OPTIMIZATION OF DAYLIGHT IN BUILDINGS TO SAVE ENERGY AND TO IMPROVE VISUAL COMFORT: ANALYSIS IN DIFFERENT LATITUDES

Michele De Carli and Valeria De Giuli
Dipartimento di Fisica Tecnica, Università degli Studi di Padova

ABSTRACT

Natural light is irreplaceable because it is a full-spectrum light, it changes during the day and it is different every day of the year. A variable illumination throughout the day, in terms of intensity and colour temperature, creates dynamic indoor environments that are more pleasant for people. Daylight needs to be controlled, especially in office buildings, to avoid discomfort glare and high luminance reflections on display screens, to provide a good lighting level even in the deeper part of a room and to reduce cooling loads. To improve the quality of light, of visual comfort and to minimize lighting, heating and cooling loads advanced daylighting systems (such as BMS, Building Management Systems) and external shadings should be used.
The aim of this study is to optimize the availability of glare-free natural daylight in a building's interior, in order to create spaces of high visual quality, where the energy demand for artificial lighting and cooling can be reduced by means of control strategies and shading devices. The same office room has been supposed at different latitudes, since each latitude needs a specific shading system . The lighting simulation has been carried out with the software Daysim, developed by the National Research Council del Canada and by the Fraunhofer Institute for Solar Energy Systems and the software Radiance, developed by Greg Ward and by the Lighting System Research group of the Lawrence Berkeley Laboratory.

INTRODUCTION

People spend large amount of their time indoors and, without proper light, they may have physiological and psychological problems, which in some cases can cause sickness (Boyce, 1998; IEA, 2000). Many studies have demonstrated that if daylight is the primary source of lighting, there is a great improvement in productivity, performance and well-being in general (De Carli, De Giuli et al., 2008). Natural light, in fact, has both direct and indirect effects on human beings: the direct effects are caused by chemical change in tissues due to the energy of the absorbed light, while the indirect ones concern the regulation of the basic biological functions and the production of hormones, connected to light exposure. Therefore, to improve well-being, satisfaction and productivity, expecially in office buildings, it is very important to project indoor spaces with specific attention to workers' comfort.
This paper shows the results, in terms of visual lighting requirements, of the application of some shading devices in a office room, located in five different latitudes: Stockholm (59°65' N), Venice (45°50' N), El Cairo (30°13' N), Bombay (19°12' N) and Colombo (6°82' N). Solar shading devices are often used in buildings to reduce overheating, to control glare from windows and to provide privacy. The control of daylighting is very important especially in office buildings because of its relationship with occupants' satisfaction and performance. On the other hand, lighting and blind control systems can reduce energy demand for artificial lighting, which can contribute to the development of environmentally sustainable buildings.
The objectives of this study are:

- to evaluate the impact of these external shading devices, both fixed and movable, on the illuminance levels inside the investigated room and on their associated energy savings;
- to evaluate the lighting energy savings from daylighting with some types of lighting control systems;
- to evaluate which shading device is to be preferred, according to latitude;
- to evaluate the office energy efficiency and sustainability by means of some dynamic daylight metrics.

METHODS

The analysis of energy savings obtained by different lighting and shading control strategies, the dynamic daylight performance parameters and the annual illuminance profiles inside the office have been performed with the software DAYSIM (Reinhart, 2005). The model DAYSIM can predict the energy requirement for artificial lighting and indoor illuminance profiles under all appearing sky conditions throughout the year – the so-called "All weather sky model" (Perez et al., 1993). These profiles are based on a weather climate file and they can be coupled with a stochastic user behaviour model, to predict some daylight performance

indicators, such as daylight autonomy, annual light exposure and lighting energy use for different lighting and shading control strategies. The energy requirement for artificial lighting depends on the user behaviour and on the control strategies for lighting and shading systems.
The user behaviour implemented in DAYSIM is based on a model, called Lightswitch (Reinhart, 2004), which is the result of some studies in buildings throughout the Western world. These behaviour models mimic how users interact with personal controls (light switches, blinds, window opening). In this study three different user behaviours have been considered, for both lighting and blind control: passive, active and mix. A passive user is defined as a “user who keeps the electric lighting on throughout the working day and keeps the blinds partly closed throughout the year to avoid direct sunlight”. An active user is a “user who operates the electric lighting in relation to ambient daylight conditions, open the blinds in the morning and partly closes them during the day to avoid direct sunlight”. The mixed user behaviour is the mix of both active and passive behaviours. For each different user, different lighting control strategies have been considered.
The inputs needed by the program are: the geometry of the room, the material of the surfaces’ room, the climate file and the position of the sensors. In the material file the description of the optical properties of the materials surfaces is specified: it has to be defined by means of five numbers, which correspond to the red, green and blue reflection, the specularity and the roughness. Glazing material is defined by the red, green and blue visual transmissivity.
The weather file is a file imported from the DOE (US Department of Energy): this climate file contains a series of hourly direct and diffuse irradiances, which can be converted into a time series of down to five minutes direct and diffuse irradiances, using a stochastic autocorrelation model.
The sensor point file contains the list of the position of the sensors in which, in this specific application, the illuminance is calculated.
Finally, the software RADIANCE (Ward et al., 1998) has been used to calculate the illuminance in specific sky condition (Standard CIE skies) and time of the year (equinoxes and solstices, at noon), to analyse the performance of the shadings considered under standardised and extreme sky conditions.

