EFFECTS OF LOUVERS SHADING DEVICES ON VISUAL COMFORT AND ENERGY DEMAND OF AN OFFICE BUILDING. A CASE OF STUDY

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SUMMARY.

Life quality of building users is based on some factors: hygrothermal comfort, visual comfort, noise, vibration, ergonomics and indoor air quality. Daylight contributes to indoor visual comfort, enhances user satisfaction and productivity, and explains partially that, in office buildings, the use of glass in the facades has increased in the last few years, even in buildings placed in Mediterranean cities where solar gains through windows contribute largely to glare, thermal discomfort and, consequently, excessive energy consumption.

This paper evaluates the building energy demand and visual comfort of a real case with a glazed façade office building placed in Málaga (Mediterranean city in the south of Spain). South oriented facades receive such a high solar gain that cooling demand cannot be handled by the current HVAC system. As an environmental friendly solution, a shading control strategy based on vertical and horizontal louvers is proposed.

The study consists of a comparison between the actual and the refurbished building with shading devices. Daylighting simulation is done with Daysim (Daysim, 2016). A group of offices with south, east and north oriented facades is chosen for the study. Horizontal louvers in the south façade and vertical louvers in the east facade are modelled and simulated. The simulation changes the angle of the louver: 0º (perpendicular to the glazing), -30º, 30º, -60º, 60º. Visual comfort parameters analyzed are: illuminance, daylight autonomy (DA) and useful daylight index (UDI). With respect to the thermal comfort, not only louvers orientation try to provide solar protection for glazed areas in cooling period but also maximize solar gains in heating period. However, an excessive daylight could affect discomfort glare. Shading control strategy must provide the equilibrium between both aspects. Thermal demand is calculated with Trnsys (TRNSYS, 2016).

In order to evaluate the importance of the louvers in the buildings, a sensitive analysis is performed. The building is simulated in different climates and with different glazings.

Finally, the results show the importance of the integration of louvers in the building reducing the cooling demand, especially in cities with a Mediterranean climate,

achieving an equilibrium between visual comfort, thermal demand and electric light consumption.

This research is an extension of the AIRZONE DOMO project, in which an intelligent control for shading devices, HVAC system and lighting is being designed in order to achieve high-energy savings and users building comfort.

Key words: daylight, visual comfort, control shading, energy demand.

1. INTRODUCTION

Energy efficiency and human comfort are the main priorities of the users in the building operation. In this sense, the coordinated performance of HVAC systems, shading devices and electric lighting, based on advanced control strategies, improve energy efficiency by minimizing heating and cooling loads, electric lighting consumption, and assuring visual and thermal users comfort.

The literature review about the effects of daylighting in buildings, the control shading strategies, the integration with HVAC and electric light control systems, etc., is very extended. In this case, the papers of interest analyzed deal with: the type of adequate shading device, the influence of simulation parameters (window to wall ratio (WWR), building orientation, glazing, etc.), the most used software for the simulations, and the results and conclusions of other cases of study.

Daylight regulation can be done with a great variety of shading devices (blinds, overhangs, venetian blinds, louvers, roller shades, etc.). Bellia (Bellia et al. 2014) and Kirimtat et al (Kirimtat et al. 2016) highlight the complexity of classifying the shading devices but suggest a simple classification based on its place in the building (external or internal) and if it is fixed or movable (manual or automatic). Meerbeek et al (Meerbeek et al. 2014) show the complexity of the interaction between an automation control of motorized exterior blinds with users in Dutch offices. Lee et al. (Lee et al. 1998) describe an experimental case of an office in Oakland (EEUU) with an automatic control of internal venetian blinds, achieving energy savings of 15% and 50% in cooling and electric lighting, respectively, with an optimal 45º slat angle.

The effects of shading devices in visual and thermal comfort depend on different parameters. Shen et al (Shen et al. 2012) investigate the balance between daylight and solar gain control in offices with internal blinds according to orientation and WWR. They obtaine optimal benefits in south orientation with a WWR of 30-50%. Datta (Datta 2001) shows how fixed and external horizontal louvers can reduce 70% the cooling demand in terms of an optimal design of louvers parameters: length, distance between louvers and the angle of the tilt. Tzempelikos (Tzempelikos et al. 2007) evaluates a manual control of a roller shade in an office building in Montreal, and study the influence of the glazing transmittance in daylighting.

