Impact of the shading system properties on the overall energy performance of office buildings in Rome, Italy

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Abstract

The cooling energy consumption in buildings is becoming a crucial point the national energy end uses. The trend is continuously growing, while is decreasing for other energy uses. Legislative bodies took note of this situation and included a number of cooling efficient solutions in latest standards. Shading devices are one of the mandatory solutions. Nevertheless shading devices affect not only the cooling energy uses but also the heating demand and the power consumption for artificial lighting. This paper present the results of a wide numerical analysis campaign performed with the objective of demonstrate the global energy benefits (heating, cooling and artificial lighting) in office buildings located in different Italian areas a function of: shading system properties, position respect to the glazing unit, glazing properties, control strategy.

1. Introduction

The increase of peak demand and energy consumption for cooling is a typical transformation of energy uses in buildings at every latitude. Once limited to commercial buildings, the increase of cooling demand is a recognised problem in dwellings as well. Few data frame the problems: according to OECD/IEA [1, 2], the energy consumption in the civil sector, including residential and tertiary, accounts for 50% for the electricity consumption. This value increases to more than 60% in the OECD (including western Europe, USA, Canada, Japan) countries. The total electricity consumption increased by 2.3% in 2005 in respect to the year before, but the percentage raised to 3.7% in building applications. The variation was 5.6% in dwellings and 1.6% in tertiary buildings. The latter point is interesting: an impressive power consumption increase in dwellings, naturally cooled until few years ago. The temperature rise as well as new comfort expectation are driving this change, even in moderate climates. The trend might have dramatic environmental impacts when this comfort expectation models will be adopted in emerging and highly populated areas of the planet.

The solar radiation in the climatic parameter that most affect the cooling demand in buildings and windows are the envelope components, which most of the solar gains are collected through. Solar gains mitigate the thermal losses in winter, but are the highest component of the cooling load in summer. Shading systems, are widely studies as an important solutions to reduce the energy consumptions and can be designed according to a number of variables. Modern architecture is often characterized by the massive use of transparent surfaces, increasing: overheating risks with associated discomfort for users; glare and cooling energy consumption. At the same time, lot of technology advances were registered within the glass and shading materials industry, offering up to date solutions, which rely on the availability of reliable and high performing control systems [3-7]. The integration of new glazing and shading materials, with advanced control systems ensure an energy efficient envelope and, at the same time, prevent users from overheating and glare through adequate controls. The objective here is trying to assess in a comprehensive approach the impact of shading systems on the overall energy performance of the building in the various energy uses.

2. Objective and methodology

This study present the first results aiming at the definition of the most performing windows for Italian office buildings. dealing with commercial buildings, the solar protection systems are a fundamental element of the window itself. The energy performance assessment is carried out considering the three main energy uses in non residential buildings: heating with ventilation, cooling with ventilation and artificial lighting. Heating and cooling are calculated as net energy loads, without considering the energy system efficiencies. The analysis is based on the energy calculation as a function of the different variables:

- Building orientation;
- Glazing units characteristics;
- Shading system properties.

The analysis was carried for several Italian localities, only the Rome results are presented and discussed in this paper for brevity.

The calculation tool used for the numerical analysis is EnergyPlus, an hourly heat balance method developed at the National Berkeley Laboratory [8]. The calculation engine is used through the commercial interface Design Builder, implemented to support the user in the input definition and model construction, as well as for the output management. The three-dimensional model allows an accurate input of the building data. Energy Plus was developed to support the building and energy system design, including the aspects related to the artificial and natural lighting.

2.1. Description of the building

The simulation were performed on a portion of a typical office building, with linear development along the east/west orientation, with the main building façade facing north and south, see scheme in figure 1. The portion consist of a simple south room plus north room plus the corridor in between (three different thermal zones). It is admitted the thermal exchange between the office rooms and the external environment through the external façade only, the other surfaces of the thermal zones, including the horizontal ones, are considered adiabatic. Thermal exchanges between the rooms and the corridor are considered. The two rooms are 3.6 meters large and 5.9 meters deep. The corridor is 1.2 meters large. The net floor height is 2.7 meters and the two rooms have a stripe window 3.4x1.5 meters, see the cross section if figure 2. The building is then rotated 90° in order to study the east and west orientations as well.

The thermo-physical properties of the opaque components are defined according to the national standards, in particular the U value of the external walls is fixed to 0.33 W/m^2 K.