CASE STUDY

The same single office (Fig.1), facing south, has been analysed in the five different latitudes. It is a box-shaped room, 3.5 m wide, 7 m long and 3 m high. No external obstructions and no internal furnishing have been considered.
Windows establish a relationship between the occupant and the outside and are probably the most important element of a room, since they provide natural light, possible ventilation and external view, which has been demonstrated to be one of the main workers requirement for their office (Heerwagen, 1986, 1990).

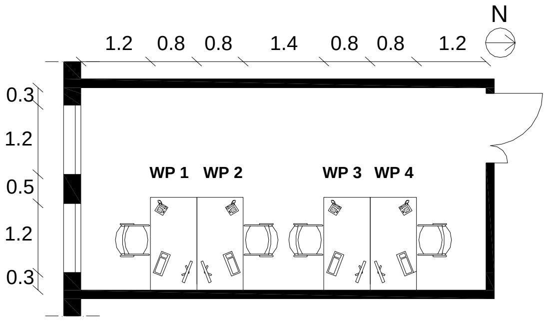


Figure 1 Office plant with the position of the four work planes

The façade has two glazing surfaces of 1.2 x 2.6 m^2 (Fig.2).

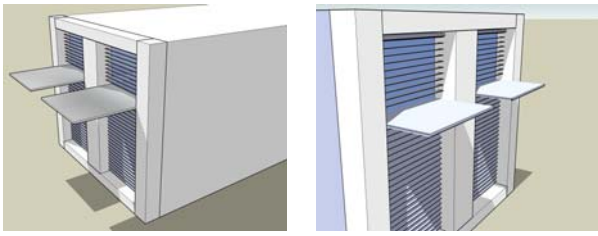


Figure 2 Office prespective

The shading system consists of a fixed light shelf, both internal and external, with a reflective upper surface, and two movable external venetian blinds, with the slats 0.08 m wide. The reflective light shelf is designed to shade and redirect light to deep areas of the room interior. Two different dimensions of both internal (0.4 m and 0.8 m) and external (0.8 m and 1.35 m) light shelf have been supposed (Fig.3), depending on the solar altitude of each location considered during the year.

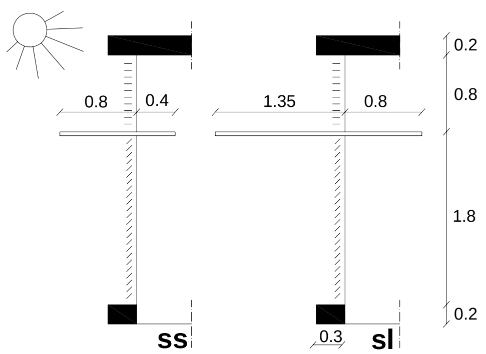


Figure 3 Office sections: light shelf short (ss) and light shelf long (sl)

Venetian blinds are the typical shading system which occurs in buildings: they protect against glare and redirect daylight, they may obstruct, absorb, reflect and/or transmit solar radiation (both diffuse and direct) to indoors, depending on the position of the sun, their location (internal or external), slat angle and slat surface reflectance characteristics.

Occupancy

The office is supposed to be occupied by four persons (Fig.1). Occupancy profiles are generated by the program. The following assumptions have been considered:

- arrival time: 9.00 a.m.;
- departure time: 6.00 p.m.;
- the work place is occupied from Monday to Friday;
- the lunch break occurs at noon and two 15 minutes breaks are scheduled around 10.00 and 15.00.

Simulation

Assumption for calculations have been done according to the Standard EN 12464-1 and the Standard EN 15193. The simulation time step was 5 minutes. It is supposed to know the position of the work places (Fig. 1) and the height of the working area is fixed at 0.75 m. The illuminances and all the dynamic parameters have been calculated on a 0.5 x 0.5 m grid over the whole office and on a 0.2 x 0.2 m grid over each work-station. The maintained illuminance in the work plane is fixed at 500 lux. The installed lighting power density load is assumed to be 15 W/m^2, which corresponds to the benchmark value for a typical office room of one star quality class (EN 15193, Annex F).
The optical properties of each building element, supposed monochrome, are reported in Table 1.