The case of study proposed in this paper is an office building with a high glazing area in south and east façades. The building is located in Málaga, a city with a Mediterranean climate with a high number of sunlight per year. Users of the building complain about thermal disconfort during all year due to high solar gains. Therefore, a solution based on static shading devices to mitigate solar gains is analyzed. Horizontal louvers for south façade and vertical louvers for east façade are proposed. This louver configuration is recommended by the daylight guidelines (Schumann, 2013) provided by the Building Technologies, Department at the Lawrence Berkeley National Laboratory. North façade is not shaded because it receives very little direct solar gain.

There are different simulation tools used for analysing, designing and evaluating the daylight value, indoor thermal and visual comfort. Some programs are specific for daylight and other for the thermal analysis. The most used in the literature review for daylight are Radiance (Radiance, 2016), Evalglare (Evalglare, 2016) and Daysim, and for thermal analysis: EnergyPlus (EnergyPlus 2016) and Trnsys. The methodology followed in this paper is shown in Figure 1.

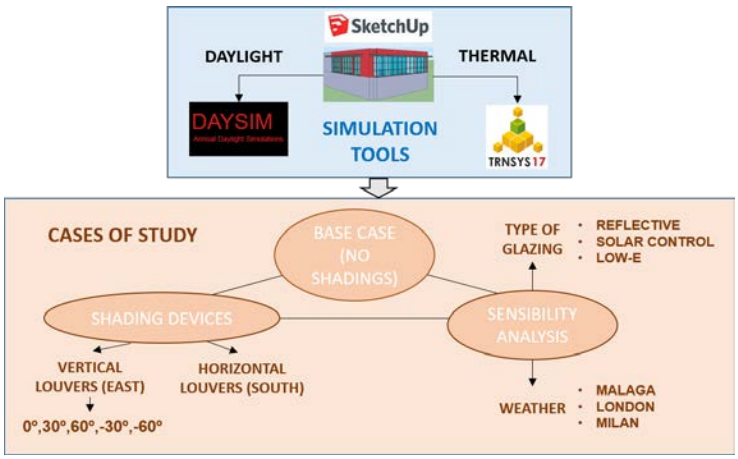


Figure 1– Shading control strategies.

Firstly, building geometry is modelling in GoogleSketchup used as interface to the simulation in Daysim and Trnsys. The cases of simulation are focused on a base case, in order to evaluate the situation and requirements of the actual building. Secondly, static shading louvers are added in south and east façades with different slat angles of the louvers. The aim is to evaluate the effect of different shading strategies in visual comfort parameters and heating and cooling demand.

After the first study comparing the building with shading devices, a sensitive analysis is proposed for getting a deeper analysis in terms of the influence of the type of glazing and weather.

In summary, this paper studies the benefits in visual and thermal comfort of installing appropriate shading devices in an office building with high cooling requirements due to a glass south and east facing. For that purpose, computational simulations are performed in dynamic conditions. The results of this paper are the preliminary work of a research based on the definition of an automatic shading control strategy in different buildings, which could be integrated with the HVAC control of Airzone.

2. CASE OF STUDY.

2.1. Description of the building.

The case of study is an office building called Málaga Bussiness Park located in Málaga, Spain (latitude 36.67N, longitude -4.49W). The studied offices are called Sports Offices with a total area of 360 m^2. Three thermal zones are considered, separated with glass walls between them. Exposed unshaded façades are oriented toward south (south zone), east (east zone) and north-west (central zone) with large window area so, a special consideration to control solar gain is required (see Figure 2).