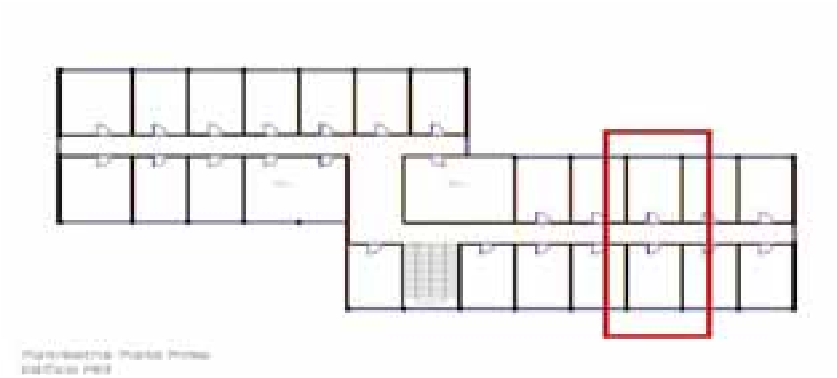

Figure 1 Schematic plan of the office building

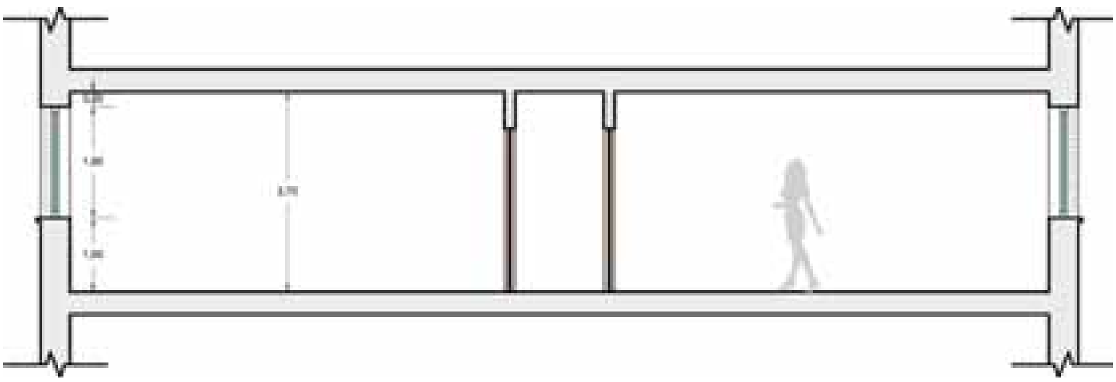

Figure 2 Cross section of the building portion

2.2. Description of the transparent envelope

The window is equipped with a thermal-break aluminium frame. Three typologies of 4-16-4 millimetres glazing units are selected: a) clear (V_{do}), b) side three low emittance coating (V_{be}), c) side two low emittance solar filter coating (V_{sf}).

The shading system consist of venetian blind to be placed outdoor, indoor or in the double glazing unit gap. Three solar/luminous reflectance values of the lamellae are selected, the value expressed as percentage is included in the following lamella code: L80, L50, L20. The last solar protection devices is a blind drape with solar/luminous transmittance and reflectance of respectively 12 and 30%.

The horizontal lamellae can rotate on a horizontal axe. It is assumed that the system is made of a series of lamellae having the same optical properties. The geometry of the system is defined by the depth, tilt, pitch of the lamella and the distance from the glazing surface. Other assumptions are also defined:

- The shading system protects the whole window;
- The lamella is flat and not curved;
- Wavelength dependence of the reflected radiation is neglected;
- Inter-reflections between the lamellae and border elements (as the window frame) are neglected;
- The reflectance mode is completely diffuse, hence no regular behaviour is admitted.

The venetian blind geometry is defined according to the position respect to the glazing unit, the characteristics are defined according to common commercial products:

- External: lamella depth 10 centimetres and pitch 6 centimetres;
- Internal: lamella depth 2.5 centimetres and pitch 1.5 centimetres;
- In gap: lamella depth 1.5 centimetres and pitch 0.9 centimetres.
- East and West cut off at 10.00 am.

The venetian blind elements are tilted according to the façade orientation:

- North - horizontal;
- South cut off at 12.00 pm;
- East and West cur off at 10.00 am.
- The lamella is flat and not curved;
- Wavelength dependence of the reflected radiation is neglected;
- Inter-reflections between the lamellae and border elements (as the window frame) are neglected.

The shading systems is automatically operated by an hypothetical energy management system, as a function of two controls: a) glare control, which means the activation od the ventian blind whenever the DGI (Daylight Glare Index) reaches the value of 22 in the selected user position; b) indoor air temperature control, which means the blinds are activated when the indoor temperature reaches 25°C, before the cooling system automatically switches on; C) the shading protection is activated when the cooling system switches on.

