EXTERNAL SHADINGS AND GLAZING MATERIALS AS PASSIVE SYSTEMS TO IMPROVE ENERGY CONSUMPTION AND INDOOR COMFORT IN OFFICE BUILDINGS

F. Gugliermetti and F. Bisegna

Department of Technical Physics, University of Rome “La Sapienza”, Italy
Via Eudossiana, 18 - 00184 Rome, Italy

ABSTRACT

External shading systems, window systems and light control systems try to reach the indoor comfort and energy saving by approaches, that are different in complexity, costs and results; besides a good coordination among them could produce better performances.
This paper analyses the office space energy demand connected to the use of different glazing materials, light control systems and external fixed shading devices for office buildings, with the aim to optimize their usage aspects and characteristics. External shading devices are studied versus different light control strategies and window systems. The approach is based on an improvement of the hourly simulation program IENUS that was developed to assess building energy demand taking into account the integration between visual and thermal aspects. The results are referred to a typical office building locate in Mediterranean climate.

KEYWORDS

Integrated energy analysis, passive systems, non residential buildings, Mediterranean climate.

INTRODUCTION

External shading devices have always represented a very simple passive systems to control the incoming of the natural light with two main purposes: improving indoor visual and thermal comfort, reducing HVACs and artificial light systems energy consumptions. On the other side industries in these last years have developed and produced different types of transparent materials and lighting control systems to take full advantage of the energy saving potential coming from daylight. Transparent spectrally selective coatings on glass or polymeric substrates are nowadays available. Low emittance (low-e) coatings can transmit either a large portion of solar radiation (high total solar energy transmittance τ_s and high visible light transmittance τ_v) or selectively a high proportion of visible radiation and reflect the near infrared component of the incident solar radiation (low τ_s and high τ_v). Coatings of pyrolytic heavily doped wide band-gap semiconductor coatings, such as flourine-doped tin oxide, are used in solar gain glazing systems, while coatings of sputtered multi-layer dielectric-metal-dielectric, such as silver-based film, are used in solar filter systems. Different lighting control systems are used to control lamp light outputs and natural light. Natural lighting controls by automatic mini-internal blinds to large exterior rolling louvered shutter systems are available and popular in office building due to their adjustability and ability to reflect light. While artificial lighting systems are dimmed or switched following day light variation to keep design lighting levels as constant as possible for all the lamps maintenance cycle. Commercial control systems can operate with algorithms that can realize either a closed-loop integral control or an open-loop proportional control.

External shading systems, window systems and light control systems try to reach the indoor comfort and energy saving by approaches, that are different in complexity, costs and results; besides a good coordination among them could produce better performances. Nevertheless, not many works are devoted to the analysis of these aspects: interesting studies have been conducted by the LBL (Lawrence Berkeley Laboratory) Group on new transparent materials, and their visual and thermal behaviors (Sullivan *et alt.*, 1994, 1996, Moeck *et alt.*, 1998), as far as by Gugliermetti and Grossi (2000a, b), Gugliermetti and Bisegna (2001a) Gugliermetti *et alt.* (2001). Moreover, specific studies have been developed on the integration of natural and artificial light in office buildings (Di Bartolomeo *et alt.*, 1996, Gugliermetti and Bisegna, 2001b, Li and Lam, 2001); others analyzed instead energetic and visual aspects of shading devices (Carbonari and Rossi, 1999, Carbonari et alt., 2001, Yener, 2001). No one however still investigated the energy performances deriving from a comparison or at least from a coordinate use of all these solutions. It is the aim of this paper then to analyze the office space energy demand connected to the use of different glazing materials, light control systems and external fixed shading devices for office buildings. External shading devices are studied versus different daylighting and artificial lighting control strategies and window systems referring to a South oriented typical office room in Mediterranean climate at several latitudes. The approach is based on an improvement of the hourly simulation program IENUS (Integrated ENergy Use Simulation), that was developed to assess building energy demand taking into account the integration between visual and thermal aspects.

CALCULATION HYPOTHESIS AND ROOM CHARACTERIZATION

An improved version of the integrated energy analysis program IENUS has been used for these simulations. IENUS was initially developed to assess the building energy demand with different kinds of climatic data, daylighting and artificial lighting control strategies due to active control systems, glazing materials, specifically innovative window systems; improvements concern the possibility to evaluate the contribution also of fixed external shading devices taking still into account the integration between thermal and visual aspects.

