Energy saving through solar lighting systems

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Abstract: - Among the energy expenses for a building, the lighting system can contribute up to 50% of the total electrical consumption, and especially large quantities of energy are used in schools and office buildings.

One possible method to reduce such consumption is to exploit solar, or natural, light. Through natural light, it is possible to illuminate indoor environments while maintaining appropriate illuminance levels necessary for indoor activities. Indeed, it is a mistake to search for the maximum energy savings, if this creates a possible disturbance to a person's visual health in the office.

Moreover, it is important to highlight that the light quantity is not enough to evaluate the working comfort; the light quality must also be held in consideration. Therefore, for optimal energy savings, the most favorable combination of the elimination of energy waste, the light quality, and the light quantity must be assessed.

Key-Words: - Natural light, solar light, energy saving, Daylighting, energy certification, insulation

1 Introduction

In many daily-life environments, it is often possible to note that artificial light is turned on when it is not necessary. Such situations are due to the habit of turning on artificial light systems (lamps) if the natural light appears not to be sufficient to illuminate the room.

The probability of turning on of artificial light sources as a function of the illuminance level on the job area is shown in Fig. 1; as an example, if the natural illuminance is around 100 lx, the probability that the lights are turned on is very high, at around the 50% [1].

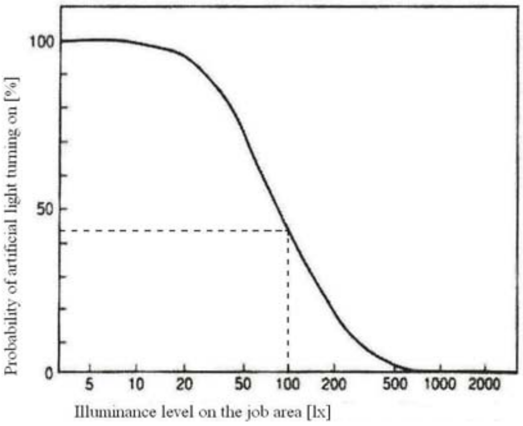

Fig. 1. Probability of turned on of the lights as a function of the level of illuminance.

Therefore, if the illuminance level is not enough when we come into an office, we turn on the artificial light systems even if the natural light should actually be sufficient for the greater part of the day. This aspect, the indoor lighting systems, has its own importance with regard to energy, even if it is not the most affects the electricity consumption; in Italy, the annual quota of electrical energy for such use is, altogether, greater than 7 billion kWh, corresponding to approximately 13.5% of the total consumption of electric energy. Any reduction on this percentage, although it may already seem reasonable, is a remarkable result. In this paper, the technique of using natural lighting systems (or Daylighting) in place of artificial ones is described, where this allows intriguing values of energy savings to be obtained. The reduction of electrical loads (derived from the lighting system) and the reduction of cooling loads (derived from the use of particular glasses or films) lead to a reduction of the energy bill. Moreover, it is possible to guarantee a good optical-visual comfort with such lighting, determined from the numerous benefits connected to solar lighting systems (Daylighting).

2 Natural light and comfort

After the lamps discovery, investigations on the effects of artificial lighting sources have been focused above all on visual fatigue, erroneously thinking that a high illuminance level is synonymous of optimal vision.

Only recently, lighting biological effects have become topics of research in the medical field. According to such studies, the eye does not exclusively perform visual functions, but it also fulfils a more important task not believed until a short time ago: the management of the biochemical equilibrium of the human body [2]

Indeed, in addition to the light communication between the retina and the visual cortex, researchers attribute another nervous system communication link to the eye. Unrelated to the visual ability, this link starts from the retina arrives at the hypothalamus[1] and controls the epiphysis, an endocrine gland situated in the brain.

This gland, also called the "third eye", is considered like a biological clock, controlled by natural light, that exerts its influence through the secretion of a hormone (melatonin) on the human been biological rhythms, for example the circadian rhythms.

Natural light, as opposed to artificial light, offers exactly what is necessary for better biochemical equilibrium of the body, which translates to a greater feeling of well-being from people who finds themselves in a room illuminated by the sun.

The reason the eye perceives sunlight differently in comparison with artificial sources (for example a filament lamp) is the differences in the emission spectra of the radiation.

In fact, although the two spectral distributions are both continuous (Fig. 2), it is observed that, for solar light (Fig. 2a), the wavelengths in the visible range are all present and in almost similar amounts, with a maximum corresponding to the relative wavelength of green light. Indeed, the spectrum of a filament lamp (Fig. 2b) shows a reduced amount of radiation that is mostly concentrated in the zone of greater wavelengths (red light).

