ENERGY AND COST SAVINGS BY USING LIGHTING CONTROLS IN OFFICES

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Abstract: In 2005, the International Energy Agency published that electricity consumption for lighting was about 19% of the total global electricity consumption, being about 48% of the total electricity consumption for lighting of the sector service. Around two thirds of the lighting systems nowadays are based on technologies developed before 1970, and they have lower performance that the current technology. A complete change of the lighting system and the implementation of control and regulation systems can provide relevant energy savings.
This work presents a comparison about the energy efficiency of different control lighting systems applied to office spaces located in Spain. The work is based on DAYSIM and DIALUX calculations to perform daylighting, lighting systems and energy consumption derived from the use of lighting control systems. Different types of lighting systems and lighting controls are compared using fluorescent lamps to determinate what is the potential energy saving maintaining or increasing the quality of lighting level distribution on the workplane.
The results show that a general localized lighting system provides higher energy savings and uniformity of lighting levels in the workplane than the other studied systems. The incorporation of a lighting control can reduce the lighting energy consumption in 15%.

Keywords: Lighting systems; energy efficiency; Office lighting; Occupancy sensors; Lighting control; DAYSIM.

1. Introduction

In 2005 electricity consumption for lighting was about 19% of the total global electricity consumption. Global electricity consumption for lighting is distributed approximately 28% to the residential sector, 48% to the service sector, 16% to the industrial sector, and 8% to street and other lighting [1]. Office buildings are classified among the buildings presenting the highest energy consumption. The total annual energy use varies in the range 100-1000 kWh/m^2yr, depending on the geographic location, use and type of office equipment, operational schedules, use of HVAC systems, type of lighting, etc. [2]. Most of the light delivered to office buildings is provided by fluorescent lamps, representing around 76'5% of the light output; the rest of the light output was provided by a mixture of incandescent, compact fluorescent and HID lamps [3].
Lighting is one of the biggest causes of energy-related greenhouse gas emissions, being about 7% of the total global CO_2 emissions. Electric lighting is one area where the energy savings are possible at reasonable cost in new buildings as well as in retrofit projects by updating to a new and modern advanced lighting installation, and incorporating occupancy sensors to adjust lighting use to effective occupancy [4]. Spanish Building Code about energy efficiency in lighting systems (CTE DB-HE3) indicates the needed for improve regulation and control of lighting systems, but it depends on building use [5]. Some studies indicate that investments in energy efficiency in lighting is one of the most rentable ways to reduce CO_2 emissions, and some of them show that electricity use can be reduced in 50% using existing technologies.
An adequate lighting system not only allow people see better, but influence in their mood. Is it possible obtaining it without increasing energy consumption? Can we design a more accuracy lighting system and reducing CO_2 emissions?

2. Literature review

Adequate indoor illuminance is accepted as a determinant condition for comfort and productivity in offices. Daylight is an important component of lighting, helping illuminate the building interior and giving information about exterior environment. Daylight is not usually welcome in offices due to its variability and the possible incidence of direct sunlight on the workplane. A European survey showed that about 35’6% of the offices working time is invested in avoid daylight, and their electric lighting use is about 85’7%. This lighting use is distributed in 30’3% for blinds closed, and 55’4% for blinds opened [6]. Energy savings related to lighting, in any way, not only depends on daylight availability, but on when and how workers use blinds and lighting control systems.

Different lighting and control systems have been studied to analyse which lighting conditions affect health, well-being, and task performance in an office [7]. The results show that a lighting system allowing control the direct component is nearly to join task lighting and quality lighting. Lighting environment from direct-indirect luminaries seems to be more comfortable than that from direct luminaries, but individually controllable workstation specific lighting was the most comfortable option. Individual control over lighting seems to be positive for motivation and well-being.
In office buildings, different case studies show that it is possible to obtain both good visual quality and low installed power for lighting with the current technology. The studies also indicate that the best performance is reached in an office environment when the luminaries are shared between two people [1].

A manual on/off switch is the most widely used and simplest lighting control system. This system cannot improve energy efficiency by itself as it depends on the user behaviour. Lighting control can provide energy savings by adjustments to real-time occupancy [1]. Some authors, as Dubois [4], Galasiu [8], and Newsham [9] between others, coincide in the positive impact of lighting control systems, but there are different opinions about quantifying their energy saving. For example, manual regulation has a range between 7% and 25%, or occupancy sensors can provide a range of energy savings between 20% and 35%.

The studies developed to determinate the relation between daylight availability, control lighting systems, blinds, electricity use for lighting and other parameters are based or in a monitoring campaign [2] or in simulations [10] using validated programs like RADIANCE or DAYSIM. Lighting simulations can be useful in stages of design of a building and its facilities, to evaluate daylight availability in the studied space and to calculate the artificial lighting that is needed during the year, depending on occupants’ performance and their interaction with blinds and lighting controls [11].

Studies developed by Bülow-Hübe [10] about daylight availability and electricity use for lighting in offices using simulations, demonstrate that it can be possible reducing energy use about 50% with different proposals of occupancy and lighting control. A similar study was developed by Roisin [12] but was focused on the effect of building orientation using different control lighting systems. The results demonstrated that daylight-linked control systems provided a high energy saving, about 45%-61%. In-Ho [13] simulated daylight and artificial light performances of office spaces related to switch on/off lighting control. The incorporation of this control system provided energy savings about 30’5%.

