 30.6.1997.

2.6 External venetian blinds

Two different blinds were studied, one with 50 mm slats and the other with 80 mm slats. The blinds were silver coloured and were mounted outside the windows. The blinds were tested in two positions, fully lowered with the slats horizontal and fully lowered with the slats at 45° to the window. See Figure 2.10.

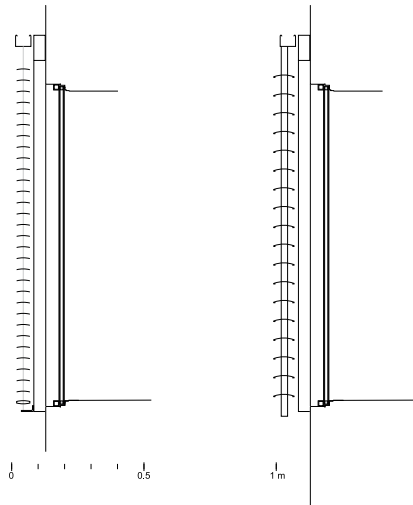


Figure 2.10 Windows with two types of external venetian blinds.

2.6.1 Blinds with horizontal slats

Figure 2.11 illustrates measurement of the total system transmittance, g_{system} , for windows and blinds with the slats horizontal. As expected, the blinds provide most shade in the middle of the day. In the early morning and evening the blind does not properly shade the whole window. The minimum solar energy transmitted through the system is 14% with the wider blind and 17% with the narrower one.

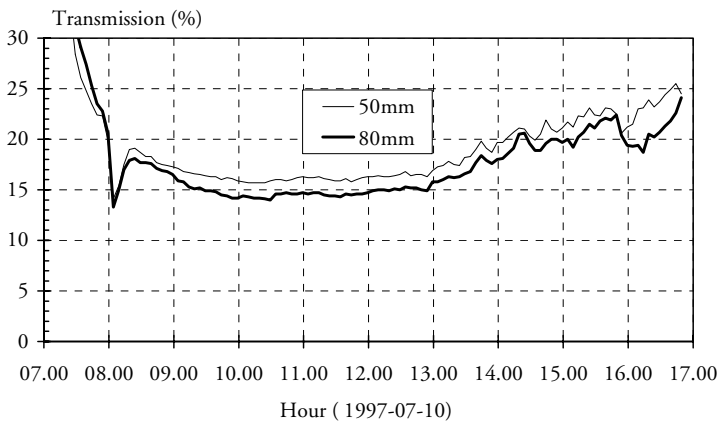


Figure 2.11 Total transmittance for system-venetian blind in combination with window (g_{system}). The blinds are fully lowered and the slats are horizontal. Southerly orientation.

Figure 2.12 shows the transmittance for the blind, g_{sunshade} for horizontal slats. The curves were measured on different days, 8.8.1997 and 30.7.1997. Conditions on these days were however essentially the same, strong direct solar radiation and weak diffuse radiation. Transmittance through the two blinds is almost the same, 25% and 28%.

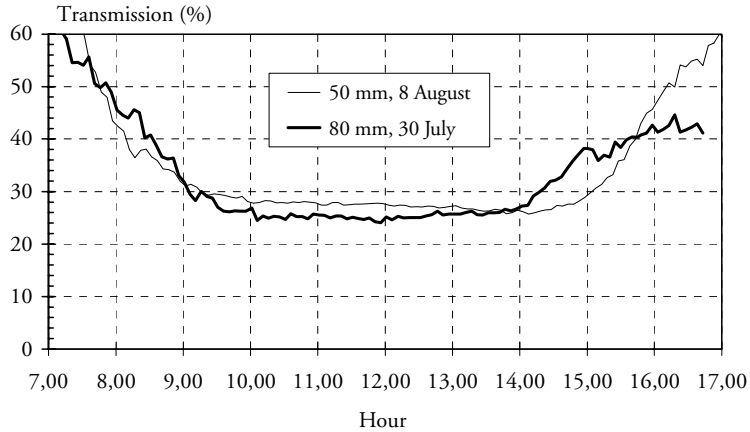


Figure 2.12 Total transmittance for blind, g_{sunshade} with horizontal slats. South-erly orientation.

2.6.2 Blinds with slats at 45°

Figure 2.13 illustrates measurement of the total system transmittance, g_{system} for windows and blinds with the slats at 45° to the window (the outer edge of slats point downwards).

The minimum solar energy transmitted through the system is 7% with 80 mm slats and 8% with 50 mm slats. Transmittance of solar radiation through the blinds with the slats at 45° is less than half that through the blinds with the slats horizontal.

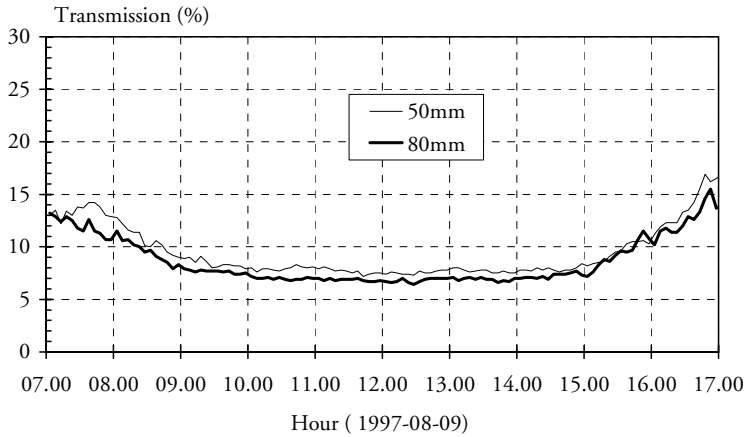


Figure 2.13 Total system transmittance, g_{system} for windows in combination with blinds with the slats at 45° to the window. Southerly orientation.

Figure 2.14 shows the transmittance, $g_{sunshade}$, for blinds with the slats at 45° to the window. The curves refer to measurements on different days, 14.8.1997 and 17.8.1997. The minimum transmittance with 80 mm slats is 13% and with 50 mm slats 15%.

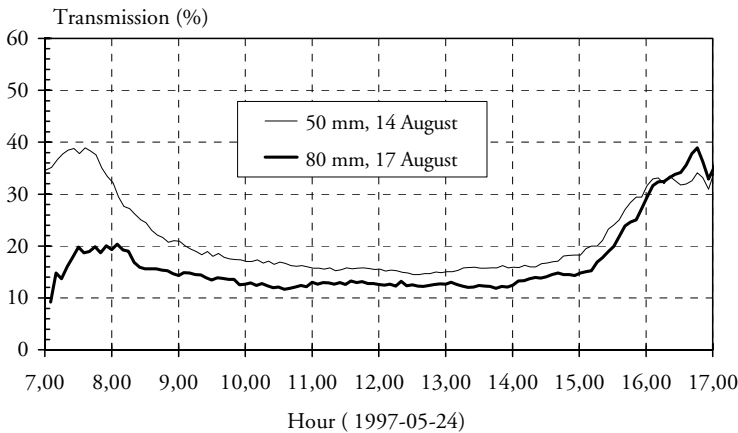


Figure 2.14 Total transmittance for blind, $g_{sunshade}$ with the slats at 45° to the window. Southerly orientation.

2.7 Italian awnings

The results relate to measurements on two Italian awnings: one with a light (beige, NCS 0502-Y) fabric and the other with a dark (dark blue, NCS 7030-R70B) fabric. The fabrics were spin bath dyed 100% acrylic fibre with 30-31 threads/cm in the warp and 14.5-15 threads/cm in the weft, weight 290-300 g/m². The Italian awnings were tested in two positions, fully extended as far as the awning permitted, and partially extended so that the arm of the awning was not extended and only the vertical portion was used. The test described covers the period 28.9.1997 – 14.10.1997.

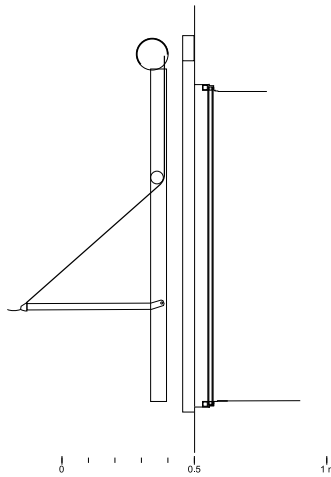


Figure 2.15 Window with Italian awnings.

2.7.1 Fully extended Italian awnings

Figure 2.16 illustrates measurement of the total system transmittance, g_{system} for windows and fully extended Italian awnings. As expected, the awning provides most shade in the middle of the day. During the morning and afternoon the awning does not shade the whole window. The minimum solar energy transmitted through the system with the dark fabric is 6% and with the light fabric 17%. Figure 2.17 shows the primary transmittance, $g_{sunshade}$, for the Italian awning. Measurements with awnings with the same fabric gave 40% and 30% transmittance. It is evident that the Italian awning covers a larger area of the window.

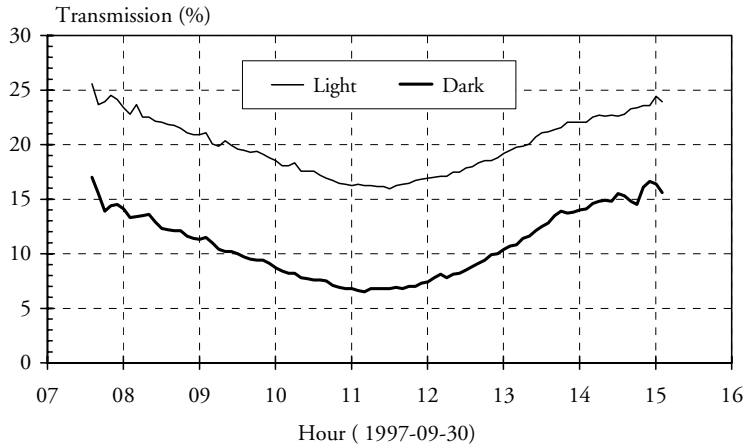


Figure 2.16 Total transmittance through system Italian awning in combination with window (g_{system}). The Italian awning is fully extended. Southerly orientation.

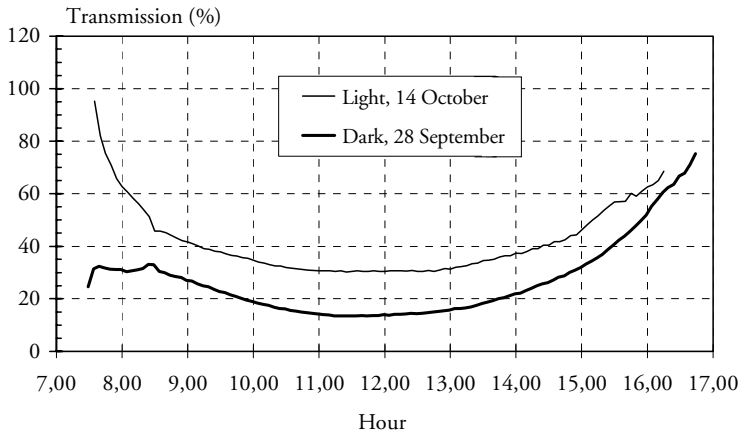


Figure 2.17 Total transmittance through Italian awning ($g_{sunshade}$). The Italian awning is fully extended. Southerly orientation.

2.7.2 Partially extended Italian awnings

Figure 2.18 illustrates measurement of the primary transmittance of the system, τ_{system} for windows and partially extended Italian awnings. Since the Italian awning has a vertical portion that affects its U-value, only the primary transmittance is reported here. Total transmittance is a few per

cent higher. Since half the window has no sunshade, the transmittance curve is very similar to that for an unshaded window. Figure 2.19 shows the transmittance through the Italian awning only. It is evident that the Italian awning fabrics have a lower dependence on angle of incidence than the window glass itself.

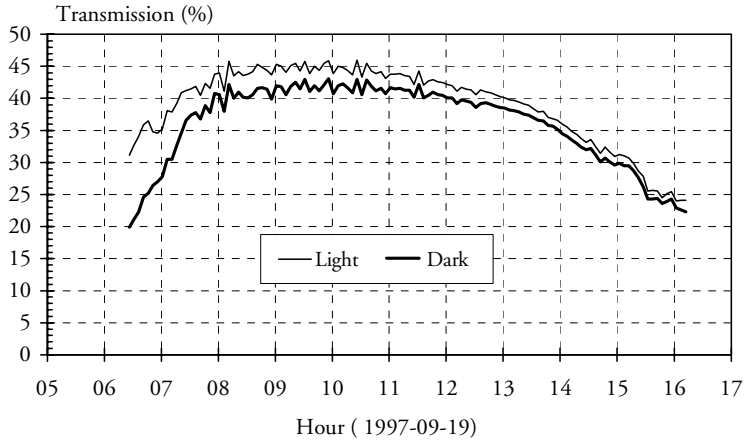


Figure 2.18 Primary transmittance for system Italian awning in combination with window (τ_{system}). The Italian awning is partially extended. Southerly orientation.

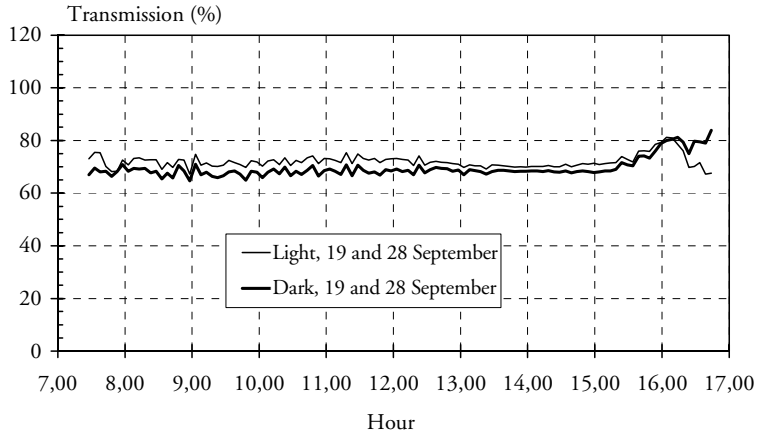


Figure 2.19 Primary transmittance for Italian awning (τ_{sunshade}). The Italian awning is partially extended. Southerly orientation.

2.8 Fabric screens

Three types of screen were tested: Hexel 21136 Satine Blanc 101, Sable 109 and Ferrari Soltis 92 1045. These were mounted immediately outside the window and covered its whole area. Tests in accordance with ASHRAE 74-73 gave the following values for the fabrics (optical readings based on perpendicular incidence):

Name in figures	Name	Transmittance	Absorption
Screen 1	21136 Blanc	27%	19%
Screen 2	21136 Sable	10%	54%
Screen 3	Soltis 92 1045	4%	71%

Figure 2.20 shows the primary transmittance of the system with the three screen types. As will be seen from Figure 2.21 which shows transmittance through the screens separately, the values given by these measurements are fairly near those from the ASHRAE measurements. The values from Screen 2 are perhaps slightly higher than expected. It is obvious that transmittance through the screens has very little dependence on angle of incidence.

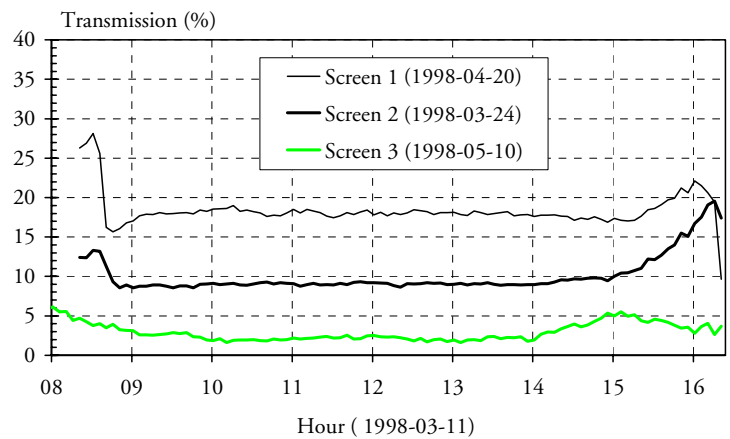


Figure 2.20 Primary transmittance for fabric screen in combination with window (τ_{system}). Southerly orientation.

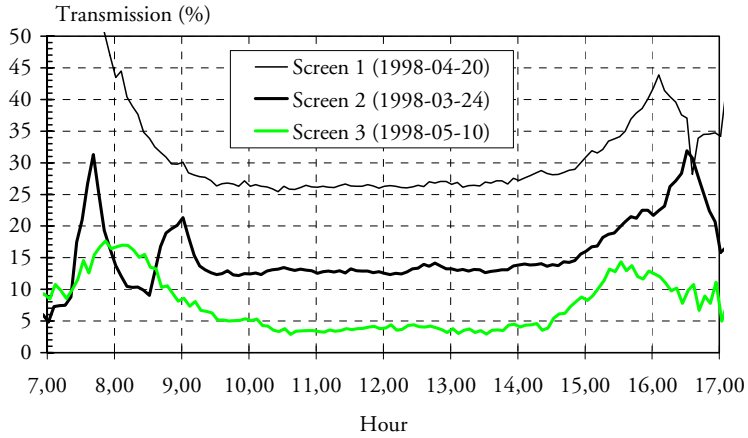


Figure 2.21 Primary transmittance for fabric screen only (τ_{sunshade}). Southerly orientation.

2.9 Horizontal slatted baffle

An aluminium horizontal slatted baffle was evaluated. Figure 2.22 shows the way the slatted baffle was mounted. However, the projection of the slatted baffle from the facade is extreme, and this must therefore be considered as an illustration of maximum shading and not as a practical proposition.

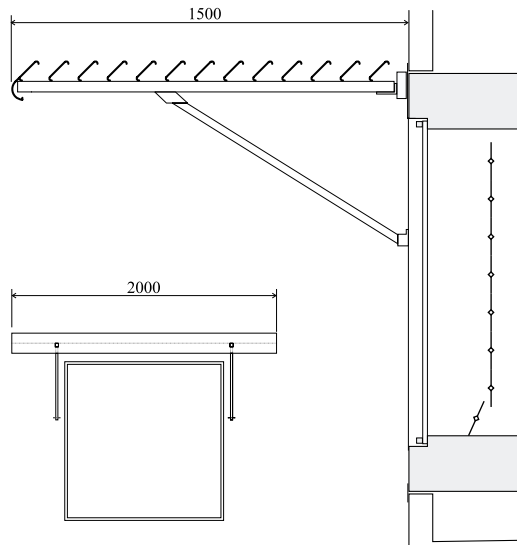


Figure 2.22 Box with horizontal slatted baffle.

The results are shown in Figure 2.23 – 2.24. The minimum solar energy transmitted through the system is 14% and through the slatted baffle on its own approx. 23%.

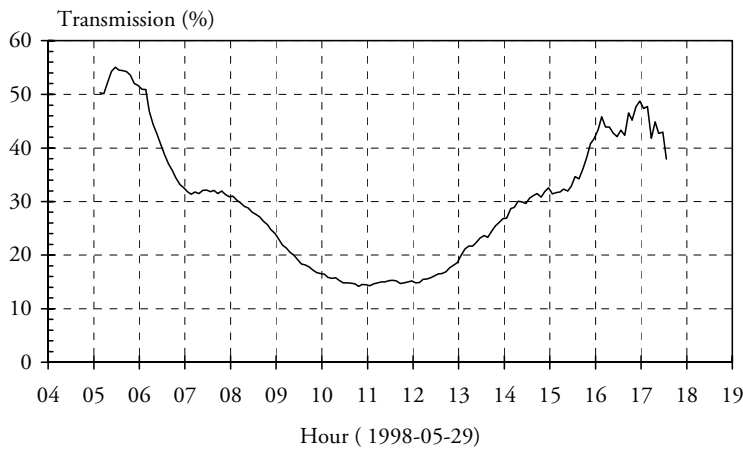


Figure 2.23 Total system transmittance for horizontal slatted baffle in combination with window (g_{system}). Southerly orientation.

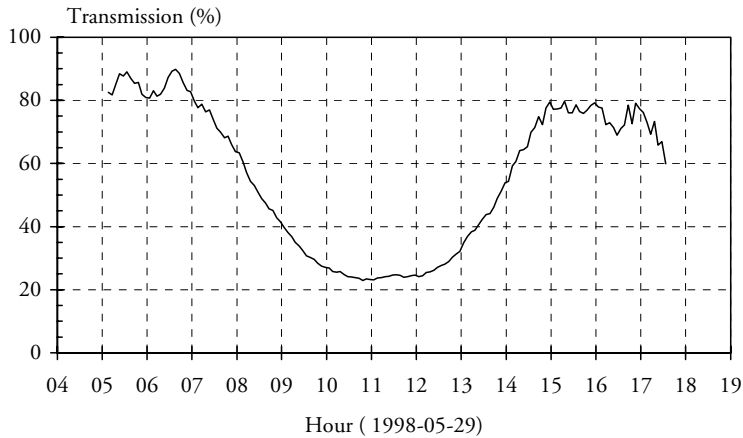


Figure 2.24 Total transmittance through horizontal slatted baffle ($g_{sunshade}$). Southerly orientation.

2.10 Roller shutters

Two types of roller shutters were tested. In both cases the roller shutters were set in the position where they are “open”, i.e. there is a little gap between slats. In spite of this only very little transmittance could be measured. In view of the measuring accuracy of $\pm 1\%$, the difference between the roller shutters is not significant.

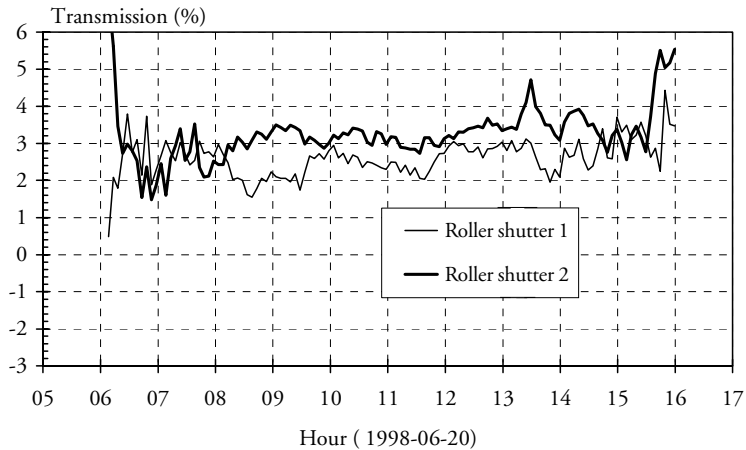


Figure 2.25 Total system transmittance for roller shutters in combination with window (g_{system}). Southerly orientation.

2.11 Solar control films

Two different solar control films were tested. The films were glued directly to the outside of the sealed unit. The primary transmittance of the system is shown in Figure 2.26. Owing to the bad weather during the measurement period, the curves are not very smooth. From Figure 2.27 it is evident that it is the window that exhibits the essential dependence on angle of incidence. In this case simulation of the film + glass must be modelled as a pane of glass of special properties.

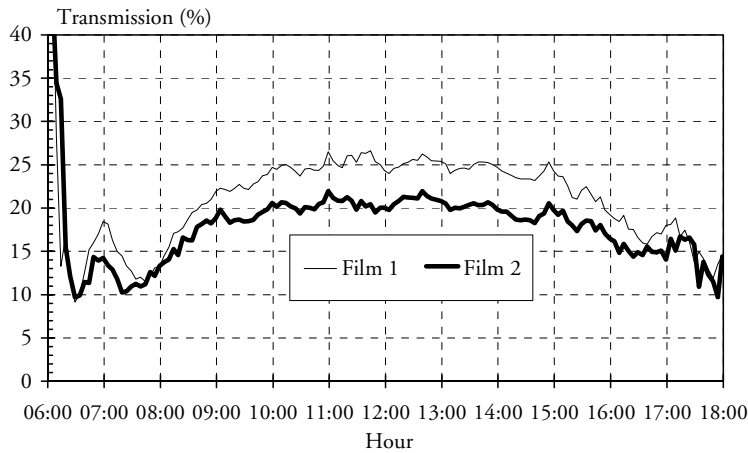


Figure 2.26 Total transmittance for the system film in combination with window (g_{system}). Southerly orientation.

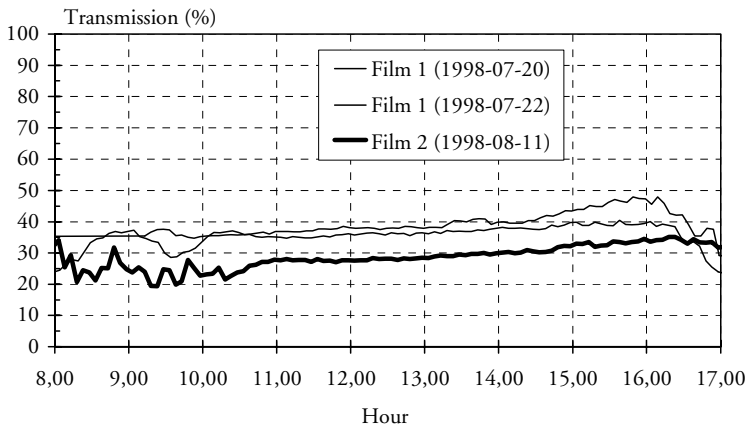


Figure 2.27 Total transmittance for film ($g_{sunshade}$). Southerly orientation.

2.12 Summary

A method has been proposed for measuring solar transmittance through window and sunshade. The method is based on calorimetric measurement where the heat input, cooling input and differences in temperature between measuring box and the surroundings are used in calculating the total and primary transmitted solar energy. The windows and sunshades were

mounted in a southerly facade and were exposed to the external climate. The estimated maximum measuring error was $\pm 5\%$ of the calculated transmittance, but was not less than $\pm 1\%$. The sunshades studied were

- two awnings
- two external venetian blinds
- two Italian awnings
- one horizontal slatted baffle
- three fabric screens
- two roller shutters
- two solar control films

The advantage of the method described was that the sunshades could be studied in a real climate. The drawback was that two different measurements cannot be compared directly since climate and solar altitude are different.

3 Solar laboratory

Håkan Håkansson

3.1 Objective

A solar simulation installation has been constructed at the Department so that solar transmission for sunshades and/or windows may be measured in a more standardised manner. Measurements can then be made for different angles of incidence and not only for those that are encountered outdoors in Lund. Due to restrictions of room height, the maximum obtainable solar altitude is 72° which corresponds to the latitude of Rome.

It is a special feature of this solar simulation installation that special efforts have been made to ensure that the incident beam of light is as parallel as possible. One of the reasons for this is to make it possible for measurements to be made on sunshades, which project outwards from the window. If divergent light is used in such a case, the shadow is enlarged and this yields an erroneous reading.

Solar simulation is carried out at full scale to make conditions as realistic as possible. In any case, it is almost impossible for most sunshades to be scaled down. The fact that the simulated irradiance is very near that of the sun also contributes to realistic conditions.

In designing the solar simulation installation, flexibility was one of the key aims. Several of the components of the window boxes and peripheral equipment are of modular construction. One example is that window boxes similar to those used for solar simulation are also designed for measurements outdoors. Another example is that it must be possible for more than one lamp cluster to be used for the same reflector arrangement.

3.2 Description of the solar simulator components

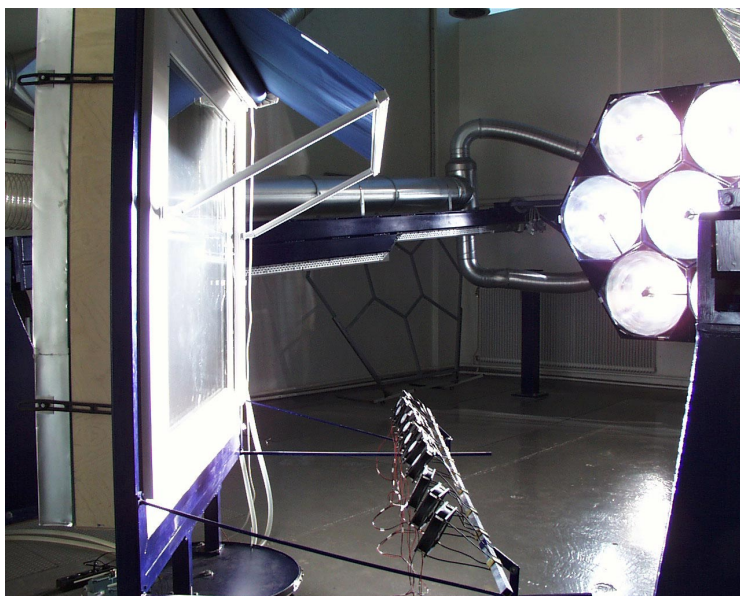


Figure 3.1 Solar laboratory with lamp cluster and box for calorimetric measurement on window with sunshade mounted.

3.2.1 Generation of angles

The horizontal angle between the sun and the facade, which results from solar azimuth and facade orientation is generated by making the object of measurement rotatable about a vertical axis. The angle of the sun above the horizon, the solar altitude, is generated by mounting the entire lamp arrangement on two moving arms. Both these angles are rotated about a point situated in the centre of the window opening. Since the studied window is kept vertical at all times, the flow pattern of air at boundary surfaces and in gaps is not changed in comparison with the window that is simulated. Windows and glazed units of a different inclination can also be studied.

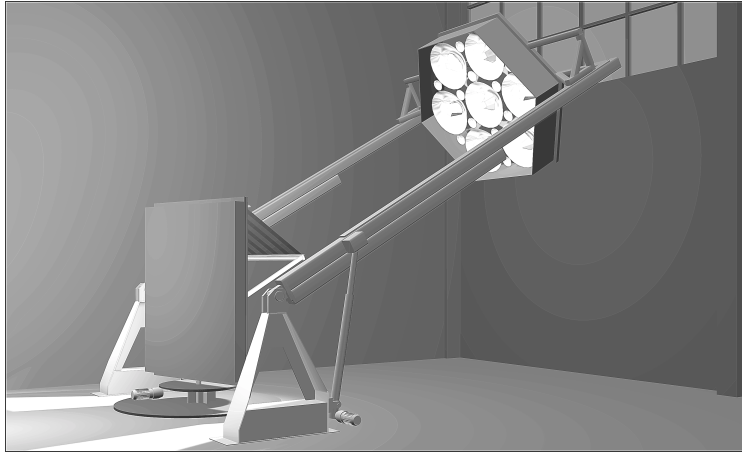


Figure 3.2 Box for calorimetric measurement, movable in the horizontal direction, with stand for radiation source that is movable in the vertical direction.

3.2.2 Properties of the reflector arrangement

All possible radiation sources for solar simulation are, on the whole, omnidirectional. In order to make the light parallel, it must be collected with a reflector or lens. We have decided to use reflectors.

In practice, no light source is a point source. The arc in a gas discharge lamp has a certain length, and the same holds for a filament. The emission from a unit area of filament has an absolute physical limitation due to the maximum possible temperature of the tungsten wire, and similar limitations apply for other light sources. The degree to which the primary radiation source approximates to a point source determines how parallel the light can be made. In order to make light as parallel as possible, the focal length of the reflector must be large in relation to the length of the primary light source. This makes for large reflector dimensions, especially if the least possible light is to be spilled (a reflector that is deeper in relative terms collects a larger solid angle of the light from the lamp, but has a shorter focal length). Because of all this, a large proportion of the radiant surface must consist of reflectors for an optimum result. We have decided to have a honeycomb pattern with seven large lamps. In the unused spaces between the large reflectors, lamps with smaller reflectors can if necessary be placed to complement the spectra of the seven large lamps.

One special problem is how to deal with the light that does not fall on the reflectors and has not the desired angle. In our case the seven large lamps are fitted with a smaller reflector which throws this light back into

focus in the lamp so that it is directed towards the large reflector. By applying the principle of using a secondary reflector, the spill light trap around the reflectors need not be made so deep, and a more distinct cut off angle is obtained.

The large reflectors are mounted on a separate loadbearing frame. A smaller frame which holds the lamps is attached to this frame. This smaller frame is interchangeable so that other lamps can be used in combination with the large reflectors. In this way it is possible to run tests with different light sources but with the same reflectors.

With parallel light, the cross section of the radiant surface is the same size as the surface illuminated by the lamp cluster, which, in turn, determines the size of the test object on which measurements can be made. In our solar simulator the radiant surface is a hexagon with a height dimension of approx. 2.3 m in the lamp arrangement chosen. For an ideal source with parallel light the distance between the radiant surface and the test object is of no significance, irradiance will be the same. In practice, the irradiance along the edges of the illuminated surface is weakened to different degrees depending on the distance. Placing the lamps near the object reduces this effect but instead increases the patchiness of the relative candlepower distribution which is caused by the variability of light emission from the various surfaces in the reflector arrangement. The distance between the lamps and the test object is therefore adjustable so that alternative distances can be used.

3.2.3 Primary light sources

Two lamp arrangements are planned. One arrangement with metal halide lamps is available. The other arrangement is a combination of lamps and has not yet been made.

Lamp arrangement No 1

The first lamp arrangement comprises seven 2.5 kW Philips discharge lamps. This model is called MSR by the manufacturer, which denotes Metal halide Short arc Rare earth. In conventional metal halide lamps some of the radiant energy is concentrated in narrow wavebands, but since this lamp contains a large number of metals the spectrum is somewhat more uniform. See Figure 3.3. Colour rendering stability during the life of the lamp is also favourable and this, together with a concentrated arc and facilities for power regulation, makes the lamp well suited for solar simulation. The thin dotted line in the UV region in the figure delineates

the spectrum without the filter that is mounted to remove harmful radiation. Measurements have not yet been made in the laboratory for the wavelength region $> 0.78 \text{ mm}$.

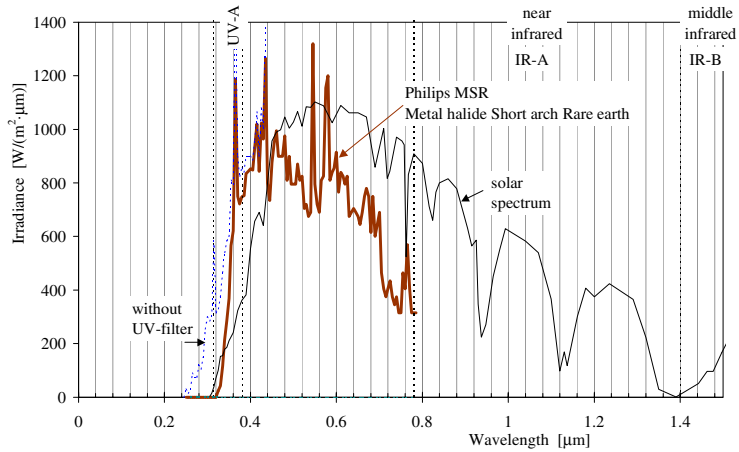


Figure 3.3 Spectrum for Philips MSR metal halide lamp (with UV filter) compared with the solar spectrum.

