Solar Protection in Buildings

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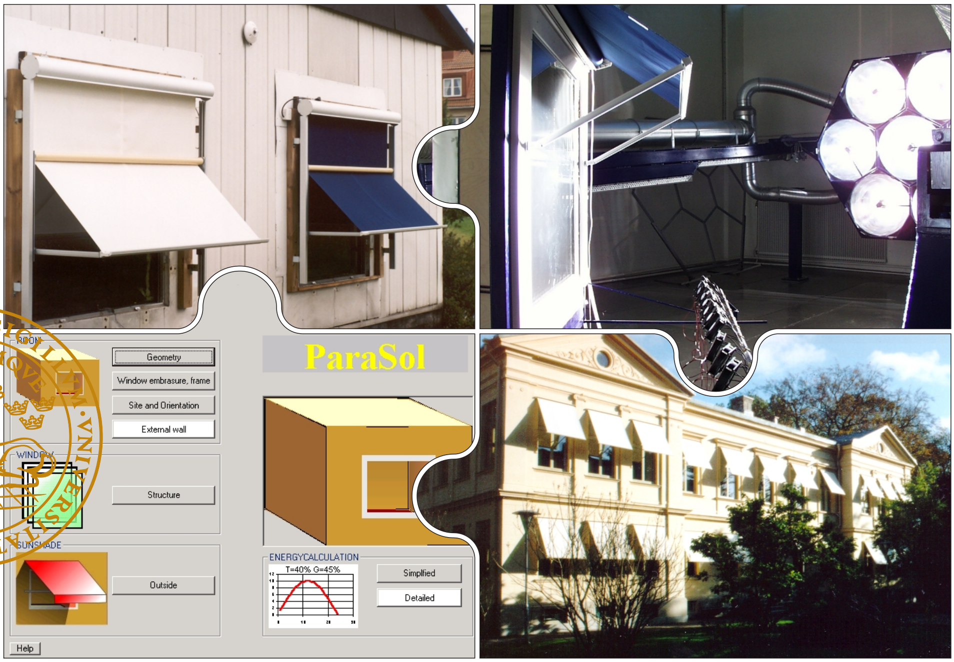

Lund University

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 mutidisciplinary 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.

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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.

Contents

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 asisstance 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

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 ±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 conditions 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 standardised 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 acount 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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