2.3. Operational hypotheses

It is assumed that the energy systems are switched on from 8.00 am until 6.00 pm during the weekdays, while the office is closed during the week end. The air temperature set point is 20°C in winter and 26°C in summer. The global infiltration/ventilation rate is fixed to 0.8 air changes per hour. The following hypotheses are defined for the internal loads: the room host 1.5 persons as an average; the installed artificial lighting power is 11 W/m^2 supplying 500 lux, as required for normal office activities; other appliances (personal computers, printers, monitors, etc.) accounts for 13 W/m^2.

3. Results

The results refer to a high number of calculation including: one locality (Rome), four different shading systems, two control systems, three shading system positions, three double glazing unit types, two orientations. It was decided not to present the west and north orientations, the former because the results are very close to the east orientation (the difference is around 10%), the latter because the absolute results and the dependence on the shading properties are very similar each other, because of the mainly diffuse irradiance. Figure 3 and 4 present the net cooling energy for the room with orientation south and east; figures 5 and 6 show the artificial lighting consumption for the same rooms.

Concerning the south façade room, the energy performances are very similar for the external devices, whatever the optical properties of the systems are. This depends on the trade off between the increase of cooling demand and the reduction of the artificial lighting as a function of the lamellae reflectance.

In this case is suggested to spend more for lighting and ensure a better daylighting in the office. The optical properties have a higher impact if placed in the glazing unit air gap. Darker lamellae have the worst overall performances, due to the high absorptance and consequent increase of indirect solar gains; coupled with lower daylighting availability.

The L20 has a energy demand 15 kWh/m^2 per year higher respect to the drape. Placing the solar protection inside the building gives the worst energy performances. In any case, L80 is the best performing systems, with energy demand reduced up to 35 kWh/m^2 respect to L20. The drape and L50 have very similar performances.

The east room has the greatest benefit when the drape is used in the external position, since it ensures a more uniform irradiance. Venetian blinds even if tilted at the cut off position at 10.00 am cannot avoid high solar gains, as a matter of fact the L80 is the worst performing due to the high solar gains, while L20 results the best. L80 is, on the contrary, the best performing when the binds are internally mounted; the reasons applied for the south room applies in this case too.

The drape, performs very good again, while darker lamellae do not; this depends on the good daylighting and on the reduced secondary solar gain, while the general energy performances remain poor for all the internal solutions. The analysis related to the artificial lighting consumption shows the impact of reflective lamellae in optimising the daylighting inside the room.

