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Design to Thrive

Buildings with large glazed surfaces: optimization of solar control strategies in relation to the building's thermal inertia

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Abstract: Many temperate climates, like most of the Italians, are characterized by considerable daily temperature ranges. In these cases, the thermal inertia of the building structure has a significant influence on the management of solar and internal heat gains, then on energy demand for HVAC, especially during the cooling period. Winter and summer requirements regarding the thermal inertia may conflict with each other, particularly when the use of the building is discontinuous, as in the case of offices. A lower thermal inertia may allow a more rapid heating in the morning and lower nocturnal losses during the winter days, whereas a higher inertia may allow a better exploitation of night free cooling in the cooling period. In this study, a typical office room has been studied by means of computer simulations. The only external wall of the room faces south and is entirely glazed; therefore it requires some device for solar control to avoid glare phenomena and excessive solar gains, resulting in overeating and high cooling loads. Relatively to this room, the combined effects of some different solar control strategies and three different constructive technologies have been explored. They were used weather data of Gorizia, in the North East of Italy

Keywords: Solar Control, Energy Saving, Comfort

Introduction

Many temperate climates, as most of the Italians, are characterized by considerable daily temperature ranges. In these cases, the thermal inertia of the building elements has a significant influence over the management of solar and internal heat gains, then on energy demand for heating, ventilation and air conditioning (HVAC), especially in the cooling period. Winter and summer requirements regarding the thermal inertia may be in conflict with each other, particularly when the use of the building is discontinuous, as in the case of offices. A lower thermal inertia may allow a more rapid heating in the morning and lower nocturnal losses in the winter, while a higher inertia may allow a better exploitation of night free cooling during the cooling period. However, the possible energy savings due to inertia depends on the energy balance of the building as a whole, in particular by its heat gains.

In this work, a case study has been analysed. It consists in a typical office room of medium size located in a typical office building. Its only external wall faces south and is entirely glazed; therefore it requires some device for solar control. In reference to this room, the combined effects of some different solar control strategies and three constructive technologies have been explored by means of computer simulations, focusing on their impact on global comfort conditions and energy demand. The simulations were related to the temperate climate of Gorizia, in the North East of Italy, which presents both the need for winter heating and summer cooling. In both seasons there are not negligible daily temperature ranges.

The case study

The case study consists in an office room of medium size: 5.88 m wide along the façade, 6.18 m deep orthogonal to it, and with internal height equal to 3.27 m (Figure 1,a). The only external wall of the room is one of the shortest, it faces south and is entirely glazed. All the other five internal enclosing surfaces are considered as adiabatic.

To avoid excessive internal gains in order to be able to study the behaviour of the room even in the presence of positive thermal loads, i.e. under heating operation mode, it is assumed the presence of only two occupants with related equipment. Then the internal gains of the room are constituted by: sensible and latent thermal flows from occupants (2 people · 65 W of sensible thermal power and 65 W latent), office devices (2 computers and 1 printer for a time averaged total power equal to 150 W) and fluorescent lamps (luminous efficacy: 91 lm/W, maximum total power: 732 W). The lighting plant is divided in two zones along two bands parallel to the glazed wall and dimmers control the power of the lamps. To study the thermal and lighting comfort they are considered four possible positions of the occupants at different distances from the glazed surface.