As will be seen, UV-A and blue light are over represented compared with the solar spectrum.

Lamp arrangement No 2

The second lamp arrangement comprises three radiant sources, which together deliver a spectrum free from the concentration to narrow bands which discharge lamps produce to varying degrees. This is achieved by a new type of lamp, a sulphur plasma lamp, and two types of filament lamps of halogen type with and without a dichroic mirror. Each of the three light sources dominates its own wavelength region, and it is thus possible to measure each light source individually and in this way to obtain more information on the wavelength dependence of the thermal properties of the test object's components.

The principle of the sulphur plasma lamp has been patented and the manufacturer has decided to suspend delivery temporarily until a new generation of lamps has been developed. We have therefore not yet been able to obtain the lamps for the second arrangement.

The sulphur plasma lamp comprises a bulb of vitreous silica which is filled with argon and a certain quantity of sulphur. Plasma discharge in the bulb is fed by an electromagnetic field of microwave frequency, which

is generated in the lamp. The diameter of the bulb is approx. 30 mm and it is supplied with 1 kW microwave energy. The bulb is both rotated and cooled by an air jet to prevent overheating. The spectrum of the sulphur plasma lamp is very uniform and the radiant energy is delivered almost exclusively in the visible region. Comparisons with the sensitivity of the eye can be made in Figure 3.4. One great advantage of the sulphur plasma lamp is that it is very stable over time and has a very long life. The reason is that no electrodes which can age are used.

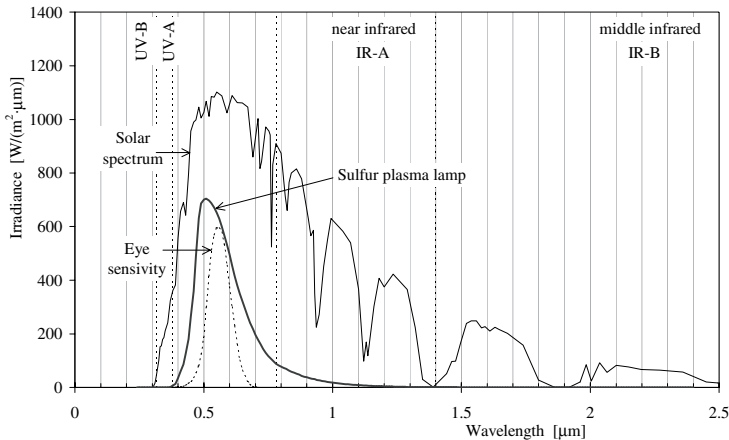


Figure 3.4 Spectrum of sulphur plasma lamp.

A tungsten filament produces a unique spectrum which only varies with the filament temperature. An example of such a spectrum is shown in Figure 3.6. In contrast, in a reflector lamp the spectrum of the light in the forward direction can be altered by making the reflector selectively transparent to certain wavelengths. The spectrum of such a lamp is illustrated in Figure 3.5. It is the same type as an ordinary low voltage halogen spotlight for the consumer market but is of higher rating. Such a dichroic mirror is made by vaporising on the glass bulb coats of specific thicknesses and different refractive indices.

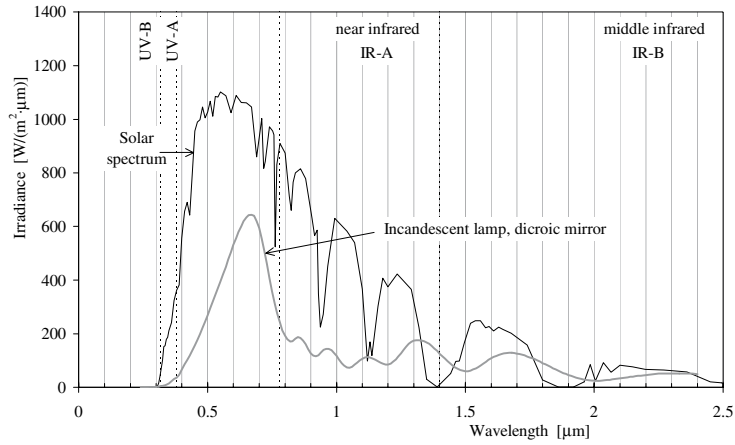


Figure 3.5 *Spectrum of Philips 13117 dichroic mirror lamp.*

The radiation source which generates the component of the longest wavelength consists of a low voltage halogen lamp of 400 W mounted in a separate aluminium reflector of 200 mm diameter. The spectrum of this is shown in Figure 3.6.

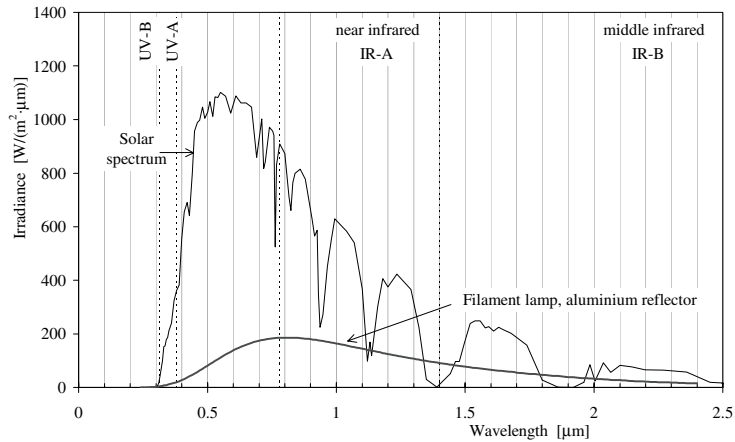


Figure 3.6. *Spectrum of a lamp of 3300 K colour temperature.*

The resultant spectrum of the three radiation sources is shown in Figure 3.7.

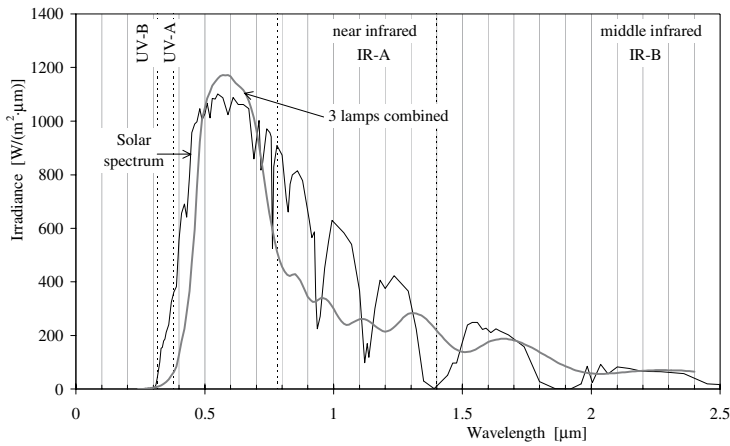


Figure 3.7 Example of spectrum where a sulphur plasma lamp, a dichroic mirror lamp and a lamp with aluminium reflector are combined.

3.2.4 Calorimeter box

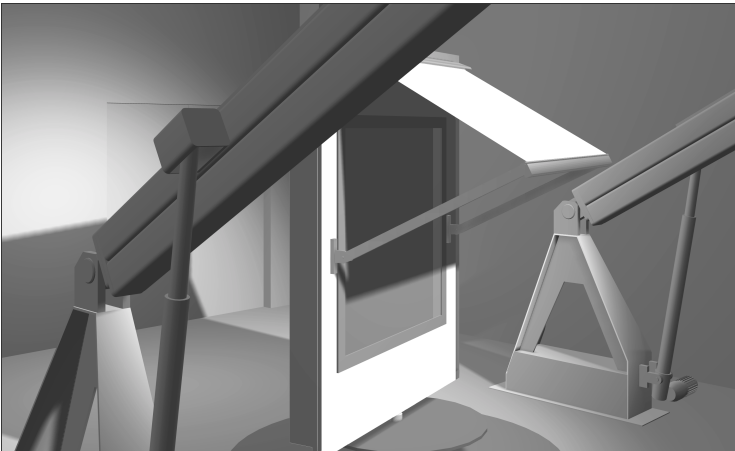


Figure 3.8 Measuring box with sunshade mounted.

Figure 3.8 shows the principle of the measuring box illuminated by the lamp arrangement.

The exploded drawing in Figure 3.9 shows the object of measurement mounted on a calorimeter box. Radiant energy is absorbed by a black painted calorimeter plate behind the window. The calorimeter plate is

cooled over its whole surface and it is placed near the window. The measuring situation is well defined since there are no secondary uncooled surfaces which are heated to excessive temperature.

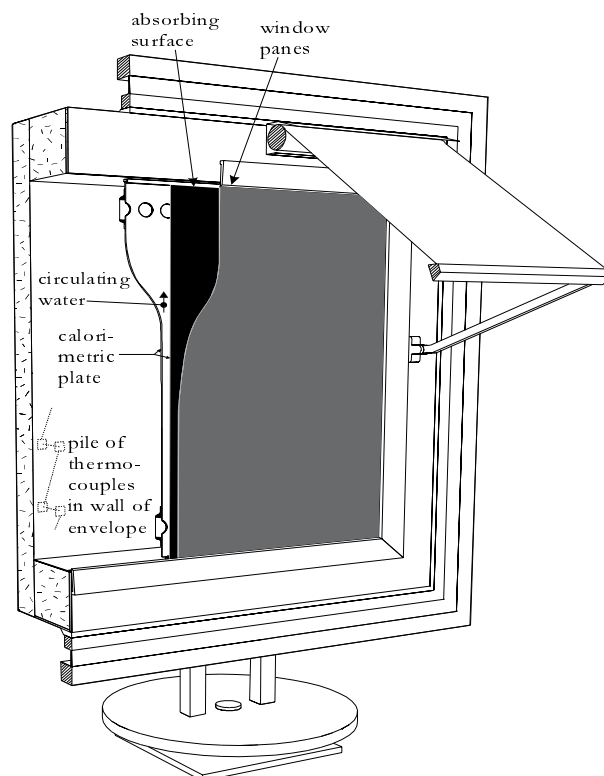


Figure 3.9 Exploded drawing of calorimeter box with calorimeter plate, window and sunshade.

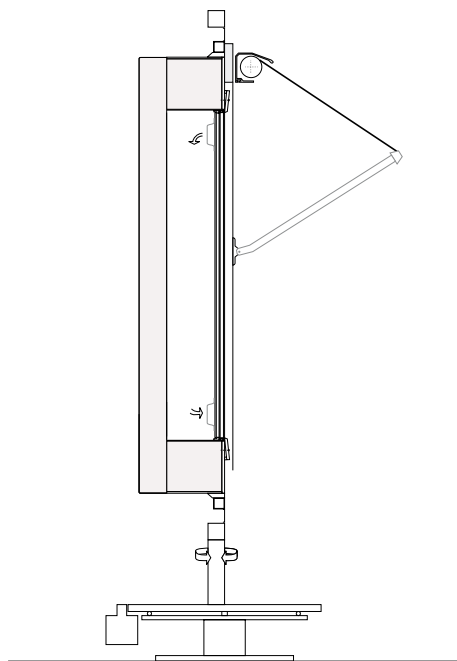


Figure 3.10 Section of calorimeter box.

The calorimeter box has a core of extruded EPX styrofoam plastic. The rear cover is a sandwich construction of 100 mm extruded plastic with a surface layer of 0.5 mm aluminium sheeting. The inner plate covers only the area that abuts on the inside volume so as to avoid thermal bridges. The whole is fitted into a frame with an extruded plastic core. The front surface of the frame consists of 10 mm plywood. The inner surface is made of only 3 mm plywood to keep down the thermal mass. On this plywood a wood frame is glued which acts as the rebate for the glazed unit and at the same time keeps the calorimeter plate at the correct distance from the glass. The inner sheet of plywood is not in contact with the front sheet in order to avoid thermal bridges. The window package is separated from the front of the facade by a wooden lining. This lining frame is screwed to reinforced fixings of Ø 12 mm wooden blocks which are glued to the extruded plastic core. In turn, the frame is permanently fixed to a reinforcing frame of rectangular steel hollow section. In this reinforcing frame the calorimeter box can be fixed to the rotatable holder.

A pump constantly circulates water through the coil in the measuring plate. The high rate of flow can be measured with a flowmeter that has good accuracy in this range. The difference in temperature is small but it can nevertheless be measured with very high accuracy with a thermo-pile comprising many pairs of thermocouples (in this case ten pairs).

The thermocouples are made of $\varnothing$ 0.08 mm thermocouple wire which is protected by being glued between two 0.1 mm sheets of glass (microscope cover slide). The sheets made in this way are mounted in longitudinal slots in two tubes. External disturbances to temperature measurement are negligible since thermal conduction along the approx. 0.3 mm thick sheets (radially in the tube) is low compared with the convective surface coefficient of heat transfer at the surfaces of the sheets which are exposed to the flowing water. The output voltage from the difference temperature measurement is therefore exclusively determined by the number of thermocouple pairs and the Seebeck constant of the thermo-couples. The difference temperature sensor need not necessarily be calibrated and can therefore be replaced without calibration.

The calorimeter plate is made of two aluminium sheets which are glued together with spacers so that a gap is created. This gap is in direct communication with (horizontal) distribution ducts at the top and bottom through large holes in the rear sheet. See Figure 3.9.

The distance between the front and rear sheets can be made small without resistance becoming too high in the flow configuration used. The total mass of water is of the order of 8 kg in that part of the loop on which the difference temperature measurement is made in the calorimeter box. Owing to the low thermal inertia, rapid measurements can be made with accuracy maintained. The thermal inertia of the material that holds together the calorimeter box and calorimeter plate within the extruded plastic shell is limited to an absolute minimum by using lightweight surface material on a core of extruded plastic.

In the water circuit inside the calorimeter box there is a heater consisting of a heating element surrounded by a silicon rubber tube. The heater is used for calibration and to supply a constant background heat when regulation of the temperature in the box is to be started without solar heat.

In the walls of the box thermopiles are placed in order to measure the flow of heat due to any difference in temperature that might arise between the inside of the box and the surroundings. Two-dimensional heat flow calculations have been made, and each of the 20 pairs of thermocouples represents an equal proportion of the total heat flow. If possible, they have been placed at the correct position for their representative heat flows. In this way, the temperature over the surface of the shell of the box may

vary and a good measure of the total heat flow through the walls of the box can nevertheless be obtained through one single reading from the series-coupled thermopiles. Temperatures on the illuminated surfaces of the box can be expected to be higher.

3.2.5 Cooling and regulation

Temperatures at the inlet and outlet of the calorimeter plate are measured separately with fast sensors. The two temperatures are weighted and controlled according to the PID principle so that stable regulation is attained. This weighted temperature is a measure of the mean temperature of the plate. If it can be kept constant, disturbance due to the thermal inertia of the calorimeter plate is equal to zero.

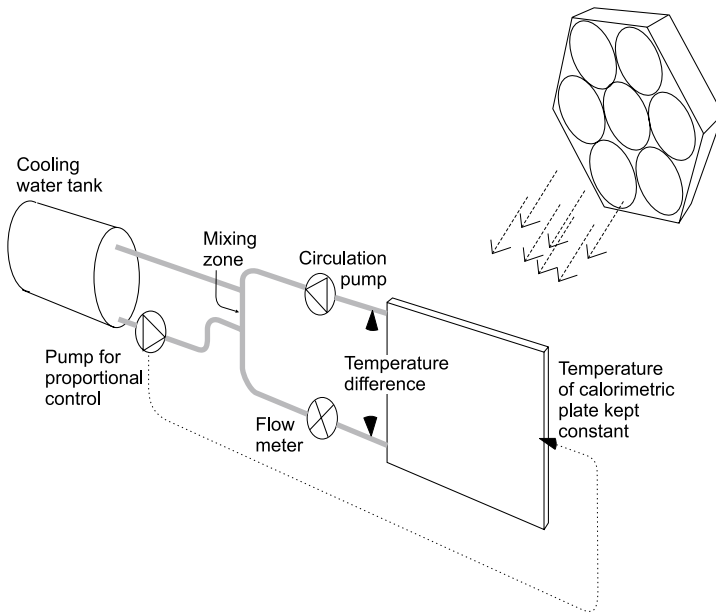


Figure 3.11 Schematic illustration of the cooling, temperature control and energy measurement of the calorimeter plate.

A control flow with cooling water is regulated by a pump and is connected to the loop described above. The pump is provided with a direct current permanent magnet motor. The loop flows through the calorimeter plate and has a constant high rate of water flow. See Figure 3.11. The principle of regulation with a permanent magnet motor has worked well in the

twin boxes in this project. In principle, rate of water flow varies linearly with the voltage applied to the motor. The connection to the loop must be such that the high rate of flow through the calorimeter plate does not induce flow in the control flow. Natural convection is prevented by supplying the warmer water from the calorimeter plate into the mixing zone from the top.

Water without additives is used as medium. A well defined, stable heat capacity is achieved, and work with water is easy and work environmental is good. The tests must however be limited to temperatures above $+5^{\circ}\text{C}$. The cooling tank is constructed as a closed stainless steel container of 315 l volume. The cooling system is illustrated in Figure 3.12. A compressor with a coaxial evaporator of ca 2 kW rating is used. A pump with filter forces water through a coaxial evaporator during the time the compressor is working. The coaxial evaporator is fitted with a frost protection device that is wired so that the compressor starts up when the temperature rises. The cooled water is discharged at the bottom of the tank so as to maintain the stratification that arises when the water from the calorimeter plate is discharged at the top of the tank. The temperature sensor for the compressor is installed in a tube so that its position can be adjusted vertically. The system is fitted with a small transparent expansion vessel.

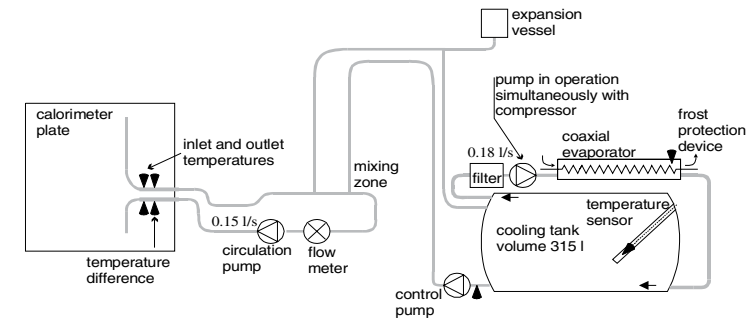


Figure 3.12 General arrangement of cooling system

3.2.6 Simulation of surface resistance

The flat calorimeter plate is placed 8 mm behind the surface of the rear pane of glass. This makes for a very well defined surface resistance with a value that is usually assumed for the internal surface resistance. The surface resistance is uniform over the entire area since only negligible convection occurs in such a narrow gap.

In indoor measurements, the surface resistance at the front which must be similar to the external surface resistance is created by a row of ten small axial fans which form a linear source that is directed towards the window from underneath. The fans are adjustable and are mounted on a bar with brackets, and rotate with the window so that the same angle of incidence is maintained. The total convective surface resistance thus obtained over the whole surface of the window can be determined by a special measurement without simulated solar radiation but with excess temperature in the box. Distribution over the surface can be controlled with a convective flowmeter that is traversed over the surface. The fan motors are brushless DC motors, which are controlled collectively by a variable voltage supply. The nominal rating of a fan is 24V 5W, 170 m³/h, but a lower voltage is used.

3.3 Measuring procedure and calibration

3.3.1 Measuring sequence with fixed angles

Figure 3.13 sets out a proposal for measurement positions, with six horizontal angles combined with five vertical angles. These steps at 15° intervals give 30 positions. It is envisaged that measurements will be made so that final registration of readings is made only after steady conditions had been attained at each position. This stabilisation time can be calculated theoretically and controlled with the results of preliminary measurements by a special measuring routine. The order of measurements between the different positions, as indicated by the arrows in the figure, should be such that there are no excessive changes between angles of incidence and thus in the energy flow. When the results of measurements are to be used for intermediate values or plotted in a diagram, some kind of algorithm must be used for interpolation.

Solar Altitude	Horizontal angle					
	0°	15°	30°	45°	60°	75°
60°	60.0° ↑	→ 61.1°	→ 64.3°	→ 69.3°	→ 75.5°	→ 82.6° ↓
45°	45.0°	← 46.9°	← 52.2°	← 60.0°	← 69.3° ↑	← 79.5° ↓
30°	30.0° ↑	→ 33.2°	→ 41.4°	→ 52.2°	→ 64.3°	→ 77.0° ↓
15°	15.0°	← 21.1°	← 33.2°	← 46.9°	← 61.1° ↑	← 75.5° ↓
0°	0.0°	→ 15.0°	→ 30.0°	→ 45.0°	→ 60.0°	→ 75.0° ↓
Angle of incidence 0° = perpendicular incidence						

Figure 3.13 Example of measurement scheme for a combination of horizontal and vertical angles, showing the resulting angles of incidence towards the window.

3.3.2 Measurement for a simulated ecliptic

In the computer that drives the solar simulation installation there is a program for simulating ecliptics. The input data for this simulation are the local latitude, the time of year, window orientation and the desired time scale between simulation and real time. The program starts at sunrise.

3.3.3 Total solar energy transmittance

The total solar energy transmittance (solar heat gain coefficient) is defined as that part of solar energy which provides heat for the volume situated behind. See also Chapter 2. It therefore comprises both the directly transmitted solar energy and that part of the absorbed solar energy which is transferred inwards. The test setup thus measures the same energy as that according to the definition. A minor correction should however be made as the absorber surface cannot be made ideally black.

The value of the incident solar energy is measured with a solarimeter which measures short wave radiation. Since the simulated solar radiation cannot be produced entirely uniformly, the solar energy must be measured at many points and integrated over the surface.

3.3.4 Relative measurements, shading coefficient

In the solar protection project two almost identical measuring boxes, twin boxes, are used. The boxes are exposed to the same climatic conditions simultaneously, and owing to this measuring principle the relative differences between two setups, e.g. a window with and a window without a sunshade, are obtained with a high degree of accuracy. The ratio of the total energy absorbed in the case with sunshade to that absorbed without sunshade can in this way be determined with a high degree of accuracy. This ratio is denoted shading coefficient and is described in Section 2.2.

When solar radiation is simulated in the laboratory, the simulated climatic conditions are repeatable and it is possible to make relative comparisons by performing two identical runs with two different setups. On the other hand, a certain degree of non-uniformity of the relative candlepower distribution is unavoidable when solar radiation is simulated. By making a run as reference without a sunshade, the proportion of the radiant energy over the illuminated surface which is absorbed through the window at different angles is determined. The subsequent run with a sunshade at the same angles then produces a good relative measurement in spite of some patchiness, because of which the light falling on the window opening varies in extent when the angles are altered. But even in this case, as in the twin box method, good accuracy can be achieved in calculating a shading coefficient.

3.3.5 Measurement of temperature in a solar radiation environment

For accurate measurement of temperatures in a solar and thermal radiation environment during solar simulation, very thin thermocouple wires (0.08 mm) are used. The copper wire adjacent to the junction that measures temperature is silver-plated. We have had favourable experience of these temperature sensors in e.g. outdoor measurements in the twin boxes where the same temperature sensors were used.

The thermocouple wires for measurement on glass surfaces are glued with a UV curing glass adhesive beneath a 0.1 mm thick microscope cover slide. In this way good thermal contact is achieved with the underlying glass, and at the same time the emissivity for long wave thermal radiation over the surface is still equal to that for glass. The surface at the point of temperature measurement is kept flat and its projection outside the surface of the pane of glass is negligible.

In the solar protection project a method has been devised for indirect measurement of the convective surface coefficient of heat transfer and the convective heat flow. These two unknown quantities have been calculated from measured quantities. One is the temperature difference between two different layers of air near the glass at different distances from the surface. The other quantity is the total difference between the temperatures of the glass and the air. A perspective sketch of the principal arrangement is shown in Figure 3.14. The one used has two pairs of thermocouples. The framework supporting the thermocouples is made of narrow pieces of glass glued together so that measurements may be possible under light conditions and together with thermal measurements, without interference being particularly large.

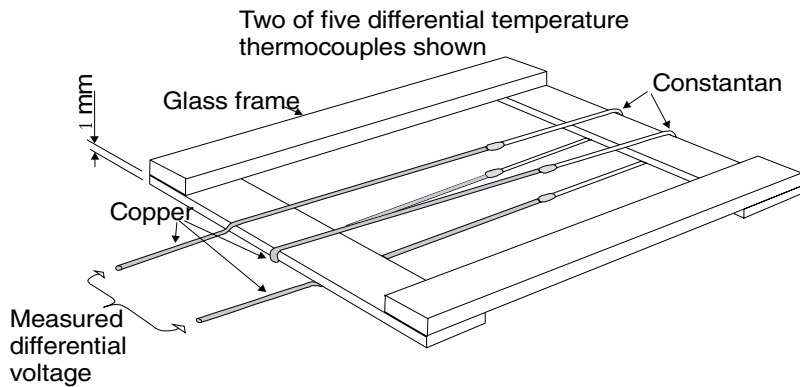


Figure 3.14 *Measurement of temperature difference between two levels in the boundary layer near a surface.*

We intend to make measurements of the convective surface coefficient of heat transfer with this method, in order that the controllable fans may be set in such a way that a repeatable standard value is obtained for surface heat transfer at the outer glass surface, and so that distribution over the surface is as uniform as possible.

Errors in measurement due to the influence of solar radiation on the measurement of air temperature are described in Wallentén (1998). With this method the measured temperature was elevated only approx. 0.2°C when the surface was lit by sun. In the report, measurement of convective heat transfer with an arrangement similar to that in Figure 3.14 is also evaluated. The results are in good agreement even when the sun is shin-

ing. This applies for natural convection in a normal room. When the arrangement is placed outside the window, the results are not so good since wind occasionally reduces the flickness of the boundary layer of stationary air at the surface is often thin when there is wind.

3.3.6 Calibration

In the same way as at the twin boxes, the box for solar simulation measurements is equipped with an electric heater for calibration. The input power is measured, as at the twin boxes, with an electronic energy meter with a pulse output. Heat energy from the box is determined by means of flow measurement and measurement of the temperature difference in the water circuit. The object of calibration is to check that the correct results are obtained. By supplying the box with excess temperature, the thermopiles which measure heat flow in the walls of the box can also be calibrated.

Comparative measurements between outdoor measurements and solar simulation are in progress. During the autumn of 2000 comprehensive calibrations have been performed and the installation will be put into service during February 2001.

4 Calculation models

Kurt Källblad (4.1 – 4.5)

Petter Wallentén (4.6)

On several occasions it is necessary to calculate indoor climate, comfort, total energy use and peak loads for the heating and cooling of buildings. The following examples may be mentioned:

- When solar protection is designed for both new and existing buildings, it is essential to have the means of calculating the effect this will have before costly investments are made.
- Measurements can usually be made only to a limited extent. In order that the results of measurements may be generalised, good calculation methods are needed which can take account of different types of sunshades, building layouts, climate etc.
- When sunshades are developed, calculations can be made to study the influence of different properties and thus arrive at new ideas as to how the sunshade should be designed.

In many cases it is also necessary to be able to make relevant calculations. In order that the energy balance of a building may be estimated with reasonable accuracy, it is however necessary to have calculation methods which can take into account the different thermal properties of a building in detail. This means that relatively comprehensive computer programs must be used.

Several computer programs of this type have been developed over the past decades. Examples that can be mentioned are DOE from USA, ESP from UK and TSBI from Denmark. At our own department the programs JULOTTA and DEROB-LTH have been used in a number of research projects. JULOTTA was fully developed at the department, while DEROB-LTH originally comes from USA but has over the years been developed in our department.

In various research projects it is very usual that new needs arise which place new demands on the calculation programs used. This means that one must have access to the source code so that the development of the

program may be carried out. Within the solar protection project it has been decided to develop DEROB-LTH to meet the new needs. This decision has been mainly due to the fact that the calculations are based on a geometric model with relatively user friendly input data management.

In order to deal with the issues in this project, development of DEROB-LTH has chiefly related to the thermal window model, solar and sky radiation at glazed surfaces, shading of diffuse radiation, comfort calculations and visualisation of the building. The new parts of the program have been put into special program modules so that changes to the original code have been minimised and subsequent maintenance of the program simplified. The new models are briefly described in the following sections.

4.1 Window model

The original window model in DEROB for a triple glazed window is illustrated in Figure 4.1. This model was highly simplified and calculated heat transfer between the outermost and innermost pane with a constant thermal resistance G_w . It was further assumed that transmission and absorption of solar radiation were independent of the view of incidence, and all absorbed solar radiation was assumed to have been absorbed by the outermost pane. There was thus a great need for a more exact window model. The basic ideas behind the new model will be given below. The used theories are fully described in Källblad (1998).

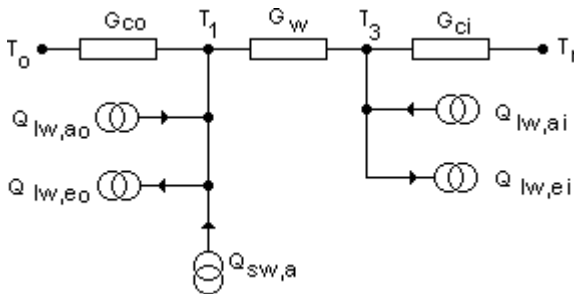


Figure 4.1 Original window model.

The new window model uses a temperature node for each pane and treats long wave radiation and convection between panes in full consideration of the dependence of the surface coefficients of heat transfer on glass

temperature, the sizes of air gaps and window inclination. Account is also taken of solar and sky radiation absorbed in each pane of glass. As in the original version, the panes are considered to be opaque to long wave radiation.

Where a “moveable insulation” is placed on the outside or inside of the window, this is treated as an air gap of constant conductance which is given as input data. In DEROB-LTH, “moveable insulation space” denotes a layer of a certain thermal resistance that is used only during certain periods, for instance overnight.

The model is illustrated in Figure 4.2 for a triple glazed window in a facade. This example is used when different details are discussed in this section. In the cases where the window is placed in an internal wall or is exposed to solar and sky radiation that is reflected into the room or transmitted by another window, the model is slightly modified.

The example refers to a triple glazed model but curtains etc can in this context also be treated in a fully analogous manner, which is also permitted by the program.

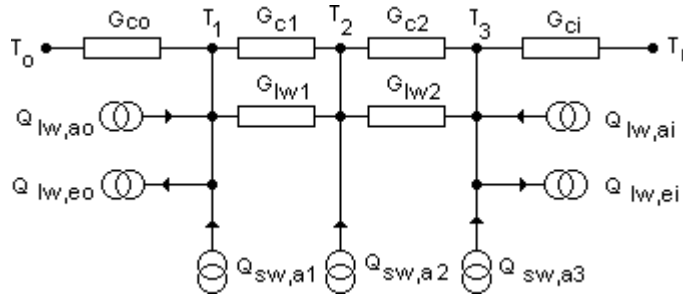


Figure 4.2 New window model.

In the program, all the temperatures in the building are calculated by an iterative method. This means that the temperatures in the vicinity of a window and radiation absorbed in the glass can be treated as boundary conditions when new temperatures on the glass in the window are to be calculated in an iteration. For the three panes of glass in Figure 4.2, the following system of nonlinear equations is obtained with T_1 , T_2 and T_3 as the unknown variables.

$$G_{co}(T_o - T_1) + (G_{c1} + G_{lw1})(T_2 - T_1) + Q_{sw,a1} + Q_{lw,ao} - Q_{lw,eo} = 0 \quad (4.1)$$

$$(G_{c1} + G_{lw1})(T_1 - T_2) + (G_{c2} + G_{lw2})(T_3 - T_2) + Q_{sw,a2} = 0 \quad (4.2)$$

$$(G_{c2} + G_{lw2})(T_2 - T_3) + G_{ci}(T_r - T_3) + Q_{sw,a3} + Q_{lw,ai} - Q_{lw,ei} = 0 \quad (4.3)$$

where

G_c	conductance for convective surface heat transfer	(W/K)
G_{lw}	conductance for long wave radiant heat transfer	(W/K)
T_i	temperature of pane i	(K)
T_o	air temperature outside the outer pane	(K)
T_r	air temperature inside the inner pane	(K)
$Q_{lw,a}$	absorbed long wave radiation	(W)
$Q_{lw,e}$	emitted long wave radiation	(W)
$Q_{sw,a}$	absorbed short wave radiation	(W)

4.1.1 Solar and sky radiation

The solar and sky radiation absorbed in the different panes of glass is given by

$$Q_{sw,ai} = a_{dir,i} \cos(\theta) I_N A_{we} + a_{dif,i} I_{dH} A_w F_{w,s} + a_{dif,i} I_{grd} A_w F_{w,g} \quad (4.4)$$

where

A_w	window area	(m ²)
A_{we}	effective window area	(m ²)
$F_{w,s}$	view factor between window and sky	(-)
$F_{w,g}$	view factor between window and ground	(-)
I_N	direct solar radiation (normal radiation)	(W/m ²)
I_{dH}	diffuse sky radiation on horizontal surface	(W/m ²)
I_{grd}	solar and sky radiation reflected from the ground	(W/m ²)
$a_{dir,i}$	absorptivity for specular radiation	(-)
$a_{dif,i}$	absorptivity for diffuse radiation	(-)
θ	view of incidence	(radians)

The effective window area takes account of the shading of direct solar radiation and is determined as in previous versions of the program. Calculation of absorptivity is discussed in Section 4.2, and calculation of the view factors which include shading of short wave radiation is discussed in Section 4.3.

4.1.2 Convection and long wave radiation at external and internal surfaces

Convection at the external surfaces of the window is determined, as on the outside of walls, with a constant coefficient of surface heat transfer of $5 \text{ W/m}^2\text{K}$. In the cases when the sky temperature is not known, both the sky and the surrounding ground are assumed to have the same temperature as the outside air, and an overall coefficient of surface heat transfer of $15 \text{ W/m}^2\text{K}$ is used. This coefficient includes both convection and absorbed and emitted long wave radiation, i.e. $Q_{lw,eo} = Q_{lw,ao} = 0$. The magnitudes of these constant coefficients of surface heat transfer can be altered via input data.

