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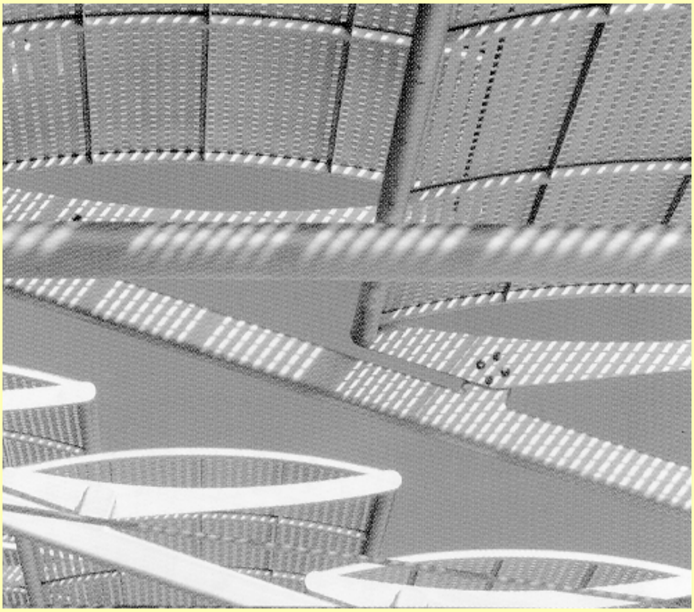
Solar Shading and Building Energy Use



A Literature Review, Part 1

Marie-Claude Dubois

Building Science

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 96 000 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 5 850 employees and 38 200 students attending 50 degree programmes and 850 subject courses offered by 170 departments.

Department of Building Science

The Department of Building Science is part of the School of Architecture within the Faculty of Technology. The Department has two professorial chairs, Building Science and Building Services. Research at the Department is concentrated on energy management, climatic control and moisture problems. The main areas of research are:

- design and preformance of new low-energy buildings
- energy conservation in existing buildings
- utilization of solar heat
- climatic control
- climatic control in foreign climates
- moisture research

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Part 1

by
Marie-Claude Dubois

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Abstract

Literature in connection with solar shading of buildings and energy use has been reviewed and classified in three main domains: 1) physical properties of shading devices, 2) effect of solar shading on energy use and daylighting and 3) calculation methods to assess the energy performance of buildings equipped with shading devices.

The review showed that the thermal resistance of shading devices has been studied extensively although work on the thermal resistance of devices attached to double and triple pane windows remains to be done. Average and normal incidence optical properties have been determined for most shading devices but solar angle dependent values still need to be measured. No standard measurement procedures have been reported.

Studies of the impact of shading on annual energy use have demonstrated that shading devices reduce the cooling demand in buildings while increasing the heating loads due to loss of beneficial solar gains. Optimal shading strategies are thus climate dependent: in heating-dominated countries, fixed devices with medium to high solar transmittance and high thermal resistance or systems that can be removed in the winter are more energy efficient. Shading strategies for daylight buildings where artificial lighting is replaced by natural light through installation of dimming systems need to be investigated further.

Finally, it was demonstrated that calculation methods associated with energy transfer through shading systems have been developed for awnings, venetian blinds and interior roller shades. Work on model validation as well as development of improved mathematical models for diffuse and ground-reflected radiation flows through different types of shading devices remains.

Contents

Summary

Since the 40's, research related to solar shading and buildings has focused on three main issues:

1) The properties (thermal and optical) of solar protective glazing and shading devices
2) The effect of solar shading on energy use and daylighting in buildings
3) The calculation methods to assess the performance of buildings equipped with shading devices or solar protective glazing.

Properties of solar protective glazing and shading devices

Thermal transmittance

A large number of studies aimed at quantifying the reduction in heat flow through windows when various types of shading devices are used and conditions of no solar radiation prevail have been made in the 70's and 80's. These studies showed that shading devices affect heat flow through windows significantly, especially when installed on single pane, clear glass windows. The thermal resistance of the window-shade system is greatly improved if the shading device traps an air layer next to the window glass. Sealing edges of the shade to the window and using air-tight fabrics are ways to improve the window-shade system's thermal resistance.

