Abstract: Many temperate climates, like most Italian ones, are characterized by considerable daily temperature ranges. In these cases, the thermal inertia of the building has a significant influence on the management of solar and internal heat gains; then on the energy demand for HVAC, this is especially true in the cooling period.

Winter and summer requirements regarding thermal inertia may be in conflict with each other, in particular when the use of the building is discontinuous, as in the case of offices. A lower thermal inertia can allow a more rapid heating in the morning and minor nocturnal losses during the winter, whereas a higher inertia may allow a slower daytime heating and a better exploitation of night free cooling during 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 the use of some device for solar control. Relatively to this room, the combined effects of some different solar control strategies and three constructive technologies, characterized by different thermal inertia, have been explored. A first strategy is based only on the use of an internal reflecting and diffusing screen, a second on the use of external movable slats, a third on the use of small slats inserted between the glasses. Strategies based on the two types of slats can be integrated with the use of an internal diffusing screen. Computer simulations were performed using a software that allows simultaneous analysis of energy and comfort issues, automatically taking into account any control action aimed at maintaining the thermal and luminous comfort. They were used climatic data of Gorizia, in the North East of Italy.

Simulations results show that the thermal inertia has a great influence on energy demand and on thermal comfort. The strategy based only on the inner screen is the least advantageous from all points of view. Between the two types of slats, the external ones allow a better thermal comfort, while the others provide a better visual comfort.

Keywords: Solar Control, Energy Saving, Comfort
1. INTRODUCTION

Many temperate climates, like most Italian ones, 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 the 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, in particular when the use of the building is discontinuous, as in the case of offices. Lower thermal inertia can enable a more rapid heating in the morning and lower nocturnal losses during the winter, while a higher inertia may allow a slower daytime heating and a better exploitation of night free cooling during the cooling period. However, the possible energy savings due to inertia depend on the energy balance of the building as a whole, in particular by its heat gains.

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, by a double glazing; therefore it requires some devices for solar control. Relatively to this room, the combined effects of some different solar control strategies and three constructive technologies have been explored. A first strategy is based only on the use of an internal diffusing screen, a second on the use of external movable slats, a third on the use of small slats located between the two glasses. Strategies based on the two types of slats can be integrated with the use of an internal diffusing screen. The different building technologies are characterized by a different weight of elements, therefore by a different thermal inertia. In the first case it is assumed that the room is located in a building with reinforced concrete structure, in the second case in a new building with light steel structure, in the third case it is hypothesized the reuse of a building with heavy structure.

Computer simulations have been performed using the Ener_Lux software, that allows simultaneous analysis of energy and comfort issues, taking into account automatically any control action aimed at maintaining thermal and visual comfort. In any examined case, the control logic of the solar control devices is aimed to ensure both the thermal and luminous comfort inside the room. Simulations are related to the temperate climate of Gorizia, in the northeast of Italy, which requires both winter heating and summer cooling, in both the cases there are no negligible daily temperature ranges.

2. 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, with internal height equal to 3.27 m. The only external wall of the room is one of the shortest, it faces south and it is entirely glazed. All the other five internal enclosing surfaces are considered as adiabatic. In this study the shading effect of surrounding buildings has not been taken into account (Figure 1).

![Figure 1: The office building with external slats array and the geometric model of the examined room](image)

To avoid excessive internal gains and to study the behaviour of the system even with positive loads, i.e. under heating operation mode, it is hypothesized the presence of only two occupants with related equipment. Therefore the internal gains of the room consist of sensible and latent heat 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 average total power equal to 150 W) and fluorescent lamps (luminous efficacy: 91 lm/W, maximum total power: 732 W). The lighting plant is divided into two zones along two bands parallel to the glazed wall and dimmers control the power of the lamps. Adopting these measures, the annual saving in lighting energy consumption, compared to a park lamps undivided and controlled according to the on/off logic, is 32%. However, if we consider the effects of internal gains
from lighting on consumption for HVAC, the total saving is 53%. This in the case of the room with light structure and equipped only with external slats. Although this configuration of lighting plant is not very widespread, it was considered appropriate to foresee some form of localized lighting control; otherwise, the ignition of the entire park lamps with fixed power, due to a small lack of illuminance in one of the workstations, alters heavily the energy balance of the room. To study the thermal and lighting comfort, four possible occupants’ positions at different distances from the glazed surface were considered.