Where the sky temperature is known and a more accurate calculation is wanted, the long wave radiation emitted from the outer pane is determined from

$$Q_{lw,eo} = e_w \sigma T_w^4 A_w \quad (4.5)$$

where

T_w	temperature of outer pane	(K)
e_w	emissivity for outside of outer pane	(-)
σ	Stefan-Boltzman constant	$(5.7 \cdot 10^{-8} \text{ W/m}^2\text{K}^4)$

The long wave radiation absorbed in the outer pane is determined from

$$Q_{lw,ao} = e_w A_w F_{w,s} T_s^4 + e_w A_w F_{w,g} e_g T_g^4 + e_w A_w F_{w,g} (1 - e_g) \sigma T_s^4 \quad (4.6)$$

where

T_s	sky temperature	(K)
T_g	ground temperature	(K)
e_g	emissivity of ground	(-)

In Equation (4.6) the same view factor is used as in calculating diffuse sky radiation, which means that shading of long wave radiation is considered in a detailed manner. In this case also the ground is assumed to have the same temperature as outside air.

Treatment of surface heat transfer between the inner pane and room air and the other inside surfaces in the room concerned has not been changed.

Convection at the inner surfaces of the window is determined with reference to the inclination of this surface and the temperatures of the inner pane and room air.

The long wave radiation emitted from the inner pane is determined as at the outer pane. The long wave radiation absorbed from the other room surfaces is calculated using distribution factors that take account of both room geometry and the emissivities of the internal surfaces.

4.1.3 Convection in air gaps

A brief description is given below of the calculation of convection in the air gaps of the window.

The program permits the user to specify different gas data, which means that gaps with e.g. argon, krypton, CO₂ or SF₆ can be dealt with.

In each gap the conductance for convective heat transfer is determined from

$$G_{c,i} = A_w \text{Nu } \lambda / d \quad (4.7)$$

where

A_w	area of window	(m ²)
d	width of gap	(m)
Nu	Nusselt number	(-)
λ	conductivity of gas	(W/m,K)

Temperature dependence of the conductivity of the gas is approximated by a linear function of the mean temperature in the gap.

The Nusselt number is a function of the Rayleigh number, gap dimensions and the view of inclination of the window. Equations from the following works are used for calculation of the Nusselt number:

Hollands et al (1976) for inclinations between 0° and 60°

ElSherbiny et al (1982) for inclinations between 60° and 90°

Ferguson and Wright (1984) for inclinations between 90° and 180°

The view of inclination is defined as follows:

- 0° horizontal window with warmest side downwards
- 90° vertical window
- 180° horizontal window with warmest side upwards

The Rayleigh number is determined using

$$Ra = Pr g_n \beta \rho^2 d^3 \Delta T / \mu^2 \quad (4.8)$$

where

Pr	Prandtl number	(-)
ΔT	temperature difference across gap	(K)
g_n	gravitational constant	(9.82 m/s ²)
d	width of gap	(m)
β	approximate thermal expansion	(1/K)
μ	viscosity of gas	(kg/m,s)
ρ	density of gas	(kg/m ³)

The temperature dependence of Pr , μ and ρ is approximated by linear functions of the mean temperature T_m in the gap, and thermal expansion is approximated as $1/T_m$. Some examples of gas data can be found in e.g. Arasteh et al (1989).

4.1.4 Long wave radiant heat transfer in air gaps

In each air gap, the long wave radiant heat transfer is also treated in accordance with fundamental principles. Conductance for the long wave radiation is thus given by

$$\begin{aligned} G_{lw,i} &= A_w \epsilon_{ekv} \sigma (T_i^4 - T_{i+1}^4) / (T_i - T_{i+1}) \\ &= A_w \epsilon_{ekv} \sigma (T_i^2 - T_{i+1}^2) (T_i + T_{i+1}) \end{aligned} \quad (4.9)$$

$$\epsilon_{ekv} = 1 / (1/\epsilon_i + 1/\epsilon_{i+1} - 1) \quad (4.10)$$

where

ϵ_{ekv}	equivalent emissivity
ϵ_i	emissivity on rear of pane i
ϵ_{i+1}	emissivity on front of pane $(i+1)$

The emissivity of each glass surface in a window can be chosen by the user, which means that different types of surface coating can be simulated.

4.2 Solar and sky radiation at glazed surfaces

In the following a brief description is given of how absorption, reflection and transmission in the glass combination of a window are calculated.

4.2.1 Single layers

When the solar radiation properties of a glass combination are to be determined, the properties of each constituent layer must first be established. These layers are usually of glass, but curtains etc can in this context also be treated in a fully analogous manner, which is also permitted by the program.

Absorption, reflection and transmission are determined for each layer without the influence of surrounding layers. Radiation from both the front and the rear can be treated for both direct and diffuse radiation.

Direct radiation can in addition become diffuse on reflection or transmission, which has been taken into account in the appropriate subroutines. This diffusion process is at present used only for “moveable insulation”.

The radiation parameters of the glass are considered to be independent of wavelength, and all data are considered to be the means for the whole solar spectrum. This implies that care must be taken when special glass is dealt with.

If thickness, refractive index and absorption coefficient are given for a homogeneous glass, the Fresnel equation and Snell's law are used to determine the coefficients for a single pane of glass.

For a glass without special coating the thickness of the glass and reflection and transmission for perpendicular incidence can be given, after which the refractive index and absorption coefficient can be calculated. These are then used in calculating view dependent data.

A pane of glass or some other layer can also be specified by reference to tables where data are given for equidistant views of incidence between 0° and 90° . In these cases the data are considered to hold for both polarisation directions.

When “moveable insulation” is used it is assumed that the given values of transmission and absorption are independent of both view of incidence and direction of polarisation. In such cases all transmitted or reflected radiation is also considered to be diffuse.

Transmission and absorption of direct radiation are first determined for views of incidence between 0° and 90° in steps of 5° . The different types of input data are then treated as follows:

If possible, data for both the perpendicular and parallel polarisation directions are determined using the Fresnel equations etc.

If data have been given in tabulated form, these are considered to hold for both polarisation directions. If necessary, data for the view of incidence concerned are determined by linear interpolation between adjacent values.

For “moveable insulation” the given data are considered to hold for both polarisation directions and all views of incidence.

Transmission and absorption for diffuse radiation for each single layer are then determined by integration over the different views of incidence, the means for both polarisation directions being used.

4.2.2 Glass combinations

In a window system with several layers consideration must be given to all internal reflections in order that the radiation that is absorbed in each layer, as well as the total transmission and reflection, may be calculated. Specular and diffuse radiation incident from both sides must be considered.

The two innermost layers are treated as a double glazed window for which the total transmission and reflection can be easily determined. In a triple glazed window these two layers can then be treated as a fictitious layer which, together with the outermost pane, forms a new double glazed window which permits the same calculation to be repeated but this time with new data. For more than three layers the procedure is repeated until all layers have been considered.

For a glass combination these calculations are performed for direct radiation in steps of 5° , a complete calculation being made for each direction of polarisation. The data for the combination for each view of incidence are then determined as the means of the two directions of polarisation.

Finally, the data for the combination for diffuse radiation are determined by integration over the different views of incidence.

The importance of considering polarisation is illustrated in Figure 4.3 for an ordinary triple glazed window. In the detailed calculation case the above calculation procedure was used, and in the other case the means for each pane were used when the data for the combination were calculated.

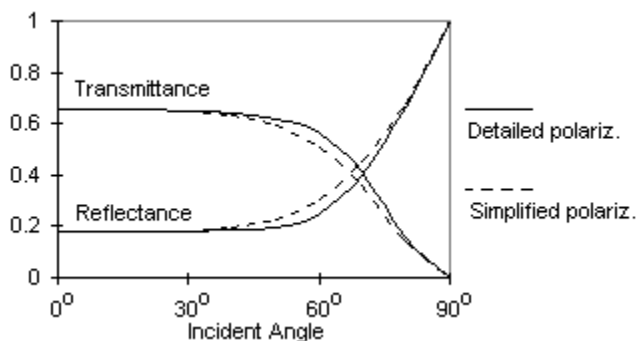


Figure 4.3 Different ways of treating polarisation.

4.3 Shading of diffuse radiation

DEROB-LTH deals with two types of diffuse radiation, short wave solar and sky radiation and long wave radiation. Shading of these types of radiation was not considered in the original version of the program, only the inclination of the surfaces was taken into account in determining the view factors from these towards the ground and sky. In order to improve the program's treatment of diffuse radiation, a new package of subroutines had been developed and implemented in the program. A brief description of the way shading of diffuse radiation is treated is given below. Källblad (1998).

4.3.1 Calculation of view factors

View factors are used to determine the diffuse radiation incident on an external surface. In many cases these can be determined analytically, see e.g. Siegel & Howell (1981). It is however in many cases very difficult to decide in a computer program which formula or formulae must be used for different geometries. In order to arrive at a general procedure, the method proposed by Källblad (1998) has been used.

Unshaded area

The way the unshaded area of an external surface can be determined is an important part of the method chosen. The term “unshaded area” has been chosen since previous work focused on shading of direct solar radiation.

Figure 4.4 illustrates a surface R' which is shaded by different screens. In the plane of the surface different regions of unions and intersections are formed. The appearance of these regions naturally depends on both the direction of radiation and the shape and placing of the screens.

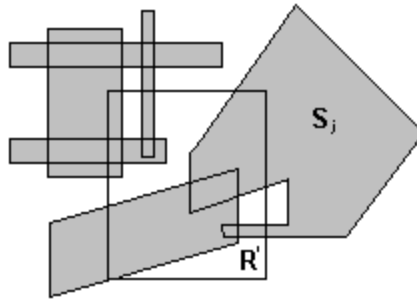


Figure 4.4 A shaded surface.

The unshaded area R' is the difference between the area of the surface and the area of the intersection between R' and the union of the shadows. Description of the union of shadows may be complex. It can consist of several regions, some of which may contain holes. In order to avoid unions a formula that contains only intersections is used.

An intersection between two regions may also be complex, for instance the intersection between R' and S_j in Fig. 4.4 must be described as two regions. In order to avoid this, the following condition is introduced for building surfaces:

All surfaces must be plane and convex, i.e. all internal views $< 180^\circ$.

It is evident that the shadow of a convex plane surface is convex, and that a non-empty intersection between two convex regions is convex. This means that the condition is sufficient for the avoidance of complex regions.

Nor is the condition critical since it is satisfied by most building surfaces. In certain cases it may however be necessary to subdivide the actual surfaces, but this is not necessary in DEROB-LTH since the permitted surface shapes are plane and convex. In the cases where a surface contains

a “hole”, for instance a window in an external wall, the “hole” may be considered to be a sunshade when the radiation incident on the surface is calculated.

View factor between a surface and the sky or ground

The intensity of diffuse radiation is independent of direction, and the total diffuse radiation from a surface is given by

$$Q = \pi i A \quad (\text{W}) \quad (4.11)$$

where

$$\begin{array}{ll} A & \text{area of surface} \quad (\text{m}^2) \\ i & \text{intensity} \quad (\text{W}/\text{m}^2, \text{sr}) \end{array}$$

Radiation in a special direction from a surface may be prevented from reaching the sky by other building surfaces or sunshades. The area of the radiation from the surface that can reach the sky is naturally equal to the unshaded area of the surface if radiation arrives from the opposite direction. Radiation from the surface to the sky can therefore be written as

$$Q_{s-sky} = \int_{\varphi=0}^{2\pi} \int_{\theta=0}^{\pi/2} i A_{ns,sky}(\theta, \varphi) \cos \theta \sin \theta d\theta d\varphi \quad (\text{W}) \quad (4.12)$$

where

$A_{ns,sky}(\theta, \varphi)$ = the unshaded area for directions towards the sky, otherwise 0.

The view factor between the surface and the sky is therefore

$$F_{s-sky} = \frac{Q_{s-sky}}{\pi i A} = \frac{1}{\pi A} \int_{\varphi=0}^{2\pi} \int_{\theta=0}^{\pi/2} A_{ns,sky}(\theta, \varphi) \cos \theta \sin \theta d\theta d\varphi \quad (\text{W}) \quad (4.13)$$

In a similar way we get the view factor between the surface and the ground as

$$F_{s-grd} = \frac{1}{\pi i A} \int_{\varphi=0}^{2\pi} \int_{\theta=0}^{\pi/2} A_{ns,grd}(\theta, \varphi) \cos \theta \sin \theta d\theta d\varphi \quad (\text{W}) \quad (4.14)$$

where

$A_{ns,gra}(\theta, \varphi)$ = the unshaded area for directions towards the ground, otherwise 0.

View factor between surfaces

At external surfaces and sunshades solar radiation can be reflected. In order to determine how much of the reflected radiation strikes another external surface, view factors are used between the surfaces; these can be calculated in a way similar to that for calculation of view factors towards the sky and the ground.

Calculation procedure

Since manoeuvrable sunshades are not yet considered, calculation of shade regarding diffuse radiation need be made only once. After this the calculated view factors can be used for each time step during the entire simulation period irrespective of its length.

Preliminarily, in the system of coordinates for the building each surface is represented by a polygon and its outward normal. The view factors for unshaded external surfaces and sunshade surfaces are determined by analytical formulae, the normal to the surface being used to determine its inclination. For every shaded external surface the calculations are performed in the following stages.

For the surface concerned, a system of coordinates is defined with the xy plane in the plane of the surface and with the z axis along the outward normal to the surface. The coordinates for all surfaces that can be reached by radiation from the surface concerned are transformed to this system of coordinates. Those surfaces which are partly situated below the xy plane must therefore be limited to the part situated above the plane.

The numerical integration is then performed in steps of 5° which provides acceptable accuracy for the calculated view factors. For each direction, the unshaded area of the receiving surface is determined, and the direction determines whether this part is to be assigned to the view factor towards the sky or the ground.

For each direction, the shaded areas are also sorted so that the contributions to the view factors between the surfaces may be determined with reference to the shade cast by intermediate surfaces.

Owing to the integration step chosen, the sum of the calculated view factors from a surface vary between 0.995 and 1.005. Since, by definition, this sum must be equal to 1, the view factors obtained are normalised in

order to satisfy this condition. In this normalisation process the view factors determined by the analytical formulae are assumed to be correct and they are excluded from normalisation.

4.4 Comfort calculations

In this section a brief description is given of the comfort calculation program, KGK-Comf, which is coupled to DEROB-LTH. The program is fully described in Källblad, K. (1996).

The aim of this program is to illustrate graphically the variations in Predicted Mean Vote (PMV), Predicted Percentage of Dissatisfied (PPD) and operative temperatures in a room. Comfort parameters are calculated for observation points in a desired horizontal plane, and each parameter can be illustrated as in Figure 4.5.

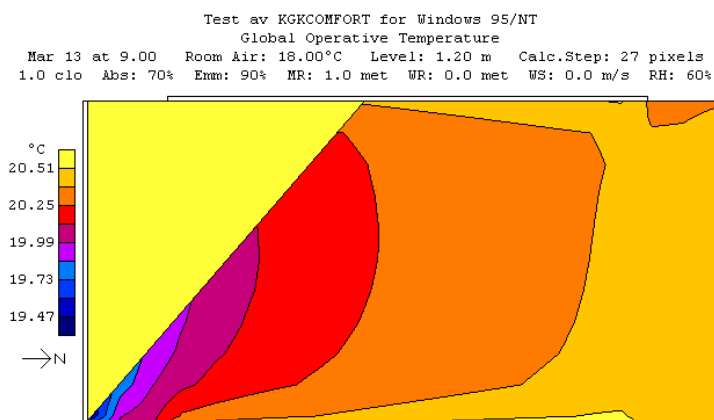


Figure 4.5 Example of variations in operative temperature in a room.

The geometry of the room, air and surface temperatures, diffuse solar radiation from the surfaces and direct solar radiation transmitted through windows is taken into account in detail. The program reads these data from a special result file with hourly temperatures and radiation values produced by DEROB-LTH.

Only one room can be illustrated and, compared with the free room shapes in DEROB-LTH, only parallelepiped rooms with rectangular surfaces can be treated.

The observation point is an infinitesimal cube whose surfaces have equal surface temperatures, absorptivities and emissivities.

The data which are not given via DEROB-LTH are obtained in a menu directly coupled to the comfort program.

4.4.1 PMV and PPD

The Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) are calculated in accordance with the international standard ISO 7730, 1994.

The formula for PMV includes the mean radiant temperature which, in KGK-Comf, is calculated exactly in accordance with the definition by Fanger (1979): “The mean radiant temperature in relation to a person in a given body posture and clothing placed in a given point in a room, is defined as that uniform temperature of black surroundings which give the same radiant heat loss from a person as the actual case under study”. Both direct solar radiation through a window and the diffuse reflected radiation from the inside walls are considered when this temperature is calculated.

4.4.2 Operative temperature

ISO 7730 defines operative temperature as follows: “The operative temperature is the uniform temperature of a radiantly black enclosure in which the occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment”. Calculation in the program is fully in accordance with this definition.

In order to make possible studies of asymmetry in the thermal environment, the directional operative temperatures in the six principal directions are also calculated.

4.5 Visualisation of a building

In DEROB-LTH the different elements of a building such as walls, windows etc are specified numerically with different basic configurations. For instance, for a square the width and length are specified after which dimensions are given for the translation and rotation of this element. The program had a module, ALKAZAM, which made it possible to draw the input geometry so that the data given could be checked. Wishes put forward by several people for a better graphic program resulted in the development of KGK-Show, and an example of how this program can show a building is given in Figure 4.6.

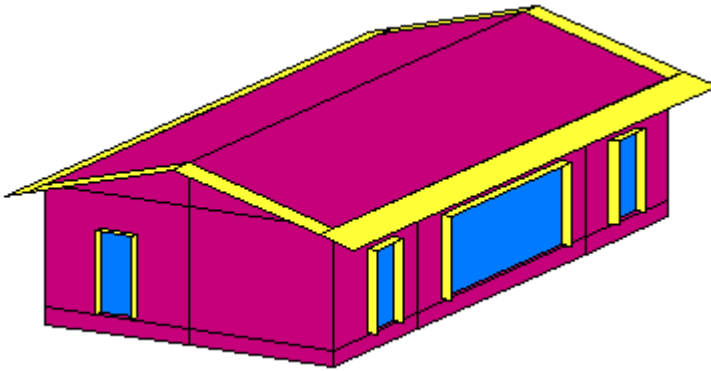


Figure 4.6 A building illustrated in KGK-Show.

KGK-Show makes use of only an ordinary parallel perspective but provides a number of different opportunities for studying the building specified.

In Figure 4.6 the building is shown in a direction specified by the user. In this case the building can be rotated in any direction. Another variant is given by selecting a perspective seen from the position of the sun. As illustrated in Figure 4.7, it is also possible to place the building in different localities, after which the time, day and month can be varied with the arrow keys to study, for instance, how sunshades shade a window during the year. The figure shows a case where no specific locality has been selected. The parameters for the position of the locality can instead be freely selected by the user.

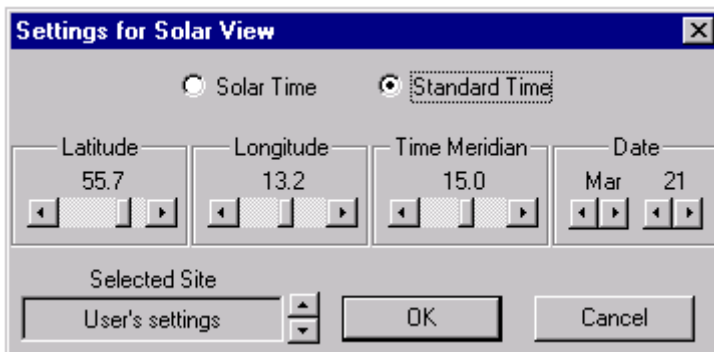


Figure 4.7 Specification of the position of the building.

Another possibility is to exclude parts of the building, which is done through the menu shown in Figure 4.8. With the selection made according to this figure, Figure 4.9 shows the same building from another view and with the floor removed.

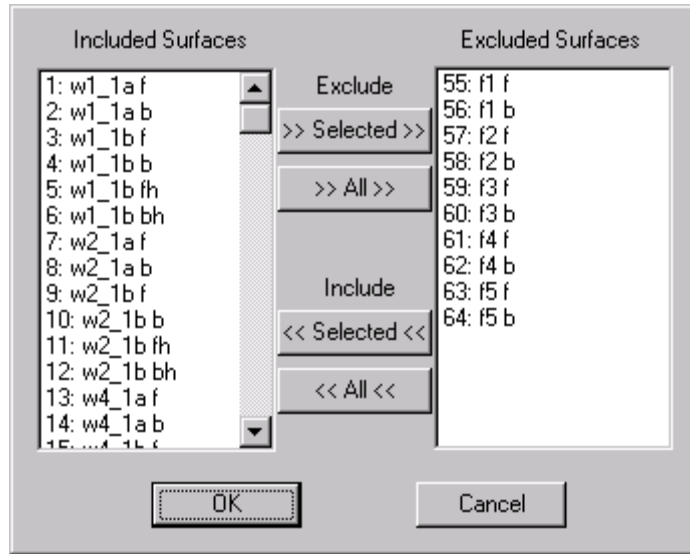


Figure 4.8 Selection of building components to be illustrated.

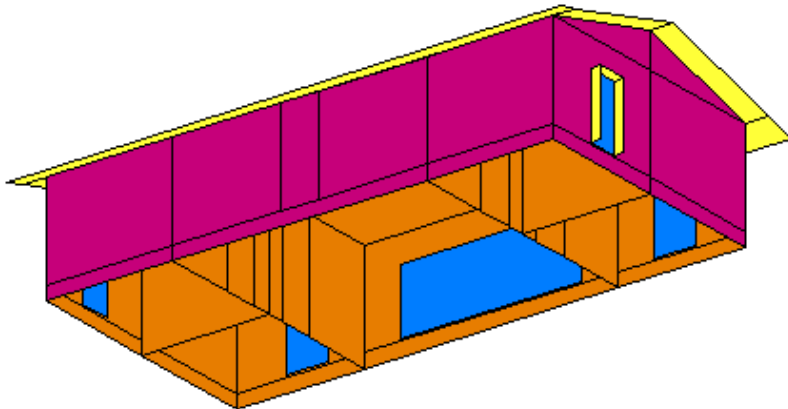


Figure 4.9 View of building with the floor removed.

Apart from the facilities described above, the picture can be enlarged or reduced and moved along the screen. The program also includes a facility to show the constituent surfaces in steps, and the picture can also be saved as a BMP file for further processing and/or use in, for instance, a word processing program.

Calculation procedure

When a building is drawn, the position of the sun with respect to the day during the year and the time concerned is only calculated if needed. For projections where civil time (standard time) is used, solar position is also corrected with respect to longitude, the standard meridian and the equation of time.

When specific projection views are used, the coordinates for the corner points of the building surfaces are rotated so that a parallel projection is obtained through the x and y values of the new coordinates. These coordinates are then transformed into screen coordinates with respect to the enlargement and translation selected.

For the actual drawing process the “painting algorithm” has been chosen. This means that the surfaces are drawn and filled so that the surfaces behind are “painted over”. In order that this should be done in the correct order, the surfaces must be sorted; this is done with the same routines as those used in shadow calculations according to Section 4.3.

4.6 Simulations

The model used for the sunshade has an optical and a thermal part. The thermal model for the sunshade is summed up in the following heat balance for the sunshade:

$$\begin{aligned}
 & A \cdot a_{\text{sunshade}} \cdot I_N + && \text{Absorption of solar radiation} \\
 & && \text{towards the normal} \\
 & 2A \cdot h_k (T_{\text{air}} - T_{\text{sunshade}}) + && \text{Convective exchange with the air} \\
 & 2A \cdot \sigma \cdot \epsilon_{\text{sunshade}} (T_{\text{sky}}^4 - T_{\text{sunshade}}^4) F_{\text{sunshade,sky}} + && \text{Long wave radiant heat transfer} \\
 & && \text{towards the sky} \\
 & 2A \cdot \sigma \cdot \epsilon_{\text{sunshade}} (T_{\text{grd}}^4 - T_{\text{sunshade}}^4) F_{\text{sunshade,grd}} && \text{Long wave radiant heat transfer} \\
 & && \text{towards the ground} \\
 & = 0 && \\
 & && (4.15)
 \end{aligned}$$

where

A	area of sunshade	(m ²)
a	absorptivity of sunshade for solar radiation	(-)
h_k	convective surface coefficient of heat transfer towards the air	(W/m ² K)
$\epsilon_{\text{sunshade}}$	emissivity of sunshade	(-)
I_N	solar radiation in direction of normal	(W/m ²)
T_{sunshade}	temperature of sunshade	(K)
T_{air}	temperature of air	(K)
T_{sky}	temperature of sky	(K)
$F_{\text{sunshade,sky}}$	view factor towards the sky	(0.4)
$F_{\text{sunshade,grd}}$	view factor towards the ground	(0.6)
σ	Stefan-Boltzman constant	(5.669·10 ⁻⁸ W/m ² K ⁴)

From Equation (4.15) the temperature of the sunshade (T_{sunshade}) can be calculated. This temperature is then used for the long wave radiant heat transfer between the window and surroundings. The convective heat transfer takes place in relation to the air temperature. The view factors between sunshade and sky, and between sunshade and the ground, are in this study specified as 0.4 and 0.6. The optical model for the sunshade permits direct and diffuse transmission through this. All transmitted radiation becomes diffuse and can be transmitted further. The reflected portion is diffuse and is included in the calculation only if it strikes the window directly after the first reflection.

4.6.1 Awning

The results of measurements of optical spectral transmission made by Arne Roos at Uppsala University gave a perpendicular total (optical) transmission of 30% and an absorption of 30% for the light awning fabric and 1% and 99% respectively for the dark fabric. These values have been used to simulate fully extended awnings. The geometric awning model is shown in Figure 4.10. See also Figure 2.4. A comparison between simulation and measurement of the difference between supplied cold and heat is shown in Figure 4.11.

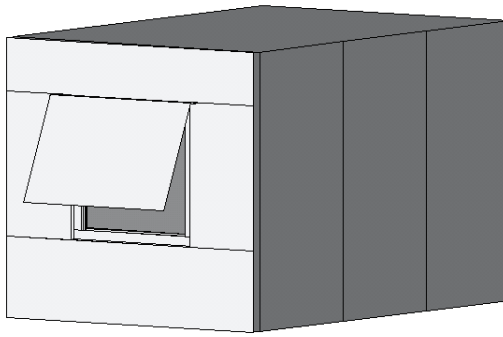


Figure 4.10 The geometric awning model used in DEROB-LTH.

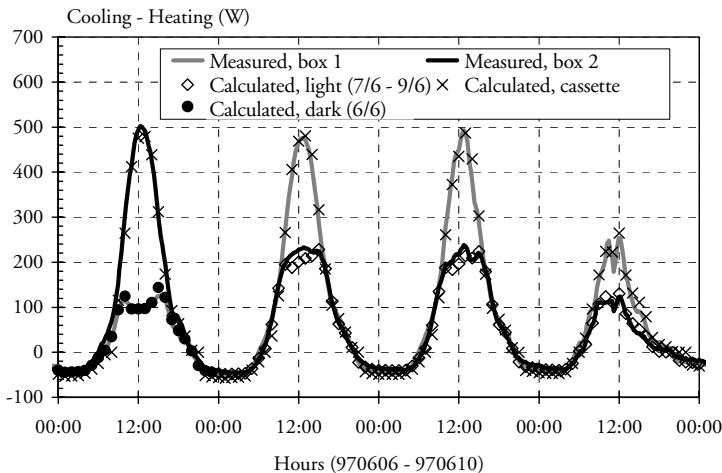


Figure 4.11 Simulated and calculated cold-heat for window with light awning, dark awning and only awning cassettes.

It is seen from Figure 4.11 that the model for light and dark awning differs from measurements by less than 20 W, which is less than 3% of the solar radiation incident on the unshaded window. This is of the same order as the estimated measuring error. The model for the light awning slightly underestimates transmission. This may be due to the awning fabric transmitting a small proportion a direct radiation. With the help of the above models, the primary transmission etc can be calculated. See Figure 4.12.

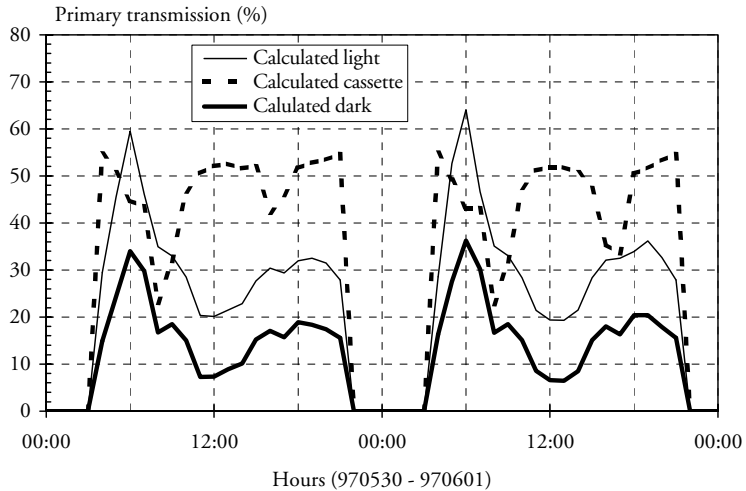


Figure 4.12 Simulated transmission for window with light and dark awning, fully extended, and only cassette.

4.6.2 Italian awning

The same fabrics as for the awning were also used for the Italian awning. The geometric model for the Italian awning is shown in Figure 4.13; see also Figure 2.15. The comparison between simulation and measurement of the difference between supplied cold and heat is shown in Figure 4.14. Just as in the case of the awning, the difference between measurement and simulation is on average less than 20 W, except during some hours for the light fabric. The explanation for this is presumably the same as for the awning, i.e. that the fabric has a partially direct to direct transmission.

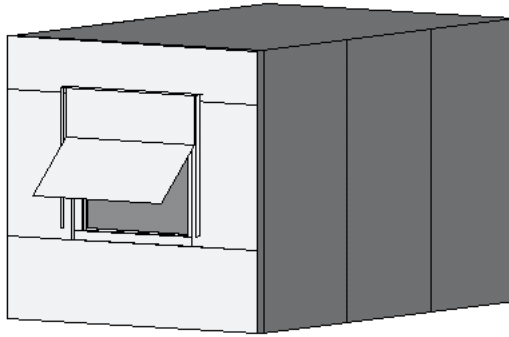


Figure 4.13 Geometric model of Italian awning used in DEROB-LTH.

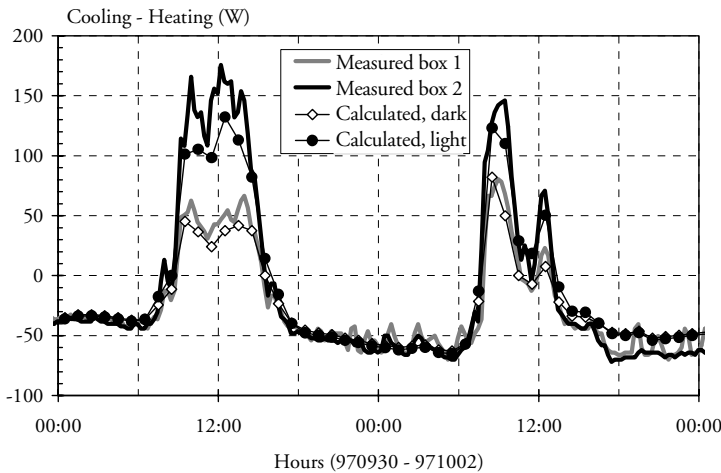


Figure 4.14 Simulated and calculated difference between cooling and heating for window with light and dark Italian awning.

4.6.3 External 80 mm venetian blind

An external venetian blind with 80 mm slats was investigated. The geometric model for this blind is shown in Figure 4.15; see also Figure 2.10. The comparison between simulated and measured difference between supplied cooling and heating is shown in Figure 4.16. The error in estimated transmission is systematically approx. 20 W more than that measured, corresponding to approx. 3% of the incident solar radiation. The reason for the overestimate may be that the calculation was made with

tabulated values for anodised aluminium, with 20% absorption and 80% emissivity for the slats. If the slats have a somewhat higher actual absorption, e.g. due to dirt accumulation, transmission decreases.

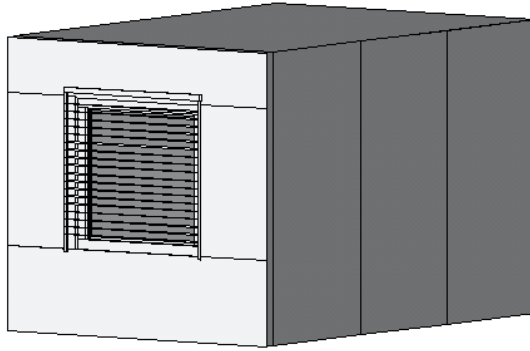


Figure 4.15 Geometric model for external venetian blind with 80 mm slats, used in DEROB-LTH.

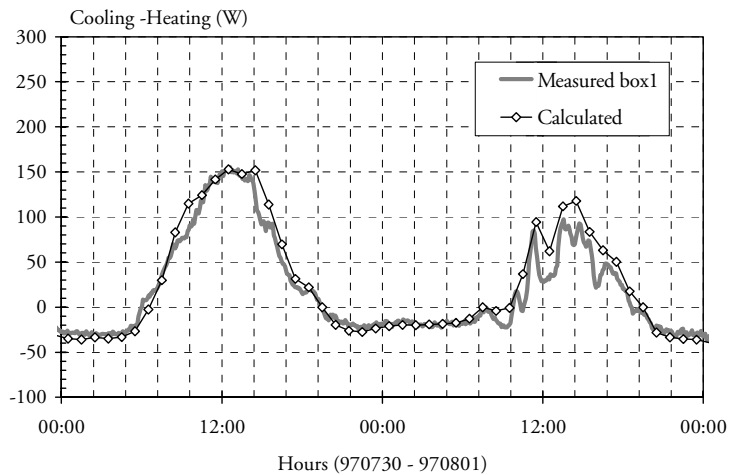


Figure 4.16 Simulated and calculated difference between cooling and heating for window with 80 mm external venetian blind.

4.6.4 Horizontal slatted baffle

A slatted baffle projecting horizontally from the facade was studied. The geometric model for this horizontal slatted baffle is shown in Figure 4.17; see also Figure 2.22. The comparison between simulation and measure-

ment of the difference between supplied cooling and heating is shown in Figure 4.18. The difference between measured and simulated cooling minus heating is approx. 20 W, corresponding to approx. 2.5% of the incident solar radiation. All metals were modelled as anodised aluminium.