Table 1
Optical properties of building elements

Building element	Material description
ceiling	80% diffuse reflection
floor	30% diffuse reflection
wall	60% diffuse reflection
glass	76% visual transmittance
blind	50% diffuse reflection
light shelf	upper side: 80% RGB reflection, 80% specularity lower side: 80% diffuse reflection

Non-default DAYSIM-RADIANCE simulation parameters are listed in Table 2.

Table 2
Simulation parameters

ambient bounces	ambient divisions	ambient accuracy	ambient resolution	direct threshold	direct sampling
7	1500	0.1	300	0	0

The DAYSIM dynamic advanced shading device model has been chosen, because, by means of this model, it is possible to simulate a specific shading device. In this case, two RADIANCE files are required to be explicited, one with the geometry of the blinds up configuration and the other one with the blinds down. DAYSIM will then calculate two sets of illuminances, one for the blinds up and one for the blinds fully down. In this work, the advanced model has been applied, for all the five latitudes, in the two façade configurations (Fig.3), trying many slat angle in the "blinds down" geometry file, in order to reach a good compromise of daylight distribution for all the four work-stations.

Lighting control systems

When using a switch off occupancy sensor, the light can only be activated manually, while the switch off can be either manual or automatic (with a delay time of 5 minutes) when the occupancy sensor is installed; in this case the consumption of a standby power is 3W when the light is switched on. An on/off occupancy sensor is permanently in standby mode (electric power of 3W) and it activates the lighting whenever occupancy is detected.
The controlled dimmed lighting system photosensor consists of a photocell (standby power of 2W) which dims the activated light until the total work plane illuminance reaches the illuminance threshold (500 lux). At a minimum lighting output of 1% the system consumes 15% of its full electric power. The lighting is activated by a manual switch on/off near the door. The combination dimmed lighting and energy-efficient occupancy sensor has a standby power of 5W.

RESULTS

Annual illuminance profiles

The simulations of the annual illuminance profile have been carried out with DAYSIM, for each latitude, in the two façade configurations, with the blinds slats at different angles, as explained in the table below (Table 3).

Table 3
Description of the façade configurations

up	no shading device, neither fixed nor movable
int_ss	internal light shelf, 0.4 m wide
int_sl	internal light shelf, 0.8 m wide
ext_ss	external light shelf, 0.8 m wide
ext_sl	external light shelf, 1.35 m wide
ss	internal light shelf, 0.4 m wide and external light shelf, 0.8 m wide
sl	internal light shelf, 0.8 m wide and external light shelf, 1.35 m wide
45	movable blind, in the lower part of the façade, with slats at 45°
45ss	internal light shelf, 0.4 m wide and external light shelf, 0.8 m wide movable blind, in the lower part of the façade, with the slats at 45°
45sl	internal light shelf, 0.8 m wide and external light shelf, 1.35 m wide movable blind in the lower part of the façade with the slats at 45°
45_0	movable blind, in the lower part of the façade, with the slats at 45° movable blind in the upper part of the façade, with the slats at 0°
45ss0	internal light shelf, 0.4 m wide and external light shelf, 0.8 m wide movable blind, in the lower part of the façade, with the slats at 45° movable blind in the upper part of the façade, with the slats at 0°
45sl0	internal light shelf, 0.8 m wide and external light shelf, 1.35 m wide movable blind, in the lower part of the façade, with the slats at 45° movable blind in the upper part of the façade, with the slats at 0°
45ss30	internal light shelf, 0.4 m wide and external light shelf, 0.8 m wide movable blind, in the lower part of the façade, with the slats at 45° movable blind in the upper part of the façade, with the slats at 30°
45sl30	internal light shelf, 0.8 m wide and external light shelf, 1.35 m wide movable blind, in the lower part of the façade, with the slats at 45° movable blind in the upper part of the façade, with the slats at 30°

The following graphs (Fig.4) show the monthly illuminance profiles for the façade with the shorter light shelf (Stockholm and Venice) and the longer one (El Cairo, Bombay and Colombo). These values have been obtained by the average of the simulated illuminance values of each month of the year. These profiles, reported in four representative months of the year (March, June, September and December), refer to the "shading down" condition, with the venetian blinds fully down, with the lower blind with the slats at 45° and the upper one at 0°, which turns to be the more efficient for all the work-stations.
In Stockholm, daylight need to be controlled, especially at midday, in spring and autumn, when the sun is low on the horizon and light, directly entering in the room, determines unacceptable high values of illuminance and therefore luminances and glare. In this case, it is necessary to keep the blinds with a greater slat angle. In Venice, the same problem occurs in winter.
In the other three sites, these configurations provide an efficient daylight control and illuminance distribution.