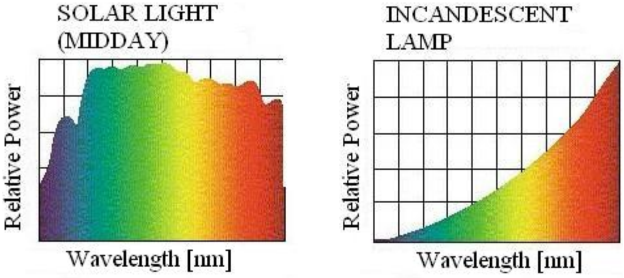

Fig. 2. Electromagnetic spectrum of emission (on the left) for solar light at midday, and (on the right) for a incandescent lamp.

The feeling of greater well-being resulting from the presence of sunlight influences mental activities considerably. Through a suitable plan for a natural lighting system, two components have to be take into consideration [3]:

- the quantitative, in terms of a correct illumination of workplace;
- the qualitative, in terms of a proportional distribution of the light and therefore of luminance.

These two components allow to obtain an increase in working stimulus; concentration ability can be enhanced, and fatigue can be delayed. Various studies demonstrate that, in a room illuminated by the sun, the ability to pay attention can increase by 15%, the activity of logical thought can increase by 9%, and the safety/rapidity of calculation can increase by 5% [4].

The two previous components are not enough for the lighting plan, since, at the *CIE Symposium on Lighting Quality* in 1998, the multidimensional nature of the lighting system plan emerged. As will be explained later, the quality of the lighting plan is dependent on the interaction of:

- the individual;
- the integration of the light with the architecture;
- the economic/environmental aspect.

3 The natural light and the energy certification of buildings

In Europe, it is estimated that approximately 40% of the total energy is destined to satisfy the energy requests of buildings; these is becoming a more onerous field than manufacturing or transportation (Fig. 3).

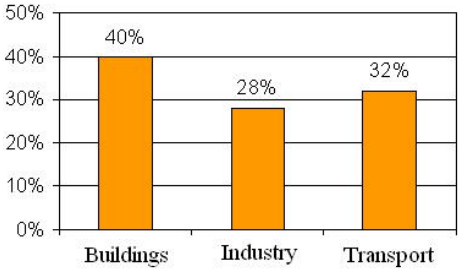

Fig. 3. Subdivision of the total energy consumptions.

In order to contain energy waste and its environmental impacts, the European Community extended the *Energy Performance of Buildings Directive* (EPBD) in 2002 with the aim to classify buildings as a function of their energy usage.

The energy certification of buildings represents an essential stage for the improvement of the energy performance in the planning and restructuring steps and it is an instrument for the transformation of the

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[1] The hypothalamus is a region of the brain situated under the thalamus that forms the extended part of the ventral region of the diencephalons. Its function is to regulate some metabolic processes, among which are the control of body temperature, hunger, and thirst.

real estate market. The energy certification supplies customers with objective information on the energy performance of buildings.

Moreover, the application of such a directive allows to:

- obtain substantial energy saving;
- satisfy the energetic requirements of the EU.

The energy efficiency expresses the amount of estimated energy that is effectively consumed in order to satisfy all the various needs connected to the use of the building (heating of air and water, air conditioning, ventilation, lighting system, etc…) [5].

According to the European standards, the value of such a parameter must be expressed by one or more numerical parameters calculated by considering the insulation, the solar and indoor lighting contributions, the state of the air, the technical characteristics, the architecture and the position in relation to the climatic aspects, the exposure to the sun and its use, the influence of the adjacent buildings and the renewable generation of energy and other factors, including the indoor climatic quality.

In particular, the European directive has a technical attachment in which the parameters that are part of the calculation method of the buildings energy efficiency are specified, and among these is the contribution of the lighting system. Moreover, continuing in the analysis of the standard, it is possible to see that the methodology of energy efficiency calculation also considers the advantages offered by a natural lighting system.

To this purpose, the European Commission, to define a calculation methodology of the total energy performances of buildings, follows the standard EN 15193 (*Energetic appraisal of the buildings - Energetic requirement of the lighting*) to calculate the amount of energy used by the lighting systems [6].

This European standard defines the parameter *Lighting Energy Numeric Indicator* (*LENI*), which describes the energy consumption in kWh per square meter annually for the lighting system:

$$LENI = \frac{W_{light}}{m^2 / year} \qquad (1)$$

where W_{light} represents the energy consumption of the lighting system defined by the following expression:

$$W_{light} = \sum \left(P_n \cdot F_C \right) \cdot \left[\left(t_D \cdot F_O \cdot F_D \right) + \left(t_N \cdot F_O \right) \right] \qquad (2)$$

where:

- P_n is the absorbed power of the entire lighting system;
- t_D is the number of hours of day employment;
- t_N is the number of hours of night employment;
- F_C, F_D and F_O are no-dimensional coefficients always ≤ 1, in particular:
  - F_C is related to the constant light sensor;
  - F_D is related to the sunlight sensor;
  - F_O is related to the presence sensor.