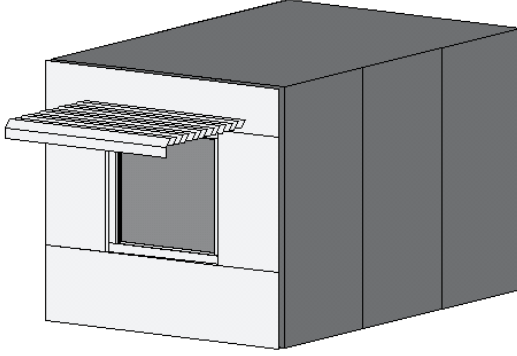


Figure 4.17 Geometric model for the horizontal slatted baffle used in DEROB-LTH.

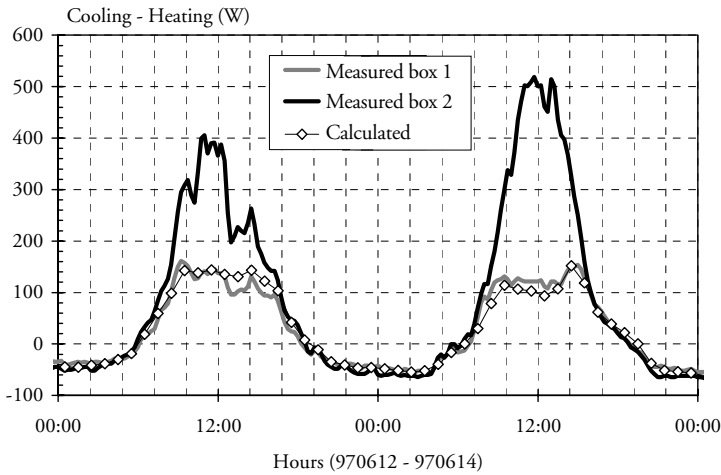


Figure 4.18 Simulated and calculated cooling minus heating for window with horizontal slatted baffle. Measuring box No 2 was completely without solar protection.

4.6.5 Fabric screen

Three types of screen were investigated: Hexel 21136 Satine Blanc 101 (transmission 27%), Sable 109 (transmission 10%) and Ferrari Soltis 92 1045 (transmission 4%). The geometric model consisted of an extra pane of glass. The properties of this pane were taken from the ASHRAE measurement (ASHRAE 74-1988), with a transmission curve independent of the incidence angle. By using a modified pane of glass as the model, transmission could be made non-diffusing. This was found necessary when a diffusing sunshade gave a too low cooling requirement. Owing to its structure, a fabric screen both diffuses and directly transmits solar radiation. The more holes there are, the greater is direct transmission. Comparisons between simulation and measurement of the difference between supplied cooling and heating are shown in Figure 4.19-4.21. The error in estimated transmission is between 40 W and 10 W, corresponding to between 5 and 1% of the incident solar radiation. The cooling requirement was systematically overestimated for the screen with high transmission and underestimated for those with lower transmission. However, the model was in better agreement for the screens which had low transmission.

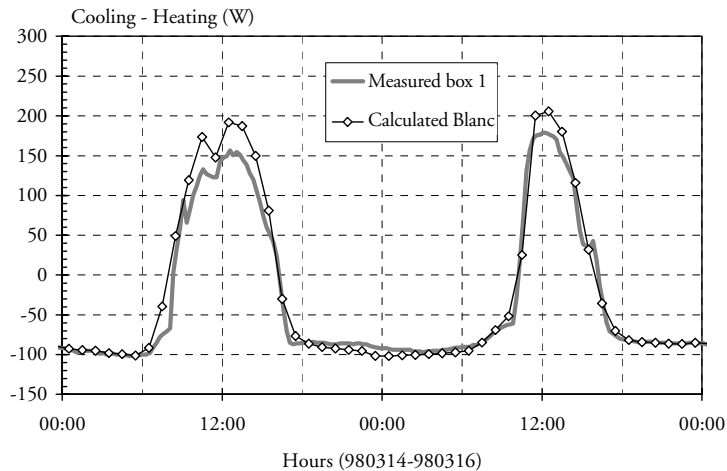


Figure 4.19 Simulated and calculated difference between cooling and heating for window with screen Hexel 21136 Satine Blanc 101.

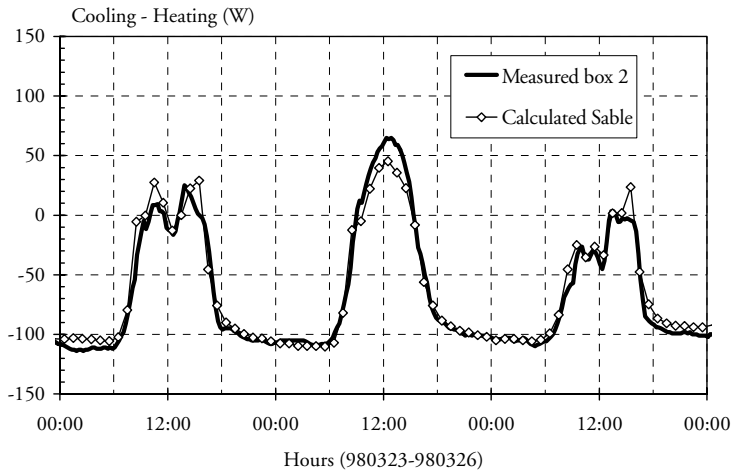


Figure 4.20 Simulated and calculated difference between cooling and heating for window with screen Hexel 21136 Satine Sable 109.

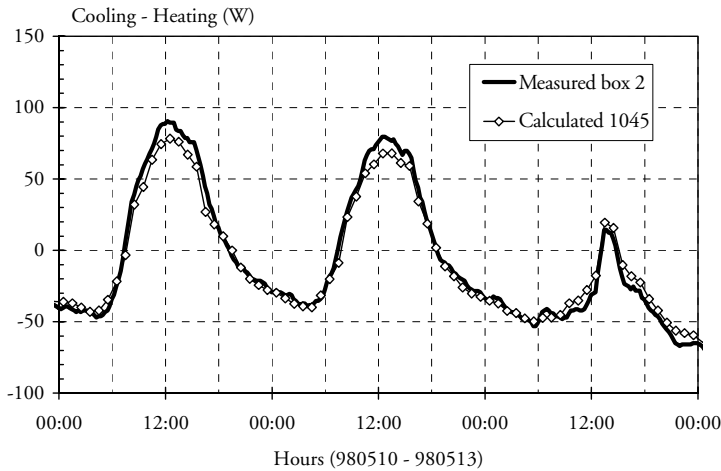


Figure 4.21 Simulated and calculated difference between cooling and heating for window with screen Ferrari Soltis 92 1045.

4.6.6 Conclusion drawn from simulations

The models are fully adequate for giving realistic estimates of the heat balance for a window with the studied sunshades. The difference between simulation and measurement is in most cases less than 3% of the incident

solar radiation. Some models underestimate, and others overestimate, the irradiated energy. These errors are however of the same order as the measuring error.

Sunshade	Absolute error (W/m ²)	In relation to insolation (%)
Awning	-15	-3
Italian awning	-15	-3
External 80 mm venetian blind	+15	+3
Horizontal slatted baffle	±15	±3
Vertical fabric screen	+40 - ±15	+3 - ±2

4.6.7 Recent developments

Further work has been made on developing models for venetian blinds. The new model for external venetian blinds has been compared with measurements. The result show very good agreement. This model has been further developed during the autumn of 2000 to include also interpane and internal venetian blinds.

5 Properties of sunshades – generalised measurement results

Petter Wallentén

It is difficult to give generally applicable values based directly on measurements on the different sunshades. The results of measurements are valid only for the time and latitude at which they are made. With the help of the models implemented in DEROB-LTH, the properties of sunshades under different circumstances can however be calculated. Owing to the interaction between the sunshade and the window, a unique calculation is in actual fact needed for each combination of window, sunshade, latitude, orientation, climate and time. However, for external sunshades a reasonable first approximation is to calculate the total solar energy transmittance (g) of the sunshade. In this way the calculation is independent of the coupling between sunshade and window. The total solar energy transmittance of the system can then be calculated from

$$g_{\text{system}} = g_{\text{sunshade}} \cdot g_{\text{window}} \quad (5.1)$$

Apart from the fact that a sunshade influences the way solar radiation is transmitted through a window construction, the purely thermal properties can also be affected. A vertical screen acts, for instance, as an additional window pane and thus reduces the total U value of the window. This type of influence is not apparent from the value of g . However, awnings, horizontal slatted baffles and other projecting external structures have very little effect on the U-value. Only the value of g is examined in this chapter, and any changes in the U-value have not been calculated.

5.1 Parametric study

Calculations have been made for a number of different sunshades and for the climates of Lund 1988 (55.72°N) and Luleå 1988 (65.55°N), and for three orientations: west, south and east. The results give an idea of the angle and climate dependence of the sunshades. All calculations were made with the same window as that in the measurements, i.e. a sealed unit of 4-12-4 mm with Pilkington Float Glass. The results of calculations can be presented in different ways. It has been decided here to show monthly means and hourly values for single days. The monthly means are weighted in two different ways: with respect to the solar radiation on the facade which gives a mean energy transmittance over the period, and with respect to solar radiation on the facade to the power 10 which gives the transmittance for the sunshade when solar radiation is strongest. The first mean is called here $g_{sunshade}^{mean}$ and the other $g_{sunshade}^{dim}$. The formulae for these are

$$g_{sunshade}^{mean}(month) = \frac{1}{\sum_{month} I_{facade}(hour)} \cdot \sum_{month} I_{facade}(hour) \cdot g_{sunshade}(hour) \quad (5.2)$$

$$g_{sunshade}^{dim}(month) = \frac{1}{\sum_{month} I_{facade}^{10}(hour)} \cdot \sum_{month} I_{facade}^{10}(hour) \cdot g_{sunshade}(hour) \quad (5.3)$$

The exponent 10 has been chosen somewhat arbitrarily. The higher it is, the greater is the weighting of the hours during the period with strong solar radiation. No separate study has been made of the significance of the exponent. The design value (eq. 5.3) has greatest significance for designing the required input power of a cooling system, while the mean value of energy (eq. 5.2) has greatest significance for total energy use. Total transmittance is calculated by using simulated heat requirement (H) and cooling requirement (C) from four different situations:

1. System with window and sunshade exposed to solar radiation
2. System with window and sunshade without solar radiation
3. Window exposed to solar radiation
4. Window without solar radiation

$$g_{system} = \frac{C_{system}^{sun} - H_{system}^{sun} - C_{system}^{no\ sun} + H_{system}^{no\ sun}}{I_{facade}} \quad (5.4)$$

$$g_{window} = \frac{C_{window}^{sun} - H_{window}^{sun} - C_{window}^{no\ sun} + H_{window}^{no\ sun}}{I_{facade}} \quad (5.5)$$

$$g_{sunshade} = \frac{g_{system}}{g_{window}} = \frac{C_{system}^{sun} - H_{system}^{sun} - C_{system}^{no\ sun} + H_{system}^{no\ sun}}{C_{window}^{sun} - H_{window}^{sun} - C_{window}^{no\ sun} + H_{window}^{no\ sun}} \quad (5.6)$$

The design transmittance $g_{sunshade}^{dim}$ represents the time when the solar radiation is strongest on the facade. The sun is strongest during the morning, at noon and in the afternoon respectively on the east, south and west facades. This corresponds in many cases to the time when the sunshade works best, except in the winter on the east and west facades when the solar radiation mostly has an acute angle of incidence.

5.1.1 Light awning

Figure 5.1 shows $g_{sunshade}$ for a unbleached white awning (primary transmittance of fabric 30%) mounted in three different directions. The fully extended awning completely shades the window from solar radiation perpendicular to the facade when solar altitude is 22°. It is evident that incidence on the awning mounted in the east, south and west is a minimum in the early morning, the middle of the day and in the afternoon respectively. The reason that the minimum is lower on the awning mounted in the east and west is presumably that the proportion of diffuse radiation is comparatively lower in the morning and evening owing to the low solar altitude (which produces a larger projected area towards the sun). Diffuse radiation is not shaded equally effectively by the awning.

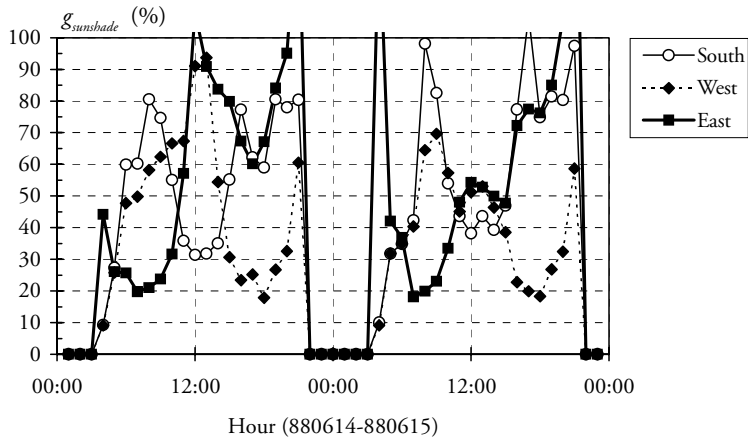


Figure 5.1 g_{sunshade} for a light awning in Lund over two days.

Figure 5.2 shows the mean energy transmittance $g_{\text{sunshade}}^{\text{mean}}$ for a light awning in Lund in 1988. The difference in transmittance between a west mounted and east mounted awning and the fact that transmittance in the summer is higher for an awning in the south is presumably due to the proportions of diffuse and direct solar radiation. The high transmittance for the east and west awning during the winter season is due to the fact that solar radiation is at such an acute angle that the awning does not shade the window. The effective total mean energy transmittance $g_{\text{sunshade}}^{\text{mean}}$ is approx. 5-20% greater than transmittance through the fabric alone.

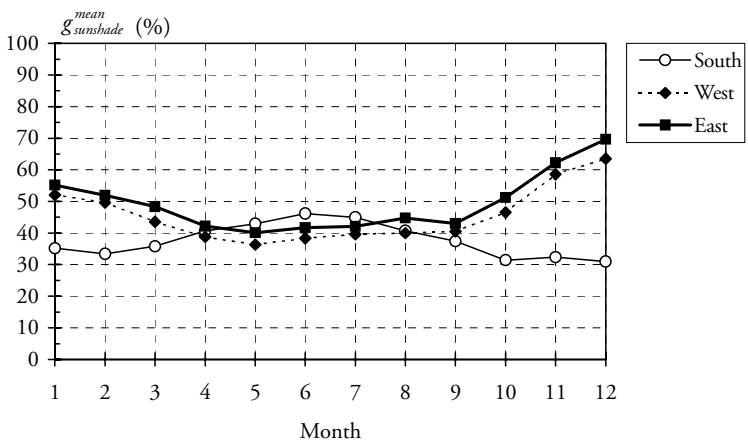


Figure 5.2 $g_{\text{sunshade}}^{\text{mean}}$ for light awning in Lund.

Figure 5.3 shows the design energy transmittance $g_{sunshade}^{dim}$ for a light awning in Lund in 1988. The systematic differences between different directions are even more evident than for $g_{sunshade}^{mean}$. The reason that transmittance during the summer for an awning mounted in the east and west (~25%) is lower than that for the fabric (30%) is that the fabric according to the model transmits all radiation as diffuse radiation. Transmittance through the glazed unit is thus lower than it would have been for the corresponding directed radiation at 10° angle of incidence.

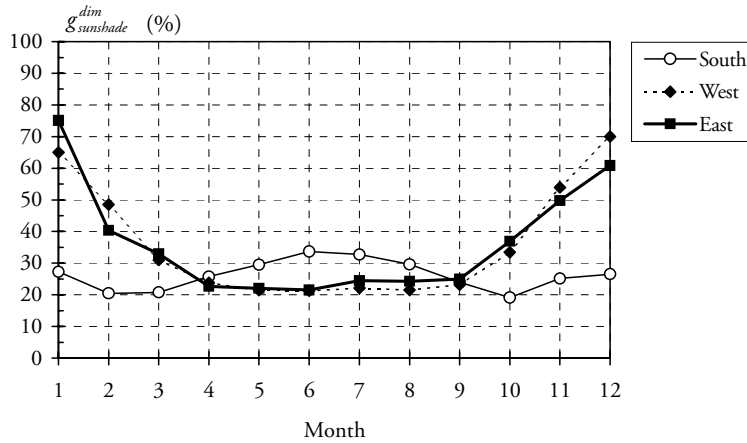


Figure 5.3 $g_{sunshade}^{dim}$ for light awning in Lund.

Figure 5.4 shows the mean energy transmittance $g_{sunshade}^{mean}$ for a light awning in Luleå in 1988. The difference between the west and east awning and the one in the south is less in summer and greater in winter than in Lund in 1988. This is due to the lower solar altitude. It is evident that the angle of incidence from November to February is very acute.

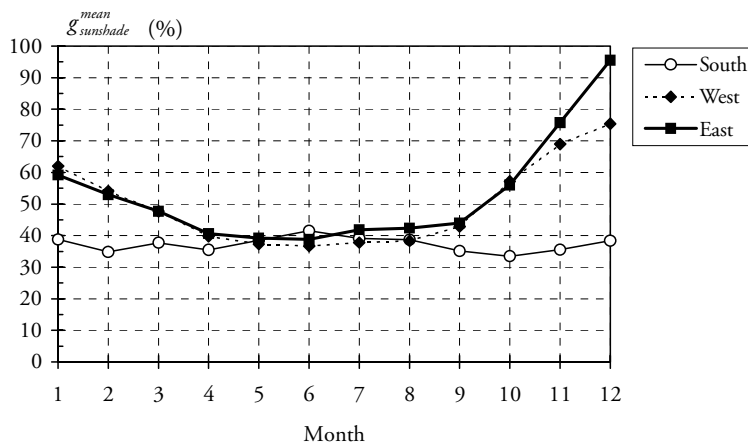


Figure 5.4 $g_{sunshade}^{mean}$ for light awning in Luleå.

Figure 5.5 shows the design energy transmittance $g_{sunshade}^{dim}$ for a light awning in Luleå in 1988. The curve is very similar to that for the same calculation for Lund 1988, most of the difference is due to the fact that transmittance for a southerly awning is lower in Luleå in the summer because of the lower solar altitude which gives less diffuse ground reflection (the awning fully shades the window in the summer at 12.00 hours).

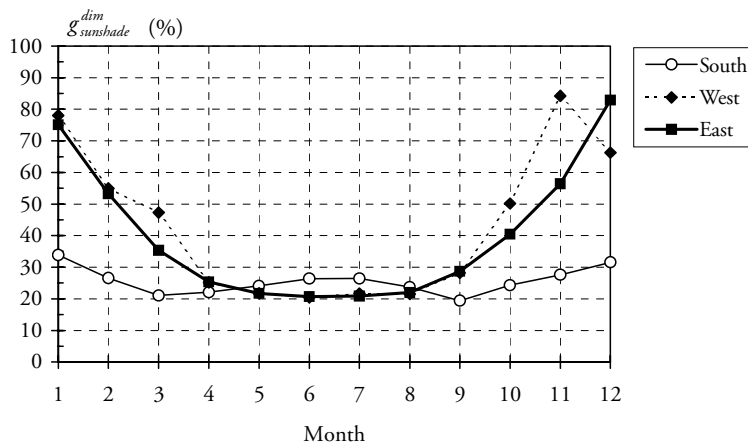


Figure 5.5 $g_{sunshade}^{dim}$ for light awning in Luleå.

5.1.2 Dark awning

Figure 5.6 shows g_{sunshade} for a dark blue awning (primary transmittance of fabric 1%) mounted in three different directions. The awning fully shades the window from solar radiation perpendicular to the facade with a solar altitude greater than 22° . It is clear that behaviour is the same as for the light awning, apart from the fact that the levels are generally lower.

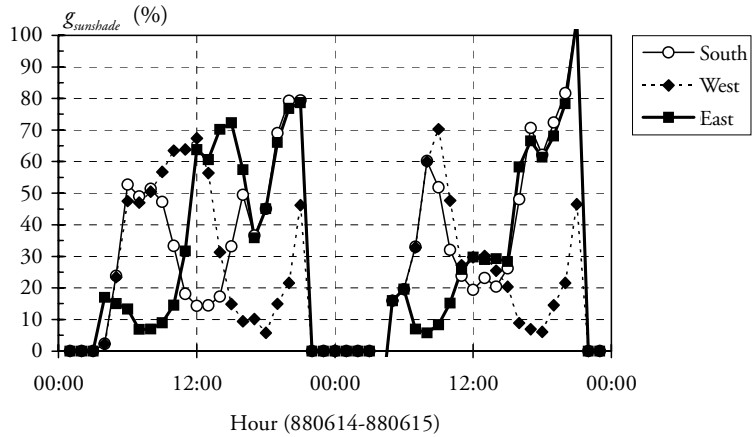


Figure 5.6 g_{sunshade} for a dark awning in Lund over two days.

Figure 5.7 shows the mean energy transmittance $g_{\text{sunshade}}^{\text{mean}}$ for a dark awning in Lund in 1988. The results are similar to the results for the light awning but total transmittance is on average approx. 20% lower. The difference between the fabrics is however 30%. The reason that the difference in effective transmittance is not the same is that the dark fabric has much higher absorption and therefore becomes warmer. In spite of the fact that the fabric only transmits 1% and the awning shades the whole window when solar radiation is greatest in summer, a mean energy transmittance between 20 and 30% must be expected.

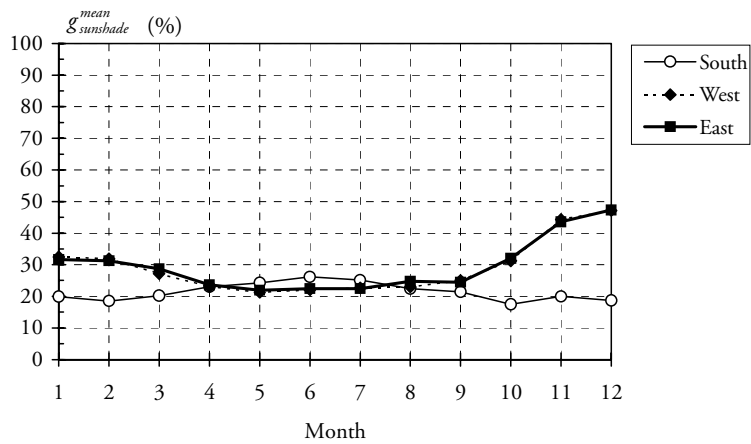


Figure 5.7 $g_{sunshade}^{mean}$ for dark awning in Lund.

Figure 5.8 shows the design energy transmittance $g_{sunshade}^{dim}$ for a dark awning in Lund in 1988. The results are similar to those for the light awning, but on average the total transmittance is approx. 15% lower. For a southerly awning at 12.00 hours in June transmittance is approx. 17%.

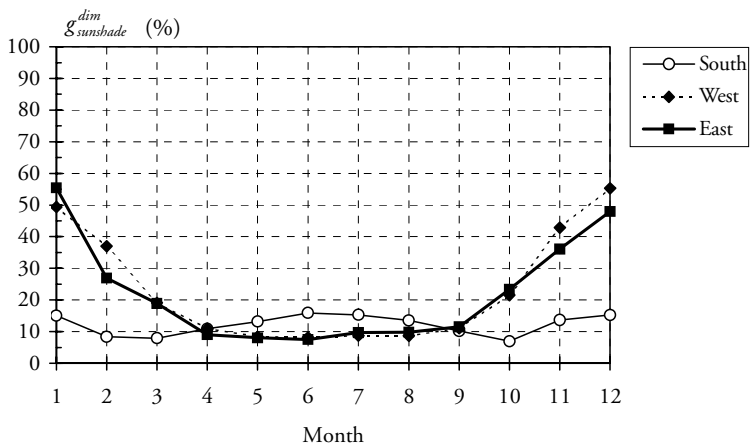


Figure 5.8 $g_{sunshade}^{dim}$ for dark awning in Lund.

Figure 5.9 shows the mean energy transmittance $g_{sunshade}^{mean}$ for a dark awning in Luleå in 1988 and Figure 5.10 shows the design transmittance $g_{sunshade}^{dim}$. The systematic difference between a light and a dark awning is the same as in Lund, i.e. approx. 20% lower mean energy transmittance and 15% lower design transmittance for the dark fabric.

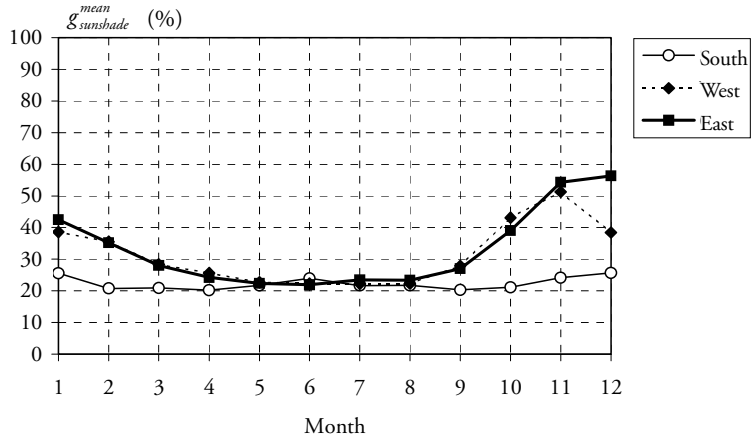


Figure 5.9 $g_{sunshade}^{mean}$ for dark awning in Luleå.

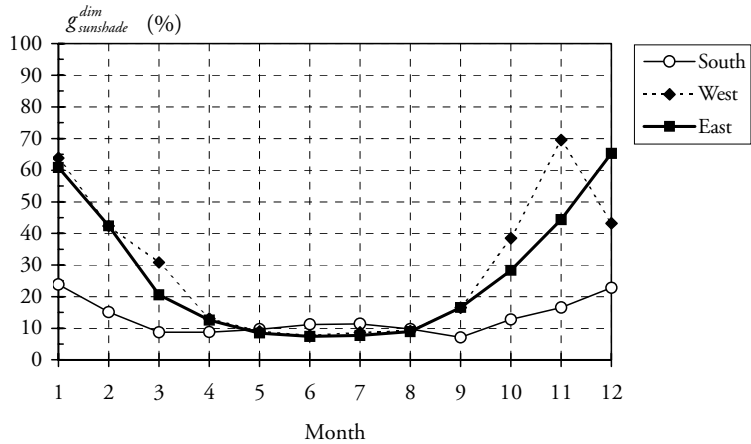


Figure 5.10 $g_{sunshade}^{dim}$ for dark awning in Luleå.

To sum up, it can be noted that the transmittance for the dark and light awnings is not particularly dependent on the difference in latitude between Lund and Luleå.

5.1.3 Light Italian awning

Figure 5.11 shows g_{sunshade} for a light unbleached white Italian awning (primary transmittance of fabric 30%) mounted in three different directions. The Italian awning fully shades the window from solar radiation perpendicular to the facade when solar altitude is greater than 30° . It is seen from the figure that in this situation the functions of the awning and Italian awning are practically identical. It is seen that incidence is a minimum in the morning, the middle of the day and in the afternoon for the east, south and west Italian awning respectively. The reason that the minimum for the east and west mounted Italian awning is lower is presumably that the proportion of diffuse radiation is comparatively lower in the morning and evening owing to the low solar altitude (which gives a larger projected area against the sun). Diffuse radiation is not shaded equally effectively by the Italian awning.

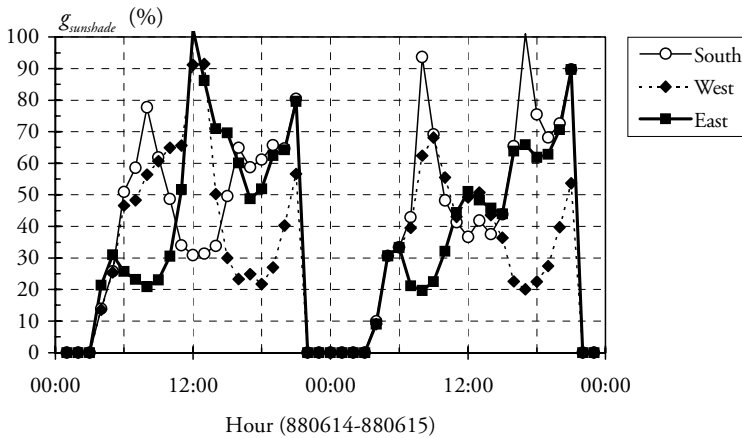


Figure 5.11 g_{sunshade} for a light Italian awning in Lund over two days in 1988.

Figure 5.12 shows the mean energy transmittance $g_{\text{sunshade}}^{\text{mean}}$, and Figure 5.13 the design energy transmittance $g_{\text{sunshade}}^{\text{dim}}$, for a light Italian awning in Lund in 1988. The results are very similar to those for the light awning. The greatest difference is that the Italian awning provides better shade for an acute angle of incidence, and transmittance during the winter months for the east and west Italian awning is therefore lower than that for the east and west awning.

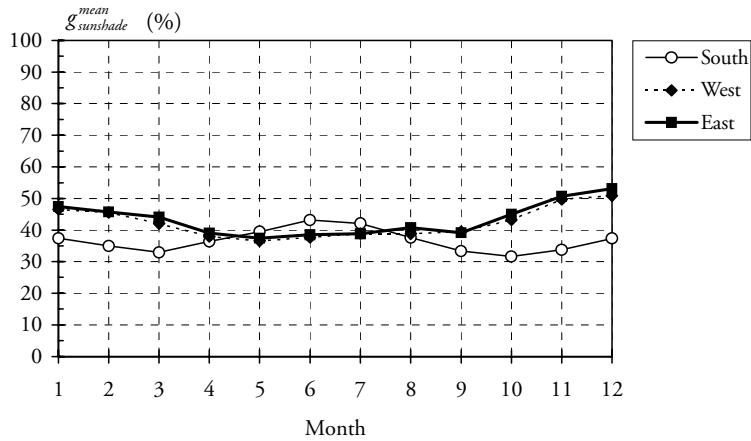


Figure 5.12 $g_{\text{sunshade}}^{\text{mean}}$ for light Italian awning in Lund.

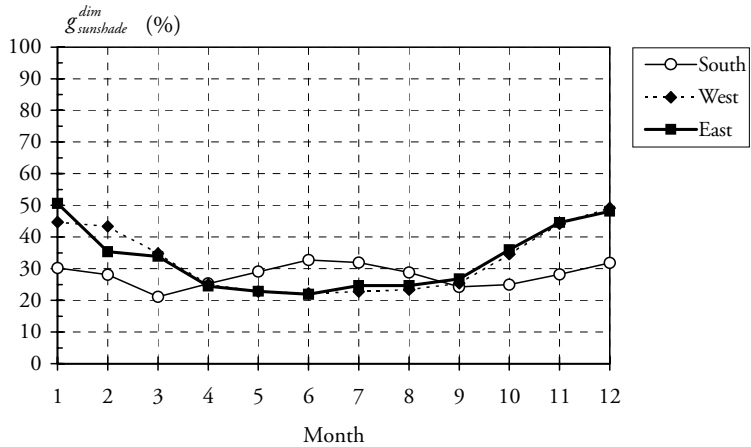


Figure 5.13 $g_{\text{sunshade}}^{\text{dim}}$ for light Italian awning in Lund.

Figure 5.14 shows the mean energy transmittance $g_{\text{sunshade}}^{\text{mean}}$ and Figure 5.15 the design energy transmittance $g_{\text{sunshade}}^{\text{dim}}$, for a light Italian awning in Luleå in 1988. The results are very similar for those for the light awning. The greatest difference is that the Italian awning provides better shade against acute angles of incidence, and transmittance during the winter months for the east and west Italian awning is therefore lower than for the east and west awning. Another difference is that transmittance during the winter months is slightly higher for the south mounted Italian awn-

ing since it does not reach down the same distance. The Italian awning shades the window from 30° solar altitude while the awning does so from 22° solar altitude.

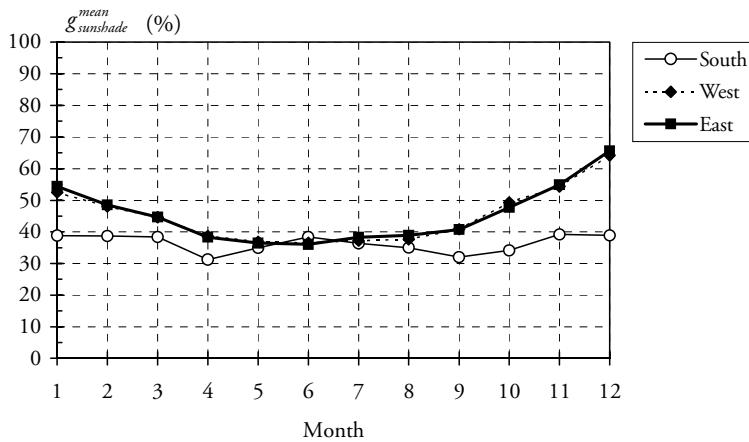


Figure 5.14 $g_{sunshade}^{mean}$ for light Italian awning in Luleå.

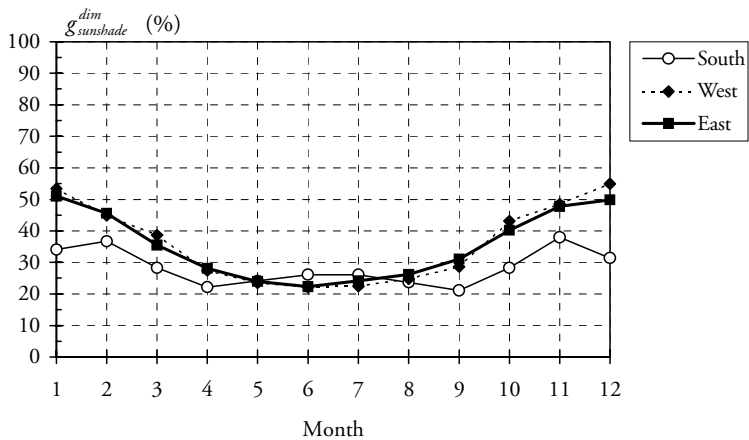


Figure 5.15 $g_{sunshade}^{dim}$ for light Italian awning in Luleå.