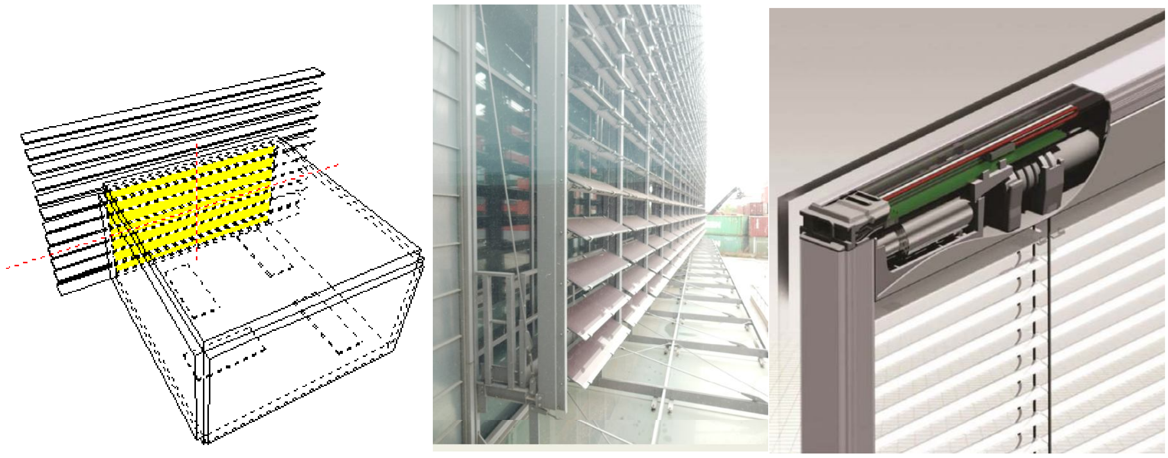

Figure 1. (a) Geometrical model of the studied room, with external slats and workplaces. (b) Sample of external slats (courtesy of Zintek S.r.l.). (c) Slats inserted between glasses (courtesy of Pellini S.p.A.).

To calculate the primary energy demand related to HVAC, it is assumed that the room is equipped with a full air centralized loop, and the daily time of utilization is from 08:00 to 19:00, but the plant is activated at 7:00. Although it is not the best efficient solution, it is assumed that the warm fluid is provided by a gas-boiler and the cold fluid by an electrically driven chiller. Internal set-point air temperatures are assumed to be 20 °C in winter and 26°C in summer (as prescribed by the Italian law), while in midseason it is assumed equal to the average daytime external temperature, since the clothing of the occupants is adapted to it. The relative humidity set-point is assumed equal to 50% all over the year. As a first step, in this work the internal air temperature is used as indoor environment control parameter, but it would be interesting and more appropriate to use the operative temperature (t_o) or the Predicted Mean Vote (PMV) (Fanger, 1970). Although devices controlling t_o or PMV are not actually diffused, this kind of control can be performed by the occupants when the manual adjustment of HVAC terminals is available.

Building technologies

The following constructive technologies were simulated.

a) Heavy structure in reinforced concrete. Internal walls are in hollow bricks 0.08 m thick, with 0.02 m thick plaster layer on both the sides. The horizontal elements are reinforced concrete and hollow tiles mixed floors: 0.24 m is the construction thickness, plus 0.06 m of screed and flooring, 0.02 m of plaster in the lower part.

b) Light steel structure, the horizontal elements are constituted by a corrugated metal sheet, to which are superimposed a wooden layer and a suspended floor. Suspended ceilings are present. Internal partition are light panels, made of rock wool and plaster, or glass walls.

c) As often happens, the office can be located in a renovated old building with heavy structure, like that of the previous case 'a'. In these cases the old partitions are replaced by light dividing elements, as those of the previous case 'b', while suspended floors are superimposed to the existing ones and suspended ceilings are added, even with sound-adsorbing characteristics.

In all the cases The only external surface of the room is the glazed one, composed by a double glazing of 0.006 m glass layers, and a 0.012 m air gap (overall U value: 2 $W{\cdot}m^{-2}{\cdot}K^{-1}$). Only in the case of slats inserted between the two glasses the air gap is 0.021 m thick.

The examined solar control devices and their control logics

The following devices were examined.