In addition, to identifying the energy consumption of the lighting system, as indicated by the *LENI* parameter, it is also important to quantify the quality of the light. Toward this aim, the *Ergonomic Lighting Indicator* (*ELI*) has been defined. The *ELI* of a space is determined through a questionnaire answered by customers present in the space under study, and it describes five ergonomic properties of the light:

A. visual performance;
B. general aspect;
C. visual comfort;
D. emotionality;
E. individuality.

Each property is quantified by a directory of survey responses that is attributed a variable score from 0 (for null) to 5 points (excellent). The value of the score for a property represents all of the corresponding survey responses. Naturally, more positive are the individual responses, greater is the associated score.

It is possible to see in the pentagonal diagram in Fig. 4 the evaluation of the various criteria. The total quality of the adopted lighting solution is function of covered surface area on the diagram (the *ELI* factor grows with covered surface).

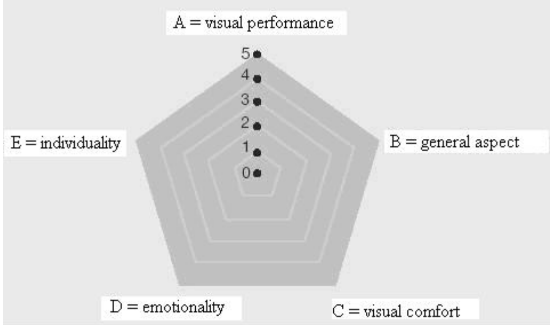

Fig. 4. Pentagonal diagram showing the divisions of the criteria for ergonomic quality of a lighting system.

A balanced lighting system assesses both parameters previously described: the *ELI*, which considers the physical and psychical effects on people; and the *LENI,* which quantifies the energy efficiency, and therefore the economic and ecological aspects of the lighting system.

Indeed, according to the medical literature, subjectival evaluations of workers appear to be related to many individual and environmental factors [7].

Only for example, Fig. 5 shows the representative pentagonal diagrams for an office, Fig. 5a) and an industry, Fig. 5b). These diagrams indicate the minimum scores necessary for the lighting systems in these two places.

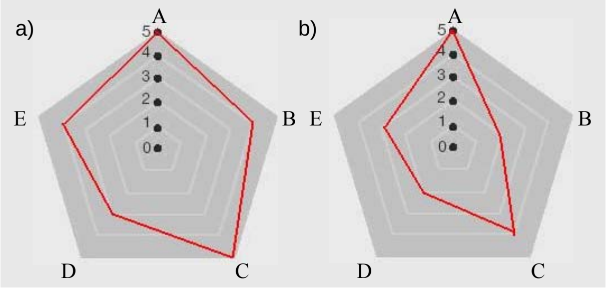

Fig. 5. Pentagonal diagram a) for offices, b) for industries.

4 Daylighting project

The lighting system in a building, similar to the heating, ventilation, and hygrometric states, helps to create the conditions of well-being that must be assured both in houses and in offices. Insufficient lighting conditions do not generate effects of immediate disturbance, which is a different bodily response than other microclimatic factors. Indeed, the eye has a large capacity to adapt to critical vision conditions. Planning a natural lighting system means [4], therefore, not only guaranteeing the availability of light in absolute terms of illuminance, but also guaranteeing it in relative terms. This requires an understanding of the correct distribution of the solar light in the space for a pleasant feeling of well-being. Besides the necessity of having a sufficient amount of light, there are other requirements that contribute to the definition of the quality of a luminous atmosphere (for instance, the absence of a dazzling source in the field of vision, the maintenance of limited fluctuation about the luminance value among the visible surfaces, etc… [8]). The Daylighting plan must be realized with the aims of both verifying if the illuminance, supplied from the sunlight, turns out to be sufficient for the activity development in the room and in agreement with the standard (in particular during the winter period), and of guaranteeing the optical-visual comfort demanded. A plan for a natural lighting system is not very different from that for an artificial lighting system; indeed, the lighting variables in either case are the same. The only difference is due to the fact that diurnal illuminance is a function of the Sun position (and therefore of the hour and the latitude) and it is variable depending on the atmospheric conditions. In order to remove the time domain from calculations, the sunlight factor or *Daylighting Factor* (*DF*) is introduced. The *DF* constitutes a pointer of the efficiency of a Daylighting system, and it provides a way to determine the proportion of glass surfaces as a function of the activity that the people carry out in a room [9]. The Italian standard, in reference to Art. 5 of the Health Ministry ordinance of July 1975, establishes that, "*the windows size have to guarantee a DF not inferior to 2%*" [10]. *DF* can be evaluated by the following expression:

$$DF = \frac{E_i}{E_e} = \frac{\tau \cdot A_v \cdot \varepsilon \cdot \psi}{A_{tot} \cdot (1 - \rho_m)} \tag{3}$$

where:

- A_v is the area of the window surfaces net of the chassis;
- A_{tot} is the sum of the indoor surfaces of the room (flat, walls and roof);
- τ is the luminous transmission factor of the glass;
- ε is the window factor; it is the fraction of the sky that can be seen through the window (0.5 for vertical windows);
- ψ is the reduction factor of the window factor, and it is a function of the position of the glass with respect to the external thread of the wall;
- ρ_m is the medium reflection ponderal factor of the inner surfaces of the room, it is evaluable by the following expression:

$$\rho_m = \frac{\sum_i A_i \cdot \rho_i}{\sum_i A_i}. \tag{4}$$

Therefore, the Daylighting plan is bound to the calculation of a single parameter (*DF*) that, on one hand, reveals the quantitative availability of sunlight, but on the other hand not does supply any indication of the quality of the lighting system.