The amount of heat flow reduction obtained through tests with various shading systems varies according to the type of shading device tested, the experimental conditions and the type and size of window used in the experiment. When shades are applied to single pane, clear glass windows, Lund (1957) found that interior aluminium foil shades on cloth reduce heat losses by 58%. ASHRAE (1972) suggested that venetian blinds, draperies and roller shades reduce the U-value ofthe window (hence the heat losses) by at least 25%. Grasso et al. (1990) found that draperies improve the thermal resistance of windows by 40% (reducing heat losses by 30%). Horridge et al. (1983) found that most shading devices (venetian blinds, translucent rollers, vertical blinds, opaque roller shades and drapery liners) improve the window's thermal resistance by up to 70% (reducing heat losses by 41%). Grasso & Buchanan (1979) showed that roller shade systems reduce heat losses by 25-30% while metallic coated roller shades reduce the losses by 45%. Finally, work at the Department of Energy (ETSU, 1990) demonstrated that thermal effects of net curtains or venetian blinds are negligible while light curtains reduce heat losses by 20% and heavy curtains by 40%. Lunde & Lindley (1988) found that roller shades, roman shades and films reduce heat losses by up to 50% when sealed to double pane, clear glass windows. Few other studies attempted to assess the heat loss reduction provided by shading devices coupled with double pane windows. The author is not aware of any existing studies which assess the thermal transmittance of triple pane windows equipped with shading devices.

In summary, most authors agree that venetian blinds, draperies and roller shades inside single pane, clear glass windows reduce heat losses by 25-40%. Metallic coated shades inside windows reduce heat losses by 45-58% depending on the material and mounting method used.

Solar transmittance

Since the end of the 50's, a number of researchers have attempted to define optical properties of shades. The optical properties have been expressed in terms of solar transmittance and reflectance values, solar heat gain factor or shading coefficient. These studies do not usually permit specific conclusions about annual energy use in buildings but they indicate, in a general manner, "how well a shade shades".

Although they express the capacity of shading devices or solar protective glass to cut out solar radiation, they do not indicate optimal shading strategies for any particular climate.
Olgyay (1963) classified shading devices according to their shading coefficient from the least to the most effective in reducing solar radiation as follows: 1) venetian blinds, 2) roller shades, 3) insulating curtains, 4) outside shading screen, 5) outside metallic blind, 6) coating on glazing surface, 7) trees, 8) outside awning, 9) outside fixed shading device, 10) outside movable shading device. According to this author, exterior shading devices are more effective by 30-35% in reducing solar radiation entering a building than interior devices which can only reflect a small part of the radiation and release heat absorbed back into the building. Heat absorbing panes and devices set between panes are about 15% more effective than are interior shading devices (Architect's Journal, 1976). Also, Olgyay (1963) mentions that off-white colours usually provide more effective shading than dark colours because they reflect more radiation. Steemers (1989) estimated that exterior fixed overhangs are more effective than vertical fins and egg-crate devices in reducing solar radiation on south, east and west facades although the difference between overhangs and fins is small for east and west facades. Also, vertical fins are better on the north facade than overhangs and egg-crate devices. Prismatic panes have a solar transmittance of 10% in the summer and 90% in the winter with direct sun and a transmittance of 70% for diffuse radiation (Christoffers, 1996). Finally, Hoyano (1985) found that vegetal vine sunscreens have a weak solar transmittance of 25%.

Effect of solar shading on energy use and daylighting in buildings

A large number of parametric studies of solar shading devices and energy use have been made since the development of energy performance computer programs. The relationship between shading and energy use has also been studied through experiments with the first work on the subject by Peebles (1940). Researchers first paid attention to the relationship between cooling loads and solar protection.