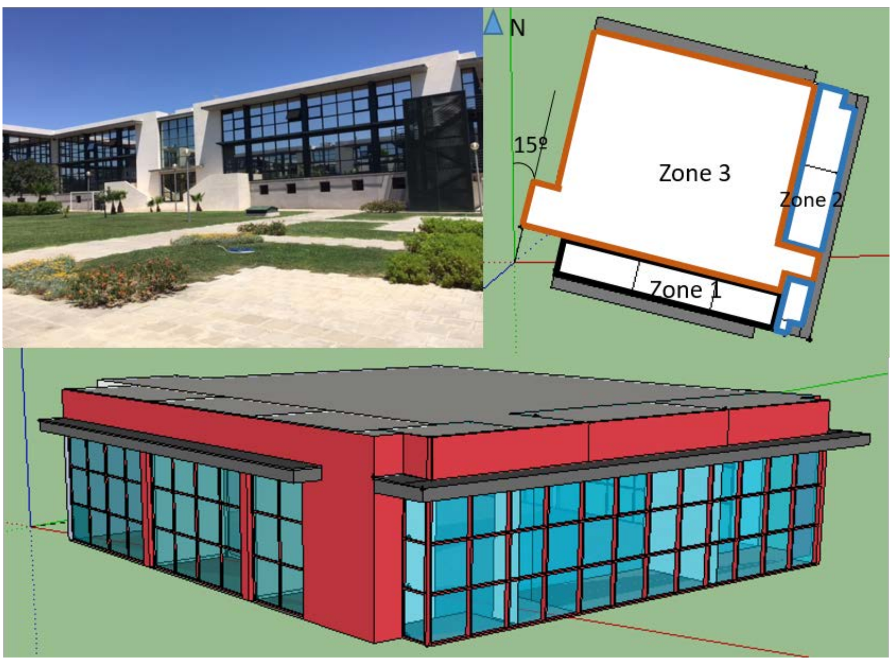


Figure 2 – Building description: real image of south façade, thermal zones and Sketchup model.

The windows properties values have been taken from International Glazing Database (IGDB) (LBNL, 2012). The window is a double reflective (6/8/6) glazing with the properties described in Table I.

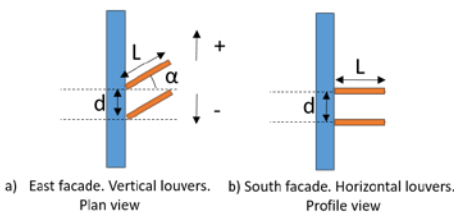
The office is occupied from Monday to Friday from 8:00 to 19:00 hours, with a break of one hour for lunch. The lighting power density is 10 W/m^2. Considering a typical work of office use, a target of illuminance of 500 lux on the work-plane is set (EN 12464-1, 2011). About 35 people work in the offices and a metabolic rate of 1.2 met is assumed, corresponded to seated and light activity at offices. Internal gains due to small equipment are included, with a mean of 17.5 W/m^2.

2.2. Simulation parameters.

Simulations have been carried out using the simulation tools Daysim for daylight and Trnsys for thermal analysis.

The work place illuminance sensor grid is at desk height, 0.85 m above the floor. It includes 3 vertical sensors positioned in south zone for the evaluation of the glare and 42 horizontal sensors uniformly placed in the total zone areas.

With respect to the louvers, in countries of the north hemisphere, south, south-east and south-west glazing exposures demand horizontal layout shadings in order to reduce solar heat gain, especially in summer. In this sense, for south façade, a horizontal louver is considered with a fixed angle of 0º. On the other hand, for the east façade, vertical louvers with different slat tilt angle are analysed. The characteristics parameters of the shading device are the length of the louver (L), the distance between louvers (d) and the slat tilt angle of louvers with respect to the horizontal (α). Figure 3 shows control shading strategies and the cases of simulation:



Orientation	L (m)	d (m)	α (º)				
Vertical	1	0.5	VL_0	VL_30	VL_60	VL_-30	VL_-60
			0	30	60	-30	-60
Horizontal	1	0.5	VH				
			0				

Figure 3– Shading control strategies.

The properties of the construction materials needed for daylight simulation are the reflectance for opaque surfaces and visual transmissivity for glazing. The external and internal walls, ceiling and floor have a reflectance of 0.9, 0.9 and 0.75, respectively. Visual transmittance of the types of glazing investigated are shown in Table I, (LBNL, 2012).