5 Case Study

To explore the possible energy savings offered by a Daylighting system and the contribution that this technique can make to the elevation of the energy class of a building, the technique has been tested for an office (6x5x3m) located in Milan. The simulations have been executed for four different situations: with exposure of the window to the South, to the West, the East and to the North, each assuming that the working hours are from 9:00^{am} to 7:00^{pm}. For the energy savings calculation, the simulations have been executed (for every case defined previously) for every hour when the office is open, for every month of the year, and for three different sky conditions (cloudy, partly cloudy and sunny), in order to determine the illuminance value through the natural lighting system.

The Daylighting system is influenced by the meteorological conditions. The distribution of the number of working days for each of the three sky conditions for every month, valid for the city of Milan, are reported for the year 2006 in Tab.1.

Table 1. Distribution of the working days in the three sky conditions for every month in 2006.

Month	*Cloudy sky*	*Partly cloudy sky*	*Sunny sky*
Jan	9	4	8
Feb	12	4	4
Mar	8	9	5
Apr	11	4	4
May	12	7	4
Jun	4	12	5
Jul	7	7	7
Aug	13	5	4
Sep	8	9	4
Oct	11	8	3
Nov	13	6	2
Dic	11	5	1

For the appraisal of the energy savings, the lighting system was first planned; in this case, the medium level of illuminance recommended by the standard is 500 lx. The illuminance demanded by the standard has been obtained by installing 9 lights (40 W each) on 3 rows. Each light has a luminous flux of about 3300 lm. The total power of the system is about 360 W. In order to estimate the energy savings, it is necessary to calculate the energy consumption per years under the hypothesis that the entire system of lamps is ignited for all opening hours of the office for every working day of the year (Tab. 2).

Table 2. Total energy consumption for every month without regulation

Month	*Working days*	*Energy consumption (kWh)*
Jan	21	75.6
Feb	20	72.0
Mar	22	79.2
Apr	19	68.4
May	22	79.2
Jun	21	75.6
Jul	21	75.6
Aug	22	79.2
Sep	21	75.6
Oct	22	79.2
Nov	21	75.6
Dic	17	61.2

Next, the level of natural illuminance has been estimated in three characteristic points of the room (indicated in Fig. 6 with roman numbers I, II, and III) that are under the rows of lights at the height of the working areas (0.8 m). In this way, it is possible to establish the correct regulation of the lamps as a function of the natural illuminance level. When one of the three points has a lower illuminance level the lamps are ignited, and artificial light is thereby used.

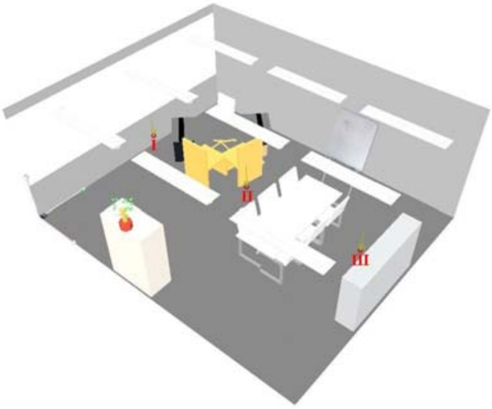

Fig. 6. Representation of the office and the points of calculation in relation to artificial sources.

It is necessary to verify that, in every zone of the office and in every hour of every day for every month, the level of illuminance demanded (500 lx) is obtained through the Daylighting system. When and where the minimun level is not met, it is necessary to use artificial sources, supposing that the entire system has been planned to activate or to exclude (on/off) 1 row of lights. The results of simulations for the four different exposures are detailed in the following section; in particular, only for the window to the South has been given greater space and all passages of the calculations have been reported here.

5.1 Window to the South

In the following pictures, distributions of the illuminance in the office have been estimated with different colours, based on the legends reported in the relative figures, for two characteristic days (the first sunny and the second cloudy). Fig. 7 represents the sunny sky condition for the 21st of June at 12.00pm.

As shown in Fig. 7, the zone near the window is characterized by an intense radiation that results in a dazzle situation due to direct solar light. It is possible to obtain beyond 2000 lx in this area. The illuminance decreases when the distance from the windows increases. Far from the windows, the illuminance values are not sufficient for conducting the normal office activities.

In Fig. 8, the illuminance values for this sky condition can be seen. In this particular situation, the first two rows of lamps can always remain turned off, while the third row (that is the farthest from the window) must always remain ignited.