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 07:00. 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 (vapor compression chiller). Since these are the solutions currently most widespread in Italy. Internal set-point air temperatures are assumed to be 20 °C in winter and 26°C in summer (as prescribed by the Italian law), whereas in half-seasons 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.

Normally the control systems of HVAC plants assume the indoor air temperature as an indoor environment control parameter, but, in order to study optimal thermal comfort conditions, it’s interesting and appropriate to simulate the use of other parameters, such as the operating temperature ($t_{op}$) or the average Predicted Mean Vote (PMV) value between the various working places (Fanger, 1970). Although automatic indoor environment control systems based on these parameters are not currently available, it can be assumed that this kind of control, in particular that based on PMV, is performed by the occupants when the manual adjustment of HVAC terminals is available. Therefore, in this work, the indoor air temperature was taken as a reference indoor environment control parameter, but the effects of the use of other parameters, i.e. $t_{op}$ and PMV, were explored.

2.1. Building technologies

To explore the influence of thermal inertia on global comfort conditions and energy demand the following building technologies have been 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 sides. The horizontal structural elements are reinforced concrete and hollow tiles mixed floors: 0.24 m is the construction thickness, plus 0.06 m of screed and flooring and 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 a wooden layer and a wooden suspended floor are superimposed. There are suspended ceilings. Internal partitions are light panels, made of rock wool and plasterboard, and glass walls.

C. Hybrid structure. As often happens the office room can be located in a renovated old building with heavy structure, like that of the previous case “A”. In these cases, the internal distribution is changed, and the old partitions are replaced by light dividing elements, like these of the case “B”, while suspended floors are superimposed to the existing slabs and suspended ceilings are added, even with sound-adsorbing features.

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 m⁻² K⁻¹). Only in the case of slats internal to the glasses the air gap is 0.027 m thick.

2.2. The Solar Control Devices and their Control Logics

The following solar control devices and related control logics have been examined and compared in reference to the office room.

A. Only an internal diffusing screen (a roller blind) with reflection coefficient equal to 0.5 and transparency coefficient equal to 0.4. Unless otherwise specified, all these coefficients are taken here with the same value both in relation to the total 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 its temperature and its emissivity. The screen can be lowered either to limit the solar gain or to avoid glare phenomena.

B. Movable external slats in metal. The vertical distance between slats (0.5 m) is equal to their depth (orthogonal to the façade when the slat is horizontal). Slats surfaces are diffusing and their total reflection coefficient is equal to 0.6 in both the sides, it would not be realistic to assume a higher value in a normal urban context. Slats are controlled by a seasonal logic, which means: in each moment, 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 cannot be lower 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 strategies have been analyzed. The first is based on the use of the slats alone, 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. In all cases, if the daylighting is insufficient, lamps are turned on.

C. Small slats in metal (Aluminum) located between the glasses. Only in this case the distance between the glasses is 27 mm. The vertical distance between the slats is 12 mm, their depth is 16 mm and their thickness is 0.2 mm. Surfaces are diffusing with coefficient of reflection for both the sides equal to 0.7 in the total solar spectrum and 0.78 in the visible range. These slats are packable, apart from that the control logics are the same as used for the external slats.

3. THE SOFTWARE

This work has been carried out by means of computer simulations, using software *Ener_Lux*. This software (Carbonari, 2012) is mainly aimed at the study of solar control devices and related operating strategies. It allows simultaneous analysis of energy aspects and those related to the thermal and luminous comfort. Therefore it takes into consideration the physical system composed by a room, its glazed surface, internal and external solar control devices (slats, blinds, overhangs and any element shading the opening) as well as the surrounding urban environment, including the building containing the room under investigation.