Table I – Type of glazing. Simulation parameters

Glazing type	Dimensions (mm)	U (W/m²K)	Window solar factor (g)	Solar Transmittance (Ts)	Solar Reflectance (Rf)	Visible Transmittance (Tv)
Reflective	6/8/6	2.76	0.46	0.377	0.322	0.299
Solar Control	6/8/6	2.76	0.40	0.260	0.111	0.365
Low-e	6/8/6	2.46	0.724	0.627	0.135	0.815

Malaga has a Mediterranean climate: hot and dry summers and warm winters. The city receives almost 3000 hours of sunshine a year (about 300 days every year with sunny weather), so clear sky conditions dominate throughout the year. Other cities are selected (the same used in Bellia (Bellia et al. 2015)) for the sensibility analysis. They belong to different climatic zones: London (oceanic climate) and Milan (subtropical climate). The weather data are obtained from the meteorological files of EnergyPlus.

Simulation time step is five minutes, short enough to couple with the current heating and cooling Airzone control in a future study. Daysim simulation parameters are listed is Table II.

Table II – Daysim simulation parameters

Ambient bounces (ab)	Ambient divisions (ad)	Ambient super samples (as)	Ambient accuracy (aa)	Ambient resolution (ar)
5	1000	20	0.1	300

2.3. Evaluation parameters.

Daylight analysis is carried out throughout the following visual comfort parameters:

- Illuminance (lux) in a grid of horizontal sensors defined in the work plane at a height of the desks;
- Daylighting Autonomy (DA): determine the fraction of the occupied time of the year when daylight levels exceed a specified target illuminance;
- Useful Daylighting Index (UDI). Based on the upper and lower threshold of 2000 and 100 lux (Nabil et al. 2006), UDI evaluates the percentage of the occupied hours of the year when the UDI was achieved (100-2000 lux), was exceeded (>2000 lux) or fell-short (<100 lux). These values are named as UDI_100-2000, UDI_100 and UDI_2000, respectively.

Furthermore, glare analysis should be performed with vertical eye illuminance values, in the critical positions of the office where user and computers could be harmed by glare. However, in this paper, the study is focused only in global visual comfort, and a future glare analysis should be performed.

For electric lighting consumption, Daysim consider a controlled lighting zone based on a light sensor reading and a calibrated control algorithm. The lighting control scenarios are:

1. Manual on/off switch near the door (reference system). A standard manually controlled electric lighting system;
2. Energy-efficient (off) occupancy sensor. The reference system plus an occupancy sensor with a switch-off delay time;
3. Photosensor-controlled dimmed lighting system: Ideally commissioned, photosensor-controlled, dimmed lighting system. The photocell dims the activated lighting until the total work plane illuminance reaches the minimum illuminance threshold;
4. Dimmed lighting system with an energy-efficient occupancy sensor. Ideally commissioned, photosensor-controlled, dimmed lighting system combined with an on/off switch and a perfectly located occupancy sensor.

With respect to the thermal analysis, due to the excessive HVAC cooling consumption and thermal disconfort, the study is firstly focused in the cooling demand, comparing the base case without shading to the rest of simulation cases described before. The reduction of cooling demand improves thermal users comfort, a better performance of HVAC systems and saves energy. For thermal simulation, the indoor air temperatures are 26ºC and 21ºC, in order to maintain thermal comfort standards (ISO 7730).

3. RESULTS.

Simulation results of the cases described before are shown and commented.

3.1. Thermal analysis.

In the design phase of the building, some decisions of geometry, orientation, glass area, etc., should consider the effect in the thermal and visual comfort of the building users. In this case, glazed south and east-facing walls are exposed to the solar radiation, which penetrates into the offices increasing the indoor temperature and, consequently, the HVAC energy consumption. As a first approximation, the effects of the louvers, according to the angle of the slat with respect to the horizontal, on the annual cooling demand in every thermal zone are shown in Figure 4.

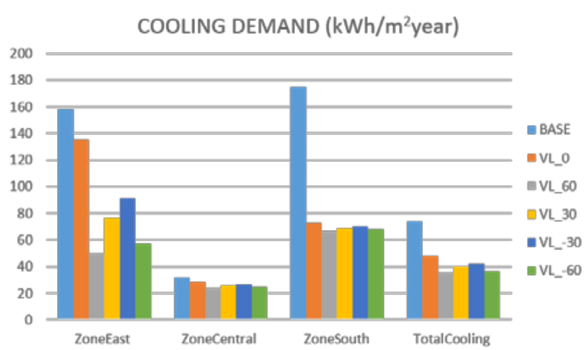


Figure 4 – The effect of the louvers in the annual cooling demand.