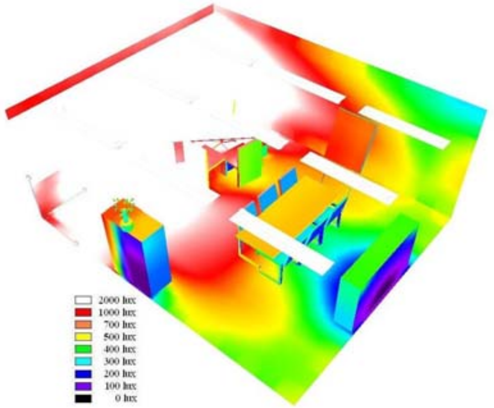

Fig. 7. Illuminance levels on 21st June at 12.00pm for sunny sky conditions.

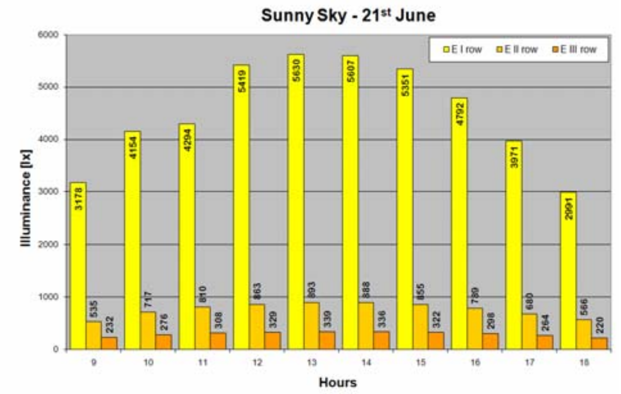

Fig. 8. Illuminance values for the three characteristic points in the room on 21st June for the sunny sky condition.

Fig. 9 is a representation of the illuminance on 21st December at 12.00pm for covered sky conditions. December is the most critical month for illuminance indeed the zone nearest the window only catches the minimum illuminance value required by the standard.

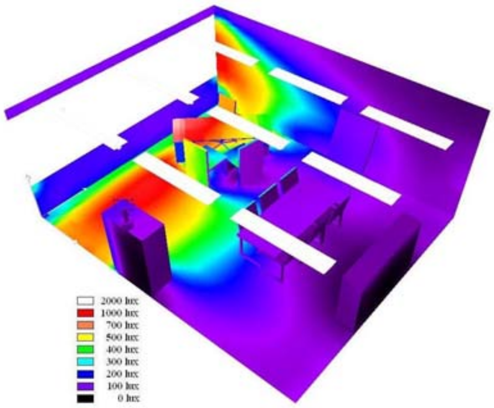

Fig. 9. Illuminance levels on 21st December at 12.00pm for cloudy sky conditions.

For these sky conditions, the illuminance values are illustrated in Fig. 10. From the diagram in Fig. 10, in December with cloudy sky conditions, the first lamps row can only be turned off from 9.00am to 3.00pm, when the illuminance value is greater than 500 lx. The procedure seen for these two days was carried out for the 21st day of every month for all the different sky conditions.

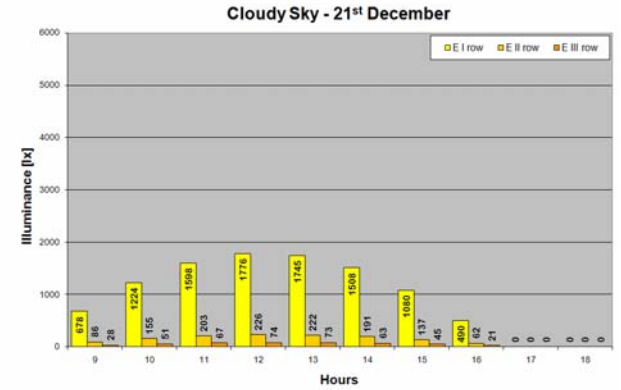

Fig. 10. Illuminance values in the three characteristic points of the room on 21st December for the covered sky condition.

Knowing the number of lamps needed and the number of sunny, partly cloudy, cloudy days for each month, it is possible to determine the power consumed by every apparatus and the total energy saving. The results are reported in Tab. 3.

Table 3. Energy consumed for every month with light regulation (kWh)

Month	*Energy consumption (kWh)*			*Total energy saving (kWh)*
	Cloudy sky	*Partly cloudy sky*	*Sunny sky*	
Jan	23.8	8.2	9.6	34.1
Feb	23.0	5.8	3.8	39.4
Mar	12.5	9.7	4.8	52.2
Apr	14.5	2.9	4.8	46.2
May	14.4	8.4	4.8	51.6
Jun	4.8	14.4	6.0	50.4
Jul	8.4	8.4	8.4	55.2
Aug	15.6	3.6	4.8	55.2
Sep	11.5	6.5	2.9	54.7
Oct	21.1	12.5	2.5	43.1
Nov	32.8	11.5	1.9	29.4
Dic	31.7	10.8	1.1	17.6

The results of the completed study are summarized in the diagram in Fig. 11.