Illuminance in the work planes

The simulations in particular sky conditions and time of day and year have been performed with RADIANCE. Different façade configurations have been simulated (Table 2), in order to determine the effect of each device separately, compared to the case with no shading provided ("up").
The graphs in Fig. 5 show the main important results obtained in a sunny day (standard CIE clear sky) of December, 21, at noon, when there is a low solar altitude. In all the sites considered, in this particular sky condition and time, the illuminances are higher than the required ones.
For Stockholm, due to the fact that December does not show significant results, the illuminance values in a sunny day of March are also reported, the month in which the annual illuminance profile (Fig. 4) reveals a peak of illuminance. In fact, in March, the illuminance, in work plane 1 is controlled only if there is a long light shelf ("sl") or a combination of light shelf and blinds ("45ss0" or "45ss30"). In the work plane 2, it is also necessary to keep the upper blind with the slats at 30°.
For an office in Venice, the illuminance in work plane 3 is over 10000 lux in every façade configuration, except the one with the light shelf and the blinds with the slats at 45° and at 30°, the lower and the upper one respectively. For work planes 1 and 2, only a blind with the slats at 45° can control the illuminance level.
The case of El Cairo reveals that the longer light shelf ("int_sl", "sl") is sufficient to control illuminance in work planes 1 and 2.
Finally, for an office located in Bombay, the work plane 1 reaches an acceptable illuminance level only with the longer light shelf.

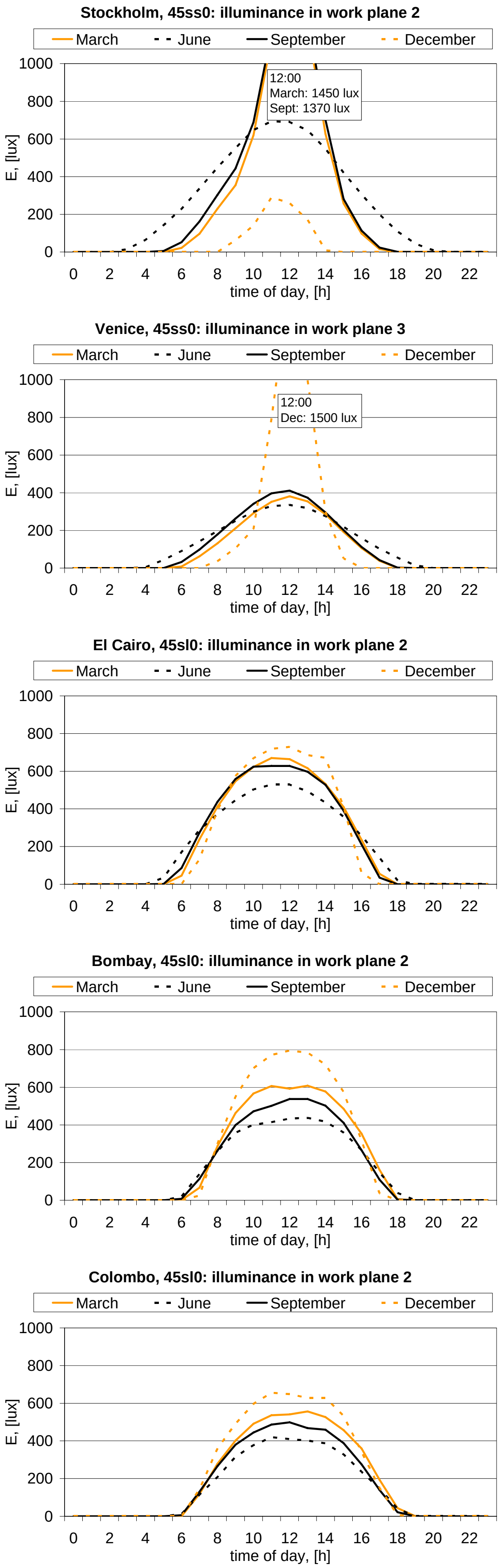
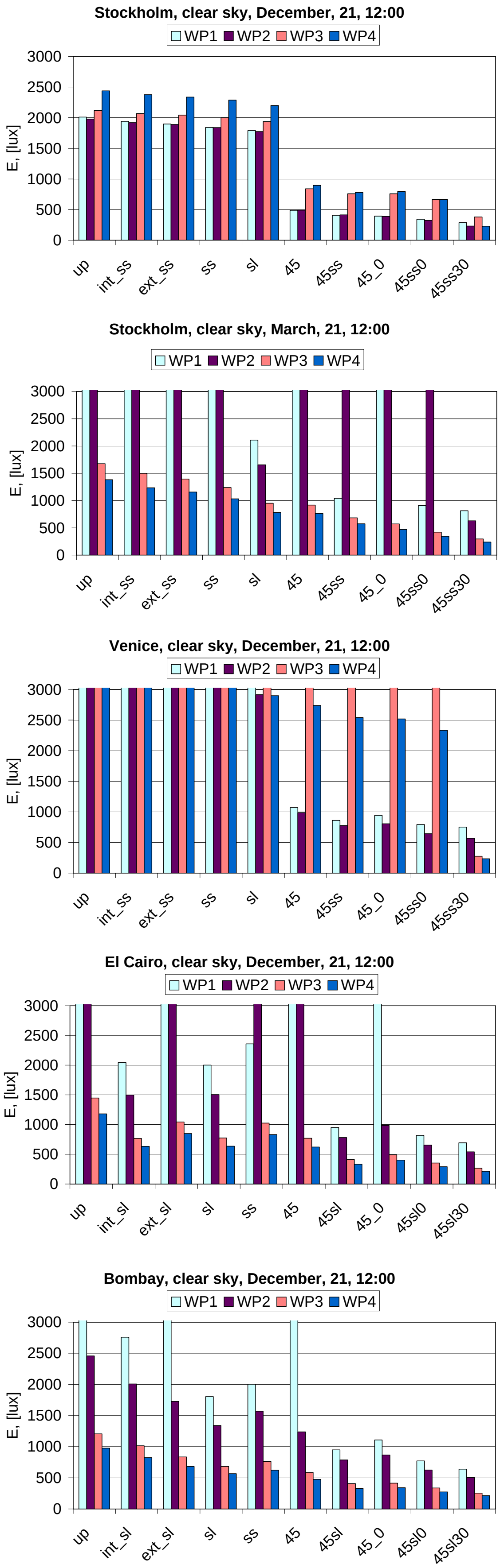