Simulations are referred to a typical office room with three working places in three different cities, Rome (RM, 42° N), Bolzano (BZ, 46° N), Messina (MS, 38° N). Working period for occupants (50 W/p of sensible heat), equipment (800 W), HVAC and artificial light system is the same, everyday from 8.00 A.M. to 20.00 P.M. Room dimensions are 5m x 7m x 3m with only one external wall presenting a 3m x 2m central window opening, with the center at 1.8m from the floor. Room furnishing is ordinary without carpet. The external wall thermal transmittance is U=0.80 W/m^{2}K, while the envelope construction weight is about 200 Kg/m^2 of floor. All internal wall surfaces are considered to have a lambertian behaviour, and present visible reflectances of 0.8 and 0.2 respectively for the ceiling and the floor, and of 0.5 for lateral walls. Attention has been focused on the three window systems showed in Table 1, whose characteristics have been evaluated by WINDOW 4.1 (Arasteh 1994) on the base of the single angular glazing material properties. In Table 1, τ_{vnh} and τ_{snh} represent respectively the central normal-hemispherical visible solar transmittances of the considered glazing system, while U is the window system central thermal transmittance.

TABLE 1.
Central window systems optical and thermal properties.

Cod.	**Type**	**Outer**	**Middle**	**Inner**	τ_{vnh}	τ_{snh}	**U [W/m^{2}K]**
REF1	Double Clear	Clear 6 mm	Air 15.7 mm	Clear 6 mm	0.78	0.60	2.74
SF1	Double Low-e	Sputtered 6 mm	Air 15.7 mm	Clear 6 mm	0.36	0.19	1.80
SF4	Double Low-e	Pyrolitic 6 mm	Air 15.7 mm	Bronze 6 mm	0.43	0.31	1.76

Daylighting management is obtained by following three different ways:

1. An internal shading device only, with an on/off strategy that closes the curtain when the direct solar radiation impinging on it after flowing through the glazing system is greater than the set point of the controller, here fixed at 30 W/m^2, and pointed with the code NF; the internal curtain present a shading coefficient SC=0.4 and T_{vnn}=50%, while the direct light transmitted diffusely is T_{vndiff}=10%. The angular dependence of the curtain light transmission is not taken into account during illuminance and thermal calculations;
2. A fixed external shading device with a depth of about 1m only, pointed with the code FNT;
3. Both the internal and external shading devices working together, pointed with the code FET.

Each of these solutions have been studied with each of the three proposed window systems. Integration of natural and artificial light management is obtained with a photosensor connected to a controller: it detects the illuminance and dims the light output of the lamps (0-600 W, to guarantee a minimum illuminance on the working plane, placed at 0.8m above the floor, at about 500 lux, according to the Italian Standard UNI 10380) following a daylight approach. A 3 equal zones dimming strategy for artificial light is considered to operate.

RESULTS

Analysis was firstly developed with the aim to understand the effect of fixed external shading devices on office space energy demand. Once fixed REF1 as the standard glazing material generally used in real offices, it has been compared the overall energy performance and the heating (H), cooling (C) and lighting (L) behaviours of the room when only an external overhang is foreseen (case FNT) or when an internal curtain works together with the overhang (FET), as an integration to control daylighting, in respect to the base case. The base case is represented by a room with a REF1 glazing system and an internal curtain working as delineated before. Heating, cooling and artificial lighting are reported into petroleum equivalent tons (Tep) with the following conversion factors:

- cooling system with electric chiller: 2.17 x 10^{-2} tep/GJ (performance COP=3.2);
- heating system with gas boiler: 3.23 x 10-2 tep/GJ (efficiency η=0.8);
- artificial light system: 8.68 x 10-2 tep/GJ (ballast factor BF=0.8).

Overall (tep) and H, C, L (GJ) energy requirements are showed respectively in Table 2 and Table 3 for South orientation and several Italian climates: it seems that the use of an overhang in substitution of the curtain (FNT) causes an increase in energy demands for all the three climates, due to a substantial increase of cooling loads (C), although both heating (H) and lighting (L) loads decrease. The FET case instead seems really interesting as the concurrent use of external and internal shading devices provide a sensible decrease of energy requirements due specifically to a decrease of C, especially for the case of Messina.