Once defined the kind of devices and their 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) (Hopkinson et al., 1963) values, together with other information about the visual environment quality. Then it calculates sensible and latent room’s thermal loads and the energy demand for HVAC and artificial lighting. To perform room’s energy balance the program use an algorithm based on heat balance of elementary zones (e.g. a single layer of a wall or a glass): a thermal grid model.

When adjustable devices are simulated, all the solar control actions aimed to maintain thermal and luminous comfort, such as slats tilting or screen lowering, are automatically simulated: in such cases, the program modifies the system’s geometric configuration and repeats the simulation of the hourly time-step. The check against visual discomfort conditions is performed only when the lamps are turned off (Figure 3).

The indexes used for the assessment of the visual comfort are calculated by means of an algorithm simulating, in a simplified manner, occupants’ visual field (Figure 4). Different kinds of glare are considered: disability glare due to direct radiation impinging on the visual task, big differences of luminance values between different points in the visual field, and discomfort glare due to large luminous sources (typically the sky seen through the windows) that is evaluated by DGI calculation. When one of these kinds of discomfort is detected, the program simulates a solar control action.

The program allows the use of different indoor environment control parameters: not only air temperature but also operative temperature ($t_o$) and PMV.
Figure 3: Scheme of the Ener_Lux calculation flow. The figure shows the behavior of the program when referring to a slat array combined with an internal screen.

Figure 4: Examples of simplified simulations of occupants’ visual field in different workplaces.

4. ANALYSIS OF THE RESULTS

The solar control strategies have been compared from different points of view: room’s total primary energy demand, thermal and visual comfort. Therefore, the thermal flows provided to the room by the plant, are converted into primary energy as a function of current value of boiler efficiency, chiller coefficient of performance (COP), and global system efficiency. The electric energy absorbed by the HVAC system as well as by lighting system is converted into primary energy by means of the Italian electric system efficiency (equal to 36%).

4.1. 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 first hours at some winter mornings, the thermal load is always negative (Figure 5). This thing is evident in the trend of monthly energy demand for HVAC (Figure 6), which is strongly influenced by outdoor temperatures, and has the
higher values in autumn (with a maximum in October). The maximum in October is due to the combined effect of external air temperature, higher than in spring, and reduced daylighting. The strange peak that can be observed in May is due to the previously illustrated criterion used for the selection of the set-point air temperatures in half-seasons. This criterion can be improved.

Certainly this situation would change by adopting a different lighting system, based mainly on individual lamps located at each workplace (the related power can be reduced from 732 W to 320 W), but the lighting system simulated is currently the most widespread in Italian office buildings.

Effectiveness of the various solar control strategies

The less convenient strategy is clearly the one based on using only the internal screen, because of the significantly higher solar gains and the consequent costs for cooling. For example: with lightweight structure the total energy demand obtained with it is more than 38% higher than the one obtained with the strategy based on external slats used alone, and more than 44% higher than that related to the slats inserted between the glasses combined with the inner diffuser. 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, in particular those using the slats between the glasses (Figure 6). Total primary energy demand depend on the combined effects of the criteria adopted for the control of the thermal and visual comfort, since in the case study the heat flow emitted by the
lamps almost always increase the plants loads. In general, the use of the slats between the glasses implies lower consumption for artificial lighting, because of their greater coefficient of reflection. This saving occurs especially in winter and generally in hours with low solar radiation. For against this type of slats entails a higher temperatures of the inner glass, therefore a greater heat transmission towards the interior, higher solar gain and higher cooling loads. Combining the two effects, the slats inserted 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. Of course, things would change with a less deep room or with a different park lamp, based on individual lamps.