5.1.4 Dark Italian awning

Figure 5.16-5.20 show the results for a dark blue Italian awning (primary transmittance of fabric 1%) mounted in three different directions. The Italian awning fully shades the window from solar radiation perpendicular to the facade for solar altitudes over 30°. The difference between light

and dark Italian awning is the same as between the light and dark awning. It is evident that behaviour is the same as for the light Italian awning, except that the levels are generally lower. Compared with the dark awning, the principal difference is that the east and west Italian awning has lower transmittance during the winter months because the Italian awning is less sensitive to acute angles of incidence than the awning, and because the south mounted Italian awning has higher transmittance during the winter months since it does not reach down as far as the awning.

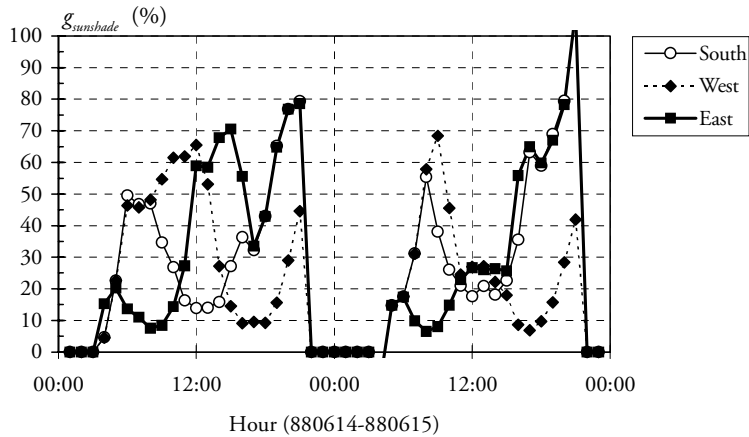


Figure 5.16 g_{sunshade} for a dark Italian awning in Lund over two days in 1988.

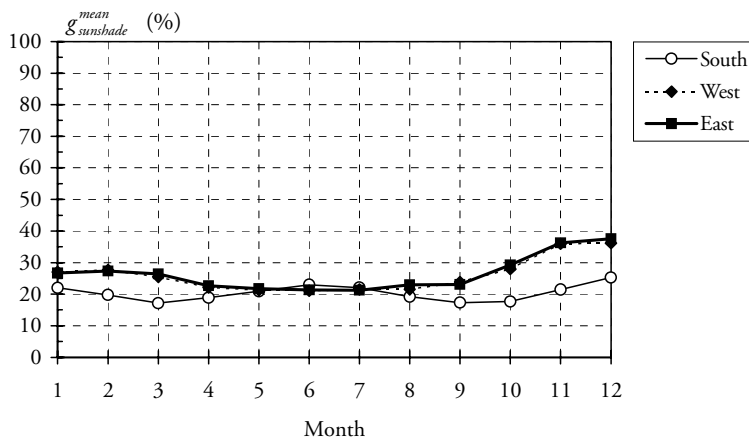


Figure 5.17 $g_{\text{sunshade}}^{\text{mean}}$ for dark Italian awning in Lund.

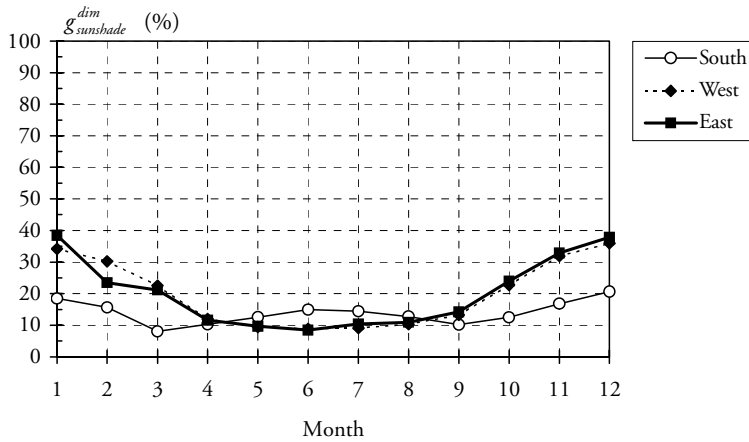


Figure 5.18 $g_{\text{sunshade}}^{\text{dim}}$ for dark Italian awning in Lund.

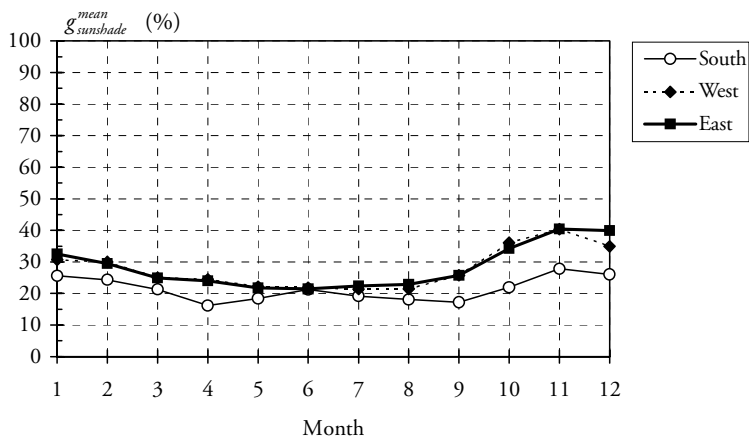


Figure 5.19 $g_{\text{sunshade}}^{\text{mean}}$ for light Italian awning in Luleå.

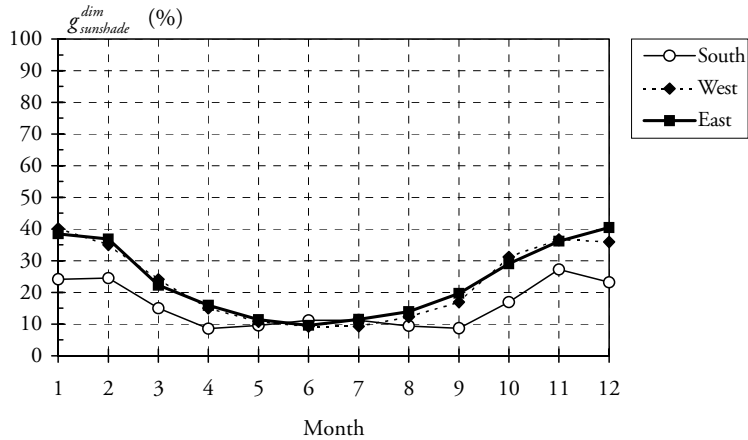


Figure 5.20 $g_{sunshade}^{dim}$ for dark Italian awning in Luleå.

5.1.5 Horizontal slatted baffle

Figure 5.21 shows $g_{sunshade}$ for a horizontal slatted baffle with slats of anodised aluminium, mounted in three different directions. The slatted baffle fully shades the window against solar radiation perpendicular to the facade for solar altitudes over 40° . Since the slatted baffle is mounted at right angles to the facade it is very sensitive to solar angle and the proportion of diffuse radiation. It is because of the diffuse component that transmittance on 15 June 1988 is higher than on 14 June 1988.

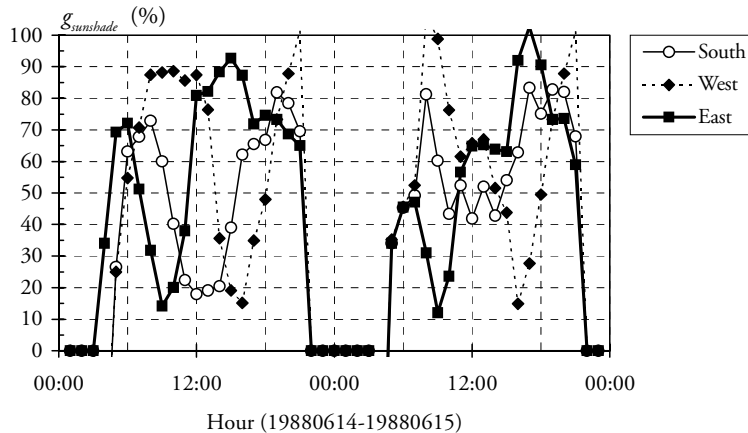


Figure 5.21 $g_{sunshade}$ for a horizontal slatted baffle in Lund over two days in 1988.

Figure 5.22 shows the mean energy transmittance $g_{sunshade}^{mean}$ for a horizontal slatted baffle in Lund in 1988. It is evident that the slatted baffle is very sensitive to solar position. For the east and west slatted baffle the sun during the whole time is too low for the window to be fully shaded. The reason that transmittance increases in June and July for the south slatted baffle is presumably that the diffuse component is relatively large during this period on a southerly facade.

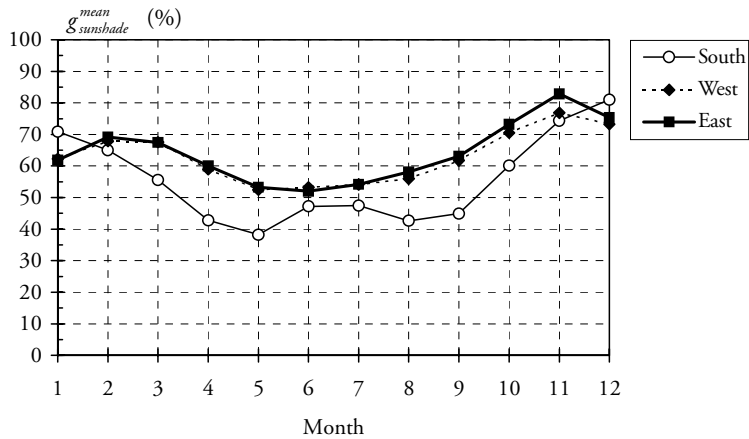


Figure 5.22 $g_{sunshade}^{mean}$ for horizontal slatted baffle in Lund.

Figure 5.23 shows the design energy transmittance $g_{sunshade}^{dim}$ for a slatted baffle in Lund. It is very clear that the sun on a southerly facade is not shaded from October to March (solar altitude at noon $< 40^\circ$).

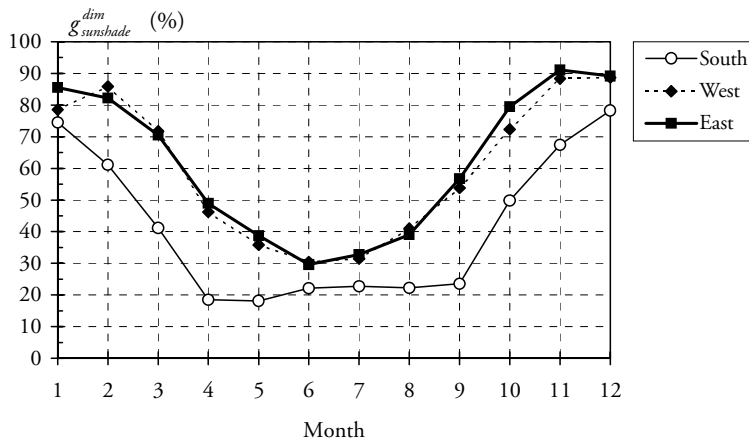


Figure 5.23 $g_{sunshade}^{dim}$ for horizontal slatted baffle in Lund.

Figure 5.24 and 5.25 show $g_{\text{sunshade}}^{\text{mean}}$ and $g_{\text{sunshade}}^{\text{dim}}$ for a slatted baffle in Luleå in 1988. The tendency is the same as for Lund in 1988. Since the sun is lower the effects are even more evident, although the solar altitude during the summer is still greater than 40° at noon against a southerly facade. Since solar altitude is lower, the diffuse component in summer is slightly lower against a southerly facade, and total transmittance is therefore lower. In the winter a southerly facade is very little shaded by a slatted baffle (transmittance 80-90%).

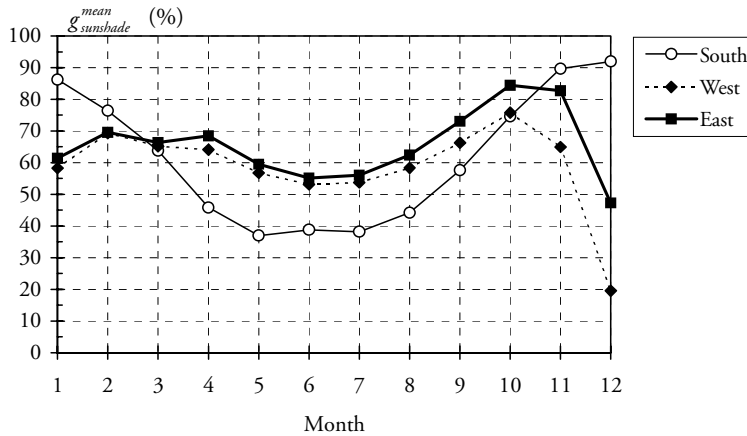


Figure 5.24 $g_{\text{sunshade}}^{\text{mean}}$ for horizontal slatted baffle in Luleå.

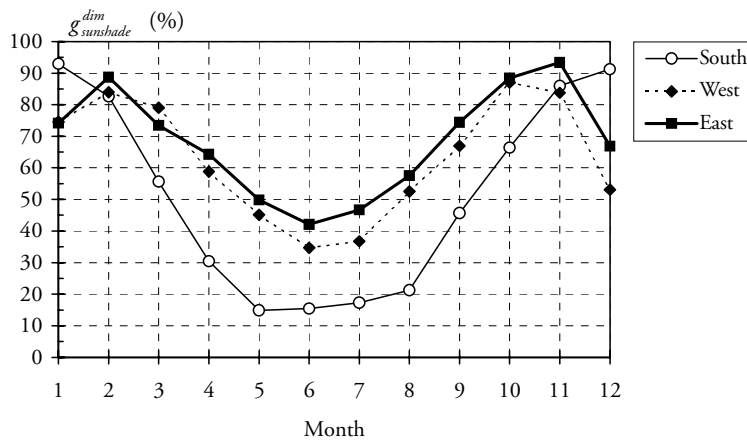


Figure 5.25 $g_{\text{sunshade}}^{\text{dim}}$ for horizontal slatted baffle in Luleå.

5.1.6 External 80 mm venetian blind

Figure 5.26 shows g_{sunshade} for an external venetian blind with horizontal slats of anodised aluminium mounted in three different directions. The blind fully shades the window against solar radiation at right angles to the facade for solar altitudes over 41° . The blind is not so sensitive to acute angles of incidence as the horizontal slatted baffle. This generally reduces transmittance. However, reflections from the slats can strike the window, which is not the case with the horizontal slatted baffle. The total effect is that the performance of the external blind is quite similar to that of the horizontal slatted baffle.

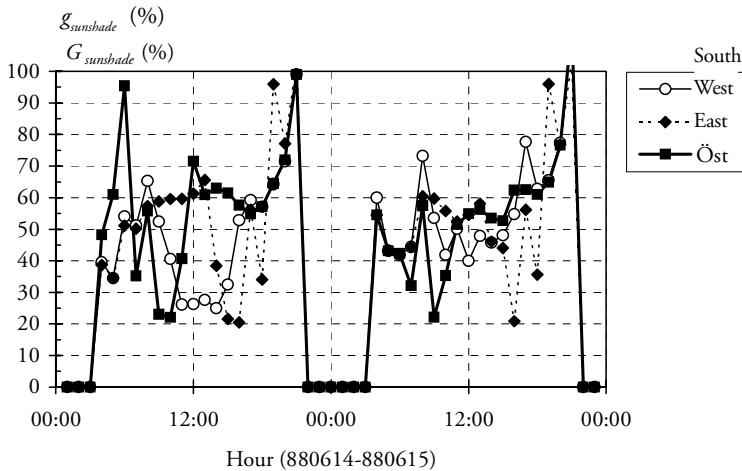


Figure 5.26 g_{sunshade} for an external venetian blind in Lund over two days in 1988.

Figure 5.27 and 5.28 show $g_{\text{sunshade}}^{\text{mean}}$ and $g_{\text{sunshade}}^{\text{dim}}$ for an external venetian blind in Lund in 1988. The general behaviour is about the same as that of the horizontal slatted baffle. The difference is that the blind is slightly less angle dependent and the curves are therefore slightly flatter. The mean energy transmittance $g_{\text{sunshade}}^{\text{mean}}$ is very similar to that for the horizontal slatted baffle while the design transmittance $g_{\text{sunshade}}^{\text{dim}}$ is approx. 10% higher during the summer months, presumably because of the reflection from the slats towards the window.

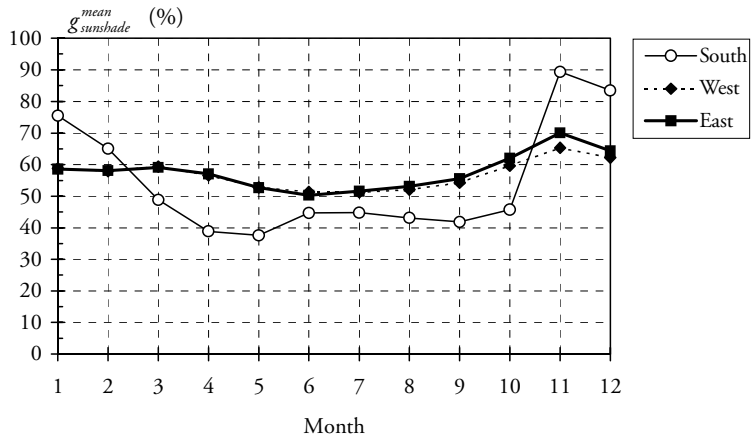


Figure 5.27 $g_{\text{sunshade}}^{\text{mean}}$ for external venetian blind in Lund.

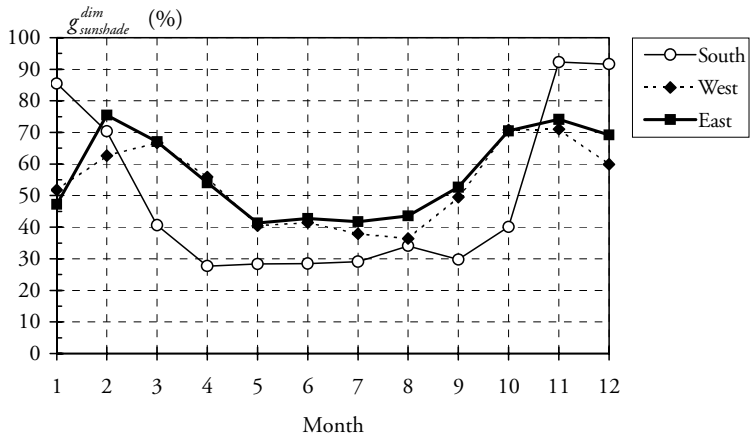


Figure 5.28 $g_{\text{sunshade}}^{\text{dim}}$ for external venetian blind in Lund.

Figure 5.29 and 5.30 show $g_{\text{sunshade}}^{\text{mean}}$ and $g_{\text{sunshade}}^{\text{dim}}$ for an external venetian blind in Luleå in 1988. The tendencies are the same as in Lund in 1988.

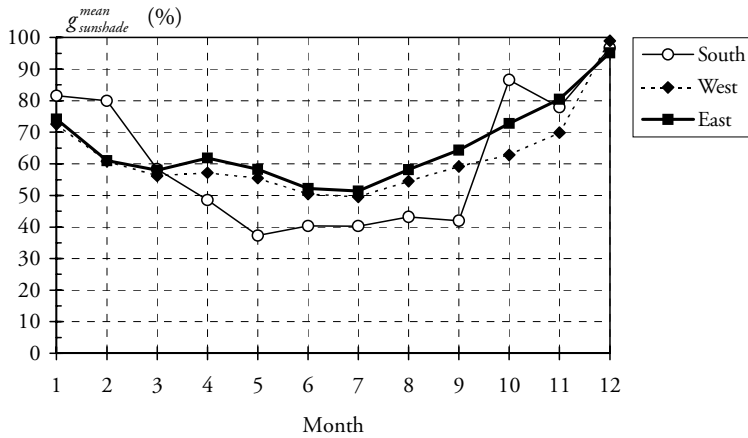


Figure 5.29 $g_{\text{sunshade}}^{\text{mean}}$ for external venetian blind in Luleå.

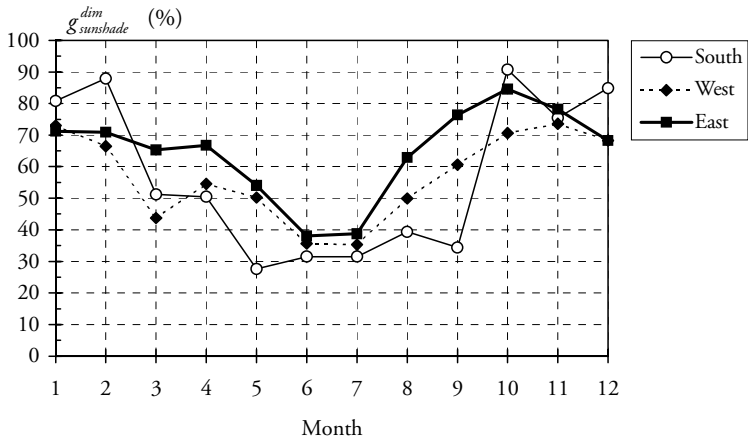


Figure 5.30 $g_{\text{sunshade}}^{\text{dim}}$ for external venetian blind in Luleå.

5.1.7 Fabric screen Soltis 92 1045

Figure 5.31 shows g_{sunshade} for a fabric screen of the type Soltis 92 1045. It has a primary transmittance of 4%. Since the screen shades the window except for very acute angles of incidence, there is very little difference between screens in different directions. Any differences are presumably mostly due to differences in outside temperature. The colder it is outdoors, the better the screen functions. For this reason the south mounted screen has a slightly higher transmittance than the others in the summer. The

mean energy transmittance, $g_{sunshade}^{mean}$, Figure 5.32 and 5.33, is approx. 14% and the design energy transmittance, $g_{sunshade}^{dim}$, Figure 5.33 and 5.34, is approx. 12%. This is three times as high as primary transmittance, which demonstrates how important it is to have a model that calculates the temperature of the sunshade.

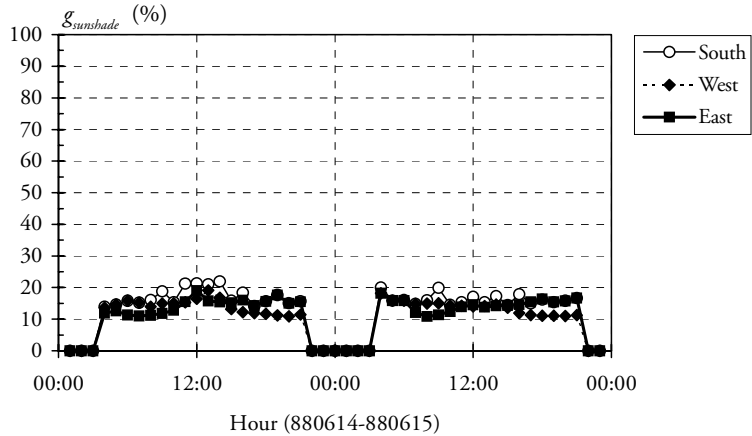


Figure 5.31 $g_{sunshade}$ for fabric screen Soltis 92 1045 in Lund over two days in 1988.

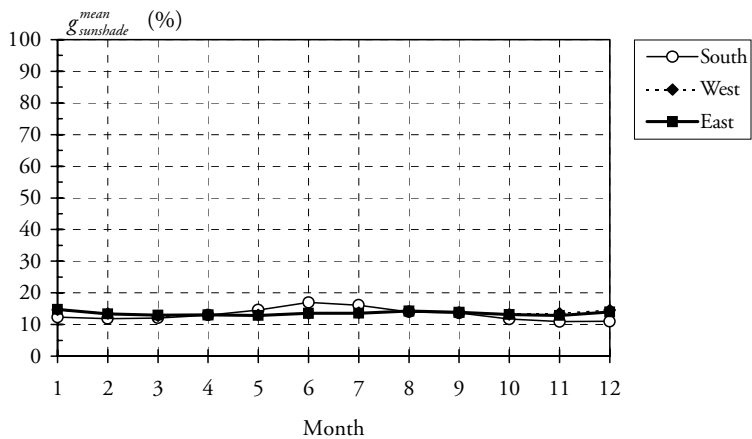


Figure 5.32 $g_{sunshade}^{mean}$ for fabric screen Soltis 92 1045 in Lund.

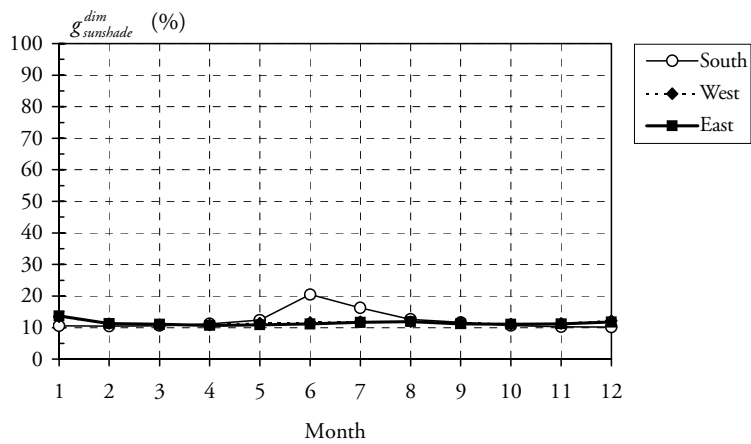


Figure 5.33 $g_{sunshade}^{dim}$ for fabric screen Soltis 92 1045 in Lund.

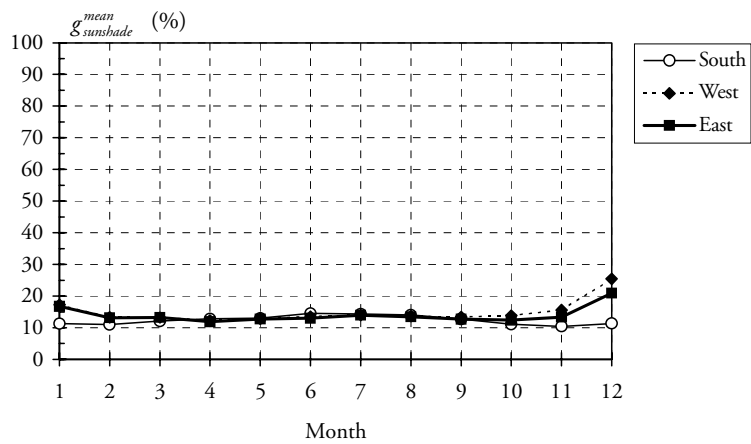


Figure 5.34 $g_{sunshade}^{mean}$ for fabric screen Soltis 92 1045 in Luleå.

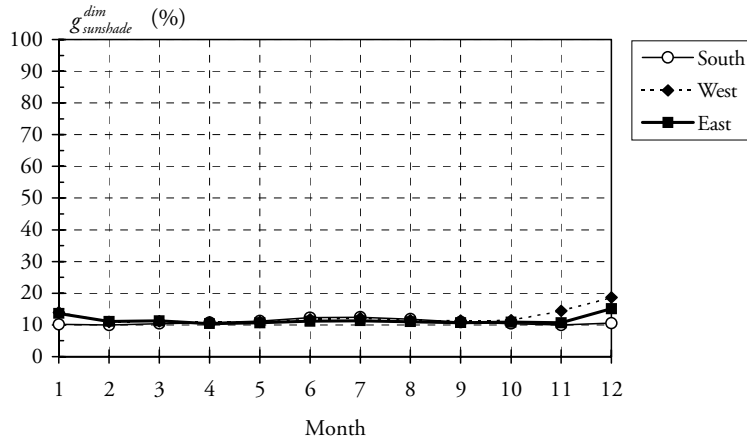


Figure 5.35 $g_{sunshade}^{dim}$ for fabric screen Soltis 92 1045 in Luleå.

5.1.8 Fabric screen Hexcel 21136 Sable

Figure 5.36 shows $g_{sunshade}$ for a fabric screen of the type Hexcel 21136 Sable. It has primary transmittance of 10%. Since the screen shades the window except for very acute angles of incidence, there is very little difference between screens in different directions. Any differences are presumably mostly due to differences in outside temperature. The colder it is outdoors, the better the screen functions. For this reason the south mounted screen has a slightly higher transmittance than the others in the summer. The mean energy transmittance, $g_{sunshade}^{mean}$, Figure 5.37 and 5.39, is approx. 18% and the design energy transmittance, $g_{sunshade}^{dim}$, Figure 5.38 and 5.40, is approx. 16%. This is about twice as high as the primary transmittance.

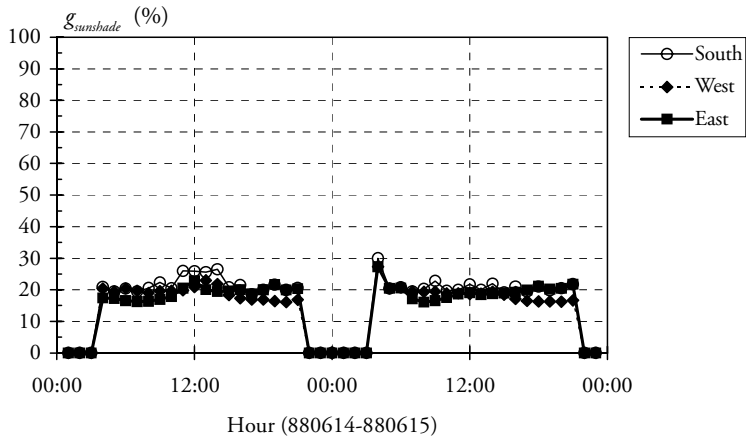


Figure 5.36 g_{sunshade} for fabric screen Hexcel 21136 Sable in Lund over two days in 1988.

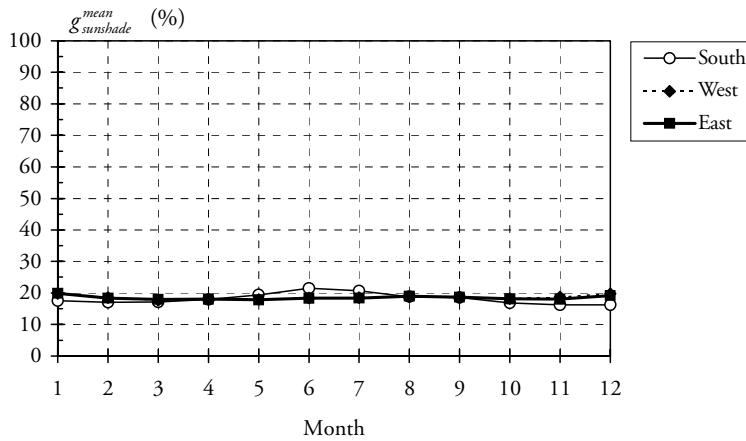


Figure 5.37 $g_{\text{mean sunshade}}$ for fabric screen Hexcel 21136 Sable in Lund.

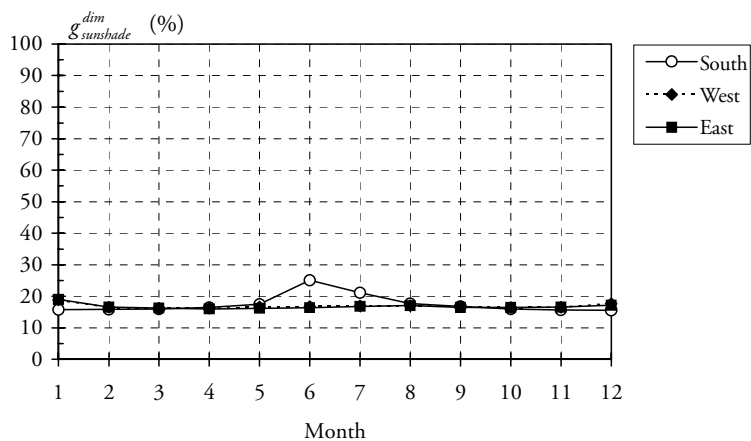


Figure 5.38 $g_{\text{sunshade}}^{\text{dim}}$ for fabric screen Hexcel 21136 Sable in Lund.

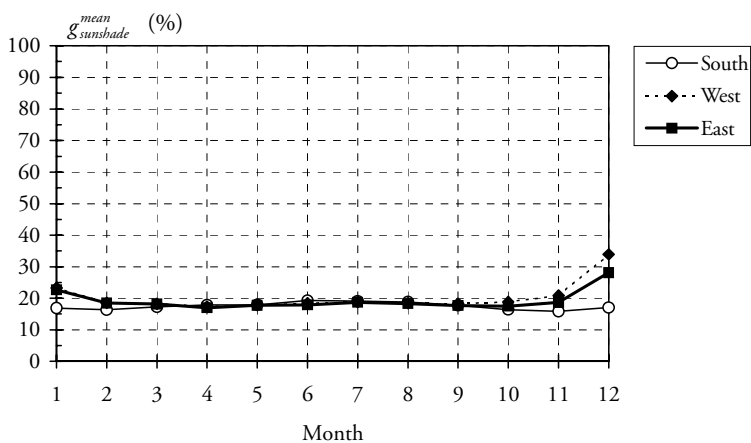


Figure 5.39 $g_{\text{sunshade}}^{\text{mean}}$ for fabric screen Hexcel 21136 Sable in Luleå.

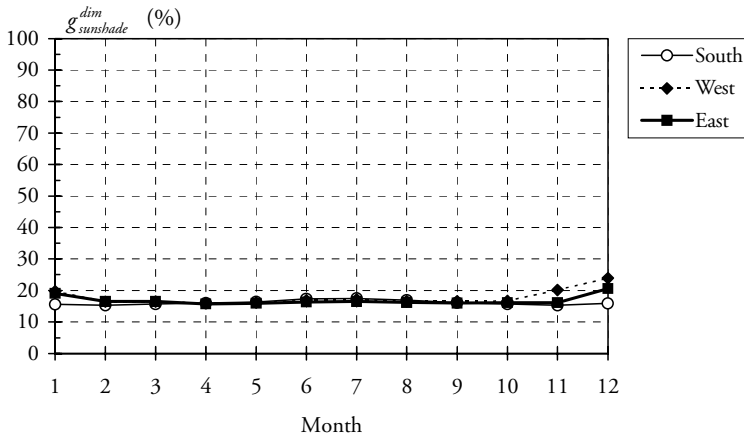


Figure 5.40 $g_{\text{sunshade}}^{\text{dim}}$ for fabric screen Hexcel 21136 Sable in Luleå.