TABLE 2
Overall energy requirements for REF1, orientation South.

Case study	ΔE [tep]		
	BZ	*RM*	*MS*
REF1 FNT	0,064	0,093	0,078
REF1 FET	-0,020	-0,022	-0,026

TABLE 3
H, C, L energy requirements for REF1, orientation South.

Case study	Load	ΔE [tep]		
		BZ	*RM*	*MS*
REF1 FNT	*H*	-0,268	-0,130	-0,012
	C	4,122	5,158	4,142
	L	-0,188	-0,165	-0,138
REF1 FET	*H*	-0,001	-0,012	0,000
	C	-1,148	-1,258	-1,399
	L	0,059	0,061	0,053

The second step of the analysis concerns the investigation of different glazing systems working with and without internal and external shading devices in respect to the base case first, and then to the other REF1 cases studied before. For both SF1 and SF4 window systems, the three cases of room with internal curtains and no overhangs (NF), FNT and FET are presented. Table 4 and Table 5 respectively represent the global energy requirements when the comparison is between each solar filter (SF) window system (SF1, SF4) and REF1 NF, or the REF1 respective case. Specifically, from Table 4 it results that a simple change of window system from a clear to a low-e one, does not show improvements: the SF1 NF case presents in fact higher tep values, but the difference decreases decreasing the latitude (hotter climates); the SF4 NF instead presents quite comparable values in respect to REF1 NF. Considering the other two solutions FNT an FET, it seems that SF1 improves its performances when an overhang works in substitution of the curtain, while the FET solution is the worst. SF4 on the contrary presents the worst performance results in the FNT configuration, and the best ones with FET, thus showing negative ΔE results, that is a better system behaviour in respect to REF1 FN. When comparing each SF case with the respective REF case instead, Table 5, it results that SF1 FNT and SF4 present better behaviours in respect to REF1 FNT at almost each latitude, while the FET case always presents worse performances.

TABLE 4
Overall energy requirements for SF window systems, orientation South, in respect to the base case.

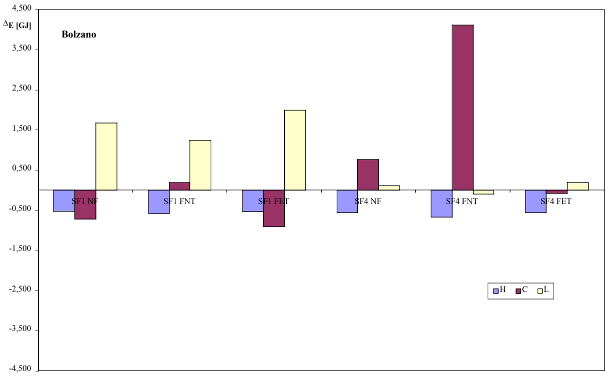
Case study		ΔE (tep)		
		BZ	*RM*	*MS*
SF1	*NF*	0,112	0,092	0,075
	FNT	0,093	0,087	0,067
	FET	0,136	0,125	0,103
SF4	*NF*	0,008	0,009	0,002
	FNT	0,058	0,076	0,060
	FET	-0,004	-0,004	-0,014

TABLE 5

Overall energy requirements for SF window systems, orientation South, referred to the respective case.

Case study		**ΔE (tep)**		
		BZ	*RM*	*MS*
SF1	*NF*	0,112	0,092	0,075
	FNT	0,028	-0,007	-0,010
	FET	0,156	0,148	0,129
SF4	*NF*	0,008	0,009	0,002
	FNT	-0,007	-0,017	-0,018
	FET	0,016	0,018	0,012

The last series of comparisons between the respective referring systems, show the always worst performances of the SF1 glazing system and the quite always comparable (or at least better) results of SF4. Figure from 1 to 6 at last present H, C, L loads for the three different latitudes when the first type of comparisons (all SF combinations versus REF1 NF, left column, Figures 1, 3, 5) or the second one (all SF versus the respective REF configurations , right column, Figures 2, 4, 6) are considered. From these Figures it results evident the effect of each system on room loads: i.e. the use of low-e causes a decrease in the use of energy for H, independently from the presence of internal or external devices; by the same way, lighting requirements seem always to increase, with the unique exception of the case SF4 FNT. From a more general point of view, it seems that the solution FNT causes a decrease of H and L energy requirements and an increase of C, while FET a general decrease of H and C and an increase of L.