Comparing the two planned strategies to prevent glare the following can be observed. When it is foreseen the use of an internal screen, it is lowered mainly in the winter and in some morning and evening hours of the other periods. That is to say: when the sun paths are lower and slats do not intercept direct radiation to consent daylighting. In these cases, the incoming solar radiation is greater than that request from energy balance, and heat the screen. Then this strategy leads higher cooling loads compared to the other strategy, based only on the further inclination of the slats, especially in the case of external slats. In return, in the same periods the use of the screen reduces energy demand for lighting, because it allows a smaller slope of the slats, thus a greater incoming luminous flux. However, 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 sun’s paths are higher, solar radiation is more intense and the slats can intercept completely the direct radiation without affecting the daylighting.

Considering all 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 6, 7).

**Effects of thermal inertia**

Unlike what usually is believed, regarding the spaces used discontinuously, in the case study the thermal inertia reduces the energy demand (Figure 6, 7). This saving is due to the dominance of cooling loads. In fact a lower inertia would be useful only to obtain a more rapid morning heating in a restricted period of winter, throughout the rest of the year the nocturnal cooling of the masses is useful to reduce the cooling loads. When the building elements have greater inertia, the internal surfaces of the room are heated more slowly during the time of use, with all the positive consequences on comfort and thermal loads.

![Figure 7: 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 various strategies [kWh/(m² floor∙month)]. Results related to light structure (left) and to heavy structure (right)](image)

The advantage of the heavy structure is particularly evident, with an annual saving of about 28%, in the case of the less advantageous solar control strategy: the one based on the use of the only internal screen. The annual energy saving due to increased inertia is 9% with external slats and 15% with slats between the glasses, when both are used without the inner screen. With the combined use of slats and internal screen the savings became 13% and 18% respectively.

The configuration resulting from the reuse of an existing heavy 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 floors in room’s heat balance.
Effects of different indoor environment control parameters

Using the others internal environment control parameters, different from air temperature, the energy demand for lighting remains substantially unaltered, while the one for HVAC increase but not too much. The biggest increases in total annual primary energy demand, respect to that obtained controlling the inner air temperature, are understandably found with the strategy based on the inner screen alone. Using e.g. the control on spatially averaged PMV value, the increase is 22% with the light structure and 23% with the heavy one. Using the same control parameter, in the room with light structure and solar control strategy based only on the external slats the total annual primary energy demand rises by 10%. With the same structure and slats between the glasses, always used alone, the increase is 11.5%. In this way the advantage of the second type of device compared to the first is reduced from 2.4% to 1.1% (Figure 8). With the heavy structure, which, as see above, results in lower cooling consumption, the total annual primary energy demand related to the external slats rises by 7%, while the one related to the slats between the glasses rises by 10%. The advantage of the second type of device compared to the first is reduced from 8% to 6%. In general, with all the simulated internal environment control parameters, the slats between the glasses retain their advantage due to lower consumption for artificial lighting.

![Figure 8: Effects of adopting different indoor environment control parameters on total primary energy demand for HVAC and lighting plant [kWh/(m² * month)]. Results related to room with light structure, with external slats (left) and slats between the glasses (right), in both cases without the use of the internal screen.](image1)

4.2. Thermal comfort

If the indoor air temperature is used as the indoor environment control parameter, the differences in thermal comfort, obtainable with the various devices, are mainly influenced by the mean radiant temperature (MRT), and this parameter is in turn affected by the temperature of the internal side of the glazed wall. This quantity can be either the temperature of the internal glass than that of the screen, when it is lowered. The differences in the PMV value between the various workstations are greater as the inner temperature of the glazed wall differs from that of the other interior surfaces.

![Figure 9: PMV values near the glazed wall on January 21, with light structure (left) and heavy structure (right).](image2)

Comparing the different solar control strategies, the worst results, that is the higher values of PMV and the lower values of its spatial uniformity, are obtained with the inner curtain used alone, because of the high temperatures that it reaches when it is irradiated, i.e. over 33 °C in July (Figure 9,10). Between the two types of slats, whose internal to the glasses in general maintain higher the temperature of the inner glass, therefore the MRT and the
PMV are higher, even the spatial disparity of PMV values is greater (Figure 1). However, when the screen is lowered it is irradiated and reaches higher temperatures than those of the inner glass, and this, as seen before, occurs more frequently with the external slats. In this case there are no remarkable differences between PMV values obtained with the two types of slats.