1. Only an internal diffusing screen (a roller blind) with reflection coefficient equal to 0.5 and coefficient of transparency equal to 0.4. Unless otherwise specified, all these coefficients are taken here with the same value both in relation to the entire solar spectrum and to the visible range. The infrared radiation (IR) re-emitted from the screen, as well as from any other surface, is calculated separately as a function of the temperature and emissivity. The screen can be lowered either to limit the solar gain than to avoid glare phenomena.
2. Movable external slats in metal (Figure 1,b). The vertical distance between slats (0.5 m) is equal to their depth. Slats surfaces are diffusing and their total reflection coefficient is equal to 0.6 in both the sides. Slats are controlled by a seasonal logic, which means: at any time the slats are inclined at an angle that allows the entry of the only amount of solar energy that can contribute to cover the sensible thermal load, avoiding overheating. In any case, the incoming solar radiation should not be less than that required for the daylighting, ensuring a minimum illuminance value in the most critical workplace (i.e. 500 lx according to Italian standard UNI 10380). To prevent glare phenomena two different strategies were analyzed. The first is based only on the use of the slats, whose slope can be further increased in order to eliminate glare, even at the cost of sacrificing the daylighting. In the second case an internal roller blind is used. Its reflection coefficient is equal to 0.4 and its transparency coefficient is equal to 0.5. When the blind is lowered, if interior illuminance is insufficient, the slats can be reopened.
3. Small slats in metal (Aluminum) located between the glasses (Figure 1,c). Only in this case the distance between the two glasses is 27 mm, the vertical distance between slats is 12 mm, their depth is 16 mm and their thickness is 0.2 mm. Slats surfaces are diffusing with reflection coefficient for both sides equal to 0.7 in the

total solar spectrum and 0.78 in the visible range. These slats are packable, apart from that their control logics are the same as used for the external slats.

The software

The computer simulations were performed using the software *Ener_Lux*, previously presented in PLEA Congresses (Carbonari, 2012). This software, is mainly aimed at the study of solar control devices and related operating strategies, therefore it takes into consideration the physical system composed by a room, its glazed surfaces, internal and external solar control devices as well as the surrounding urban environment.

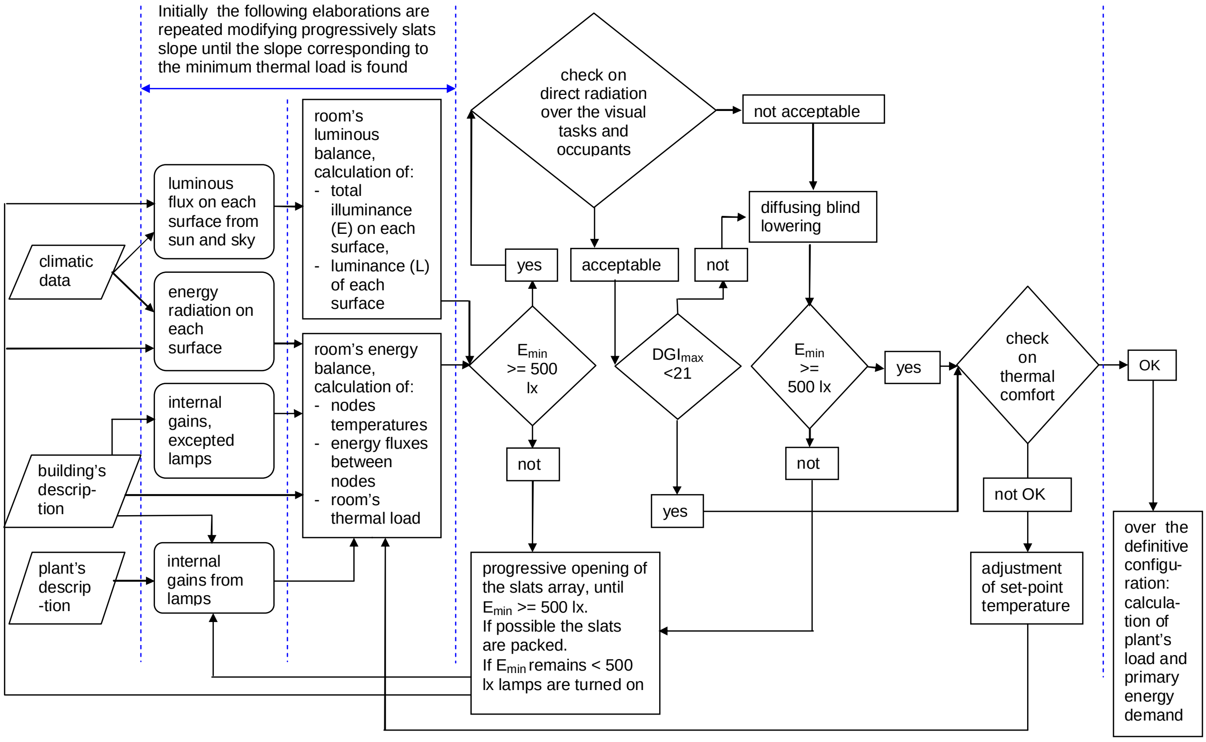

Figure 2. Scheme of the *Ener_Lux* calculation flow. The block diagram shows the behavior of the program when referring to a slat array combined with an internal screen.