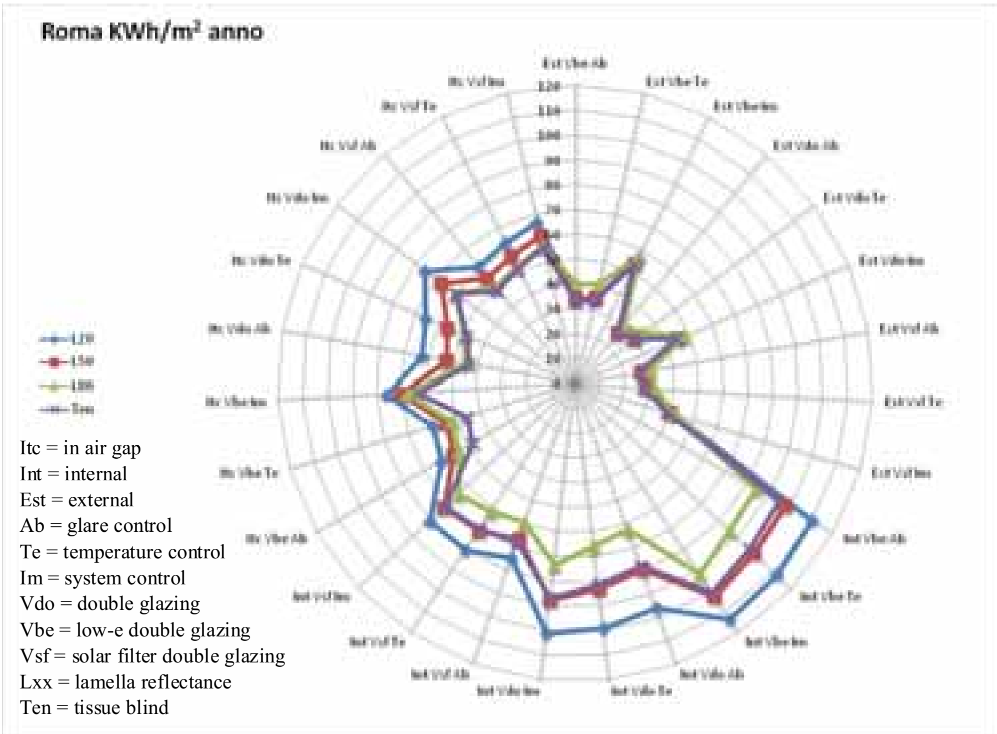

Figure 3 Calculation results – Net cooling demand - South orientation

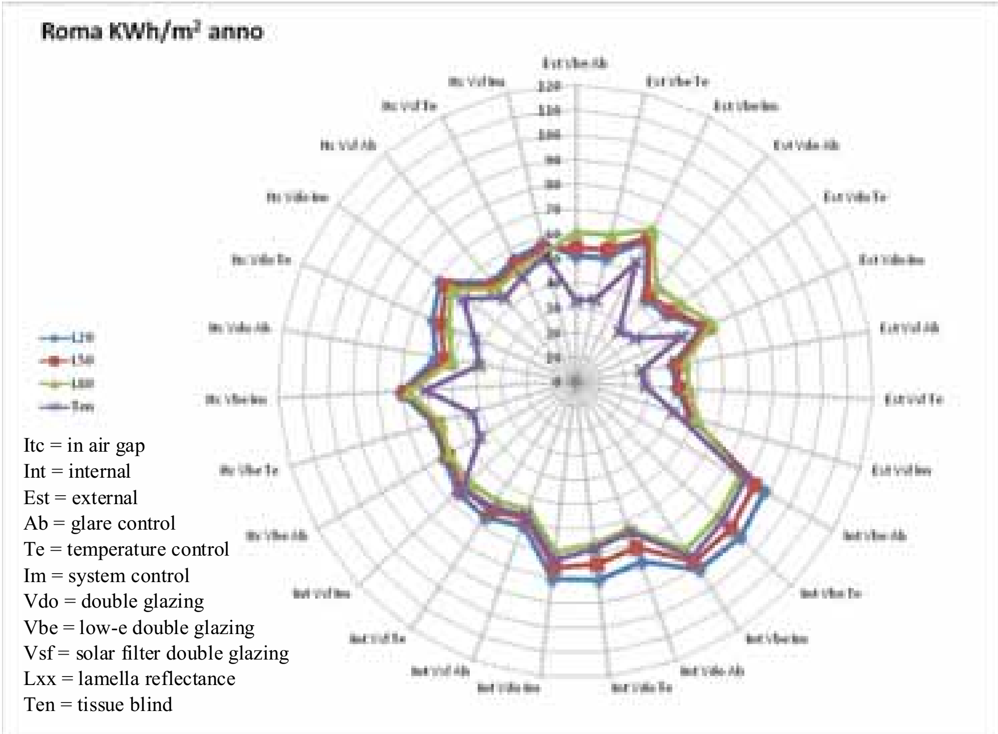

Figure 4 Calculation results – Net cooling demand - East orientation

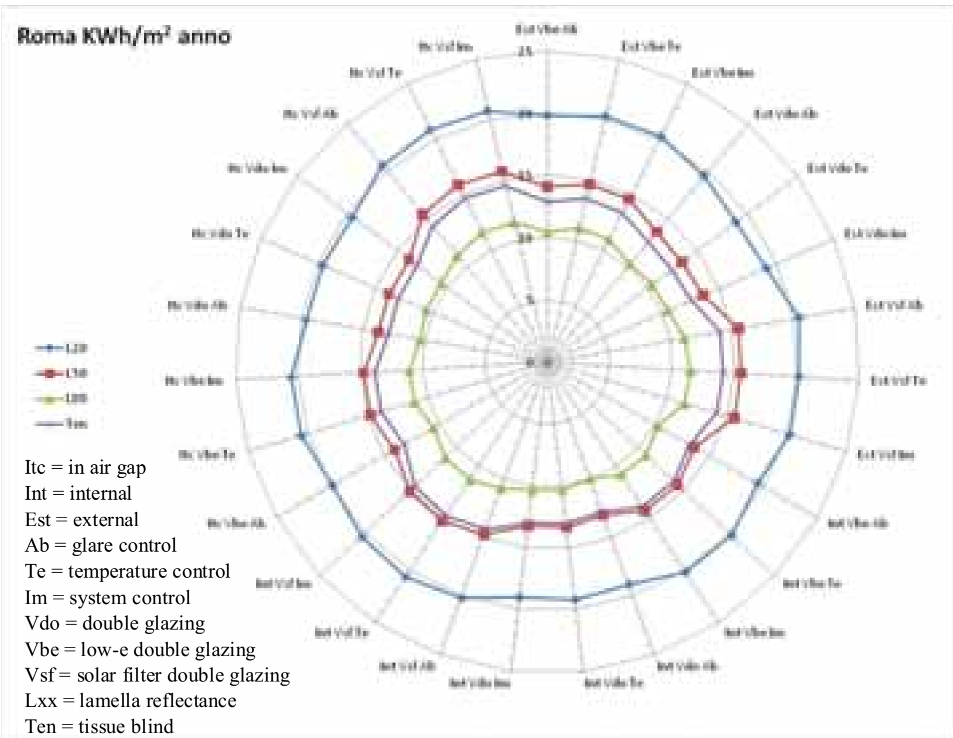

Figure 5 Calculation results – Artificial lighting - South orientation

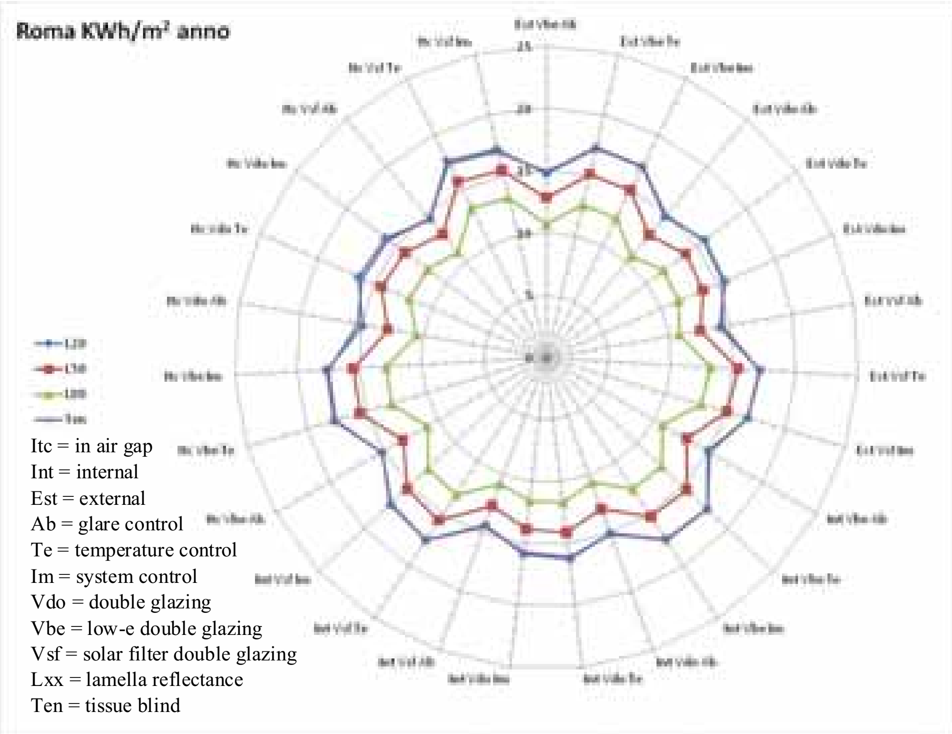

Figure 6 Calculation results – Artificial lighting - East orientation

A significant result regards the drape in the gap, which gives the best results in absence of external shading. In fact the performances good for the clear and the low emittance glazing, ad less for the solar filter unit. This depend on the spectral properties of the drape, which are more effective if the solar load is reduced before it reaches the drape itself, reducing the shading power as the other systems do.

4. Conclusions

Some general conclusion can be drawn from this study:

• High reflectance lamellae ensure the overall best energy performance for south oriented office rooms. The reflectance has a minor impact for east and west façade and, more in general, venetian blind systems perform worse than conventional drapes. More investigation are needed to assess the performances of vertical lamellae for such orientations.

• The glare prevention and temperature comfort applied to the dynamic shading systems are the best performing, since they affect both the energy performances and the thermal/visual comfort. The energy system control demonstrated to be the less efficient.

• External shading are bay far the best energy solutions, in few cases the gap solution coupled with the low emittance glazing gives better results.

• The solar filter glazing is the best performing at this climate a for these buildings. No significant differences are found between the standard and the low emittance glazing units, and this should address some policy issues for situations where the cooling demand exceeds by far the heating demand.

Next steps will move towards the assessment of vertical shading systems. The final goal will be guidelines for a coherent design of commercial buildings, characterised by large glazed façade, and support the national normative framework, according to the peculiarity of the Italian climates and the most *intense* energy uses in this building category.

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