Figure 4 Average illuminance profiles in March, June, September and December



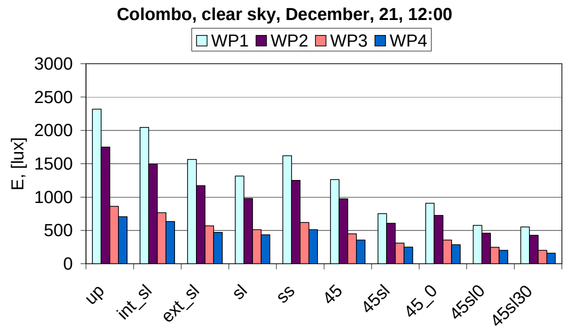


Figure 5 Illuminance in the work planes

For Stockholm and Venice, in December, the effect of the longer light shelf is the same of the shorter one, while in a sunny day of March the longer one provides a better shading in the area close to the window. However, the annual profile reveals that the shorter light shelf performs better all over the year.

In general, an internal light shelf reduces daylight penetration in the first part of the room, increasing illuminance uniformity, while an external light shelf controls the thermal load.

The simulations in overcast conditions are not reported, since they do not show significant results.

Illuminance values along the central axis

For the different façade configurations explained in Table 3, the predicted illuminance values along the central axis at work plane level (0.75 m) have been simulated and they are shown in Fig. 6. For each site, the sky condition is the standard clear CIE and time is December, 21, at noon.

In Stockholm, the higher illuminance values are in the deep part of the office, because of very low solar altitude. In Venice, and in the other three locations, it is possible to reduce the high illuminance values close to the windows only by means of blinds.

Daylight Factor (DF)

The daylight factor is a parameter which indicates the availability of daylight in buildings. In an office, a DF_{med} of 2% is required.

The Figure 7 reports the DF over the work planes. The Standard EN 15193 classifies the daylight penetration as a function of the DF: if $1\% \leq DF < 2\%$, it is considered weak, if $2\% \leq DF < 3\%$, medium, if $DF \geq 3\%$ strong. A DF of less than 1% is irrelevant. In this case, a medium daylight penetration is reached only with the blinds up.

The daylight factor measures the amount of daylight in buildings in a specific sky condition – the overcast one- which is the worst sky condition.