5.2 Roller shutters

Two different non-transparent roller shutters were studied in the outdoor measurement. The result was that for windows with roller shutters in a fully lowered position (but with open gaps between the slats) the total solar energy transmittance was approx. 3%. Total solar energy transmittance (g) for the roller shutter alone varied therefore between 4% and 100% depending on how far the shutter is lowered, the geometric design of the cassette and the direction of solar radiation. In practice g presumably varies between 4% and 90% during the cooling season. It cannot be expected that g will be 0% when the shutter is fully closed since the material is heated up and thus has secondary transmittance. Since the total solar energy transmittance of non-transparent roller shutters is so low, the sunshade functions as a reduction of the window area. This implies that the solar energy transmittance for a non-transparent roller shutter can be calculated as for the unshaded window but with a smaller area. For this reason no parametric study was performed for roller shutters, and the value of g in summer can quite simply be assumed to be 5% - 90%.

Roller shutters and fabric screens mounted vertically in front of the window are the outside sunshades that have the greatest effect on the U-value of the system. Roller shutters have the greatest effect since they are most airtight and insulating. Overnight this can be a desired effect. In this investigation no detailed study has been made of the effect which the different sunshades have on the U-value, and this will be done in further

investigations. A first measurement has however shown that the total U-value dropped from 3.5 to 2.9 W/m²°C when the roller shutters were fully lowered.

5.3 Summary

It has been found necessary to use two measures in describing how well an outside sunshade functions:

- $g_{sunshade}^{mean}$ which represents the total mean energy transmittance
- $g_{sunshade}^{dim}$ which represents the total transmittance when solar radiation on the facade is greatest.

These measures are relatively insensitive to window type and facade. When a double glazed sealed unit (4 mm – 12 mm – 4 mm) was replaced by a triple glazed sealed unit (4 mm – 12 mm – E4 mm – 12 mm – 4 mm), the transmittance of the light awning increased by approx. 3%. For the dark awning the difference is presumably lower since the fabric does not let through diffuse solar radiation. In most cases dependence on latitude and climate is surprisingly weak.

Since some of the sunshades have a very strong dependence on the seasons, the behaviour of the different sunshades cannot be easily summarised in tabular form. Table 5.1 gives a random sample (July, southerly facade in Lund in 1988) for the mean energy transmittance and the design transmittance.

Table 5.1 $g_{sunshade}^{mean}$ and $g_{sunshade}^{dim}$ for the different sunshades in July 1988, mounted on a southerly facade in Lund.

Sunshade	$g_{sunshade}^{mean}$	$g_{sunshade}^{dim}$
Light awning	45%	33%
Dark awning	25%	15%
Light Italian awning	42%	32%
Dark Italian awning	22%	14%
Horizontal slatted baffle	47%	23%
External 80 mm venetian blind	45%	29%
Soltis 92 1045	16%	16%
Hexcel 21136 Sable	21%	21%
Roller shutters	4-85%	4-85%

6 Design tool

Petter Wallentén
Hasse Kvist

A design tool with the name ParaSol v1.0, based on models produced for awnings, venetian blinds, fabric screens and fixed overhangs has been developed. ParaSol is essentially a specially developed interface for the energy calculation program DEROB-LTH which is the aid in which the proposed simulation models for different sunshades have been implemented. The target group for the tool ParaSol are architects, building services consultants and other engineers whose job is to choose sunshades for a given building. Since this group has a very varied technical background, the intention is to make a tool that is sufficiently advanced to produce relevant data, but not so complicated that the user introduces unnecessary errors in the input data or quite simply will not use the tool at all. The original intention was that a simplified calculation program should be used, but since ordinary personal computers have sufficient capacity to run DEROB-LTH, it was decided to use this program directly.

ParaSol is a Windows 95/98/NT program written in Visual Basic. Data for ParaSol are input via a number of windows.

Output data from the program can be produced in different degrees of detail depending on the degree of detail in the input data. The simplest output data is total transmission (g) for sunshades and for the combination sunshade and window. Detailed output data are power demand for cooling and heating, duration curves for temperatures, etc.

6.1 Start window

The start window for the program is shown in Figure 6.1. A brief review of the parameters which must be determined is given below. A change in geometry and sunshade is directly visible in the geometry of the model at top right in the window. There are a number of buttons for the windows that can be accessed from this window.

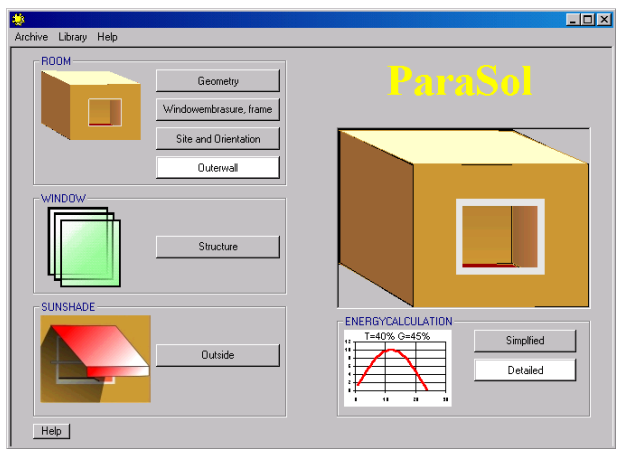


Fig. 6.1 Start window

6.2 Geometry

In the first version of the program only one geometry is used: a rectangular office module with *one* external wall and *one* window. It may be possible to define several other geometries at a later date. All geometrical dimensions can be changed.

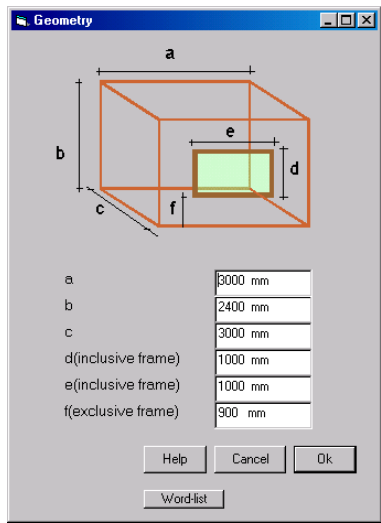


Fig. 6.2 Geometry window

6.3 Window embrasure and frame width

Window embrasure and frame width are needed to describe how the window is mounted in the wall. These are parameters whose importance is often underestimated. In the present version a wooden frame is assumed.

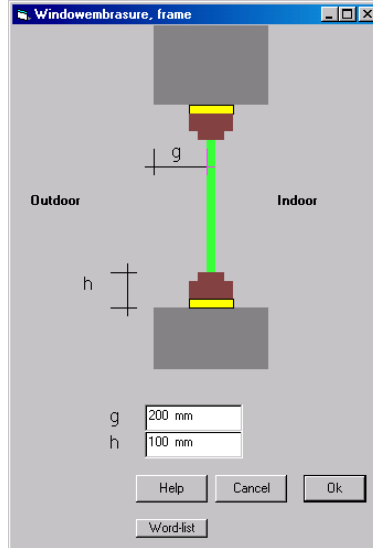


Fig. 6.3 Window embrasure and frame width

6.4 Site and orientation

Orientation is naturally important for calculation of transmission properties. For the calculation of direct transmission T the latitude is needed, but not the climate. For the calculation of the total transmission g both latitude and climate are needed. In order to enhance interactivity, the room rotates according to the input orientation.

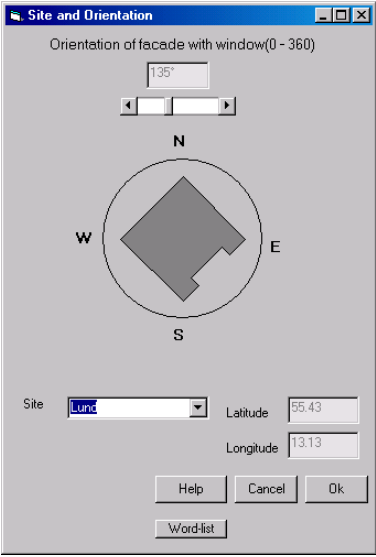


Fig. 6.4 Locality and orientation

6.5 Walls

Description of the walls is made as simple as possible. Since it is only the external wall that abuts on a different climate, only its U value is needed. The subdivision into lightweight and heavy construction is perhaps too simple a description. It is however easy to make a more detailed subdivision, perhaps with different types of construction.

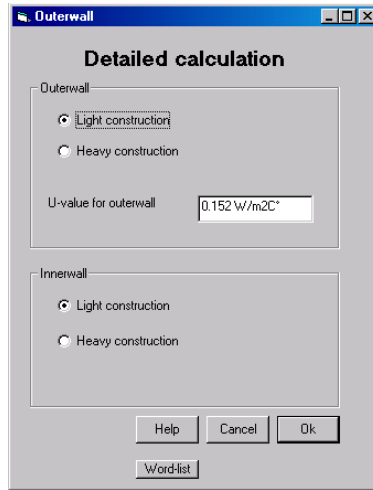


Fig. 6.5 Walls

6.6 Window construction

Information for the window concerns

- glass type
- glass thickness
- width of air gap
- gas in the gap
- coatings on the glass

There are ready made examples of window constructions. The user can input his/her own data as needed. Glass- and gastypes used in the window construction are stored in a library managed from the main menu. The program calculates the heat transfer coefficient for the window constructions exclusive frame.

6.7 Description of sunshade

The data needed for the selected sunshade are described. The only example shown here is that for an awning. Other sunshades are described in the same way.

6.7.1 Awning

For an awning, geometric data and information on the fabric used are needed. The fabrics for which there are data are tabulated.

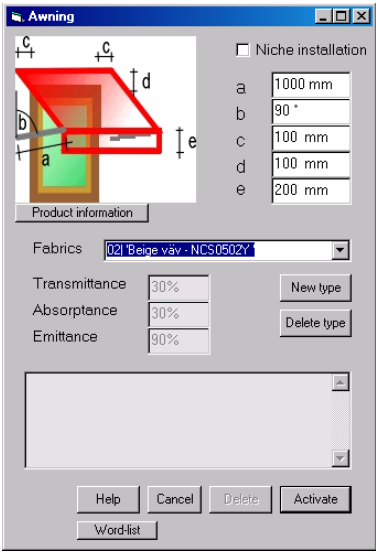


Fig. 6.6 *Awning*

6.8 Simple data input

Two results are displayed for direct and total transmission: mean effectiveness and design effectiveness. The calculated transmissions are means for the period as a whole and monthly values during the period. These values can be saved in a file for later export to some other energy calculation program.

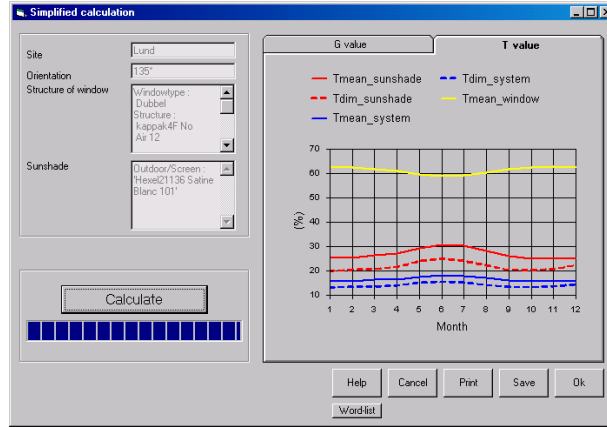


Fig. 6.7 Simple data input

6.9 Detailed data input

If the user has access to more detailed information concerning e.g. installed cooling capacity, heating capacity, ventilation, internal load and control temperatures for heating and cooling, a more detailed calculation can be performed. The results given are then design temperatures, cooling and heating loads, duration curves for temperatures, etc. In this case also the output data can be exported to a file for later use in other programs.

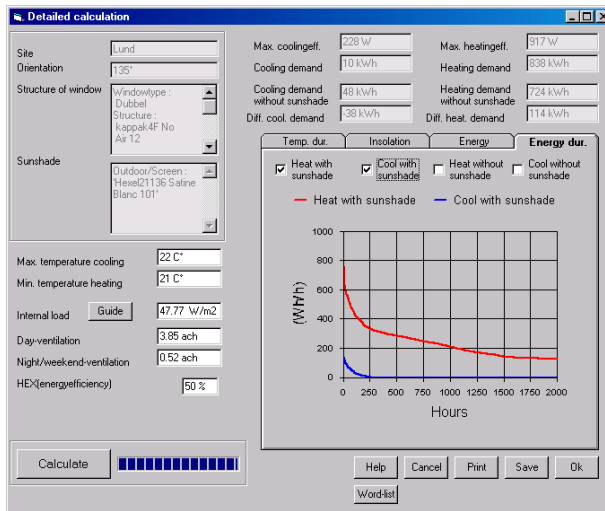


Fig. 6.8 Detailed data input

6.10 Further work

Version 1.0 of this program has been completed in a Swedish version and refers to external sunshades. An English version is underway and will be available in early 2001. If finance can be arranged, further versions are planned. The following versions will be able to handle interpane sunshades, and internal sunshades. An important part that should be incorporated as soon as possible is the facility to judge the effects of controlling sunshades.

7 Impact of solar shading on energy use

Marie-Claude Dubois

7.1 Introduction

The use of solar-protective glazing or solar shading devices can significantly reduce the cooling demand of buildings. The question is not whether solar shading should be used or not but rather: how much shading is needed or what is the best shading strategy in any particular case?

One means to shade windows is to use solar-protective (reflective or heat-absorbing) glass. This solution has gained popularity during the past decades, especially in North-America, where high-rise buildings are common. Solar-protective glazing is easier to integrate to a building's facade, requires less maintenance and lower investment costs compared with shading devices. However, solar-protective glass reduces the building's solar gains year-round, which usually results in an increase in the heating demand. Likewise, solar-protective glass reduces the transmission of daylight at all time of the year, which might reduce the interior illumination to unacceptable levels during the winter season. This is an important issue for Scandinavian countries, where only a small amount of natural light is available during the winter.

Compared with solar-protective glazing, shading devices have several advantages: they are easy to add to existing buildings as a retrofit measure; they can be used only when overheating occurs; some devices (e.g. overhangs, side fins) leave the view out almost unchanged while others (e.g. tight screens) reduce the thermal losses through the windows. Some research (e.g. Christoffersen, 1996) also indicates that some types of devices (e.g. venetian blinds) might improve the daylight distribution in the building, which can improve the visual comfort of the occupants. Moreover, one study about electrochromic glazing (Moeck et al., 1996) suggests that the only way to avoid glare from windows is to use shading devices since coloured glass cannot reduce the sky luminance to the required levels for visual comfort.

Another reason to use shading devices instead of solar-protective glazing is a larger potential for energy savings during the cooling season. Exterior shading devices like e.g. awnings have a lower shading coefficient since 1) they reject solar energy before it reaches the window and 2) most of the heat absorbed in the shade is convected to the outdoor air. This has been confirmed by the measurements in the twin boxes described in Section 5.3. These measurements show that dark blue awnings and some types of screens have an average total solar transmittance (g -value) of around 20%, which is lower than the transmittance of most solar-protective glazing assemblies.

Since it appears that shading devices have many advantages over solar-protective glazing, it is necessary to study and compare the performance of each shading alternative on energy use in buildings. For this purpose, two parametric studies were carried out as part of the Solar Shading Project. In the first study (Dubois, 1998), the impact of various solar-protective (reflective, heat-absorbing) glazing assemblies on heating and cooling loads was analysed and compared to the impact of ordinary clear and low-emissivity coated glazing and of a clear glass plus awning assembly for a typical office room located in Lund, Sweden (latitude 55.72°N; longitude 13.22°E). Eight glazing options and two shading strategies were studied. The glazing-to-wall area ratio (GWAR) was varied 0-70% and the office room was alternately orientated towards N, NE, E, SE, S, SW, W and NW. The office room was also placed in different climates (Stockholm, Luleå, Oslo, Montreal) to verify whether the optimum glazing properties were climate-dependent. This part of the study is only reported in Dubois (1998).

In the second study (Dubois, 1999), the impact on energy use of the seasonal management, geometry (i.e. length, width and slope) and properties of a conventional awning was analysed for a single, south-oriented office room in Stockholm, Sweden (latitude 59.35°N; longitude 18.07°E). The aim of this study was 1) to identify the optimum awning design and 2) to estimate the relative impact of each design characteristic (length, width, slope, colour, etc.) on energy use for heating and cooling the office.

7.2 Method

7.2.1 First study: solar-protective glazing

Computer simulations

In the first study, the room's annual energy use was studied using the dynamic program *DEROB-LTH* version 97.02. This version of the program contained the improved window model described in Sections 4.1 - 4.5. This model calculates the solar and sky radiation absorbed by each windowpane and takes into consideration the solar angle dependent properties of the glazing or glazing combinations. This model also uses one temperature node for each pane, includes long-wave radiation and convection between panes taking into consideration the heat transfer coefficients, which depend on the glass temperature, the space between the panes and the window slope. However, this version of the program did not include the thermal model for shading devices described in Section 4.6. Thus, the impact of the awning's temperature on the temperature of the windowpanes is not taken into consideration in this study.

Angle-dependent optical properties of the glazing

In *DEROB-LTH* version 97.02, the angle-dependent optical properties of each glazing layer can be either calculated using the Fresnel formalism or defined directly for an arbitrary set of incidence angles. In this study, the latter input format was chosen since the only information available from the glazing manufacturer was the transmittance and reflectance of the glass at normal incidence. The angle-dependent transmittance and reflectance of each glazing layer were calculated separately using the program *WINDOW 4.1* (LBL, 1985, 1988). This program 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.

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 with one window and one door opposite to the window (Figure 7.1). The room was constructed according to ordinary building practices for commercial offices in Sweden. However, to simplify the model, the room was assumed to be surrounded by office

space at the same temperature. Thus, all the “interior” walls were modeled as adiabatic elements. Moreover, the thickness of the insulation layer in the wall facing the “exterior” (surrounding the window) was purposely adjusted to yield equivalent overall thermal losses for all the cases studied. This procedure allowed to study windows with different U-values and isolating the energy effect of interest i.e. the impact of the glazing optical properties on energy use.

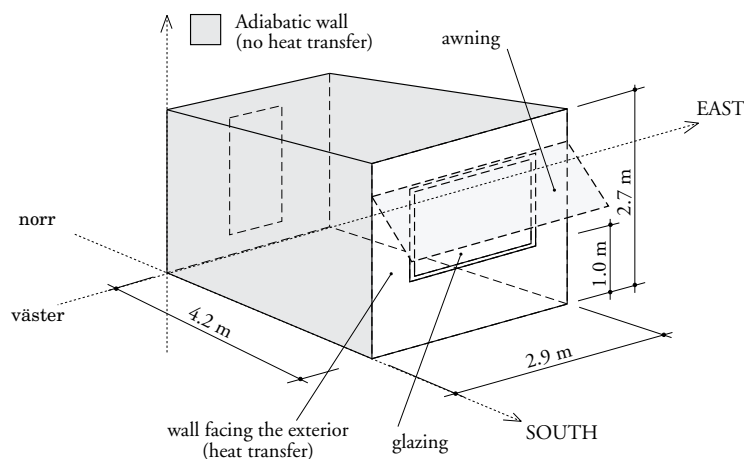


Figure 7.1 Office module.

The internal loads in the office room consisted of the heat from one occupant (90 W), a computer and monitor (120 W) and energy-efficient lighting (120 W). The thermostat settings for heating were 20°C every day during work hours (8-17), with a night setback temperature of 18°C. For cooling, the thermostat settings were 24°C (8-17), with a night setback of 28°C. These settings were also assumed during weekends. The ventilation rate was 10 l/s and the infiltration was 0.1 ach. For simplification the ventilation air was not preheated and no heat recovery of the exhaust air was made. A free horizon with no obstruction and a ground reflectance of 30% were assumed.

Variables

The glazing type, glazing-to-wall area ratio (GWAR) and the orientation were varied alternately. Moreover, one shading system consisting of a conventional awning was tested. The glazing library was selected to represent

a wide range of solar transmittance values (Table 7.1). The GVAR was varied from 0 to 70% as shown on Figure 7.2 while the orientation was varied by 45° increments (N, NE, E, SE, S, SW, W and NW).

Table 7.1 Glazing assemblies.

#	Glazing assembly	U-value (W/m ² °C)	Total solar transm. (g-value) (%)	Shading coefficient	Solar transm. at normal incidence (%)	Visual transm. at normal incidence (%)
A	D-reflective bronze*	2.06	14	0.16	5	9
B	D-reflective blue	2.62	27	0.32	18	27
C	T-reflective silver	1.87	38	0.44	30	29
D	T-heat absorbing blue	1.87	41	0.48	31	44
E	D-heat absorbing blue*	2.63	48	0.56	38	48
F	T-low-e coated*	1.00	58	0.68	44	65
G	T-clear	1.88	65	0.76	55	73
H	D-clear*	2.65	74	0.86	67	80

D = double pane; T = triple pane

* = with argon (others are with air)

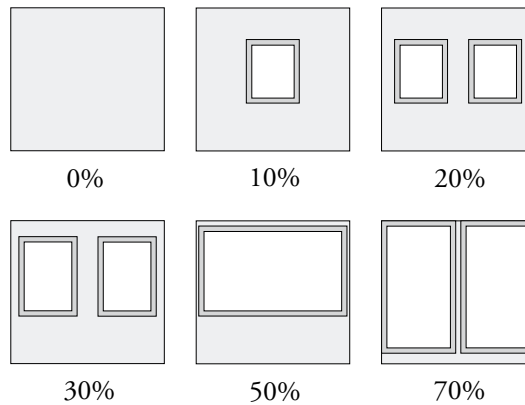


Figure 7.2 Glazing-to-wall area ratios (GVAR).

Shading system

A dark blue awning (transm. = 7%, absorpt. = 67%) with a slope of 30° was placed in front of the window so as to block all direct solar radiation on the south facade during the cooling season (May 01-September 30). The same awning geometry was applied to east, west and north facades in spite of different sun angles. Two shading strategies were tested: an awning in place year-round (fixed) and an awning installed only during the cooling season (May-01 to September-30).

7.2.2 Second study: seasonal awning

Computer simulations

The dynamic calculation program DEROB-LTH was used in the study about seasonal awnings. This version of the program uses a thermal node on the shading device to determine the impact of the shade's temperature on thermal radiation to the window. This calculation model is described in Section 4.6. This new shading model was validated experimentally using two full-scale guarded hot boxes exposed to the natural climate as described in Section 4.6.1. It was found that the model for a light and a dark awning differed from the measurements by less than 20 W, which corresponds to less than 3% of the solar radiation incident on an unshaded window. This difference is of the same order of magnitude as the estimated measurement uncertainty in the guarded hot boxes.

Office module

In the study about seasonal awnings, the south-oriented office room was similar to the one described in Section 7.2.1 (Figure 7.1). The room had a triple-pane, clear glass window, which measured 1.8 m (width) by 1.3 m (height), had a U-value of 1.88 W/m²°C and a shading coefficient of 0.76. A 0.1-m wide frame with a 0.1-m recess with respect to the glazing was assumed. The exterior wall was a standard construction with respect to Swedish norms with a U-value of 0.18 W/m²°C. The room was also assumed to be surrounded by office space at the same temperature. Thus, all "interior" walls were modeled as adiabatic surfaces.

The 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). These gains were only assumed during weekdays and normal office hours (8-17). As in the previous study, the ventilation air was not preheated and no heat recovery of the exhaust air was assumed due to limitations of the simula-

tion program. The temperature set points were 20°C (heating) or 24°C (cooling) during work hours (8-17) and 18°C (heating) or 28°C (cooling) the rest of the time and during weekends. A free horizon with no obstruction and a ground reflectance of 20% were assumed.

Base case awning

Initially, a dark blue awning with a slope ($q = 30^\circ$) was built in the model. The awning's geometry was determined so that the window would be completely shaded during the “typical” cooling season i.e. from May 01 to September 30 for incidence angles comprised within a cone of 120° with respect to the glazing surface (Figure 7.3). The glazing transmittance drops dramatically beyond this angle making it unnecessary to provide additional shading to the window. Note also that, during the cooling season, the sun's azimuth was within the 120° angle during most of the work hours. The initial awning's length (L) and width (W) were determined as a function of the lowest solar altitude (α) within the 120° cone during the May-September period using the following relationships:

$$L = \frac{1.3 \cdot \cos 60^\circ}{[(\tan \theta \cdot \tan \alpha) + \cos 60^\circ] \cos \theta} \quad (7.1)$$

$$W = 2(L \cdot \sin \theta \cdot \tan 60^\circ) + 1.8 \quad (7.2)$$

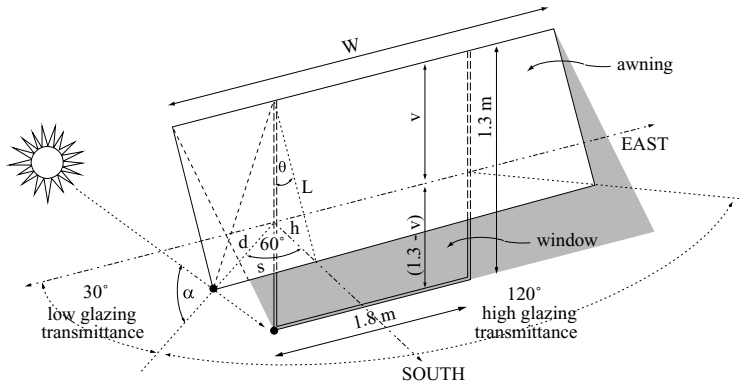


Figure 7.3 Determination of the length (L) and width (W) of the base case awning.

7.3 Results

7.3.1 First study: solar-protective glazing

Variation of the glazing type and orientation

In the first series of simulations, energy use was analysed for the office room with 30% G_{WAR}, for eight glazing types and eight orientations. The results of these simulations are shown in Figure 7.4. The results indicate that low solar transmittance glazing (type A) yielded the lowest annual cooling load and the highest annual heating load while the high transmittance glazings (types G, H) exhibited opposite trends. The results also indicate that the south facing room had the lowest annual heating load while the north facing room had the highest. 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.

The heating load was more affected by a change in orientation than the cooling load. This is clearly shown in Figure 7.4: the maximum reduction in heating load due to a change in orientation was about 23 kWh/m²yr (23%) while it was only 15 kWh/m²yr for cooling (58%). The absolute maximum reduction in heating load due to a change in glazing type was about 29 kWh/m²yr (27%) while, for cooling, it was about 22 kWh/m²yr (86%). A change of glazing type thus affected both heating and cooling loads in a more significant manner than a change in orientation.

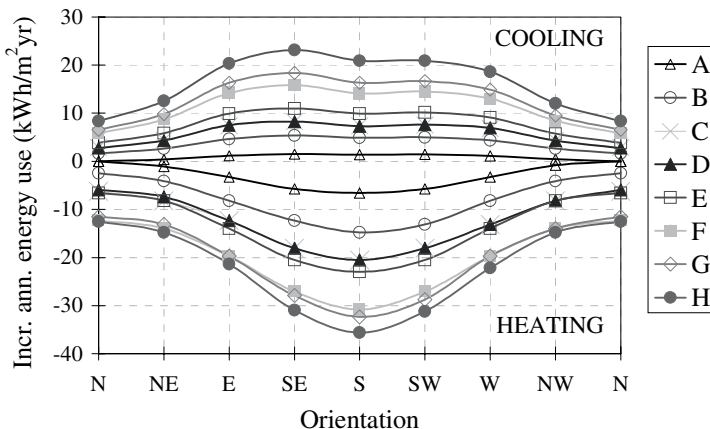


Figure 7.4 Incremental annual energy use (kWh/m²yr) for eight glazing types and eight orientations, G_{WAR} = 30%, Lund.

Heating and cooling loads were added up in a 1:1 ratio assuming equivalent conversion factors for the heating and cooling installations used in the building. The result of this sum is shown in Figure 7.5 below. This figure shows that the optimum glazing strategy was orientation-dependent: on south and north facades, higher transmittance glazing (types F, G, H) yielded lower annual energy use while on east and west facades, 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.

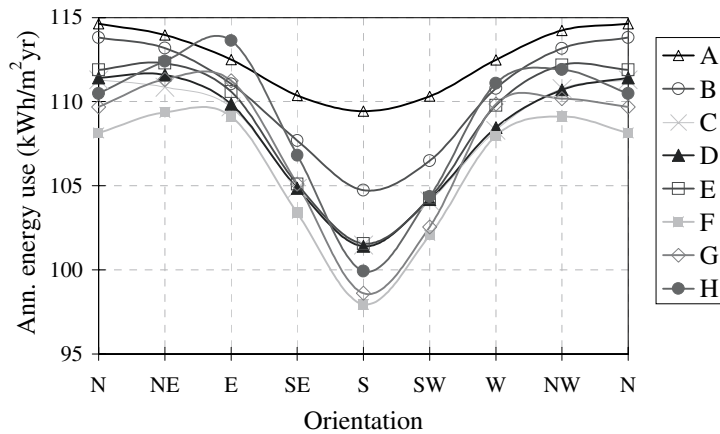


Figure 7.5 Annual energy use ($\text{kWh}/\text{m}^2/\text{yr}$) for eight glazing types and eight orientations, $\text{GWAR} = 30\%$, Lund.

Variation of the GWAR, glazing type and orientation

In the second series of simulations, the GWAR was varied for the north, east and south orientations and for glazing types A, C, D, F and H. The results of these simulations are presented in Figure 7.6 and 7.7 as a function of the solar aperture (SA). The SA is the product of the shading coefficient (SC) and the glazing-to-wall area ratio (GWAR). The results indicate that the cooling load increased with increasing solar aperture (SA). The opposite trend was observed for heating loads (Figure 7.6). In general, the south orientation was more affected by a change in SA than other orientations. A significant feature of Figure 7.6 is that the cooling load of the east and south orientations increased in a similar way with an increase in SA while the heating load decreased more steeply with an increase in SA for the south than for the east orientation.

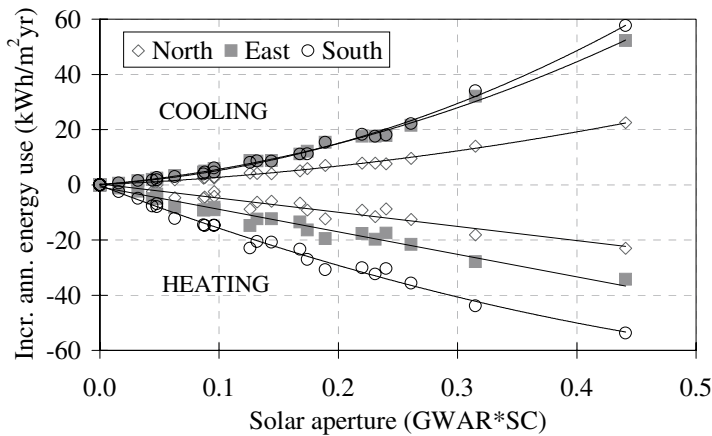


Figure 7.6 Incremental annual energy use ($\text{kWh}/\text{m}^2\text{yr}$) as a function of solar aperture (SA) for three orientations, Lund.

Assuming equivalent conversion factors for the heating and cooling installations used in the building, annual energy use was analysed as a function of SA. It was found that the annual energy use was minimised at SA around 0.2 for the south and around 0.12 for the east orientation. For the north orientation, the flat horizontal curve shown in Figure 7.7 indicates that the impact of a variation in SA on annual energy use was small. In general, the results indicate that the annual energy use was minimised at smaller SA on east facades than on the south facade.

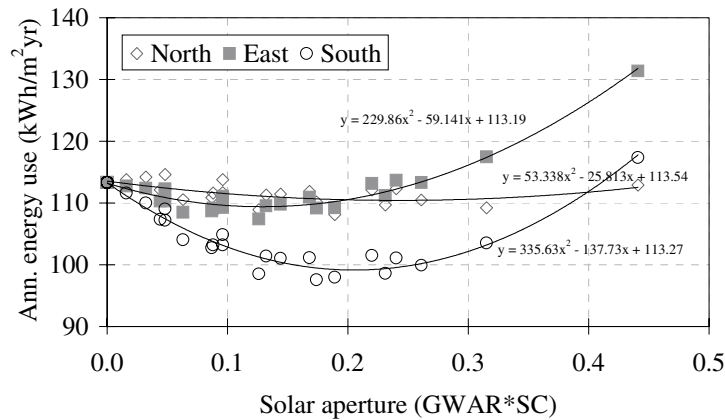


Figure 7.7 Annual energy use ($\text{kWh}/\text{m}^2\text{yr}$) as a function of solar aperture (SA) for three orientations, Lund.

Introduction of a conventional awning

In the last series of simulations, a conventional awning was added to the clear glazing window (type H) with 30% G_{WAR}, for three orientations. Two shading strategies were tested: a “fixed” awning (i.e. in place year-round) and a “seasonal” awning (i.e. installed from May 01 to September 30). The results of these simulations show that the fixed awning increased the annual energy use on all orientations (Figure 7.8) due to an increase in the heating demand.

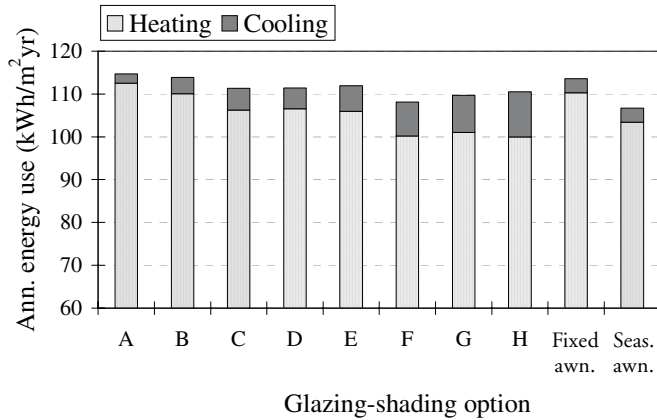


Figure 7.8 a) north

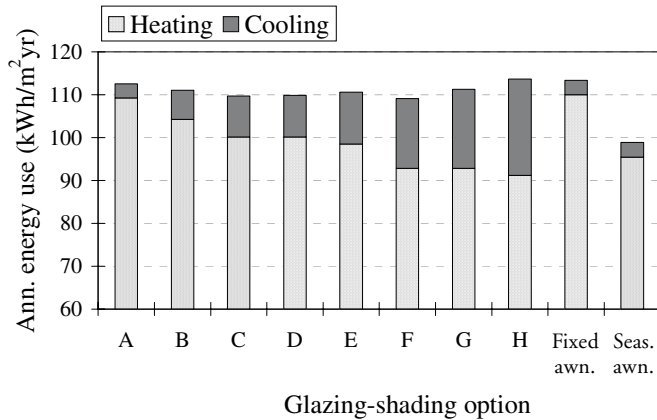


Figure 7.8 b) east

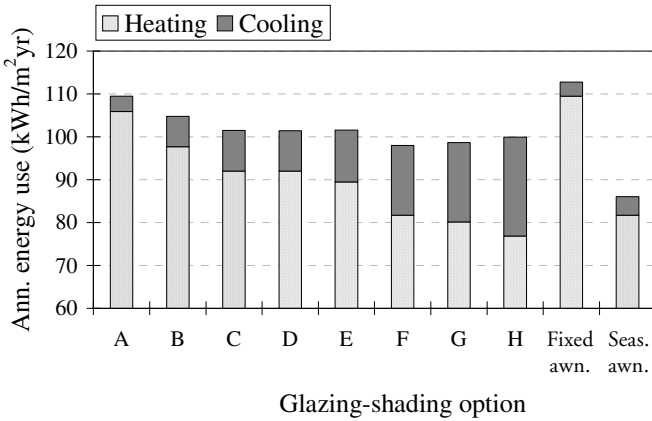


Figure 7.8 c) south

Figure 7.8 Annual energy use ($\text{kWh/m}^2\text{yr}$) as a function of glazing and shading option for a) north, b) east, c) south and $\text{GWAR} = 30\%$, Lund.