Once defined the kind of device and its control logic, the program simulates the dynamic thermal and luminous behaviour of the physical system at hourly time-steps, and provides: Predicted Mean Vote (PMV), Predicted Percentage of Dissatisfied (PPD) (Fanger, 1970) and Daylighting Glare Index (DGI) values (Hopkinson et al, 1963), together with other information about the visual environment quality. Then it calculates sensible and latent room's thermal loads and the primary energy demand for HVAC and artificial lighting. All control actions aimed at maintaining comfort and energy saving are automatically simulated (Figure 2). To perform room's energy balance the program use an algorithm based on the heat balance of elementary zones (e.g. a single layer of a wall or a glass): a thermal grid model. The indexes used for the assessment of the visual comfort are calculated by means of an algorithm simulating occupants' visual field. For each position the worst line of sight was considered: i.e. the one implying the major difference of the luminance values within the visual field. Thus, the glazed surface must be present in the visual field, but it is empirically assumed that should not occupy more than half of it; otherwise the occupant's eyes adapt themselves to the luminance of the glazed surface.

Analysis of the results

The solar control strategies were compared from two points of view: room's total primary energy demand, thermal and visual comfort.

Energy performance

The room under investigation is characterized by relevant internal and solar gains. For this reason the cooling loads are dominant in the composition of its total primary energy demand. In facts, with the exception of the early morning hours in the coldest period, the thermal loads are always negative.

Effectiveness of the various solar control strategies.
The less convenient strategy is clearly the one based only on the use of the internal screen, because of the significantly higher solar gains and the consequent costs for cooling. For example: with light structure its total energy demand is greater than 38% compared to that of the external slats used alone, and 44% compared to that of the slats inserted between the glasses combined with the screen. This strategy can be a feasible solution only in colder climates. All the strategies based on the use of the slats are sensibly less consuming.

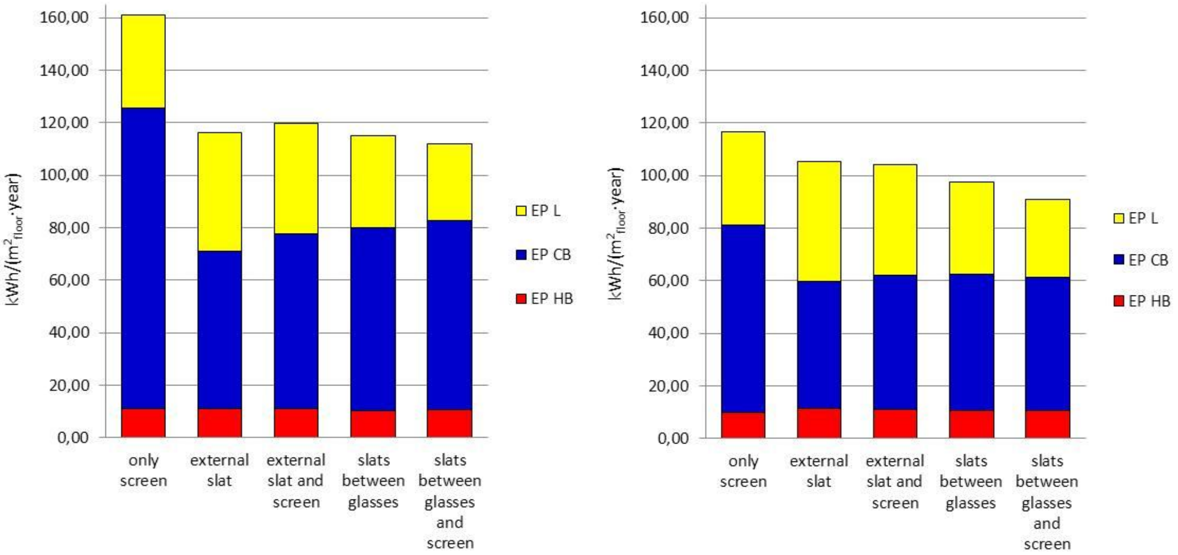

Figure 3. Annual primary energy demand (per square meter of floor area) for lighting plant (EP L), hot battery (EP HB) and cold battery (EP CB) of HVAC plant. With light structure (left) and heavy structure (right).