The first important conclusion is that the louvers reduce thermal demand in all the cases proposed. A proportion of the solar radiation is blocked and solar gains are mitigated.

The horizontal louvers in south-facing wall decrease cooling demand more than 100 kWh/m^2·year, about a 60% reduction. The effect of the slat angles in central zone and south zone is not important, so the effect of the slat angle should be analyzed only for east zone. Case VL_0 is less effective due to direct solar radiation penetrates to the zone easier than the other cases. The results for the cases VL_60 and VL_-60, where slats are more inclined, are similar. In both, the reduction of cooling demand is about 68 and 64%, respectively. The cases VL_30 and VL_-30 also achieve cooling demand savings of 51 and 42%, respectively. Optimal angle should be analyzed considering also the electric lighting consumption and visual comfort.

3.2. Daylight analysis.

Base Case Scenario.

A detailed analysis of daylight is presented for the building without shadings. Visual comfort parameters DA, UDI_100, UDI_100-2000 and UDI_2000 distribution are represented as a color map in Figure 5.

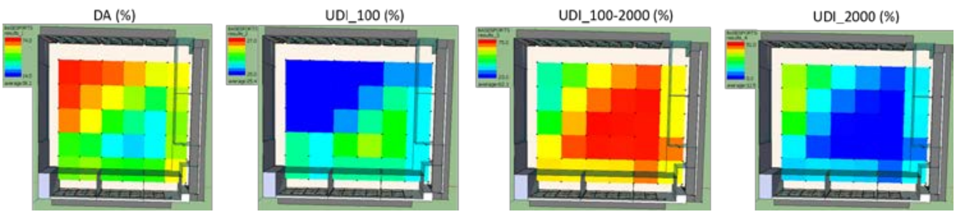


Figure 5 – DA, UDI100, UDI100-2000,UDI2000 daylight simulation results.

The average DA value is about 56%, so daylight is guaranteed in the offices a high percent of hours of the year. The DA map shows DA values about 45-55% in south and east zones, and in the middle of the central zone, and high values in the upper left corner of this zone. The UDI100-2000 map reveals that visual comfort is achieved in all the offices, with an average value of 62.1%. However, despite this favourable result, UDI100 map shows that about 25-27% of the hours, the illuminance is insufficient with daylight, and electric lighting should be activated to maintain the target illuminance of 500 lux. The UDI2000 map show a low possibility of a high level of excessive illuminance with values less than 10%. Reflectance glazing contributes to avoid high illuminance values.

Shading Cases Scenario.

Figure 6 shows a comparison of average values of visual comfort parameters and average annual light exposure, for the different cases of simulation proposed.

Figure 6 – Visual comfort parameters and annual light exposure comparison between shading simulation cases.

DA values reveal that VL_60 and VL_-60 are the cases that block more daylight than the others do. Therefore, the annual light exposure is reduced and DA values are the minimum (7.5 and 17.7%, respectively), what implies a reduction with respect the base case of 87 and 69%, respectively. The main reason is due to the angle of louver has a high inclination that blocks more solar radiation and makes the shading more effective than the other cases.

This conclusion is confirmed in the analysis of the UDI values. We can see high values of UDI_100 in VL_60 and VL_-60 cases, which will provoke an increasing of the electric lighting consumption. Besides, the reduction of the UDI 100_2000 in cases VL_60 and VL_-60 with respect the case base is about 28 and 21%, respectively. However, UDI_2000 is more favorable in these cases because the shading reduces the possibility of glare. If VL_30 and VL_-30 cases are compared, better results are obtained. The important reduction of the annual light exposure with respect to the base case lead to obtain DA values of 26 and 35%, respectively, lower than the base case, but with better values of UDI_100-2000 and, especially, decreasing UDI_2000 from 18.6% of the base case to less than 6%.

Figure 7 shows annual electric lighting consumption according to the different lighting control scenarios.