The results also show that the seasonal awning reduced the annual energy use significantly, especially on the south facade. Compared with the clear glazing option (type H), the seasonal awning reduced the cooling load by $18.8 \text{ kWh/m}^2\text{yr}$ (81%) and increased the heating load by $4.8 \text{ kWh/m}^2\text{yr}$ (6%), reducing annual energy use by $13.9 \text{ kWh/m}^2\text{yr}$ (14%).

For the north (Figure 7.8a) and east (Figure 7.8b) orientations, the clear glazing plus seasonal awning combination also resulted in the lowest annual energy use but the overall energy savings were smaller than for the south orientation. Even on the north facade, the seasonal awning resulted in annual energy savings compared with all the solar-protective glazing options studied.

7.3.2 Second study: seasonal awning

The plan of the second parametric study as well as the results obtained are presented in Figure 7.9.

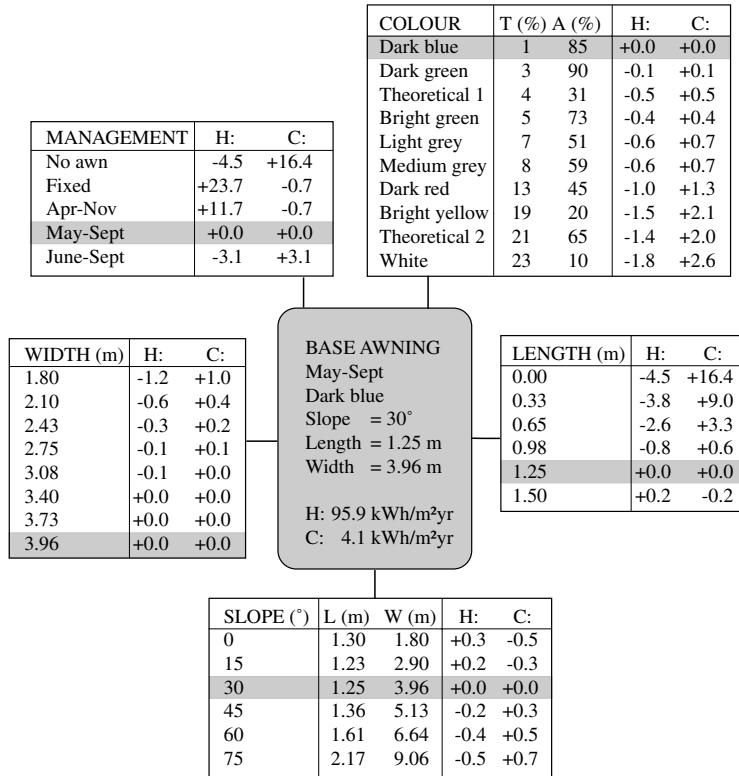


Figure 7.9 Plan of the parametric study and incremental heating (H:) and cooling (C:) loads (kWh/m²yr) with respect to the base case awning. (Negative values mean that energy was saved).

Seasonal management strategy

Keeping the base case attributes constant, various seasonal management strategies for the awning were studied:

- 1) no awning (No awn)
- 2) an awning in place year-round (Fixed)
- 3) an awning installed from the first to the last cooling day of the year (Apr-Nov)
- 4) an awning installed only during the “typical” cooling season (May-Sept)
- 5) an awning installed from the last to the first heating day of the year (June-Sept).

Figure 7.10a shows that the seasonal schedule had a large impact on both annual energy use and peak loads for cooling. The use of a seasonal awning reduced the annual cooling load by up to $17.1 \text{ kWh/m}^2\text{yr}$ (80%) while using an awning year-round (Fixed) increased the heating load by $28.1 \text{ kWh/m}^2\text{yr}$ (31%) compared to a case without awning (No awn). Figure 7.10a also shows that the use of a seasonal awning had a large impact on the cooling peak load, which was reduced by up to 35 W/m^2 (55%), and no impact on heating peak loads (occurred at night). Overall, the May-Sept schedule was optimum: it yielded one of the lowest annual heating and cooling loads combined with the lowest peak cooling load.

Colour

It was found that the annual energy use varied mainly as a function of the awning's transmittance. Increasing the transmittance from 1-23% yielded a reduction in annual heating loads of $1.8 \text{ kWh/m}^2\text{yr}$ (1.9%) and an increase in cooling of $2.6 \text{ kWh/m}^2\text{yr}$ (63%) (Figure 7.10b). Note that although this relative increase in cooling seems large, the absolute additional load was marginal compared to the total annual energy use for the base case ($100 \text{ kWh/m}^2\text{yr}$). Since the transmittance had a larger impact on cooling than on heating loads, dark-coloured awnings (low transmittance) yielded a lower annual energy use than light-coloured ones. However, the optimum solution depends on the relative efficiency of the cooling and heating systems. (In this study as in the previous one described in section 7.3.1, the space loads were added up in a 1:1 ratio). Note also that increasing the transmittance affected cooling peak loads moderately ($+7 \text{ W/m}^2$, 23%) and had no effect on peak heating loads.

Width

Figure 7.10c shows that a reduction of the awning's width from 3.96 m (base case) to 1.8 m (window width) yielded a reduction in annual heating of $1.2 \text{ kWh/m}^2\text{yr}$ (1%) and an increase in cooling of $1 \text{ kWh/m}^2\text{yr}$ (24%). Most of the impact of the width was between 1.8 m and 2.4 m and, thus, negligible additional cooling savings were obtained with awnings larger than 2.4 m (0.3 m on each side of the window). Note also that the awning's width had a negligible impact on peak cooling loads and no impact on peak heating loads.

Length

Figure 7.10d shows that a reduction in the awning's length from 1.25 m (base case) to 0.33 m (25% of the base case) more than tripled the cooling demand ($+9.0 \text{ kWh/m}^2\text{yr}$) and reduced the heating demand by $3.8 \text{ kWh/m}^2\text{yr}$ (4 %). The length thus generally had a larger impact on the cooling

than on the heating demand. Note also that above 0.9 m, the awning's length had a negligible impact on annual energy use. Figure 7.10d also shows that the awning's length had a large impact on the peak cooling load, which was reduced by around 32 W/m^2 (52%) through an increase in length from 0-1.5 m.

Slope

In order to study the impact of the slope on diffuse and reflected radiation (from the underside of the awning), the awning's length and width were adjusted for each slope angle studied so that an equivalent shade from direct radiation was produced on the window. Figure 7.10e shows that increasing the awning's slope from $0-75^\circ$ reduced the annual heating demand by $0.8 \text{ kWh/m}^2\text{yr}$ (0.8%) and increased the annual cooling demand by $1.2 \text{ kWh/m}^2\text{yr}$ (33%). The relationship between the slope and the annual heating and cooling loads was roughly linear and the slope generally had a larger impact on cooling than on heating loads. Steeper slopes ($0-30^\circ$) yielded a lower annual cooling demand resulting in a lower annual energy use than shallow slopes. Overall, the impact of the slope on peak loads was negligible.

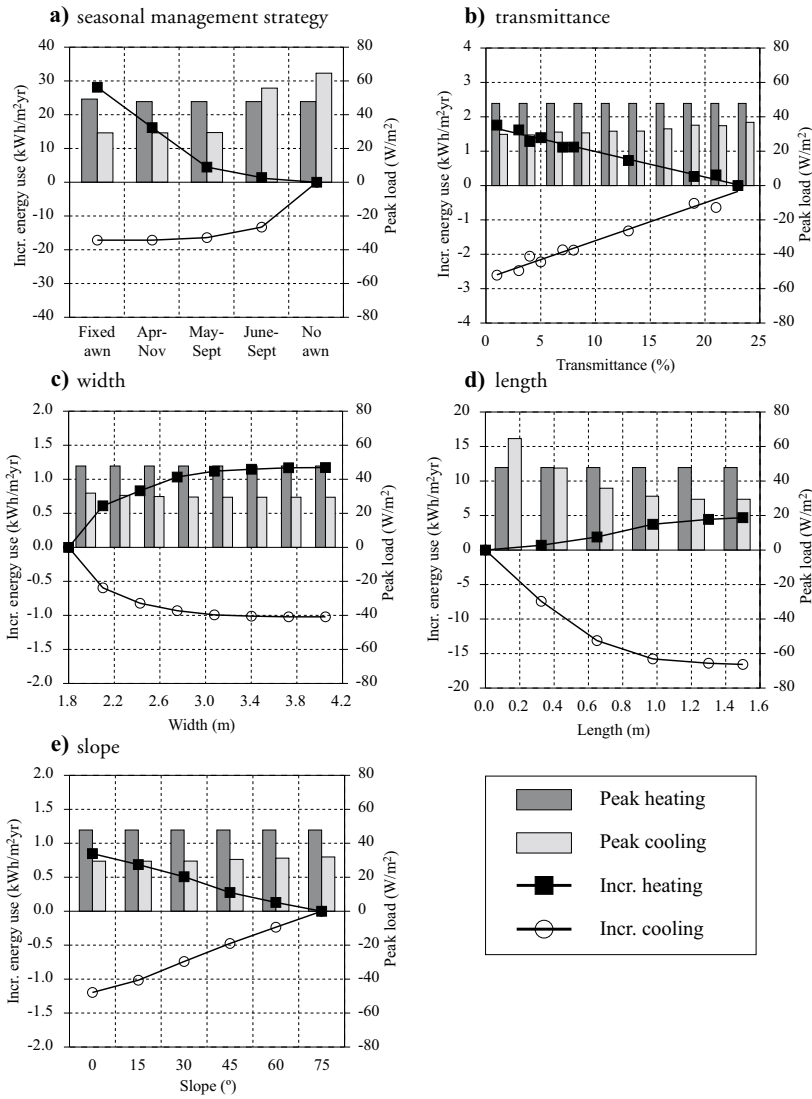


Figure 7.10 Incremental annual energy use (kWh/m²yr) and peak loads (W/m²) for heating and cooling as a function of a) the seasonal management strategy, b) the transmittance, c) the width, d) the length and e) the slope.

7.4 Discussion

7.4.1 First study: solar-protective glazing

One finding of the first study was that the glazing type and orientation had a more significant impact –in absolute values– on the heating than on the cooling demand. This is probably due to the fact that the heating season is dominant in Sweden. Heating is thus more affected by a change in the glazing type or orientation than cooling. This finding is rather interesting since solar-protective glazing is normally selected in a building project to avoid large cooling loads.

In this study, the space loads for heating and cooling were added up in a 1:1 ratio and it was found that the optimum glazing properties were orientation-dependent. In a real building, equivalent space loads for heating and cooling are seldom equivalent when the efficiency of the heating and cooling installations are taken into consideration. This means that the optimum glazing also depends on the type of heating and cooling installations used in the building. The curves shown in Figure 7.5 should thus be considered bearing in mind the assumptions of the current study. Nevertheless, it is not surprising to find that the best glazing choice depends on the orientation since at high latitudes, the solar position varies significantly over the year. For instance, the east and west facades receive a large amount of solar radiation during the summer but very little during the winter, which means that the optimum glazing properties are according to the summer rather than the winter conditions on these facades. This also explains why an increase in solar aperture generated a larger increase in cooling than the corresponding reduction in heating load on the east facade.

It was found that on the south and north facades, the best glazing choice was high-transmittance i.e. clear glazing. These results are promising since the impact of the glazing choice on electricity use for lighting was not included in this study. The potential to replace artificial lighting by daylighting is much higher with clear than with reflective and heat-absorbing glass. It is thus likely that the clear glazing plus seasonal awning option will result in much larger overall energy savings than the ones reported here.

Finally, it was found that the dark blue awning provided the largest annual energy savings amongst all cases, even on the north facade. However, the version of the simulation program used in this study did not take into consideration the impact of the awning's temperature on the long-wave radiation to the window. In reality, a dark blue awning will absorb some energy from the sun and become warm. Part of this energy

will be radiated as heat to the window, which will absorb this energy, convect and radiate it in to the building. The cooling savings presented in the diagrams are thus a little optimistic.

7.4.2 Second study: seasonal awning

The findings of the second study generally indicate that the base case awning was oversized. There is a possible relationship between the total awning area (width and length) and energy use which has not been thoroughly investigated here. However, it should be noted that a simulation (not presented) with reduced awning dimensions ($L = 0.9$ m; $W = 2.1$ m) yielded results similar to the ones obtained for the base case (-1.4 kWh/m²yr for heating; $+1.3$ kWh/m²yr for cooling). Note that there are clear advantages of reducing the awning's dimensions such as a reduction of production costs, an improvement of the view out from the interior, and an increase in daylighting availability in the space, which can provide additional energy savings for lights.

Also, in this study, various seasonal management strategies for the awning were studied:

- 1) no awning (No awn)
- 2) an awning in place year-round (Fixed)
- 3) an awning installed from the first to the last cooling day of the year (Apr-Nov)
- 4) an awning installed only during the "typical" cooling season (May-Sept)
- 5) an awning installed from the last to the first heating day of the year (June-Sept).

The second (2) and third (3) schemes represent the minimum cooling loads achievable with the awning while the fifth (5) scheme represents the minimum heating load possible since the shading system does not cover any heating day of the year. We can assume that a "dynamic" (i.e. adjusting according to the conditions at each hour) awning would have the cooling load of schemes (2) and (3) and the heating load of scheme (5). It is interesting to observe that the May-Sept scheme (4) resulted in negligible additional cooling energy use compared with the minimum load achievable (schemes 2 and 3). This strategy also resulted in slightly more heating energy use (around 4 kWh/m²year) than shading strategy (5). This suggests that a seasonal shading device can be rather energy-efficient even compared to a "dynamic" awning.

The study also indicated that an increase in the awning's width had much less impact on annual energy use than an increase in the awning's length. Over a certain width, little additional energy savings were obtained. This is due to the fact that, at steep angles of incidence, both the incident and transmitted solar radiation is reduced compared to the near-normal incidence. The solar radiation coming from the sides of the awning is thus relatively unimportant with respect to annual energy loads, which suggests that awnings with sides will not provide much larger annual energy savings than conventional awnings.

Finally, it should be mentioned that the conclusions of both parametric studies were solely drawn from computer simulations. Although the computer program used (DEROB-LTH) was validated experimentally and it has been shown (Chapter 4.6) that it predicts heating and cooling loads with a maximum error corresponding to 3% of the incident solar radiation, investigations and measurements in real buildings should be made to confirm the findings of these two parametric studies.

7.5 Conclusions

Two parametric studies were presented. In the first study, the impact of the glazing optical properties on energy use was analysed for a standard office room. The room's orientation and glazing-to-wall area ratio (GWAR) were alternately varied and the impact of these variations on energy use was analysed for the climate of Lund (Sweden). (Other climates i.e. Stockholm, Luleå, Oslo, Montreal were also studied but are not reported here, see instead Dubois, 1998). In the second study, the impact of a conventional awning on annual energy use was studied for a similar south-oriented office room located in Stockholm (Sweden). The awning's seasonal management strategy, properties, as well as geometry (length, width, slope) were alternately varied and the impact of these variations on annual energy use was analysed.

These two parametric studies generally show that, in cold climates, a seasonal awning combined with clear or low-emissivity coated glazing of high transmittance can provide larger energy savings than any solar-protective glazing combination on any facade since:

- 1) the shading device can be used only when the overheating problem occurs and
- 2) high transmittance glazing allows for maximum passive solar heat gains during the spring, winter and autumn.

Some other conclusions of these studies are summarised below:

- 1) The optimum optical properties for glazing are orientation-dependent: on south and north facades, it is more energy-efficient to select high transmittance glazing or higher solar apertures (SA) than on the east and west facades. This is for Lund, assuming that heating and cooling space loads are added up in a 1:1 ratio and that the U-value of the windows is not taken into consideration (constant thermal losses).
- 2) A seasonal awning is energy-efficient and can provide close to maximum achievable energy savings compared with a “dynamic” awning.
- 3) The seasonal management strategy and length of the conventional awning are the two most important parameters affecting energy use.
- 4) In comparison, the awning’s colour, width and slope have a moderate to negligible impact on annual energy use.
- 5) The transmittance of the awning’s fabric is the dominant optical property. Darker awnings yield a lower annual cooling demand because dark-coloured fabrics have a lower transmittance than light-coloured ones. This finding suggests that opaque awnings should yield lower cooling loads than translucent awnings (in fabric).
- 6) An increase in the awning’s width did not yield significant additional energy savings. Moreover, over a certain width, no additional energy savings were achieved. This is due to the fact that the solar radiation coming from the sides of the awning is not important compared to annual energy loads. This finding suggests that awnings with sides might not be more energy-efficient than conventional awning.

Overall these studies suggest that more research is needed about solar shading devices since shading devices offer the potential for large energy savings in buildings. Future research should consider the impact of various types of shading devices on energy use and on interior daylighting conditions and glare in the building.

8 User aspects

Helena Bülow-Hübe

8.1 Introduction

Shading devices are often used in buildings, perhaps mainly to reduce cooling energy use, but also to control glare and daylighting. The control of daylighting is actually very central because it is linked to occupants' satisfaction and performance.

Up til now the solar shading project has dealt with the thermal aspects of shading devices. However, the daylight aspects are equally important, not only the effects on illuminance levels, but also on the view out and the perception of a room. Further, increased knowledge on the preferences of occupants would be useful in the selection process of shading devices and also to improve automatic control systems.

According to Littlefair (1999) shading of windows is needed for three main reasons: to reduce overheating, to reduce glare from windows and to provide privacy. Even so, some sunlighting may still be wanted. The positive impacts of sunlight is to enhance the visual, emotional, and psychological well-being of occupants, or using it as a heat source (Boubekri et al., 1991). Unfortunately, the study by Boubekri et. al. (1991) largely failed to demonstrate the effect of window size or sunlight patches on office worker's mood and satisfaction. However, sunlight penetration significantly affected the feeling of relaxation when the observer was sitting sideways to the window. The authors suggest that only small amounts of sunlight penetration should be allowed in order to promote positive feelings of relaxation. One weakness of the study was that most of the 40 recruited subjects normally worked in office environments without access to windows. In the study, all subjects were exposed to a situation with a window and a nice view. The conditions were always sunny with sunlight penetration. This may have biased the results somewhat. Compared to having no access to windows or view out, people generally prefer windowed space, (Collins, 1976).

8.1.1 Glare

Glare is among the mentioned negative impacts of windows. Since the luminance of the sky may well be several times higher than that of the interior walls – even on an overcast day – glare discomfort can arise from a direct view of the sky (Chauvel et al. 1982). Chauvel et al. also found that glare from windows is perceived differently than glare from large artificial sources, due to the psychological differences in the contents of the field of view. They also found large individual differences in the tolerance of glare. In another study on sunlight penetration, glare was only moderately affected by window size (Boubekri & Boyer, 1992).

8.1.2 Occupant behaviour

In a study on office worker's behaviour, Rubin et al. (1978) changed the position of venetian blinds during weekends to either fully up, or down and closed, and then studied the occupant's response by taking external photographs of the facades of the building. They found that most blind positions were changed only once per week (on Monday morning). Moreover, they were generally put back in the same position as before the treatment. The most significant influence was that of the orientation: on the north side, blinds were generally kept more open than on the south side. There were also some effects, although more subtle, of climatic season and view out.

In another study, Vine et al. (1998) compared occupant response and satisfaction of an automated blind with an auto user control mode (manual override of auto mode) and with full manual control. Although no statistical analysis was made of the subjects' responses, over 75% of the subjects preferred more daylight in the auto user control mode. They were generally satisfied with the lighting in the auto user control mode, but experienced some glare in the manual mode.

Boyce (1997) claims that if people sitting near to a window have expectations of thermal or visual discomfort to occur, and if they consider that their electric lighting is adequate, they will leave the blinds down, unless they have strong values about the environment. He further believes that few people have such values. He calls this seemingly lack of response to changing environmental conditions for human inertia. For any new automation system to be successful, this inertia must be used to its advantage. He suggests that a simple timer might be enough: one that for example switches off the lighting at a time in the morning when the daylight is usually sufficient, or pulls up a blind at dawn.

8.2 Experimental design and methods

8.2.1 Aim of the study

The aim of this study was to investigate the function, operation and effect on daylight of a couple of solar shading devices. Further, when people are allowed to control the shading devices we wanted to see how they decide to use them in relation to the outdoor climate.

Another issue was whether different shading devices need more or less complementary electric lighting. The experiment was considered as a pilot study to identify typical positions (or settings) of the shading devices for use in later studies. Therefore, only two different shading devices were included: one awning and one exterior venetian blind.

8.2.2 Test rooms and solar shading devices

At a laboratory at the Dept. of Construction and Architecture, there were already two identical south-facing office rooms, 3.0×3.6×2.45 m (W×D×H), used in an earlier study by Bülow-Hübe (1995). New office desks in blond wood were purchased, the walls were repainted in a warm white colour (NCS 0003-Y20R), trimmings and ceilings were white, and the linoleum floor had colours in beige-blue-brown. (Reflectance: $R_{\text{wall}} = 0.8$, $R_{\text{ceiling}} = 0.9$, $R_{\text{floor}} = 0.4$, $R_{\text{desk}} = 0.5$).

Each room was furnished and equipped with a computer to resemble a real office room. (Figure 8.1). The lighting consisted of a pendant direct/indirect luminaire with dimmable HF-ballast, one T8 36 W facing upwards, and two downwards. The control mechanism was a potentiometer placed on the desk. Measured workplane illuminance was 900 lux at full light output (potentiometer setting = 35), fully dimmed it was 25 lux (setting = 0).

The 1.2×1.3 m, triple-glazed window was in one room equipped with an exterior retractable venetian blind with 80 mm aluminium slats. (Figure 8.2). In the other room, it was equipped with an exterior retractable awning with a beige and brown striped fabric. (Figure 8.3). In both rooms the shading device could be operated from the inside by two buttons placed on the desk. One button was for retracting the shading device (up position), the other for closing it (down position). For the venetian blind, the adjustment of the slat angle was done with the same two buttons, which meant that to change the slat angle, the position of the bottom slat had to be changed somewhat.

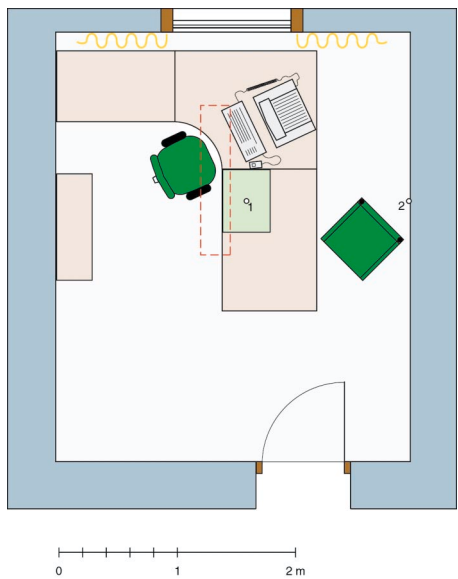


Figure 8.1 Plan of the offices with 2 points for illuminance measurements as indicated.

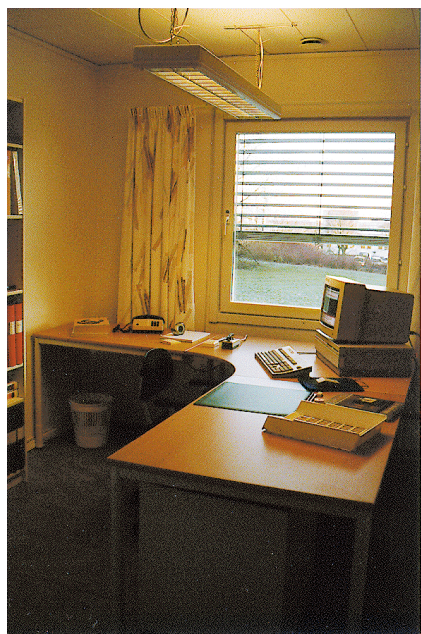


Figure 8.2 Interior of the office with a venetian blind.

8.2.3 Method for room assessment

The subjects performed two tasks. The first task consisted in adjusting the shading device until a pleasant daylight situation was created. A simple questionnaire was filled in containing three questions: (1) How well does the operation system of the shading device work? (bad–good) (2) How satisfied are you with the lighting conditions? (unsatisfied–satisfied) (3) How does the shading device affect your possibility to see out? (not at all–to a large extent).

The second task was to see whether the lighting situation was improved with electric lighting, and if so adjust the light level until a pleasant situation was reached. This was followed by a last question: (4) How satisfied are you with the lighting conditions? (unsatisfied–satisfied).



Figure 8.3 *Detail of the office with an awning.*

On all 4 questions, the answers were given on seven-grade scales with the word-pair given in brackets above on either side of the scale.

8.2.4 Procedure and subjects

The study was conducted in September and October 1998. The rooms were assessed by 50 subjects in a balanced design with repeated measures. This meant that each subject assessed both rooms at one occasion.

Upon arrival to the laboratory, the subject was given a short introduction to the experiment. Thereafter, he/she was shown into the first room where further instructions were given on the computer screen. At the start of each experiment, the shading device was always fully open (up) and the lighting was turned off.

Before the experiment started, the experiment leader noted the weather and lighting conditions, time and temperature and measured the interior illumination levels (see below). The subject was then left alone to perform the first task.

The experiment leader then returned to note the position of the shade and repeat the lighting measurements before the subject could proceed with task 2. When this was finished, the lighting measurements were again repeated and the potentiometer setting was recorded. After that, the subject was guided to the other room to repeat the same procedure.

The subjects were recruited from the School of Architecture, and consisted of office workers: clerks, researchers and doctoral students. They were all used to working close to a window. Totally, 24 women and 26 men between 23 and 64 years participated (*mean* = 43.3; SD = 10.8).

8.2.5 Measurements

As a reference of the outdoor lighting conditions, both the interior horizontal illuminance level and sky luminance seen through the window of a neighbouring office room were measured continuously by two Hagner Universal photometers (S2) connected to a data logger.

Before and after each room assessment, the weather situation, lighting conditions in the room, time and indoor temperature were recorded. The illuminance level was measured at the desk (work surface) (pt. 1, Figure 8.1) and vertically on the wall in front of the person, 1.2 m above the floor (pt. 2, Figure 8.1), with a hand-held Hagner digital luxmeter (EC1). If there was a sun patch in the visual field, this was noted as follows: 1 = no, 2 = sometimes (varying conditions), 3 = yes. The weather situation was rated on a four-grade scale: 1 = sun, some lighter clouds may exist, 2 = sunny, there are clouds that sometimes cover the sun, 3 = cloudy, there are some blue spots where the sun can be seen, and 4 = overcast, the sky is covered by thick clouds. Further, the cloudiness was rated on an 8-grade scale, that defines how many eighths of the sky are covered by clouds.

If the electric lighting was turned on, the potentiometer setting was recorded.

The position of the shades were assessed in the following way: For the awning we constructed and mounted a protractor on the boom which allowed for reading the boom angle with the accuracy of $\pm 1^\circ$. The boom angle ba was later transformed to the awning's slope by the simple relationship: $slope = 45 + ba/2$. (Figure 8.4).

For the venetian blind, a scale was drawn next to the window, so that the bottom slat position could be read from the interior to the accuracy of ± 5 cm, while the slat angle was estimated manually.

8.2.6 Data analysis

The data from the rating scales was treated by analysis of variance using the SPSS MANOVA procedure (Norusis, 1993). The design included both within-subject and between-subject variance.

Further, regression analysis was used to study the relationship between the position of the shading device and the lighting and weather conditions.

Since the position of the shading devices had been assessed, a transformation of these data was made to determine which portion of the window surface was covered by the shade, called here the coverage of the shade.

For the awning it was made in a simple way: The measured boom angle was transformed to a percentage: when the awning was fully retracted, this was interpreted as a bare window (coverage = 0%). The fully down position was interpreted as fully closed awning (coverage = 100%). (Figure 8.4).

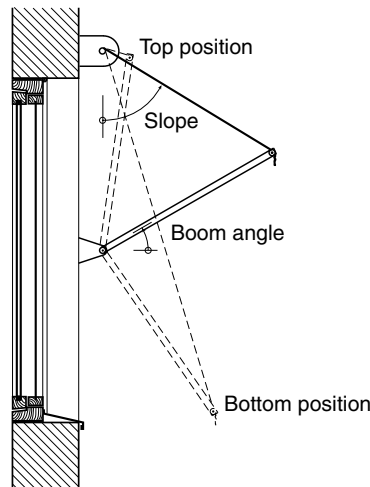


Figure 8.4 Section through window with awning, and definition of boom angle and slope.

For the venetian blind two factors were weighed together to estimate the coverage: (1) the distance of the bottom slat to the top of the window and (2) the slat angle. (Figure 8.5). From the position of the viewer, the percentage of how much of the window that was covered by the blind had previously been estimated for different slat angles. This value was then multiplied by the distance (1) (in per cent) to give the coverage.

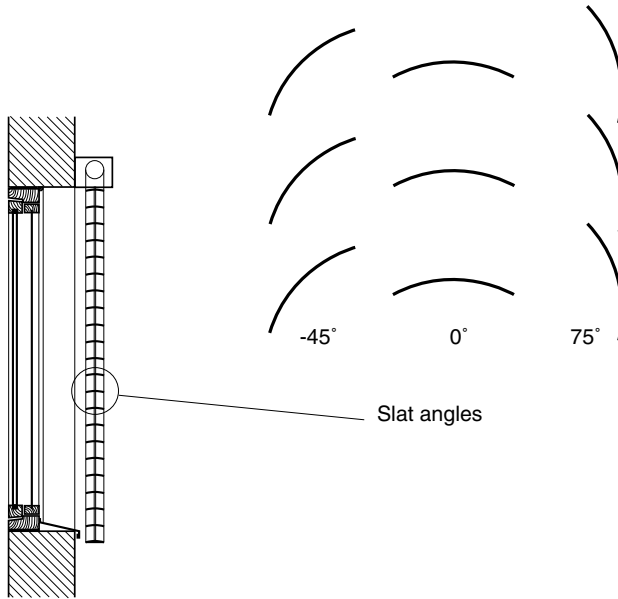


Figure 8.5 Section through window with exterior venetian blind, and examples of slat angles.

8.3 Results

8.3.1 Weather, light and temperature

The illuminance levels, sky luminance, indoor temperature and weather recordings before and after the assessments in the two rooms are summarised in Table 1. The differences between the two rooms are very small and are not significant. Therefore, the environmental conditions must be considered equal between the two rooms (awning and venetian blind).

Table 8.1 Summary of measurements of environmental conditions before and after assessments. (Mean values).

	Awning		Venetian blind	
	Before	After	Before	After
Illuminance level (lux)				
Point 1	2590	675	2610	580
Point 2	950	460	875	400
Ref. room, pt 1	2500	2400	2960	2870
Sky luminance (cd/m ²)	14400	16400	14700	15200
Indoor temp. (°C)	20,7	20,7	20,4	20,4
Weather type (1–4)	2,60	2,66	2,60	2,60
Cloudiness (1–8)	4,36	4,38	4,36	4,38
Sun in visual field (1–3)	2,06	1,58	2,08	1,66

8.3.2 Perception of shading devices

The operation system of both the awning and the venetian blind was perceived to function well (*mean* = 6.4/4.9 awning/ ven. blind respectively on the seven-grade scale), but the awning was most easy to operate ($p = 0.000$). The subjects were rather satisfied with their lighting situation after task 1 ($m = 5.5/5.7$). After having tried the electric lighting in task 2, they were somewhat more satisfied with the lighting condition than before ($m = 5.7/6.0$). The possibility to see out was somewhat affected by the solar shading devices ($m = 3.4/3.7$). However, there were no significant differences between the shading devices in questions 2–4.

There was a grouping effect of age in question 2 (the satisfaction of the lighting condition): the older the subject, the more satisfied ($p = 0.008$). The subjects had then been divided into three age groups: (1) 23–38 years, $N = 16$; (2) 39–50 years, $N = 18$; (3) 51–64 years, $N = 16$.

The answers were also checked for interaction effects regarding sex and age, but no such effects were found.

8.3.3 The position of the shading devices

The shading devices were used frequently to control glare. They were not only used on clear sunny days, but also on overcast days. Typical positions of the shading devices are perhaps best described by frequency distributions as for the awning's slope in Figure 8.6. This shows that the awning was used by all but 7 subjects, and that the most frequent posi-

tion was when the boom angle was close to slope 45° (0 degrees boom angle). Only 7 subjects chose to pull it down significantly more than that.

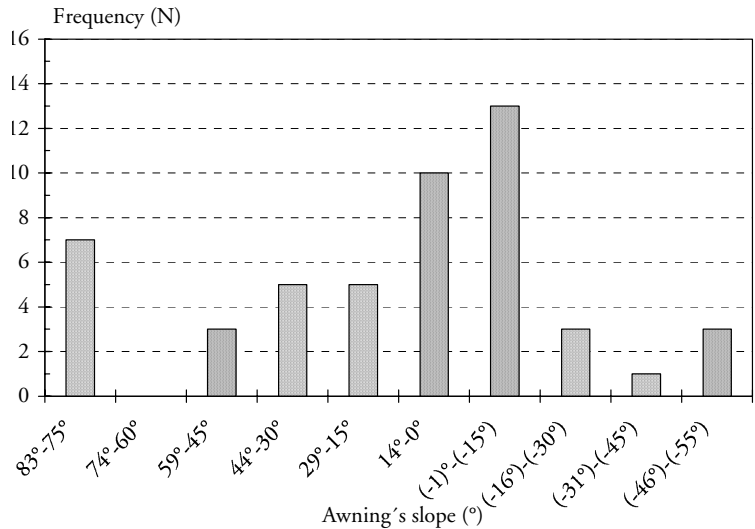


Figure 8.6 Frequency distribution of the slope of the awning.