Total primary energy demand depends on the combined effects of the criteria adopted for the control of the thermal and visual comfort. In fact, in the case study, the heat flux emitted by the lamps almost always increases the cooling loads. In general, the use of the slats between glasses implies lower consumption for artificial lighting, because of their greater reflection coefficient. This savings occurs particularly in winter and in general in the hours with reduced solar radiation. For against this type of slats causes higher temperatures of the inner glass, therefore a greater heat transmission towards the interior with consequent higher cooling loads. Combining the two effects, the slats placed between the glasses result in a total annual consumption slightly lower than the external ones, and their advantage is due to lower consumption for lighting (Figure 3). Of course, things would change with a less deep room or with a different lighting plant, based on individual lamps.

When, in addition to the slats, it is provided the use of the inner screen to avoid glare, this is mainly lowered in winter and in some morning and evening hours of the other periods, that is to say: when the sun paths are lower. In these cases, the presence of the screen allows the slats to assume a smaller slope in order to improve the daylighting without causing glare. This reduces energy demand for lighting. In return, solar gains and the consequent cooling loads are greater, especially when the use of the screen is combined with that of the external slats. But in practice the two effects balance each other. In the other periods, with the exception of some morning and evening hours, the screen is not used. This is because the solar paths are higher, solar radiation is more intense and the slats intercept completely the direct radiation without affecting the daylighting.

Considering everything, the two strategies based on the use of external slats, with and without the internal screen, appear slightly less convenient than the other two, which are based on the use of the slats inserted between the glasses.

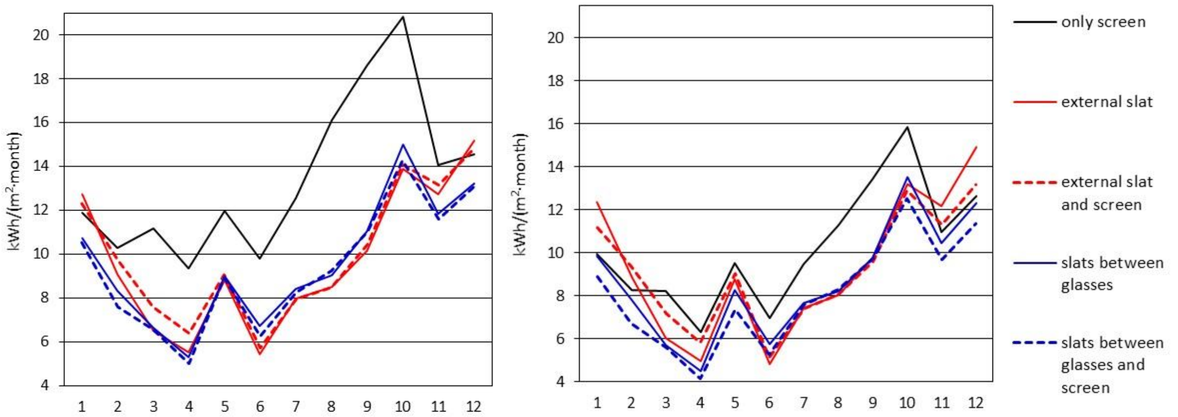

Figure 4. Monthly primary energy demand (per square meter of floor area) for HVAC and lighting plant with various strategies [kWh/(m$^2_{floor}$·month)]. Results related to light structure (left) and to heavy structure (right).

Effects of thermal inertia.