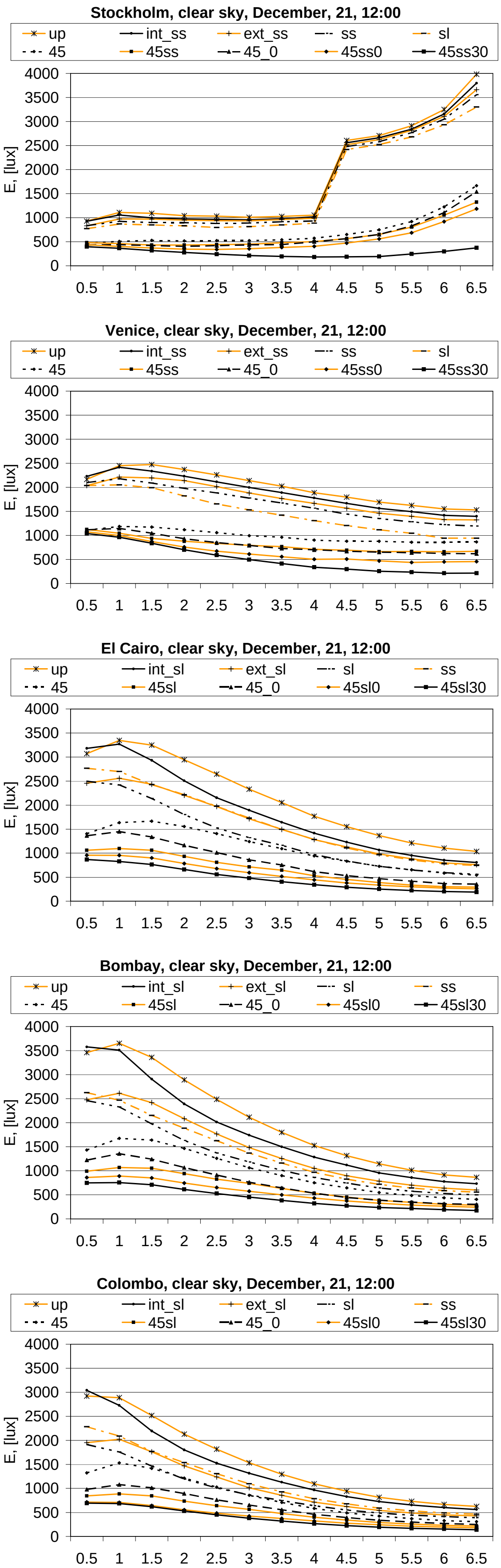


Figure 6 Illuminance along the office central axis

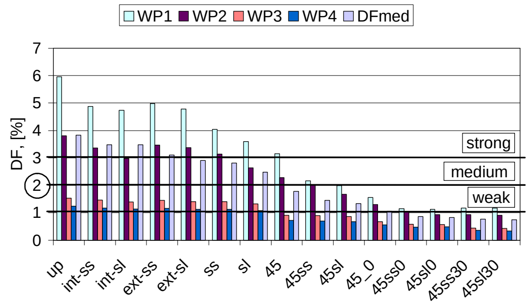


Figure 7 Daylight Factor in the four work planes

This parameter takes into account the building geometry, the external obstructions and the material properties. It is a factor that gives information about the quantity and not about the quality of light inside a building. It does not take into account the building orientation, the time of day, the season, the site, the weather conditions, the variable sky conditions, etc. Despite of that, all the Standards refer to the daylight factor as a performance metric for daylighting. In this work, some dynamic daylight performance metrics, which consider the climate of the building site and the occupational profile of the building, have been calculated with the software DAYSIM.

Dynamic daylight performance metrics

Some daylight indexes have been proposed as alternatives to the daylight factor metric to evaluate the performance of buildings (Reinhart, Mardaljevic et al., 2006). In Table 4 these metrics are reported for each work-station, comparing the difference between a passive and an active user who operates the blind manually and an automated shading control.

Table 4
Dynamic daylight performance metrics

	Shade control	Passive Manual				Active Manual				Automated			
	WP positions	WP1	WP2	WP3	WP4	WP1	WP2	WP3	WP4	WP1	WP2	WP3	WP4
Stockholm	DA, [%]	40	35	9	4	53	49	25	19	64	60	35	26
	DA_{cont}, [%]	60	57	42	36	70	67	54	48	76	74	61	55
	DA_{max}, [%]	0	0	0	0	0	0	0	0	1	0	0	0
	$UDI_{<100}$, [%]	28	29	36	40	20	21	28	31	16	18	25	27
	$UDI_{100-2000}$, [%]	72	70	64	60	71	73	71	68	68	74	75	73
	$UDI_{>2000}$, [%]	0	1	1	0	10	5	1	0	16	8	1	0
Venice	DA, [%]	41	34	5	2	67	62	38	27	77	72	43	30
	DA_{cont}, [%]	68	65	45	36	82	79	66	59	88	85	71	64
	DA_{max}, [%]	0	0	0	0	0	0	0	0	0	0	0	0
	$UDI_{<100}$, [%]	16	18	25	30	8	9	16	20	6	7	13	15
	$UDI_{100-2000}$, [%]	84	82	73	70	76	86	82	80	75	86	86	84
	$UDI_{>2000}$, [%]	0	0	1	0	16	5	1	0	19	7	1	0
El Cairo	DA, [%]	67	48	2	0	90	87	56	39	94	91	63	46
	DA_{cont}, [%]	88	83	54	45	94	93	84	78	97	96	87	82
	DA_{max}, [%]	0	0	0	0	0	0	0	0	0	0	0	0
	$UDI_{<100}$, [%]	4	4	7	9	3	4	5	6	1	2	3	4
	$UDI_{100-2000}$, [%]	96	96	93	91	81	94	95	94	77	93	97	96
	$UDI_{>2000}$, [%]	0	0	0	0	16	2	0	0	22	6	0	0
Bombay	DA, [%]	58	40	1	0	95	91	56	39	96	93	59	42
	DA_{cont}, [%]	88	81	53	43	99	97	87	80	99	98	89	82
	DA_{max}, [%]	0	0	0	0	0	0	0	0	0	0	0	0
	$UDI_{<100}$, [%]	1	1	3	6	0	0	1	1	0	0	0	1
	$UDI_{100-2000}$, [%]	99	99	97	94	81	97	99	99	79	97	100	99
	$UDI_{>2000}$, [%]	0	0	0	0	19	3	0	0	21	3	0	0
Colombo	DA, [%]	53	32	0	0	97	94	60	41	98	95	61	41
	DA_{cont}, [%]	86	79	50	41	99	98	90	83	100	99	90	84
	DA_{max}, [%]	0	0	0	0	0	0	0	0	0	0	0	0
	$UDI_{<100}$, [%]	0	1	3	6	0	0	0	1	0	0	0	0
	$UDI_{100-2000}$, [%]	100	99	97	94	82	98	100	99	82	98	100	100
	$UDI_{>2000}$, [%]	0	0	0	0	18	2	0	0	18	2	0	0