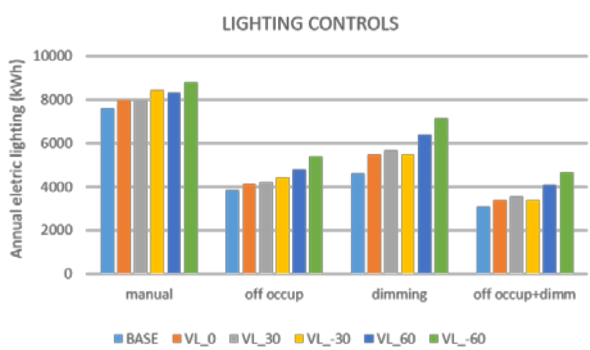


Figure 7 – Annual electric lighting consumption with different lighting controls in every shading simulation cases.

In every control scenary, electric lighting consumption is maximum in VL_-60 because is the shading case more effective, and it is necessary to activate the electric lighting to maintain the threshold desired. On the other hand, the optimal control scenario is the dimmed lighting system with an energy-efficient occupancy sensor. If it is combined with the case VL_30, assuring an optimal relation between energy saving (a reduction of east zone cooling demand of 50% and similar electric light consumption as the base case) and visual comfort (UDI_100-2000 of 69% and UDI_2000 of 4.6%).

3.3. Sensitivity analysis.

The sensitivity analysis is performed with respect to the base case in order to emphasize the requirement of shading devices. Two different parameters are analysed: type of glazing and weather.

Figure 8 compares annual cooling and heating demand of the building per area with different types of glazing and location.

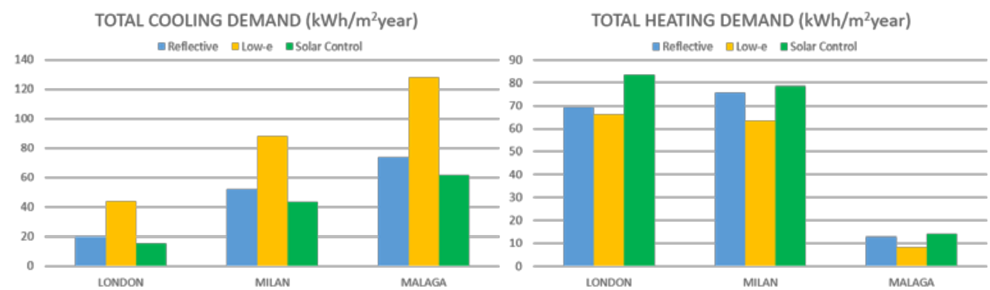


Figure 8 – Total cooling and heating demand in terms of type of glazing and location.

The comparison between heating and cooling demand in Malaga shows that heating demand is less important than cooling demand; therefore, the best option adopted in the study in a Mediterranean climate will be the most favourable with regard to decrease the cooling demand. In Milan and London, the thermal results are opposites. Cold winters make the solution of glazing façades more suitable than in a Mediterranean climate and the installation of shading devices in these cities is a solution less necessary, focused to visual comfort and avoid possibility of glare.

In relation to the type of glazing solar control windows reduces the cooling demand in all the weathers with savings with respect to the reflective window about 23% in London and 16% in Malaga and Milan. On the other hand, low-e window has the highest solar transmittance, therefore the solar radiation penetrates easier and affects negatively to the indoor comfort temperature, increasing the cooling demand considerably in all the cases. Furthermore, for heating demand, the results are opposites. For low-e windows, heating demand decreases, but the reduction of heating in relation to the increasing of cooling makes this type of glazing not adequate in this situation. For solar control windows, an equilibrium between the rise of heating demand and the reduction of cooling demand is achieved.

Figure 9 analyses the visual comfort parameters in the sensibility cases proposed.