In general, the heavy structure always causes less consumptions than the light one, and the advantage is greater, around 28%, with the least effective solar control strategy: one based solely on the use of the inner screen. If it not used the inner screen, the annual energy savings due to higher inertia are 9% with external slats and 15% with slats between the glasses. With the combined use of the slats and the inner screen the saving becomes 13% and 19% respectively (Figure 3-4). These savings are always due to lower cooling loads: when the building elements have a greater inertia the internal surfaces of the room are heated more slowly by solar and internal gains, with the due consequences on comfort and thermal loads. The resulting configuration from the reuse of a heavy existing building has very similar performance to the new lightweight building. Evidently, the added cavities are sufficient to make irrelevant the masses of the lower and upper horizontal elements in room’s heat balance.

Thermal comfort

Using the internal air temperature as the indoor environment control parameter, the differences in the thermal comfort, obtainable with the various devices, are mainly influenced by the mean radiant temperature (MRT), and this parameter is in turn mainly affected by the temperature of the internal side of the glass wall. This quantity can be either the temperature of the internal glass than that of the screen, when it is lowered.

Comparing the different solar control strategies, the worst results, that is the higher values of PMV, are obtained with the inner curtain used alone, because of the high temperatures that it reaches when it is irradiated (Figure 5-6). Between the two types of slats, whose internal to the glasses in general maintain higher the temperature of the inner glass, therefore also the MRT and the PMV values are higher. However, when the screen is lowered it reaches higher temperatures than those of the inner glass, and this occurs more frequently with the external slats. When the screen is lowered, there are no relevant differences in the thermal comfort between the two types of slats (Figure 5).

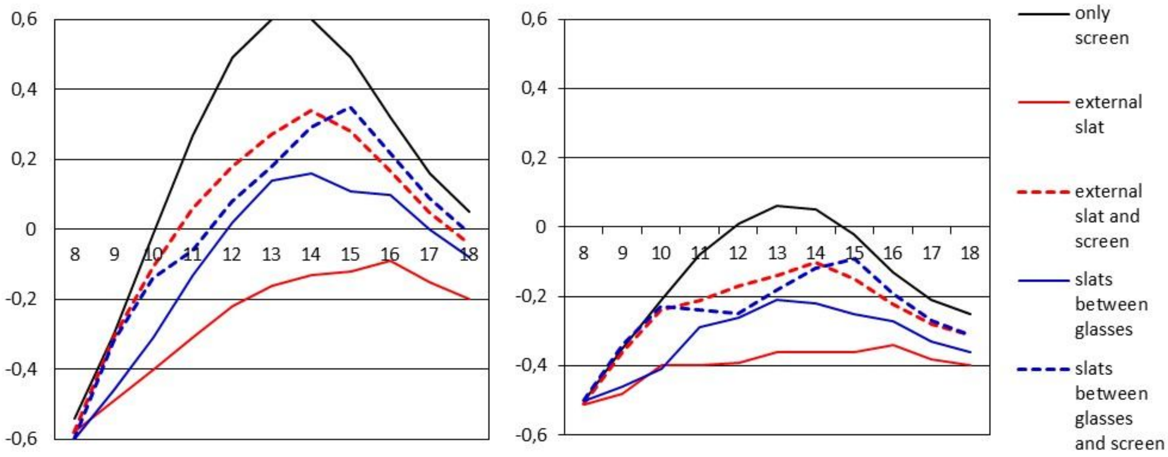

Figure 5. PMV values near the glazed wall on January 21, with light structure (left) and heavy structure (right).

