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Università Politecnica delle Marche

Extended summary

Design of a sustainable building enclosure: experimental and numerical analysis of the solar heat-reflecting shields for the home comfort and energy saving

Curriculum: Architettura, Costruzioni e Strutture

Author

Andrea Ursini Casalena

Tutor(s)

Alessandro Stazi

Costanzo Di Perna

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Abstract. The objective of this research is to evaluate both the thermal and lighting aspect in the application of solar heat-reflecting and semitransparent shielding in the buildings, to optimize the interaction between daylighting, summer overheating and winter heating. For this purpose has been realized both experiments on real building and numerical analysis to deeply analyze the behavior of the heat-reflecting shield among the traditional screens. The analysis results showed that also the heat-reflecting shields have poor thermal performance when installed on the internal side of the window, causing a light warming of the internal air. The best performance scenario is when they are installed on the external side, during summer, and on the internal side during the winter. In both cases the overall performance in terms of energy consumption for heating and lighting as well as thermal and visual comfort, are higher than other types of screens.

Keywords. Energetic efficiency, solar factor, solar shield, summer overheating.

1 Problem statement and objectives

The control of energy due to the summer air conditioning loads, in buildings located in areas with mild and warm climates represents one of the main problems to be addressed.

The increasing energy demand for summer cooling of buildings is likely to be-come dramatic in the coming years. An effective strategy for the conditioning, in order to allow the reduction of power consumption, may be the application of devices that shade the external sides of the building.

We have a good knowledge both of the lighting properties of not shielded windows and about how they distribute the light through the environments, but not always, the openings are simple holes on which a glass is applied.

Increasingly, in fact, the punch is made of a more complex system resulting from the integration of insulating glass realized with high-performance glasses that give to the window selective properties against solar radiation; in this complex system are integrated shield mechanisms as Venetian blinds, which can be of different types, and that can be installed in presence of horizontal and / or vertical overhangs.

The purpose of this complex system is to control both the daylighting and the power consumption. Some of these shields are fixed; others are mobile and controlled, sometimes automatically, sometimes manually. These complex systems represent now very widespread solutions for the warmer climates of Europe. However it is necessary to know their performance in terms of energy and lighting. In assessing the overall performance of the building it also needs to consider, among many variables, the influence of users on the control systems.

The problem is related to the behavior of the users that often regulate, to their liking, the entrance of natural light. However the comfort is very important and where the automated control systems are based only on the energy saving, ignoring the comfort of man, the results become unacceptable. When in the warm seasons we use a venetian blind to protect from direct sunlight, often we also reduce the levels of illumination inside increasing the use of artificial light. So, in buildings equipped with solar protection systems, the minimal energy consumption due to the use of artificial light is linked to external lighting levels through a complex physical system. The designer, oriented to energy savings, never should ignore to consider the effects that its architectural choices will have on the visual perception of the user that will live in those environments. The designer should learn what conditions are capable to ensure the visual comfort.

Several studies in an international context [1-39] have addressed the problem of internal and external opaque and low-reflectance shielding. The aim of the following research is, therefore, to evaluate the thermal and lighting behavior in the application of solar and heat reflective translucent shields in the buildings, to optimize the interaction between the daylighting, the control of the overheating in summer and the control of the winter heat-ing. The experiments and numerical simulations are carried out to identify the best configuration of the "window system", capable to minimize the energy requirements necessary to maintain the thermo-hygrometric conditions of com-fort and visual design in a limited environment.

2 Research planning and activities

The research has been divided in three experimental phases and a numerical analysis by means parametrical energetic simulations in dynamic conditions. The experimental steps has been necessary to analyze the behavior of the shield both during the winter, through a climatic chamber located in the laboratory, both during summer, using two rooms of a building and some rooms of the School of Engineering Faculty of Ancona.

The analyzed shield is a new type of semi-rigid perforated blind, consisting of two layers: a black vinyl film with a 0.65 emissivity and an aluminum film with a 0.19 emissivity. The percentage of perforation is 21%.

2.1 Sperimentazione in camera climatica (Climatic room experiment)

The climate room used in the experiments consists of a compartment that contains a smaller environment inside. In this way it has been possible to monitor the trend of surface temperatures of the internal compartment. Three walls of the smaller compartment have been settled as adiabatic and the other has been settled to a temperature equal to the temperature of a typical window in winter conditions. On the same wall, later, a heat reflective shield has been placed and the room has been alternately arranged with electrical radiator and radiant floor. The measurements of comfort have been made on more points in order to create a three-dimensional map of PMV in the small room.

The objective has been to evaluate, in addition to the thermo-hygrometric comfort, also the reduction of heat flux coming out of the window due to the application of the internal heat reflective shield.

2.2 Experiment in a school building

During the summer monitoring has been realized in two classrooms exposed to the west of a school to analyze the behavior of the heat-reflecting shield when it is positioned on the internal side of the windows in one of two classrooms. The classrooms have not been occupied for the entire monitoring period. This has minimized the variability of the boundary conditions of the system windows + shield object of analysis. Data has been acquired on surface and environmental temperatures and also on heat fluxes on opaque and transparent building components.