Then, the impact of shading devices on heating loads and annual energy use was assessed. Since the middle of the 80's, however, the development of dimming systems allowing daylighting to replace artificial lighting in buildings means that the impact of shading on daylighting levels and, hence, electricity use for lights must be considered along with heating and cooling loads.

Considering cooling and/or heating loads

Studies of the effect of solar protection on heating and cooling loads show that shading strategies are climate dependent. While most authors agree that solar protection does reduce energy use for coolng and tends to increase heating loads, few of them agree on how much energy can be saved and what is the best shading strategy overall.

Shading devices lower the energy use for cooling. Harkness (1988) showed that exterior precast concrete overhangs and fins reduce the cooling load by at least 50% in Brisbane, Australia. Brambley et al. (1981) showed that sunscreens reduce cooling loads by 23% in San Diego. Halmos (1974) demonstrated that external shading devices installed on double pane, clear glass windows reduce the cooling load by 75%.

A number of researchers showed that most shading devices contribute to increases in energy use for heating while they reduce the cooling load. Bilgen (1994) found that automated venetian blinds between panes increase the heating load by 4-6% and reduce the cooling load by 69-89% in Montreal. Treado et al. (1984) showed that various types of shading devices increase the heating load while the cooling load is reduced; the net energy savings only occur if the reduction in cooling energy use exceeds the increase in heating energy use. In general, it was demonstrated that cooling loads are reduced with decreasing shading coefficient (better shade) while the opposite was observed for the heating load. Higher shading coefficient (poor shade) results in lower heating loads. According to Treado et al. (1984), as the respective shares of total energy use due to heating and cooling loads depend on the climate where the building is erected, so does the shading strategy. In an earlier study, Treado et al. (1983) also found that window films do not result in annual energy savings in heating dominated climates. Films generally contribute to larger increases in heating loads than to reductions of energy use for cooling. Emery et al. (1981) also found that shading strategies are strongly climate dependent. According to them, fixed overhangs and fins yield a modest reduction in energy use and the best shading strategies in three American cities are reflective glazing, heat absorbing glazing and glazing with exterior aluminium louvres. Hunn et al. (1990,1993) tested a variety of interior and exterior shading devices in a heating dominated climate and found that a higher performance is obtained with interior shading devices (as opposed to exterior fixed) when energy cost and use and peak demand reduction are analysed. Interior devices, which shade the entire glass while providing additional insulation to the window can save as much as 30% energy for cooling, resulting in annual energy savings of the order of 10% for offices. These authors (1990, 1993) also showed that external shading devices are often net energy losers because they reduce useful solar gains during the winter. Heat absorbing glass, reflective glass, annual solar screens and overhangs plus fins almost always result in increased annual energy use. These observations confirm results obtained by Pletzer et al. (1988). Mc Cluney & Chandra (in Germer, 1984) found the opposite for the climate of Florida: exterior devices (overhangs, awnings, window screens) are the best energy savers while tinted glass is the least energy efficient solution.

Few authors showed that shading devices can reduce the energy use for both heating and cooling seasons. Cho et al. (1995) showed that internal venetian blinds reduce heating loads by 5% and cooling loads by about 30% in South Korea. However, the reduction in heating load was due to increased thermal insulation provided by the shading device at night. During the day, the devices were net energy losers. Rheault & Bilgen (1987a, 1987b) demonstrated that automated venetian blind systems between panes can reduce heating loads by 30-70% and cooling loads by 91% in Montreal. However, results from this study were obtained through calculations with a computer program which was not validated experimentally

Considering annual energy use including electricity for lights

It is a fact that using dimming systems to replace artificial light by natural light reduces the energy use for lighting. Sullivan et al. (1992) showed that perimeter electricity use for lighting is reduced by 73% through the use of daylighting.