For the venetian blind, most subjects did not pull it down fully. Over 50 % of the subjects pulled it down less than 70 cm compared to the glazing height of 120 cm. (Figure 8.7). Normally, an automatic motorised blind will be pulled down fully, and the manual override is limited to adjusting the slat angles.

Concerning the slat angles, 75 % of the subjects chose a slat angle of 30° or larger. Only on 4 occasions did the subjects choose a negative (sky view) slat angle (Figure 8.8).

Beyond slat angles of approximately 45°, the view through the blind becomes very limited.

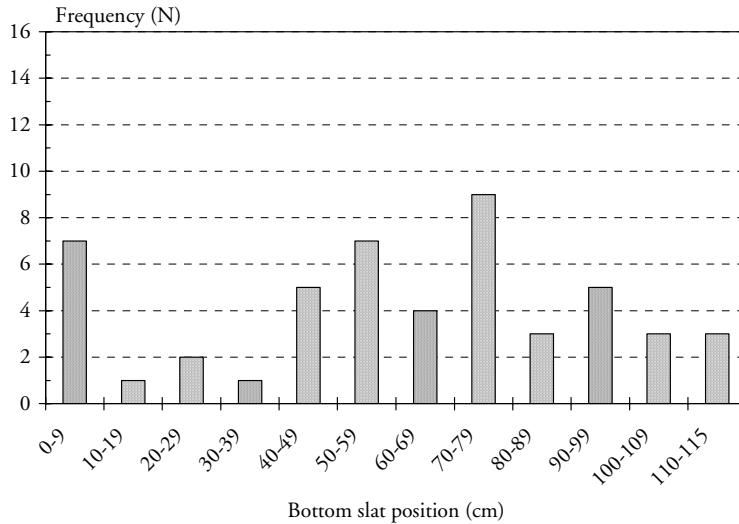


Figure 8.7 Frequency distribution of bottom slat position of venetian blind.

At a linear regression analysis between the coverage of the shading device and the measured parameters, no relationships were found between illuminance levels or sky luminance. However, a relationship was found between the coverage and the existence of sunlight patches in the field of view. This was found both for the awning and for the venetian blind. The cloudiness also appeared in the regression equation for the blind. The regression equations could however only explain a small part of the variation (adj. $R^2 = 0.22-0.34$).

Since the existence of sunlight patches appeared in the regression equations, two new variables were introduced: the azimuth of the sun's position (i.e. the angle between the horizontal projection of the sun and the south axis) and the perpendicular distance from the wall to the end of the sunlight patch. However, they did not appear in the regression analysis.

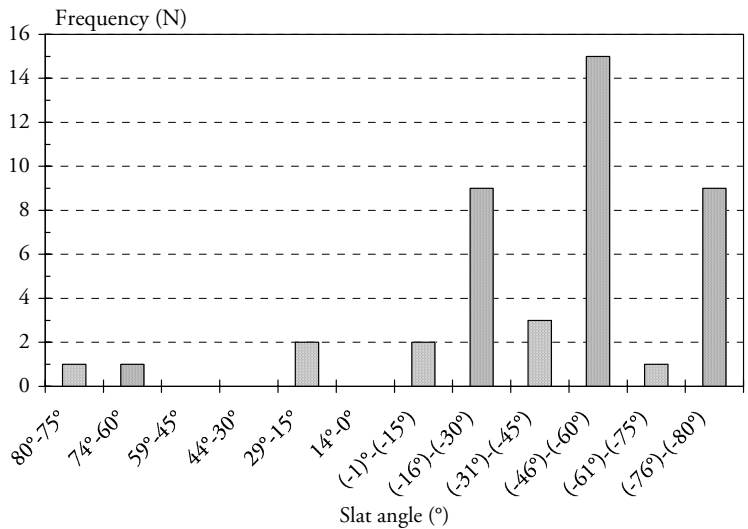


Figure 8.8 Frequency distribution of slat angles of venetian blind.

Another test was made with a logarithmic transformation of the measured lighting data. Both the logarithm (to the base of ten) of the desk illuminance and the sky luminance appeared in the regression equation, but only for the venetian blind. The adj. R^2 -value was also low (0.34). Since these variables only appeared for the blind, the interpretation of this regression equation was unclear.

8.3.4 Artificial lighting

The artificial lighting was used in about 30% of the cases, just as often in connection with the awning as with the venetian blind. There was no significant difference in the use of this complementary lighting between the awning and the venetian blind. The potentiometer was used frequently to control the light level, and the average setting was 19 which corresponds to an additional 350 to 500 lux. (The uncertainty is due to how long the lighting has been turned on).

8.3.5 Comments

The subjects were encouraged to give their own comments on the questionnaire, and some of the more common ones have been put together here:

Regarding the artificial lighting: the user's ability to dim the electric lighting generated several positive comments, but it became obvious that the chosen lighting installation was not optimal. Many subjects commented on the fact that there was no individual light source, just the ceiling mounted luminaire. Most people wanted more light on the desk to be able to read, than on the computer screen, and this was not possible with the chosen solution. When the subjects chose a setting for the lighting it was obvious that most persons did this according to the computer task, but more light was really needed for paper tasks.

Regarding the operation of the shades: The awning was more easy to adjust than the venetian blind as previously mentioned. Most subjects agreed that the venetian blind would have been more easy to operate if the function for adjusting the slat angle had been separated from the function of bringing the blind up or down, as was the case. The motor pulling the venetian blind up and down was also perceived as being too slow.

A few people said that they made a compromise between glare and the possibility to see out: they would have been more comfortable with the lighting situation if they had pulled down the shade even more, but they chose a more open position in order not to lose too much of the view out.

On windy days it became apparent that the awning was much more wind sensitive than the venetian blind. This led to a disturbing noise created by the fabric, but even more disturbing was the light flicker of the sunlight patch. On sunny afternoons, the sunpatch could often not be totally removed on the desk due to the oblique angle of the sun. As the sunpatch was in the field of view, the flickering effect that was created when the awning was blowing up and down in the wind gusts was rather disturbing.

The two shading devices also created quite different impressions of the two rooms. While the grey slats of the blind did not affect the colours in the room, the fabric of the awning gave a yellowish tint to the whole room. One person remarked that it reminded her of an old striped men's pyjamas, while for another person it recalled happy memories of childhood camping trips. A few others commented on the blinds: for them, the wide slats created associations with prison bars.

8.4 Discussion

This study demonstrates the difficulty in predicting when and how much solar shading devices need to be pulled down, in order to create a good interior lighting environment. Glare or contrasts are probably responsible for when solar shading devices need to be used, but there seems to be a large individual spread as to how much glare people tolerate. This is in line with the findings of Chauvel et al. (1982). Given more measuring points on luminances in the field of view, it would perhaps have been possible to find relationships between these and the use of the shading devices, but in this study no relationships between the sky luminance or the interior illumination level and the use of the shading devices were found. One parameter showed a weak relationship to the use of the shading device: the existence of a sunpatch in the field of view. But this could only explain a small portion of the variance. Since the variance among people is large, even more subjects and more weather situations would also have been needed.

Generally, solar shading is needed as soon as the sun enters the room, since the sunpatch will often directly, or indirectly cause disturbing glare and reflexes in the computer screen. One example is when the sunpatch is on the wall behind the subject, it will be so strongly lit that it will cause disturbing reflexes on the screen. This agrees with the opinions of Littlefair (1999).

The placement of the computer and of the furniture in relation to the window will of course strongly influence the glare situation in each individual case. This will, in turn, affect when and to what extent shading is needed. It is however clear that computer tasks require some sort of glare control during a major part of the day, be it interior or exterior shading devices or curtains, single or in combination.

The fact that the shading devices and the electric lighting could be controlled was perceived as very positive. This is a general conclusion in experiments of similar nature: individual control over physical parameters in a person's environment are preferred to having no control (Bell et al, 1996).

This study also shows that there is no simple relationship between the use of electric lighting and the lighting parameter that is most often used to estimate the potential for energy savings of electric lighting through dimming: the interior illuminance on the work surface. Only when it became very dark outdoors (and indoors) was there a trend that the subjects used the electric lighting more frequently. Also here was there a large

individual variation. However, it did not matter whether it was an awning or a venetian blind: the same amount of additional electric lighting was preferred.

Another conclusion is that individual task lighting should be present so that the lighting on the paper task can be different from that on the computer screen since more lighting is generally preferred on the paper than on the screen.

Interestingly enough, at the end of the experiment, the illuminance on the desk was on average between 600-700 lux. This is rather close to typically recommended light levels in office rooms, 500 lux is an often cited number. Since the eye perceives light levels in a logarithmic way, there is a very small perceived difference between 500 and 700 lux.

Clearly, shading devices can have effects on mood and the general perception of a room. Which effects, and if these are enough to affect satisfaction and performance remain to be answered.

This study indicates that several aspects of shading devices must be considered. Even if the solar shading properties of shading devices are central, it is also necessary to pay attention to the daylight properties, effects on view, presence of sunlight patches, adjustability, etc. For example we found that awnings caused disturbing flickering sunlight patches on sunny, windy days, an effect which was not present for the venetian blind. However, in measurements it was found that light coloured awnings had better shading properties than exterior venetian blinds (see chapter 5).

8.5 Conclusions

The main conclusions from this study are:

- It is difficult to predict the use or need for shading devices by common measurable factors such as interior illuminance and sky luminance.
- There is some correlation between the use of shading devices and the existence of sunlight patches in the room.
- Shading devices are necessary to control glare in the working environment.

8.6 Acknowledgements

The author gratefully acknowledges Professor Rikard Küller and Dr. Torbjörn Laike (Lund University, Environmental Psychology Unit) for their good advice during this study.

9 Discussion and conclusions

Maria Wall
Bertil Fredlund

This project comprises many different parts, and the report describes how far we have progressed in our research on these parts. The studies have mainly been focused on the properties of sunshades with regard to total solar energy transmittance and thus their effect of energy use for cooling and heating. The reason that work was in the first place limited to this is that comparable physical data have not been available for different types of sunshades. This part is of fundamental nature and has therefore received priority. However, it does not imply that other factors such as daylight and thermal comfort are less important. These and other factors will be treated at a later date.

9.1 Measurements in a real climate

Measurements of the properties of different sunshades in a real climate have been very valuable and instructive. A double hot box arrangement has been used in the measurements. The method is based on calorimetric measurement in which the supplied heat input, the cooling input and temperature differences between the measuring box and the surroundings are used in calculating the primary and total transmitted solar energy. The measurements have so far been limited to external sunshades in combination with a double glazed sealed unit with clear panes. The estimated relative error in measurement was $\pm 5\%$ of the calculated transmission.

This type of measurement is used to study the properties of sunshades in a real climate and to compare the results with calculations so that the calculation models may be validated. The limitations of this type of measurement are that they are specific to each climate, latitude, orientation and window type. A solar simulation installation has therefore been constructed as a complement.

9.2 Solar laboratory

Using the solar simulator, solar transmittance can be measured in a more standardised manner for sunshades and/or windows. Measurements can be made for different angles of incidence and not only those that occur outdoors in Lund. Further, measurements can be performed quicker, all-year around, independent of the outdoor climate. Since this installation is unique, a lot of development work and comprehensive calibration work are required. The intention is to develop a standardised method for measurements and calculations of the thermal properties of sunshades and therefore also to participate in international standardisation work (ISO).

9.3 Calculation models

Calculation models for different types of sunshade in combination with windows have been developed and implemented in the computer program DEROB-LTH. Development of DEROB-LTH within the solar protection project has mainly related to the thermal window model, solar and sky radiation on glazed surfaces, shading of diffuse radiation, calculation of thermal comfort and visualisation of the building. One limitation in the window model which still remains is that the radiant parameters of the glass are considered to be independent of wavelength and that all data are considered to be the means for the whole solar spectrum. This implies that care must be taken when special glass is used.

Comparisons between the outdoor measurements and simulations with DEROB-LTH have been made in order to validate the new calculation models. These comparisons show very good agreement between models and actual behaviour. The models are fully adequate to give realistic ideas of the heat balance for a window with the investigated sunshade. In most cases, the difference between simulation and measurement was less than 3% of the incident solar radiation. Some models underestimate, and others overestimate, the transmitted solar energy. These errors are however of the same order as the error in measurement.

Further work has been made on developing models for venetian blinds. The new model for external venetian blinds has been compared with measurements. The result show very good agreement. This model has been further developed during the autumn of 2000 to include also interpane and internal venetian blinds. The calculation model for fabric screens was constructed by using a modified pane of glass with non-diffusing transmission. This was found necessary since a diffusing sunshade

produced too low a cooling requirement, i.e. too low transmission. A screen has small holes which usually means that some solar radiation is transmitted as diffuse and some as directed radiation. Further development of the screen model may have the result that shades may be permitted to have both direct and diffuse transmission.

9.4 Properties of sunshades – generalised measurement results

Presentation of generalised data for the total solar energy transmission g clearly demonstrates that one constant value of g for a solar protection product is in most cases unacceptable. The value of g varies depending on the type of sunshade and material, type of window, orientation, climate and the time during the day and year.

When a cooling plant is designed and energy use is assessed, it must be possible to estimate the energy increment from the sun depending on e.g. window type and the use of solar protection. For this purpose, two values of g have been produced as monthly values, one value for the estimation of power demand and one for energy assessments. The value of g for the estimation of power demand is weighted with respect to incident solar radiation for each orientation and climate. In this way a representative value of solar transmission is obtained that occurs for the strongest solar radiation in a specific orientation, i.e. at the time when the power demand for cooling is greatest.

The values presented for the total solar energy transmission g are only examples since, in principle, there is an infinite number of combinations of sunshade types and window types, and this affects the value of g . This effect is not very great for external sunshades but is appreciable for interpane and internal products. The values of g presented can however be used in calculating the power demand and energy requirements for the sunshade products and situations which have so far been dealt with.

9.5 Design tool

A design tool is under development and the first version handles external sunshades. This version was released in September 2000. Later versions of the program will be able to deal with interpane and internal sunshades.

The computer program calculates direct and total solar energy transmission for the sunshade and window type selected. Data can be obtained as hourly or monthly values for calculation of energy and power demand. Data can be saved in a file that can be imported by other calculation programs. There is also the possibility in the program to calculate directly the power and energy requirement for heating and cooling and to study temperature conditions in office rooms with or without sunshades. The design aid is intended mainly for energy and building services consultants, architects and other technical people in the construction industry.

9.6 The effect of sunshades on energy use

A comparison has been made between using sunshades in combination with windows with clear glass and using only solar control glass, and the results give an idea of the potential for reducing energy use. It is found that in a northern climate seasonally adapted solar protection is a more promising technique for energy saving than the use of different types of solar control glass. The reason is that solar control glass screens solar radiation even during the winter months when heating is needed and the energy increment from the sun is beneficial. The results also show that considerable savings in energy can be achieved by simple seasonal sunshades of relatively small dimensions. These "minimised" awnings which have been studied shade most of the window while at the same time they obstruct vision only through a small part of the window, which is appreciated by the users. If, on the other hand, the awning is extended during the whole year, total energy need for heating and cooling is greater than when no sunshade is used. Automatic control of solar protection is something that can have great potential for energy saving. It is however important that the users should nevertheless be able to alter the position of the sunshade and should not feel that they have no control.

9.7 User aspects

In an introductory study different types of user aspects and the effect of daylight in the room were studied when sunshades were used. The aim was limited to investigation of the function of the sunshade, its manoeuvrability and effect on daylighting as judged by test persons. From the study an idea can be gained of how people, when they can control the

sunshade themselves, decide to adjust it in relation to the outdoor climate at the time of the test. The study also included registration of the amount of additional lighting the test persons choose when different types of sunshade are installed. The investigation was limited to only two types of sunshade, awning and external venetian blind. It was thus very limited in nature and must in the first place be seen as an introductory study for the development of an appropriate test procedure. Some general conclusions can however be drawn from this study.

It is difficult to judge when and to what extent a sunshade is used with reference to the lighting situation. There is great individual variation between test persons. This implies that considerably more test persons and more weather situations are probably needed if the tests are to have a better coefficient of determination. It is clear that work on a computer demands some kind of shading during a large proportion of working time. The ability to control lighting from the work station was seen as very positive. It is a general conclusion from tests of this kind that individual control of physical parameters in the environment of a person is preferred to no control at all. No simple relationship could be discerned between the use of additional lighting and recorded illuminance on the work surface. This implies that control of additional lighting on the basis of daylighting control is not seen as very successful. There is far too much individual variation. Nor did the choice of an awning as against an external venetian blind make any difference to the amount of additional lighting that was preferred.

9.8 Goal attainment

This report describes the results achieved while finance has been available for the project. As regards overall goal attainment for the project, only parts of the project have thus been completed as yet. The method for measuring solar energy transmission in a real climate has been developed and works well for external and interpane sunshades. The method must however be modified slightly when measurements on internal sunshades are to be made. Thanks to an investment grant from Lund University and an additional grant from the Swedish Council for Building Research, another important target has also been attained, the construction of a solar simulator. Calculation models for external sunshades have also been developed which was also the aim so far. Existing resources also permitted development of a first version of a design tool.

Economic stringency has however obliged us to limit work so far to studies of energy. Aspects such as daylighting, thermal comfort etc are also very important, but have been deferred until a later date. However, work regarding daylighting has recently started. Other parts that we had not expected from the beginning have however been added, namely general studies of potential energy savings when sunshades are used, thanks to scholarships from Canada for guest researcher Marie-Claude Dubois. A small study regarding user aspects could also be carried out.

9.9 Further work

Extensive research work remains to be done in the project, and provided that further finance can be arranged the following work will be done during the next three years:

- Development of measuring method
- Measurements on interpane and internal sunshade products in a real climate
- Development of calculation models for these products
- Measurements on external, interpane and internal sunshade products in the solar laboratory and calibration with reference to measurements in a real climate
- International standardisation work
- Development of design tools for external, interpane and internal sunshades
- System verification of adjustment and control of sunshades
- Daylighting and artificial lighting – measurements and calculations
- Thermal comfort
- Production of an information brochure.

10 Summary

Maria Wall
Bertil Fredlund

10.1 Background

Development of windows with low U-values and thus low energy losses has made it possible for large glazed surfaces to be used in buildings without problems due to draughts or high heating costs. However, large glazed surfaces need solar protection, since otherwise there is a risk of excessive temperatures and/or large cooling requirements in summer. The term solar protection refers here to awnings, roller blinds, horizontal slatted baffles, venetian blinds, coatings on the glass, etc. They may be placed on the inside, between panes or on the outside. Some sunshades can also act as overnight insulation for the windows.

During the design stage it must be possible to assess the comfort and energy for heating/cooling, if the building is to function properly. The situation at present is that sunshades are seldom designed during the design stage, but they are installed as an emergency measure when problems are encountered, i.e. after the first summer that the building has been in use.

It is difficult to market shading devices and to justify their use unless they can be accompanied by a sound assessment of the effects on cooling load and indoor temperature. The difficulty is that there is a lack of relevant and comparable data regarding the amount of solar radiation that is transmitted through different types of sunshades and their performance in combination with windows. Most manufacturers and retailers of sunshades can present only very rough estimates of the amount of solar radiation that can be screened out – or no data at all! Obviously, for correct design of air conditioning installations in buildings, it is necessary to know what is the effect of sunshades. There is also a lack of simple and reliable design aids for building services engineers and architects. The result of all this is that the potential of effective solar protection is

not considered during design. In turn, this results in the design and installation of unnecessarily large air conditioning plants, with high investment and running costs.

The research project *Solar protection in buildings* was therefore started in January 1997. This project involves collaboration between the Lund University, the Swedish Solar Protection Association, the Norwegian Solar Protection Association and the (building services) consultants Erichsen & Horgen O/S in Oslo. The Swedish and Norwegian Solar Protection Associations represent the industry whose members are associated with solar protection products for buildings. The member firms include both wholesalers, producers and retailers.

The object of this project as a whole is to ascertain the physical properties, e.g. the g -value, of different types of sunshades and to use these as input data in a *calculation model* developed within the project. The model shall be verified and developed into a *design aid* for consultants. A proposal for a *standardised laboratory method* for the measurement of the physical properties of sunshades should also be produced. There is no such method available at present, as has been found within international standardisation work (ISO, CEN).

This project comprises many different parts, and the report describes the progress we have made in research in the different parts. The studies have been mostly limited to a study of the properties of sunshades with regard to the g -value of solar energy and thus their effect of energy use for cooling and heating. The reason that work was in the first place limited to this is that comparable physical data have not been available for different types of sunshades. This part is of fundamental nature and has therefore received priority. This does not imply that other factors such as daylight and thermal comfort are less important. These and other factors will be treated at a later date as soon as finance can be arranged.

10.2 Measuring method and accuracy

It has been found that there is a lack of relevant data available today as to how much protection different sunshades provide against unwanted solar radiation. From firms that manufacture and market solar protection products, only very approximate data can be obtained. The manufacturers of screen fabrics who all comply with an ASHRAE standard 74-1988 are one exception. This standard provides information only on solar transmission of mainly perpendicular incidence, and therefore it is applicable only for products whose properties are independent of the direction of solar radiation.

In this project, a method based on a double hot box arrangement with real solar radiation as the radiation source has been used in studying the properties of sunshades. This method is based on calorimetric measurements where the supplied heating input, cooling input and temperature differences between the measuring box and the surroundings are used to calculate total and primarily transmitted solar energy. Windows and sunshades were mounted in a southerly facade and were exposed to outside climate. Relative accuracy in measuring transmission has been estimated as $\pm 5\%$.

The products so far studied are external sunshades, namely two awnings, two external venetian blinds, two Italian awnings, a horizontal slatted baffle, three fabric screens, two slatted window blinds and two solar control films. In the case of products for which more than one test was carried out, several variants and in some cases even different operating strategies were tested. The awnings were tested with a light and a dark fabric. The external venetian blinds were silver in colour with 50 mm and 80 mm slats. Awnings were tested when fully and partially extended. The venetian blinds were also tested in two positions, fully lowered with slats horizontal, and fully lowered with slats at 45° .

Owing to the fact that a double glazed window was used as reference in the measurements, the solar transmission calculated in the tests for the different sunshades is the same as the shading coefficient.

In order to calculate solar transmission from the tests, a heat balance is set up for the hot boxes. In this heat balance a number of terms are known from measurements, so that it is possible to solve it for the total solar radiation that enters the box through sunshade and window. In order to calculate the total solar transmission of the system, the total solar transmission is divided by the global radiation incident on the window and by the area of the window.

The properties of a specific sunshade can be easily calculated if it is assumed that total solar transmission is a product of the different parts of the system, i.e. window and sunshade. Since the transmission through the window may be considered known through calculations or measurements, the transmission through the sunshade can be easily calculated as the quotient of the transmission of the system and the window. The measuring procedure has facilities for measuring the properties of the sunshade plus the window in one box, and to measure simultaneously the properties of only the window in the other box. This is particularly attractive in the case of outdoor measurements where solar radiation varies at random due to different weather conditions. One great advantage of the method used is that sunshades can be studied under real conditions. The drawback is that the results of measurements represent only the con-

ditions that prevailed during the measurement period. This demands a well developed theoretical model in order that the measured properties may be generalised.

10.3 Solar laboratory

A solar simulation installation has been designed and constructed. This installation permits a more standardised measurement method and thus comparison of the properties such as solar transmittance of sunshades and/or windows in full scale under realistic conditions. Owing to the availability of this equipment it is possible to study conditions, such as angles of incidence, different from those at the latitude of Lund.

The principal components of this installation comprise a light source which can be equipped with two different lamp clusters, a calorimeter box, a reflector arrangement for generation of parallel light, and mechanical equipment for setting different angles of incidence. Equipments for measurement and control are added to these.

The horizontal angle between sun and facade is obtained by rotating the object of measurement about a vertical axis. Solar altitude is generated by mounting the lamp arrangement on a lifting arm.

The first lamp arrangement comprises seven 2.5 kW discharge lamps from Philips, model MSR (Metal halide Short arc Rare earth) which provides a somewhat more uniform spectrum than conventional metal halide lamps. The other lamp cluster consists of three different radiation sources which together produce a spectrum free from the concentration to narrow bands which discharge lamps exhibit. These three radiation sources are a new type of lamp, sulphur plasma lamp, and two types of filament lamp of halogen type with and without a dichroic mirror.

The seven discharge lamps or sulphur plasma lamps are placed in 7 large reflectors in a honeycomb pattern. In the solar simulator the luminous surface is a hexagon of 2.3 m height.

The object of measurement is mounted on a calorimeter box made of expanded plastic. In the box there is a black painted absorber which is cooled and controlled to a constant temperature. Control is achieved by measuring the inlet and outlet temperatures of the absorber plate whose mean temperature regulates water flow. The measured cooling input into the absorber is a measure of the solar energy received by the box.

The installation which is a unique type demands comprehensive calibration work that is in progress at present. It is expected that the installation can, after adjustments, be put forward as a proposal for a standard-

ised laboratory method for the determination of the thermal properties of sunshades. However, this requires extensive participation in international standardisation work.

10.4 Calculation models

Within the project, calculation models for external sunshades in combination with windows have been developed and implemented in the computer program DEROB-LTH. Development work has mainly related to the thermal window model for dealing with physical phenomena such as solar and sky radiation on glazed surfaces, shading of diffuse radiation, calculation of thermal comfort and visualisation of the building. In the new window model a temperature node is used for each pane. Long wave radiation and convection between the panes is treated with full consideration of the dependence of the surface coefficient of heat transfer on glass temperature, air gap dimensions and window inclination. Solar and sky radiation absorbed in each pane is also taken into consideration. The panes of glass are considered to be opaque to long wave radiation. In the present model, the radiation properties of the panes of glass are assumed to be independent of wavelength and to represent the mean for the whole solar spectrum. This is a limitation that must be noted when the glass combination contains special glass.

In DEROB-LTH two types of diffuse radiation, short wave solar and sky radiation and long wave radiation, are treated. Previously it was not possible to take into account the shading of these types of radiation. In order to improve handling of diffuse radiation, new calculation routines have been developed and incorporated in the program. For determination of the diffuse radiation incident on an external surface, angle factors are used. These can in many cases be determined analytically, but a newly developed general procedure has been implemented in the computer program. The routines can also deal with radiant transfer between external surfaces and sunshades.

The calculation models developed for sunshades have been compared with outdoor measurements. The results of these comparisons show that the model is in very good agreement with reality and is fully adequate for practical application. The difference between simulation and measurement is often less than 3% of the incident solar radiation which is of the same order as the error in measurement.

10.5 Properties of sunshades – generalised measurement results

It is difficult to quote generally applicable values on the basis of measurements on the different sunshades. The results of measurements are valid only for the time and the latitude at which they are made. With the help of calculation models implemented in the computer program DEROB-LTH it is however possible to calculate the properties of sunshades for other conditions. Depending on the interaction between sunshade and window, a unique calculation is in actual fact needed for each combination of window, sunshade, latitude, orientation, climate and time.

For external sunshades which have so far been treated it is a reasonable first approximation to calculate the total solar energy transmission (g -value) of the sunshade. Apart from the fact that a sunshade influences the way solar radiation is transmitted through a window, the purely thermal properties can also be affected. This type of effect is not included in the value of g . However, awnings, horizontal slatted baffles and other projecting structures have very little effect on the U-value. In this report only the value of g is given, and any changes in the U-value have not been calculated.

Calculations have been made for awnings, Italian awnings, horizontal slatted baffles, external venetian blinds and fabric screens. In sizing cooling equipment and in assessing energy use, it must be possible to judge the magnitude of energy increment from solar radiation as a function of e.g. window type and sunshade use. For this purpose, two different values of g have been produced as monthly values, one value for energy assessments and one for the estimation of power demand. The value of g for power demand is weighted with respect to the incident solar radiation for each orientation and climate. In this way a representative solar energy transmission is obtained which prevails when solar radiation is maximum for a specific orientation, i.e. on the occasions when the power requirement for cooling is greatest.

The results show that the annual variation of g is large for some types of sunshade and small for other types. For instance, the design value of g , $g_{sunshade}^{dim}$ for an external venetian blind with horizontal slats varies between 30% and 90% depending on the time of year. For a type of fabric screen, on the other hand, the design value of g varies only between 10% and 20% over the year.

The values of total solar energy transmission g which are presented are only examples since, in principle, there is an infinite number of combinations of sunshade and window types, and this affects the value of g .

This effect is not very large for external sunshades, but is considerable for interpane and internal products. The g -value given can however be used for calculations of energy and power requirement for the sunshade products and situations so far considered. For this reason it is extremely important that a calculation program should also be developed as an aid at the design stage, in which the properties of different combinations of sunshades, windows etc can be calculated.

10.6 Design tool

A design tool called ParaSol has been developed on the basis of the models produced for awnings, external venetian blinds, fabric screens and horizontal slatted baffles. ParaSol is essentially a specially developed interface for the energy calculation program DEROB-LTH which is the tool in which the proposed simulation models for different sunshades have been implemented. The target group for ParaSol are architects, building services consultants and others in the building industry who choose sunshades for a given building.

ParaSol is a Windows 95/98/NT program written in Visual Basic. Data for ParaSol are input via a number of windows. Output data from the program can have different degrees of detail on the basis of the degree of detail in input data.

In the first version of the program only one geometry is possible. It comprises an office room with *one* external wall and *one* window. All geometrical dimensions can however be altered by the user. The user also inputs orientation and the locality where the building is to be situated. Other options are wall construction, window type and sunshade type.

The computer program calculates direct and total solar energy transmission for the sunshade and window type selected. Data can be obtained as hourly or monthly values for power or energy calculation. It is possible to save data in a file which can be imported by other calculation programs. There is also a facility to calculate directly in the program the power and energy required for heating and cooling and to study temperature conditions in the office room with and without solar protection.

This first version was ready in September 2000. Later versions of the program will then be able to deal with intermediate and internal sunshades. The program should also be developed as soon as possible so that the effect of sunshade control may be judged.

10.7 The effect of sunshades on energy use

With the aim of developing aids for the design and control of high performance sunshades, a series of parametric studies have been made. Through such calculations different factors can be varied, one at a time, in order to study the influence on the energy needed for heating and cooling. The computer program DEROB-LTH with the new calculation models for sunshades was used in this study.

A comparison has been made between using sunshades in combination with only clear glass in the window and using different types of windows (glass combinations) e.g. solar control glass, to obtain an idea of the potential for reducing energy use. It is found that in a northern climate a seasonally adjusted sunshade is a more promising technique for energy saving in buildings than the use of different types of solar control glass. The reason is that solar control glass screens solar radiation even during the winter months when heating is needed and the solar energy increment is beneficial. The results also show that considerable energy can be saved by a simple seasonally adjusted shade of relatively small dimensions. These "minimised" awnings which have been studied shade most of the window while at the same time they obstruct vision only through a small part of the window, which is appreciated by the users. If, on the other hand, the awning is extended during the whole year, total energy need for heating and cooling is greater than when no sunshade is used. Automatic control of solar protection is something that can have great potential for energy saving. It is nevertheless important that the users should be able to override the position of the sunshade and should not feel that they have no control.

10.8 User aspects

In an introductory investigation the performance of some sunshades, their manoeuvrability and effect on daylighting have been studied through judgments made by test persons. The study was limited to two types of sunshades, awnings and external venetian blinds. From this study we can gain an idea of how people, when they can exercise control themselves, will adjust the sunshade in relation to the outdoor climate at the time of test. The test also comprised registration of the amount of additional lighting the test persons choose to have for different types of sunshade.

Since the investigation is very limited in scope, no general conclusions can be drawn concerning user aspects when sunshades are used. The study must in the first instance be seen as an attempt to test and develop an appropriate test methodology.

The investigation shows that it is difficult to judge when and to what extent a sunshade must be pulled down with reference to the lighting situation. It is probably glare or contrasts that determine when a person decides to lower the sunshade. There appears to be great individual variation as to how much glare is tolerated. It is clear that work on a computer demands some kind of shading during a large proportion of the working time. To have the ability as in the tests to control lighting from the work station was seen as very positive by the test persons. It is also a general observation from tests of this kind that individual control of the physical environment is preferred. No simple relationship could be discerned in the tests between the use of additional lighting and measured illuminance on the work surface, which is interpreted to mean that daylight responsive lighting control is not a successful technique. No difference in the use of additional lighting could be noted whether the window was fitted with an awning or an external venetian blind.

When it comes to the research method used, it is clear that there is a large individual variation between different subjects. This means that these types of studies require an even larger number of subjects and more weather situations to achieve a higher degree of explanation in the experiments.

10.9 Goal attainment

This report describes the results achieved while finance has been available for the project. As regards overall goal attainment for the project, only parts of the project have thus been completed as yet. The method for measuring solar energy transmission in a real climate has been developed and works well for external and interpane sunshades. The method must however be modified slightly when measurements on internal sunshades are to be made. Thanks to an investment grant from Lund University and an additional grant from the Swedish Council for Building Research, another important target has also been attained, the construction of a solar simulator. Up to now, calculation models for external sunshades have been developed which was also the aim so far. Existing resources also permitted development of a first version of a design tool.

Economic stringency has however obliged us to limit work so far to studies of energy. Aspects such as daylighting, thermal comfort etc are also very important, but have been deferred until a later date. However, work regarding daylighting has recently started. Other parts that we had not expected from the beginning have however been added, namely general studies of potential energy savings when sunshades are used, thanks to scholarships from Canada for guest researcher Marie-Claude Dubois. A small study regarding user aspects could also be carried out.

10.10 Further work

Extensive research work remains to be done in the project, and provided that further finance can be arranged the following work will be done during the next three years:

- Development of measuring method for internal sunshades
- Measurements on interpane and internal sunshade products in a real climate
- Development of calculation models for these products
- Measurements on external, interpane and internal sunshade products in the solar laboratory and calibration with reference to measurements in a real climate
- International standardisation work
- Development of design tools for interpane and internal sunshades
- System verification of adjustment and control of sunshades
- Daylighting and artificial lighting – measurements and calculations
- Thermal comfort
- Production of an information brochure.

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