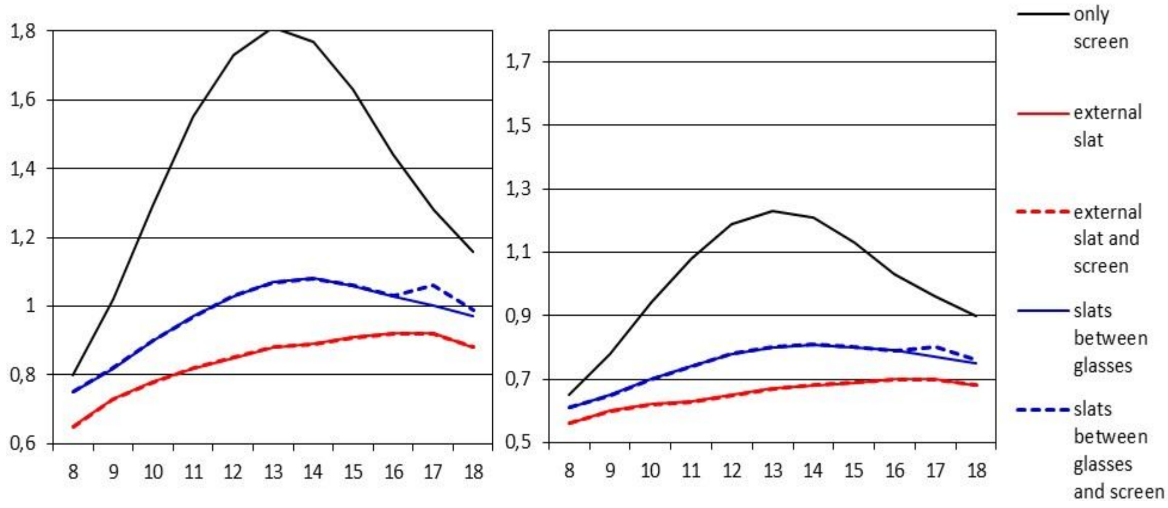

Figure 6. PMV values near the glazed wall on July 21, with light structure (left) and heavy structure (right).

Comparing the different constructive technologies, the heavy structure tends to maintain lower temperatures of the inner surfaces, including that of the glass. This occurs for most of the time, with the exception of the early morning hours in the coldest period. In this way, the differences between the MRT obtained with the various devices are attenuated, and the PMV assume values closer to those of comfort (Figure 5-6).

Luminous comfort

To assess the visual comfort they were considered mainly two types of glare: the disability glare due to solar direct radiation impinging on the visual tasks and the discomfort glare due to the presence of extended light sources in the visual field of the occupants, typically the sky seen through the glass wall. In the case study the first kind of glare occurs only with the configuration devoid of slats and in the positions nearer to the glass wall. This kind of glare can be connected with thermal discomfort too, because of the direct radiation impinging on the occupants. Even the worst values of DGI and uniformity of the illuminances are obtained with this configuration.

In presence of slats only the second type of glare occurs, it is assessed by the DGI, whose limit value is assumed equal to 21 according to Italian standard (UNI 10840). This kind of glare occurs more frequently with the use of external slats, in winter and in general in the hours characterized by a reduced radiation's intensity. In these periods, because of their lower reflection coefficient, the external slats assume a slope minor than that assumed by the slats between the glasses, consequently the visible sky is more extended and DGI value results to be higher. This requires control actions that can cause an excessive reduction of internal daylighting, then the use of artificial light. In the same periods the slats between the glasses provides a better uniformity of the illuminance values too.

In all other periods, there are no significant differences between the DGI values obtained with the two types of slats. In both the cases slats assume high slopes, totally intercepting the direct radiation, and luminous sky is not visible. However, in these periods, the daylighting source is constituted by the internal surfaces of the slats, which is brighter in the case of the slats inserted between the glasses; consequently, the DGI value may be slightly higher, however within the limits.

Conclusion

In the case study the solar control strategy based only on the internal screen results to be the less convenient from all point of view, because of the higher solar gains and the non-uniform internal distribution of the incoming solar radiation. While the slats inserted between the glasses imply higher solar gains and higher cooling loads for most of the time, the external ones result in higher consumption due to the lamps and related heat gains. Combining the two effects, the slats between the glasses present a slightly lower total annual primary energy demand, and their advantage is due to less use of the lamps.

When it is not used an internal screen to avoid glare the slats inserted between the glasses imply higher inner temperature of the glazed wall, then a lower thermal comfort for most of the time. Therefore, using an indoor environment control parameter different from the air temperature, as t_o or PMV, the primary energy demand for HVAC related to this device would be higher. In the winter and in general in the hours characterized by a reduced radiation's intensity the slats between glasses allow a better visual comfort.

With all the examined devices, the greater thermal inertia reduces the energy demand for HVAC. Also the thermal comfort improves with the increase of thermal inertia.

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