Authors disagree, however, on the benefits of using daylighting to reduce overall energy use (lighting, cooling and heating). Andresen et al. (1995) showed that for south racing windows in Trondheim, the use of daylighting results in 48% reduction in lighting load, 11% increase in heating loads and 70% reduction in cooling loads. Winkelmann & Lokmanhekin (1985) demonstrated that daylighting reduces the overall energy use by 10-22% and is cost effective in Miami, Los Angeles, Washington DC, and Chicago. The lowest energy use option is obtained when daylighting is coupled with clear glazing and external sun-control blinds for all the cities studied. Rundquist (1991) showed that, in Minneapolis and New York, increasing daylighting levels (through increases in window-to-wall ratio or shading coefficient) always reduces utility costs. He showed that when daylighting is used, windows provide utility savings relative to a solid wall. When daylighting is not used, increasing the window-to-wall ratio and the shading coefficient always leads to increased cooling and heating loads. This contradicts findings by Sullivan et al. (1992) who demonstrated that electricity use (cooling and lighting) and peak demand are almost linearly increased with increasing window-to-wall ratio and solar aperture (product of the shading coefficient and the window-to-wall ratio) in Los Angeles, when daylighting is used.

In short, the shading strategy to adopt when daylighting is used has not been clanified yet and is a complex problem. Although most researches demonstrate that daylighting use yields lower annual energy use, more work is needed in this area to define appropriate shading and daylighting control strategies that make an efficient use of energy.

Shading devices and daylighting

Few studies have looked at the problem of solar protection and daylighting levels in rooms. Collett (1983) and Bull (1953) attempted to determine optimal blind blade angle arrangement as a function of illuminance levels in rooms. Results obtained by these authors cannot be compared because experimental settings and measurement points and conditions were too different. No specific conclusion can be drawn from the work by

Brown (1993) who attempted to measure illuminance levels when daylighting and shading systems were installed in a real building during different stages of construction.

Calculation methods to assess the performance of buildings equipped with shading devices and solar protective glazing

Geometric models

Since the beginning of the 80's, a number of computer programs have been developed to determine accurately the optimal shape of exterior shading devices—such as awnings and overhangs—with respect to the sun under clear sky conditions. Bouchlaghem (1996), Kensek et al. (1996), Etzion (1985), and Wagar (1984) all contributed to provide such models which are mainly concerned with the geometry of shading devices and do not contain energy simulation algorithms to assess the performance of the devices in terms of energy use.

Programs to calculate the amount ofsolar radiation entering a building

Parallel to this work, dynamic (hour by hour) computer programs calculating the radiative energy flows through solar protective glass and shading devices have been developed since the middle of the 80's. One of the most important contributions is the work by Pfrommer et al. (1996) who developed a dynamic model to calculate radiation flows through venetian blinds located outside and inside windows, taking into account both the diffuse and direct part of solar radiation and varylng solar angles. Also, Cho et al. (1995) developed a calculation module to connect with *TRNSYS* (a dynamic energy simulation program) for the assessment of the effect of interior venetian blinds on energy use. Grau & Johnsen (1995) developed analgorithm to determine the solar reduction factor when exterior fixed shading devices are used. However, the program does not calculate reductions of diffuse radiation entering the building. Mc Cluney & Mills (1993) provided an algorithm to model radiative energy flows when vertical planar shades are used on the interior side of a window. This algorithm does not take into account solar angle dependent optical properties of shading devices. Mc Cluney (1986, 1990) also provided a program calculating the reduction of the solar factor (direct, diffuse and ground reflected) when awnings are used.

Finally, texts by Mc Cluney (1991) and Prassard et al. (1992) about calculation methods associated with shading and energy use should be mentioned because these authors identified some of the most important problems left to be solved in energy calculation models: the replacement of the shading coefficient concept by appropriate solar angle dependent properties of window-shade systems and the accurate representation of radiative and heat transfers through complex fenestration systems coupled with shading devices. Algorithms by Furler (199 1), Papamichael & Winkelmann (1986) and Pfrommer (1995) to determine solar angle dependent optical properties of glazing are promising advances in this field. These developments will eventually contribute to improve the accuracy of dynamic energy calculation programs for buildings equipped with complex fenestration and shading systems.

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