The Daylight Autonomy (DA) in a particular point of a building is defined as the fraction of the occupied times per year when daylight is sufficient to guarantee the required illuminance level. This metric consider all sky conditions throughout the year, while the daylight factor refers only to the overcast one. It also depends on the occupancy hours, the status of the blinds during the year and the required illuminance; it does not take into account the installed electric lighting power and lighting control, so it cannot be considered a parameter to evaluate energy savings. An automated shading control can efficiently improve Daylight Autonomy only in Stockholm and in Venice, while in the other three sites an active user can reach almost the same results.
The Continuous Daylight Autonomy (DA_{cont}) is a quite recent metric that considers the fact that many office occupants work under the minimum illuminance required by the Standards. This index, in fact, attributes a credit even when daylight ensures an illuminance level under the required one. In the analysed building, for the two work planes in the back of the office, the DA_{cont} value is twice the DA for the active manual and for the automated shade control while, for the passive manual, it is even higher (i.e. from 0% to 50%).
The Maximum Daylight Autonomy (DA_{max}) indicates, in percentage, if, during occupied hours, direct sunlight occurs or excessive daylight conditions are present. In this case, this value is every time 0%, except for WP1 in Stockholm.
The last index is the Useful Daylight Illuminances (UDI): it gives informations about how “bright” is an environment and if the daylight levels exceed the required and the actual useful ones. This metric is divided in three indexes, $UDI_{<100}$, $UDI_{100-2000}$ and $UDI_{>2000}$, depending on the illuminance threshold considered (< 100 lux, 100-2000 lux and > 2000 lux). If there is a high percentage of $UDI_{<100}$, the ambient would result too dark, while if $UDI_{>2000}$ is high it would result too bright and then glare would occur.
From Table 4, it can be deduced that, for lower latitudes, the “useful daylight” lies almost all around the range of 100-2000 lux, while, for Stockholm, the $UDI_{100-2000}$ is around the 70%.

Electric consumption for artificial lighting

The different lighting and blind control strategies analysed, combined with the user behaviour, are summarised in Table 5.
The electric energy demand for artificial lighting is represented in Fig. 8. The user behaviour is very important: only if the user interacts with the building a significant reduction is possible to be reached. For example, the combination passive user with the most performant BMS system (SFD), compared to the one with an active or a mixed user, confirms this statement.

Table 5
User behaviour and control strategies analysed

User beviour type		Lighting control	Blind control	Symbol
lighting	blind			
passive	passive	manual switch on-off	man	PM
active	active	manual switch on-off	man	AM
mix	mix	manual switch on-off	man	MM
active	active	automatic switch-off	autom	ASF
mix	mix	automatic switch-off	autom	MSF
mix	mix	dimmer	autom	MD
active	active	dimmer	autom	AD
passive	passive	autom switch off and dimmer	autom	PSFD
active	active	autom switch off and dimmer	autom	ASFD
mix	mix	autom switch off and dimmer	autom	MSFD
mix	mix	autom switch on/off and dimmer	autom	MSNFD

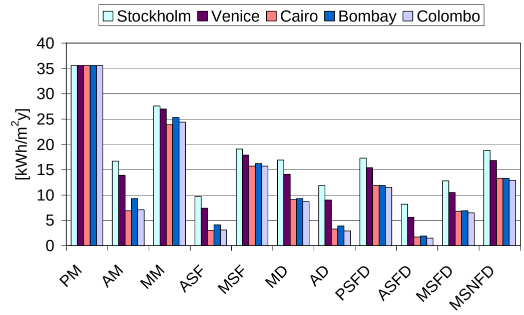


Figure 8 Energy requirement for artificial lighting, for the five investigated places, considering users' behaviour and different control strategies

The combination passive user and manual control has the same energy consumption in all the latitudes, because it is supposed that the occupants leave the blinds fully down all the time.
The reduction of energy consumption by means of BMS systems are listed in Table 6.