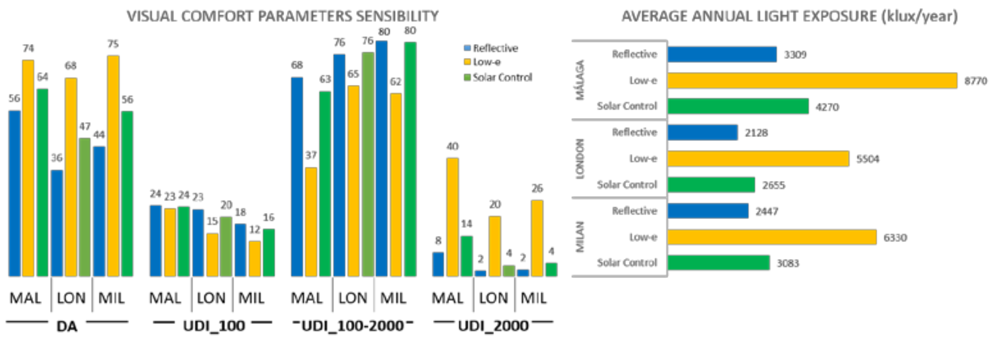


Figure 9 – Visual comfort parameters in terms of type of glazing and location.

The graph on the left compares the DA and UDI values in every city according to the type of glazing. Low-e windows assure high levels of daylight in the building with the highest values of DA (more than 68%), but also leads to high values of UDI_2000 (40% in Malaga or 26% in Milan). In particular, low-e glazing is inadequate for Malaga, where the differences are more important if we compare UDI_100-2000 values with respect to London or Milan, with values of 37% against 65 and 62%, respectively.

As regards, solar control windows obtain better DA results and similar UDI_100-2000 values than reflective windows, in all the locations. Both glazing has similar visible transmittance, so the differences between visual comfort parameters are not very important. In the comparison between solar control and reflective windows, the differences are negligible, so from the point of view of visual comfort, both are adequate in this case of study.

Considering the differences in relation to the weather, it is important to notice that the maximum average annual light exposure is in Malaga and next in Milan and London. It means that shading devices are more convenient for Mediterranean climates.

CONCLUSIONS

The results reported in this paper demonstrate the importance of shading devices in thermal and visual comfort of building users and the viability of them in relation to important parameters as the type of glazing or the weather.

In a first analysis, the base case results show a high level of visual comfort, with a high values of DA and UDI_100-2000, where users take advantage of daylight due to the glass south and east facing walls. Consequently, electric lighting consumption should be lower than other office buildings without glass façades. Besides, the reflective windows, with low value of visible transmittance, avoid excessive illuminance in offices near the windows. On the contrary, the benefits of daylight carry negative effects in thermal comfort. The solar radiation penetrates into the zones increasing considerably indoor air temperatures and cooling energy consumption.

The solution proposed for mitigating solar gains is the installation of static louvers: horizontal in the south façade and vertical in the east façade. Analyzing the effects of the louvers in the cooling demand, it is important to note that horizontal louvers give cooling demand savings of about 68% in south zone with respect to the base case. Besides, cooling demand in the east zone is evaluated in terms of the angle of the slats louvers. The angles of 60 (facing north) and -60 (facing south) are more effective in the reduction of cooling demand, but also affect negatively in daylight (low values of DA and UDI_100-2000), increasing the electric energy consumption. The angles of 30 and -30 are a better solution, giving a good equilibrium between cooling demand, visual comfort and electric light consumption.

A second study is performed in order to analyze the influence of weather and type of glazing in this type of office building. In a Mediterranean climate, buildings with glass façades lead to a high cooling demand. The results demonstrate how a shading device is a possible solution to decrease the cooling requirements. Indeed, solar control or reflective windows, with low solar and visible transmittances properties, guarantee less cooling demand than conventional or low-e windows.

On the contrary, this type of building is usual in cities with oceanic or continental climates (London or Milan), where the cooling demand is low and solar gains are favourables for reducing the heating demand. The most adequate glazing in this case is low-e glazing, with higher values of solar transmittance.

According with these results, we can conclude that low-e windows is more appropriate in northern countries where the annual light exposure is lower than in Mediterranean countries, where reflective and solar control windows integrated with shading devices are a good solution to achieve a good equilibrium between daylight, electric lighting consumption and thermal comfort.

In a future research, the aim is to take advantage of the results of this study to design an intelligent algorithm for an automatic control of louvers, determining the optimal slat angle, light dimming level and performance of HVAC system, in every simulation step time.

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