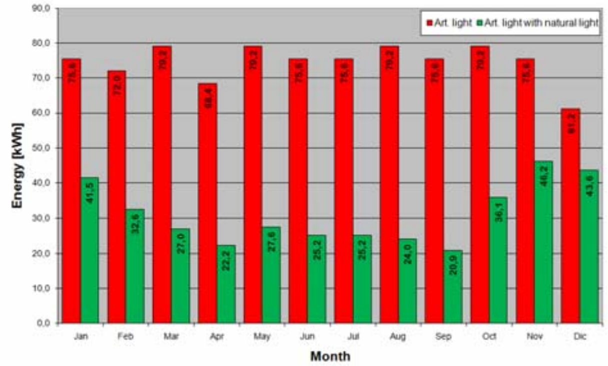

Fig. 11. Trend of the electric power consumption for every month (South-facing window).

Fig. 11 expresses the trend of the energy consumed per month without regulation (red) and with (green). Using Daylighting it is possible to obtains a 51% energy savings per year.

5.2 *Other cases: window to the West, East and North*

The results of the simulation with the window to the other three cardinal points are shown in Fig. 12. The diagram expresses the trend of the energy consumed per month without regulation (red) and with, green for West, yellow for East and blue for North windows facing.

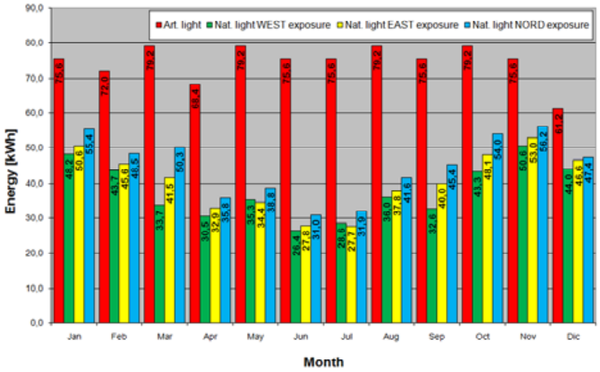

Fig. 11. Trend of the energy consumed per month without regulation (red) and with, green for West, yellow for East and blue for North windows facing.

Tab. 4 lists the electric power consumptions (kWh), for the three directions the window faces and the percentage of energy savings derived from using the natural lighting system.

Table 4. Energy consumed (kWh), for every month for artificial light only, and for using natural light with the window facing to the West, East, and South.

Month	*Energy kWh*			
	Artificial lighting system	*WEST*	*EAST*	*NORTH*
Jan	75.6	48.2	50.6	55.4
Feb	72.0	43.7	45.6	48.5
Mar	79.2	33.7	41.5	50.3
Apr	68.4	30.5	32.9	35.8
May	79.2	35.3	34.4	38.8
Jun	75.6	26.4	27.8	30.9
Jul	75.6	28.6	27.7	31.9
Aug	79.2	36.0	37.8	41.6
Sep	75.6	32.6	39.9	45.4
Oct	79.2	43.3	48.1	54.0
Nov	75.6	50.6	53.1	56.2
Dic	61.2	44.1	46.6	47.4
Saving	-	49.0%	47.0%	40.0%

6 Consideration

It is easy to understand the advantage that the natural lighting system can provide in terms of energy saving. However, the energy savings are only one of the components of the lighting plan. Therefore, the total Daylight Factor (*DF*) and the punctual factors ($DF_{I,}$ DF_{II} and DF_{III}) have been calculated and verified independently of the considered guideline (see Section 4). The *Building Research Station* (BRS) method has been used to calculate the punctual Daylight Factor. This method assumes that the punctual *DF* is given from the sum of three contributions of the total *DF*: the sky component plus the external reflection component plus the inner reflection component. These contributions depend on:

- ➢ the relation of the window dimensions;
- ➢ the distance between the point of calculation and the window;
- ➢ the reflection coefficient of the inner surfaces of the room.

Using the following values:

- ➢ $A_v = 7.5$ m^2;
- ➢ $A_{tot} = 107.5$ m^2;
- ➢ $\tau = 89.8\%$;
- ➢ $\varepsilon = 0.5$;
- ➢ $\psi = 1$ (external windows);
- ➢ $\rho_m = 50\%$;

the values listed in Tab. 5 are obtained. Although the total *DF* medium value respects the Italian standard, the uniformity of illuminance distribution is not guaranteed, even in the sunnier months, provoking the ignition of the lights far from the windows.

Table 5. Total Daylight Factor (*DF*) and punctual Daylight factors (DF_I, DF_{II} and DF_{III}).

DF (global)	DF_I	DF_{II}	DF_{III}
6,3%	19.4%	8.3%	1.33%

In fact, from the calculation of the punctual Daylight Factors, it is apparent that very different results are obtained at points closer to the window (under and before the row of lamps, DF_I), midway through the room (under the second row of lamps, DF_{II}), and at points farthest from the window (under the third row of lamps, DF_{III}). This remarkable difference among the locations examines the no-uniformity of the natural illuminance distribution and justifies the tendency to use artificial sources in the dark zones even during the sunny periods of the year.