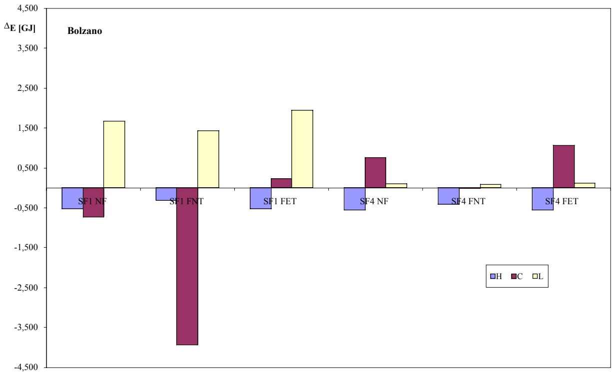
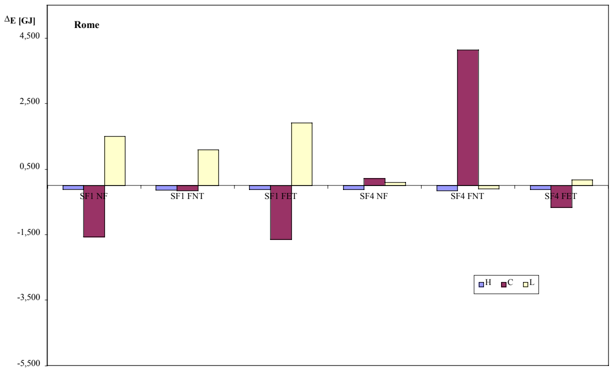


Figure 1. H, C, L for BZ South, in respect to base case.

Figure 2. H, C, L for BZ South, referring each to the respective case.



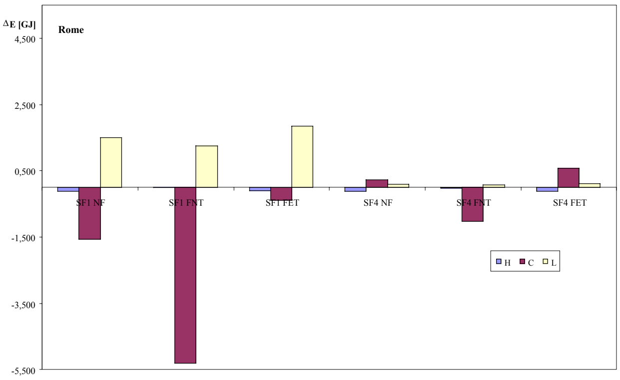


Figure 3. H, C, L for RM South, in respect to base case.

Figure 4. H, C, L for RM South, referring each to the respective case.

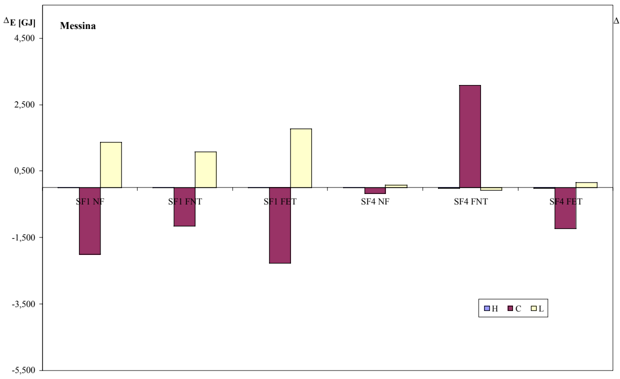


Figure 5. H, C, L for MS South, in respect to base case.