2.3 Experiment in the Engineering School classroom

At this stage we have realized a monitoring system to analyze the behavior of the shield when it is positioned on the external side of the window. Data has been acquired about external climatic conditions and about surface temperatures of shields and windows. In addition to the heat-reflecting shields, we have analyzed, by comparison, other types of present in adjacent classrooms, including sliding panels like Venetian blinds and shields composed of horizontal metal slats.

2.4 Numerical analysis of the solar shield

At this stage, we have analyzed the thermal and lighting behavior of the heat-reflecting shield using a software (EnergyPlus) to simulate the dynamic conditions of the buildings parametric simulations has been implemented to analyze the following items:

- analysis of energy consumption during winter and summer relating to daylighting and thermo-hydrometric comfort and relating to other types of screens;
- analysis of the comfort conditions during summer in non air-conditioned environment with adaptive model for the opening of the windows and applied shield with reflective side on the external;
- analysis of shields depending on the type of glass: Traditional double glazing, and double glazing with low-emission coating on the internal glass or on the external glass.

3 Analysis and discussion of main results

3.1 Experimental and analytics results during the winter

The results of the experiments in the climatic room show that the low-temperature radiator provides more comfort than the underfloor heating when a reflective shield is applied on the internal side of the window. The radiator is more effectively in contrast with the effect of low temperature on the internal surface of the window. The heat reflective shield allows having a good comfort level already at 50 cm from the window. The decrease of thermal flows going out the window with reflective screen are comparable to the flows that we could have applying and internal tent with opaque tissue, but with the advantage of a greater visual comfort because of its semi-transparency.

The best scenario, in terms of thermo-hygrometric comfort, is when we have used a shield and an underfloor heating. The decrease in the instantaneous heat flux coming out of the window is around - 20% compared to the scenario without the shield.

From the simulations data collected during the winter, we can notice that the total outgoing heat loads from the window shield are about 9% lower compared to the scenario with no window shield (a traditional tent reduces energy loss by about 0.6%). Analyzing the total energy consumption, that takes into account all the thermal loads in addition to those going out from the window, we can see that the effect of shield is less important, it is about 3%. A traditional tent, instead, increases the energy consumption by about 2%. The greatest benefit is in terms of internal thermal comfort. In fact, thanks to the translucent shield, the hours of discomfort are reduced by 14% compared to the use of a traditional tent (4%).

3.2 Experimental and analytics results during the summer

With the experiment in the school building during summer we have verified the behavior of the heat-reflecting shield installed on the internal side of the window, in relation to the greenhouse effect that is naturally produced when the solar radiation passes through a glass surface and is absorbed and reemitted from surfaces and objects within a room.

Analyzing the collected data we have verified the above physical phenomenon that causes an increase of about 0.5 ° C on the average air temperature in the room with the internal solar shields. The differences in the internal surface temperature in the two analyzed scenarios two cases are more emphasized: the heat-reflecting glass with internal shield reaches about 14 ° C higher than the other.

The glass absorbs all the infrared energy reflected from the shield and re-emits it from both sides. In fact, even the external surface temperature of the glass is higher than the surface temperature of a glass without shield. For this reason, the surface temperature of the internal shield is 2 ° C higher than that of an unshielded glass, with a disadvantage of the internal air temperature.

The use of heat reflective shields in the summer is unfavorable, because of the impossibility to dissipate the heat generated between the shield and the glass. This is also found with other types of internal shielding analyzed and compared with reflective shields.

The same phenomenon is noticed using different types of low-emission internal or external coating glasses. The reflecting shield, however, has the advantage of being translucent.

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Analyzing the data of the mean internal lighting, analytically simulated, we can notice that internal heat-reflecting solar shield generates values almost double compared to other types of shields, close to 260 LUX in clear sky conditions.

During the summer, the heat reflective shield works very well when placed on the outside. The external surface temperature of the glass with reflective shield, reaches values similar to the temperature generated by the sliding panels in a clear sky condition. The sliding panels are composed of small dark metal plates and they are characterized by a low transmittance to visible light, but they provide a very good shield for the solar radiation.

During cloudy days, in absence of direct solar radiation, the metal sliding panels shield generates on the rear glass a surface temperature lower than the heat-reflecting shield.

On sunny days, however, the performance is similar to the reflective shield. This difference is determined by the metal shield overheating, caused by the direct solar radiation that re-emits heat to the glass, increasing the surface temperature.

The heat-reflecting shield has the tendency to not overheat under the direct solar radiation, because of its very low surface mass and its intrinsic thermal properties.

This shows that under clear sky conditions, the heat reflective shield has a similar performance compared to the sliding panel, with the advantage of a high transparency to visible light.

4 Conclusions

This thesis has provided a detailed analysis of the thermal and lighting behavior of solar shading both heat reflective and semitransparent. This objective has been achieved by means of testing applications on real buildings, and in a climatic room, as well through numerical simulations to extend the results. The experimental activities, such as analytical, have demonstrated and confirmed that the solar screens have poor performance when installed on the internal side of the window because of the heat generated by the greenhouse effect. During the summer, the best performance is achieved when we have solar shields installed on the external side of the window. In this case, the heat-reflecting shield performs, overall, better than any other, particularly when we consider all the aspects of energy and comfort, both thermal and visual. Even during the winter, the shield under analysis has the best thermal performance compared to other types of shields. The numerical analysis has confirmed that the nocturnal behavior of the shield is the best solution during the winter, because they provide maximum optimization of the daily heat contributions through the window.

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