It is important to underline that the results of the four cases considered are realistic but are not comparable to each other. Indeed, it is not practical to carry out work functions with beyond 2000 lx on the working area, and with excessive luminance differences [11] [12]. In these cases, the office customer will automatically screen the solar light with diffusing curtains. For this reason, in the following section, the results are optimized by using innovative technologies that can avoid this kind of problems.

7 Energy savings optimization

Considering the results of the punctual Daylight Factors, it is possible to observe the remarkable difference in the values assumed in the three characteristic points of calculation. This means that there is a different illuminance distribution in the room. Such a distribution of natural light determines the necessity of igniting artificial sources. Obvious by all lights igniting the distribution is not modified. However, careful sources management allows a more uniform distribution of the total value of illuminance, as reported in Fig. 13 for illustrative purposes only.

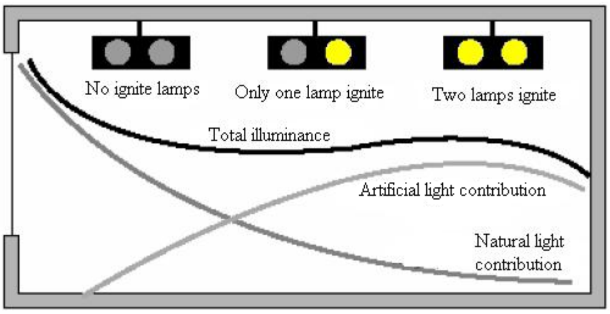

Fig. 13. Illuminance distribution integrating the artificial and natural lighting systems.

An additional saving of electric energy can be obtained installing shielding components on the windows [13]. In the following some possible strategies in function of the different window exposures are presented.

7.1 *South exposure*

In the case of the window facing to the South, one of the following strategies can be adopted:

- reflecting horizontal console or light-shelf (as reported in Fig.14);
- lamellas sunbreaker;
- grills sunbreaker;
- curtains;
- window blinds or horizontal lamellas.

In the next, the light-shelf is discussed in detail because it is the most efficient, feasible strategy in this case of exposure.

A light-shelf, shown in Fig. 14, reflects natural light on the ceiling and the sidewalls of an inner room by diffusing the light, which renders the illuminance more uniform and reduces the overheating and dazzle problems. The light-shelf is an opaque horizontal console that is external and/or internal exposed of the window; in this way the window is divided into two parts, in which the low windows part is a traditional window and, consequently, the light-shelf cannot obstruct the outside view.

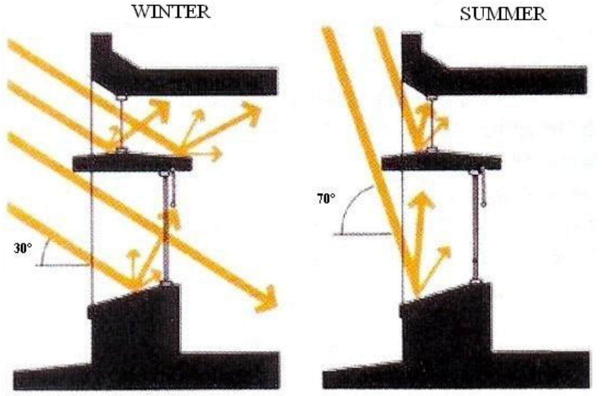

Fig. 14. Solar beams exploitation from a light-shelf.

Moreover, light-shelves allow the shielding of direct solar beams in the summer period, reducing, therefore, the consumption of electric power for air conditioning; while in the winter period, they also allow the solar beams to enter in the room. In Fig. 15 it is possible to see the light-shelf performance; the best illuminance distribution is guaranteed by an internal/external solution because the light penetrates more in the room depth.

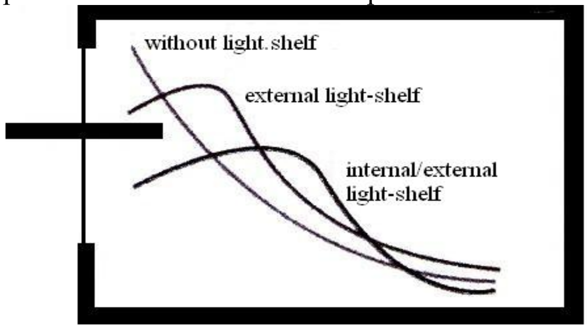

Fig. 15. Illuminance trend without, with an external and with an internal/external light-shelf.

If an internal/external light-shelf solution is used, with a height of 2.2m with respect to the floor, then an energy savings [14] of about 58% is obtained. The results, with and without the light-shelf, are shown in Fig. 16.