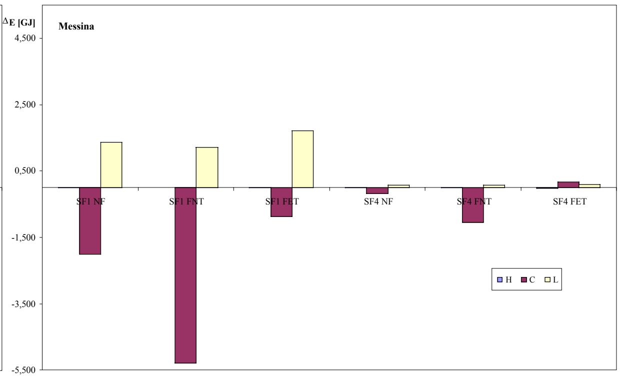


Figure 6. H, C, L for MS South, referring each to the respective case.

CONCLUSIONS

It has been developed a preliminary analysis on the effectiveness of several passive systems to reduce energy consumption in office buildings. Different daylighting control strategies, as the use of external or internal shading devices, and transparent materials have been tested with the aim to individuate the optimal energetic solution still assuring indoor visual and thermal comfort. It seems that a simple change of the window system doesn't improve energy performances of the environment; the same happens when an external overhang is used in substitution of the internal shading device; interesting results have been obtained when both the shading devices are used. This can however only be considered as an approach to the problem, characterized by a lot of degrees of freedom, from the window typology to the flexibility of the daylight control system, till to the optimal dimensions of the external shading devices, or to the optimal, energetic as far as visual, set point values to regulate the internal curtain.

REFERENCES

Arasteh D. (1994), Window 4.1, *LBL 35298,* Lawrence Berkeley Laboratory, Berkeley, CA

Carbonari A and G. Rossi, (1999). *Metodologia per l'ottimizzazione energetica ed illuminotecnica degli elementi ombreggianti applicati alle facciate degli edifici,* 54° Congresso ATI, 1999, L'Aquila

Carbonari A., Rossi G., Romagnoni P. (2001), *Optimal Orientation and Automatic Control of External Shading Devices in Office Buildings,* 18th International Conference on Passive and Low Energy Architecture, Florianopolis, Brazil, 7-9 November 2001

Di Bartolomeo D. L., Lee E. S., Rubinstein F. M., Selkowitz S. E., (1996). *Developing a Dynamic Envelope/Lighting Control System with Field Measurements,* IESNA Annual Conference, August 1996, Cleveland, OH

Gugliermetti F. and F. Bisegna (2001/b), *Strategie di controllo della luce naturale ed artificiale per ambienti con finestre elettrocromiche*, Convegno AIDI, Perugia, 4-6 dicembre 2001

Gugliermetti F. and F. Bisegna (2001/a), *Natural and artificial light control systems and strategies for energy saving and environmental comfort in Mediterranean climate*, Proc. of CIE International Lighting Congress, 12-14 September, Istanbul, Turkey

Gugliermetti F. and L. Grossi(2000/a), *Prestazioni energetiche delle superfici trasparenti innovative in edifici ad uso non abitativo*, Proc. of 41° Cong. AICARR, 23-25 March, Milano, Italy

Gugliermetti F. and L. Grossi, (2000/b), *Integrated energy demand for advanced glazing system in Mediterranean climate*, Proc. Euro Conf. New and Renewable Technologies for sustainable development, Madeira, 26-29 June, Portugal

Gugliermetti F., L. Santarpia and F. Bisegna (2001), *Integrated energy use in office spaces*, Proc. of 7th Int. IBSA Conference, Building Simulation, 13-15 Agust, Rio de Janeiro, Brazil

Li D., Lam J., (2001), "Evaluation of lighting performance in office buildings with daylight controls", Energy and Buildings 33, 793-803

Moeck M., E. Lee E., M. Rubin, R. Sullivan and S. Selkowitz (1998), *Visual quality assessment of electrochromic and conventional glazings,* Solar Energy Mater. Solar Cells, 54, 157-164

Sullivan R., E.S. Lee, K. Papamichael, M. Rubin and S. Selkowitz (1994), *Effect of switching control strategies on the energy performance of electrochromic windows*, SPIE, 2255, 443-455

Sullivan R., E.S. Lee, M. Rubin and S. Selkowitz (1996), *The energy performance of electrochromic windows in heating dominated geographic locations*, LBNL report NR:LBNL 38252

Yener A., (2001), "A study on the daylight availability of rooms with various solar control alternatives", Proc. of CIE International Lighting Congress, 12-14 September, Istanbul, Turkey