Comparing the different constructive technologies, the heavy structure tends to keep the temperatures of the inner surfaces lower, including that of the glass. This occurs for most of the time, except that in the early hours of the morning in the coldest period. In this way, the PMV assume values closer to those of comfort and the differences between the MRT obtained with the various devices are attenuated. However, the spatial differences between PMV values increase when the temperature of the inner surface of the glass is higher.

4.3. Luminous comfort

To evaluate visual comfort they have been considered mainly two types of glare: that due to solar direct radiation impinging on visual tasks (that is a kind of disability glare) and that due to the presence of extended light sources in the visual field of the occupants (a kind of discomfort glare). In this case the extended light sources is the sky seen through the glass wall. This last kind of glare is evaluated by the DGI index, the limit value of which is assumed equal to 21, according to Italian standard (UNI 10840). It is also calculated the uniformity factor of the illuminance within the room (CU), which is defined as the ratio between the minimum and the average values of illuminance on visual tasks. To calculate the DGI value, for each position the worst line of sight is considered, i.e. the one implying the greatest difference in luminance within the visual field. Thus, the glazed surface must be present in it, but it is empirically assumed that it cannot occupy more than half the visual field; otherwise the occupant’s eyes adapt themselves to the luminance of the external landscape.

In the case study, the first kind of glare occurs only with the configuration devoid of slats and in the workplaces 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 value of DGI and CU are obtained with this configuration.
In presence of slats only the second kind of glare, due to extended light sources, can occurs, and this happens more frequently with external slats, in the 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 is higher. This requires control actions that can imply a reduction of internal illuminance, then the use of artificial light. In the same periods the slats between the glasses provides better CU values too.

In the other periods, excluding some morning and evening hours, not are remarkable differences between the DGI values obtained with the two types of slats. In both cases, slats assume high slopes to fully intercept the direct radiation, so the bright sky is not visible. In these periods, the main daylighting source is constituted by the internal slats surfaces, which is brighter in the case of slats between the glasses; consequently, with this kind of slats the DGI value may be slightly higher, however within the limits (Figure 12).

![Graph](image.png)

*Figure 12: DGI values in a workplace near the glazed wall with different devices, on December 21 (left) and July 21 (right). Values are calculated after the control of solar gain and before the actions finalized to avoid glare.*

5. CONCLUSION

In the case study, the solar control strategy based on the inner screen alone is the less convenient from all points of view, because of the higher solar gains and less uniform distribution of incoming radiation on the internal surfaces. There are not large differences in total energy demand between the two types of slats studied. While the slats inserted between the glasses imply higher solar gains, then higher cooling loads, for most of the time, the external ones imply minor internal illuminance values, thus greater energy consumption due to the lamps and related heat gains. Combining the two effects, the slats between the glasses entail a slightly lower total annual primary energy demand, and their advantage is due to less use of the lighting plant.

In general the slats inserted between the glasses imply higher temperature of the inner glass, therefore, if it is not used an internal screen to avoid glare, this type of device results in lower thermal comfort for most of the time. The use of the PMV, instead of indoor air temperature, as an indoor environment control parameter, implies higher cooling loads, then higher energy consumption for HVAC. However, the increase of total primary energy demand is considerable (up to 23%) only in the case of the strategy based on the inner screen alone. With all the other strategies, this increase is within 12%, and there are not significant differences between the two types of slats. The slats between the glasses maintain their small advantage, even if slightly reduced. In the winter, and in general in the hours characterized by a reduced radiation’s intensity, like some morning and evening hours, the slats between the glasses allows a better visual comfort.

Contrary to what is usually believed about the spaces used in a discontinuous manner, in the case study with all the examined solar control strategies, a greater thermal inertia reduces the energy demand for HVAC. This is due to the dominance of the cooling loads. Even thermal comfort improves with increasing inertia.

6. REFERENCES