Table 6
Electric energy reduction, depending on user behaviour and control strategies

	S-45ss0	V-45ss0	CA-45sl0	B-45sl0	C-45sl0
PM--AM [%]	53	61	81	74	80
PM--MM [%]	22	24	33	29	31
PM--PSFD [%]	51	57	67	67	68
AM--ASF [%]	42	47	57	56	56
AM--AD [%]	29	35	52	58	59
AM--ASFD [%]	51	60	75	80	79
MM--MSF [%]	31	34	34	36	36
MM--MD [%]	39	48	62	63	64
MM--MSFD [%]	54	61	72	73	73
MM--MSNFD [%]	32	38	44	47	47
MSFD--ASFD [%]	36	47	75	72	77
PSFD--ASFD [%]	53	64	86	84	87

CONCLUSION

This work shows that daylighting systems are necessary to control visual environment, because they provide solar shading, protection from glare and redirection of light. Each latitude needs different shading devices: in high latitudes (Stockholm), cloudy skies are predominant and the exterior illuminance on winter days at noon is often even less than 5000 lux, while a realistic horizontal illuminance for a brightish overcast sky is about 10000 lux. In these latitudes light shelves are not sufficient, while for low latitudes they can correctly control visual comfort in indoors.

On the other hand, daylighting systems can reduce peak demand especially during summer peak periods, when there is a good daylight availability: if no shading device is provided, solar heat gains can increase the cooling load. The optimization of the use of BMS system, integrated with daylight, can save energy, both for artificial lighting and cooling demand: they can reduce electric power for artificial lighting from 31 % to 73 %, supposing a mixed user behaviour, depending on control strategies and site latitude.

The evaluation of sustainable buildings cannot be drawn without considering how the occupant behaves and interact with the environment, in terms of shading and lighting control. In many office buildings it happens that people work with the light switched on, leaving the blinds down, even when there is no possibility of glare appearance (Rea, 1984). Simulations carried out in this work, confirm that the combination "passive user" and "manual control" is responsible of a non efficient building. For that reason an automated lighting and shading control system should be provided.

The actual Standards evaluate the amount of daylight entering a space by means of the daylight factor, a parameter that is just a "quantitative" information, not sufficient to evaluate the "quality" of light (i.e. a complete glazed building would reach a very high DF, but it would have many problems, in terms of thermal comfort and energy consumption). The software DAYSIM is very useful, since it includes a behaviour occupancy model and it can help the designer to analyse and compare critically the impact of different shading devices and control strategies, by means of some dynamic daylighting metrics.

Finally, the concept of visual comfort depends on people and a lighting condition can be acceptable for a person but not for another. The Standards try to give some suggestions with the purpose to create a acceptable and safe environment, but they miss many aspects (i.e. people preferences and behaviour, etc).

It would have been interesting to compare these simulation results by directly measuring the illuminance values in a real office room, asking the occupants, by means of questionnaires, how they feel in those conditions, which shading they prefer and how and if they operate the lighting and shading systems.

REFERENCES

Boyce, P. 1998. Why Daylight? Proceeding of Daylight Technologies for Energy Efficiency in Buildings. Ottawa, Ontario, Canada, p. 359-365.

De Carli, M., De Giuli, V., Zecchin, R. 2008. Review on visual comfort in office buildings and influence of daylight in productivity, Indoor Air 2008, Copenaghen, Denmark.

Heerwagen, J.H., Orians, G.H. 1986. Adaptations to windowlessness: a study of the use of visual decor in windowed and windowless offices, Environ. Behav., n. 5, 623-39.

Heerwagen, J.H. 1990. The psychological aspects of windows and window design, Environ. Des. Res. Assoc., n. 38, 260-80.

IEA, Daylight in Buildings 2000. A source book on daylighting systems and components.

Perez, R., Seals, R., Michalsky, J. 1993. All-Weather Model for Sky Luminance Distribution– Preliminary Configuration and Validation. Solar Energy, 50 (3): p. 235-245.

Rea, M.S. 1984. Window blind occlusion: a pilot study, Building Environ., n. 19, pp. 133-7.

Reinhart, C. F. 2004. Lightswitch 2002: A model for manual control of electric lighting and blinds. Solar Energy, 77: p. 15-28.

Reinhart, C.F. 2005. Tutorial on the Use of Daysim Simulations for Sustainable Design. IRC, Institute for Research in Construction.

Reinhart, C.F., Mardaljevic, J., Rogers, Z. 2006. Dynamic daylight performance metrics for sustainable building design, NRC-CNRC, Canada.

Ward, G., Shakespeare, R. 1998. Rendering with Radiance. The Art and Science of Lighting Visualization. Morgan Kaufmann Publishers.

2002. EN 12464-1, Lighting of work places - Part 1: Indoor work places.

2007. EN 15193, Energy performance of buildings - Energy requirements for lighting.