Regarding the case without a light-shelf, in addition to a greater energy savings, it is also possible to obtain a better uniformity of illuminance and luminance. This last parameter, like described in the previous sections, is very important for visual comfort and the health of the customer [15] [16].

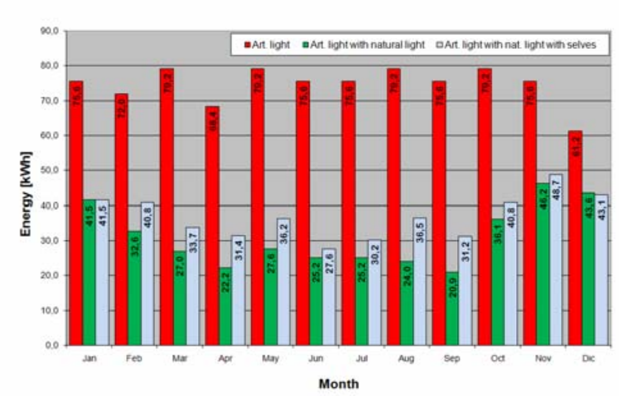

Fig. 16. Electrical energy consumption trend for every month without regulation (red), using natural light without a light-shelf (green), and using natural light with a light-shelf (cyan) for the South exposure.

7.2 *Other cases*

For window exposure to the East or the West, the following strategies can be adopted:

- vertical console;
- glass sunbreaker;
- curtains;
- window blinds or horizontal lamellas;
- innovative transparent components;
- films.

Here, the use of films is considered [17]. There are many film typologies, according to the use.

They are used if a reduction of dazzle, solar light, or thermal loads is necessary. They are available in the traditional reflecting versions or in diffusing versions with numerous different tonalities.

With these films, it is possible to reduce the infrared beams (heat) up to 80% and to eliminate 92% of the glare which reduces the conditioning costs up to 50% (proportional to the window dimensions). In this way, it is possible to get electrical energy savings derived from not using artificial light sources and a remarkable thermal energy savings both in summer (reduction of the energy consumption derived from less cooling) and in winter (reduction of the thermal dissipation). In any case, it is possible to resolve the serious problem of dazzle, and therefore the visual comfort is improved.

Fig.17 shows a thermal image of two buildings, where films are not applied on Tower 02 and are applied on half of Tower 01.

The thermal analysis on the front of Tower 01 has found a diversity of skin temperatures between the covered zone (AP01) and the zone lacking films (ASP01) equal to approximately 8 °C.

On the one hand, with these films, the transmission of light into the room is not improved; therefore, the energy savings deriving only from the light component could be inferior with respect to the energy savings that are shown in Tab. 4.

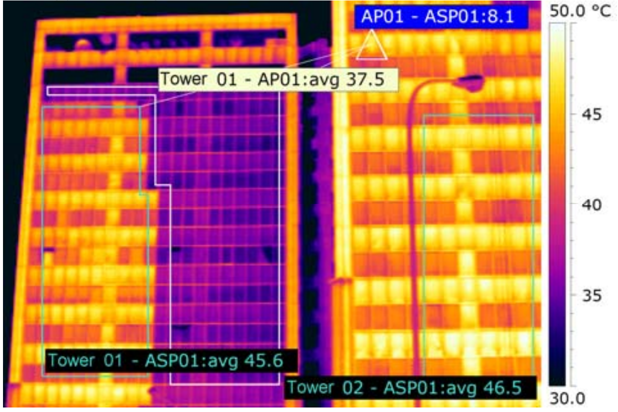

Fig. 17. Thermal analysis on the front of two buildings.

On the other hand, the total energy savings obtained should be greater, because of a reduced consumption of cooling energy. Only a small part of the infrared (responsible for heating) can penetrate into the room where the cooling system is installed. A possible disadvantage of films is a suboptimal view towards the outside, as shown in Fig. 18.

Fig. 18. External view without film (left window) and with film (right window).

When the window is exposed to the North, there are not particular problems like dazzle from directed solar light, so this paper has not dealt with strategies for rooms with that layout.

8 Conclusion

This research has demonstrated that a natural lighting system can contribute in a favourable way to the energy savings of buildings. In particular a natural lighting system can help to increase the energy classification of buildings. In fact, natural light is one of the factors included in the energy expense of buildings, even if it is not considered very much.

This last aspect is also emphasized by the actual laws, in the matter of energy certification of the buildings. The laws elucidate the technique of a natural lighting system as one possible way of saving. Currently, the introduction of solar light into a room is only considered for the remarkable advantages in terms of visual comfort while the energy savings has a decidedly smaller importance.

In particular, the proposed study attempts to demonstrate that the lighting system can occupy a rather important role in the energy consumption by quantifying in numerical terms the possibilities that sunlight can offer to energy savings, above all for the offices in which the artificial lighting sources remain turned on all day, even when it is not necessary.

The energy savings identified for a single office is small because the total power is little, but if the natural lighting system were extended to all offices of the building, then the saving would be decidedly more remarkable.

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