3. Objectives and methodology

The main objective of this work is study and analyse the energy and cost savings we can obtain by proposing different light systems and improving some lighting controls for each system.

The model under study is an open-plan office located in Seville (Spain) measuring 20 m x 12 m x 3.5 m. Openings are distributed in two opposing façades. There are 6 windows on each façade (North and South) measuring 1.35 m x 0.90 m each, and giving a window-to-wall-ratio of 17.50% (10% window-to-floor-ratio). There are no interior partitions and work stations are parallel to the glazed façades. The workplane is 0.80 m above the floor (Figure 1).

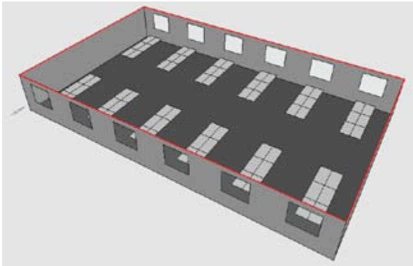

Figure 1: Open-plan office simulating model

Table 1: Optical characteristics of case study

Start point conditions	
Workplane height	0'80 m
Widow-to-wall	17'50%
Window-to-floor	10'00%
Sill height	1'00 m
Glazing	Simple clear
Glazing transparency	0'90
Floor reflection coefficient	0'30
Ceiling reflection coefficient	0'75
Walls reflection coefficient	0'55
Furniture reflection coefficient	0'35

The minimum lighting level is determined by European Standard EN 12464-1 about Lighting of Workplaces [14], which suggests a maintained average illuminance of 500 lux for normal desk-based office tasks. To know the daylight availability, the Daylight Autonomy (DA) is calculated using DAYSIM (RADIANCE-based software). Daylight Autonomy (DA) is a climate-based daylight metric defined as the percentage of the year during which there is a minimum threshold of illumination provided only by daylight.

DA and energy use for lighting have been calculated considering a time range from 8'00h to 18'00h during all workdays, an active user model by default and a manual switch on/off lighting control located near to the main door.

The base case studies the maximum energy use for lighting. To do this, the model is simulated without openings, as a way to ensure that lighting will be working all the working hours. The lighting system for this case was a general lighting with linear fluorescent lamps, calculated with DIALUX. Energy and cost savings are calculated and then every proposal is compared with the results obtained in the base case. Four lighting systems and two occupancy lighting controls performance have been compared.

4. Proposed lighting systems and controls

4.1. Lighting systems

Three lighting systems using fluorescent lamps have been proposed and calculated using DIALUX software. They correspond with a proposal of general lighting (GL), a proposal of general localized lighting (LL) and two proposals of general lighting in combination with local lighting (G+L1, G+L2) (Figure 2). The number of luminaries was determinate by spatial configuration, workstation distribution and average illuminance at workplane.

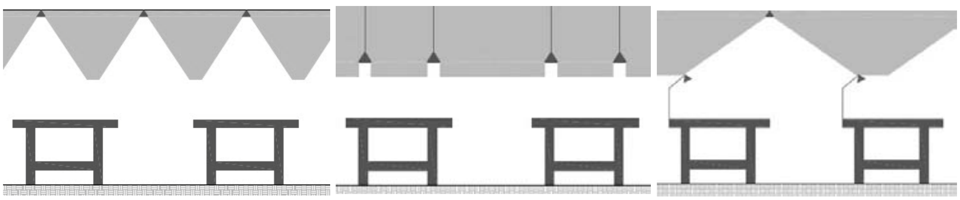

Figure 2: (a) General Lighting system; (b) General localized lighting system (c) General + Local lighting system

The lighting design criterion was 500 lux at workstations with a high uniformity and at least 300 lux at circulation areas. The general lighting proposal uses embedded luminaries for T16 linear fluorescent lamps (24w G5) (Figure 3 (a) (b)). The general localized lighting uses suspended luminaries for TL5 linear fluorescent lamps (54w) (Figure 3 (c) (d)).

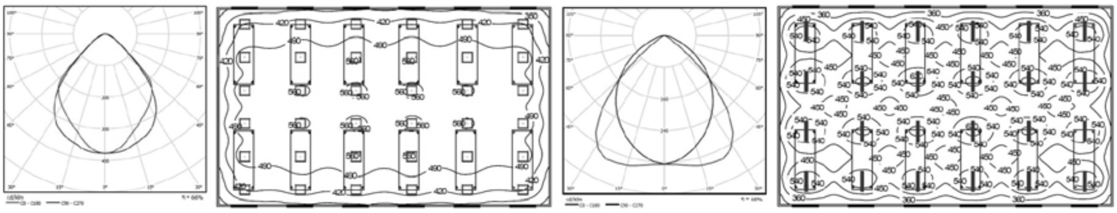

Figure 3: (a) Curve photometric GL luminaries; (b) Isolux curves GL; (c) Curve photometric LL luminaries; (d) Isolux curves LL.

The two G+L lighting proposals have the same general lighting (described before). The first proposal (G+L1) completes the general lighting with desk luminaries for fluorescent lamps for each two workstations (Figure 4). The second proposal (G+L2) combines the general lighting described before with the general localized lighting described before too (Figure 5). In both cases, general lighting has fewer luminaries as it is complemented with a local lighting.

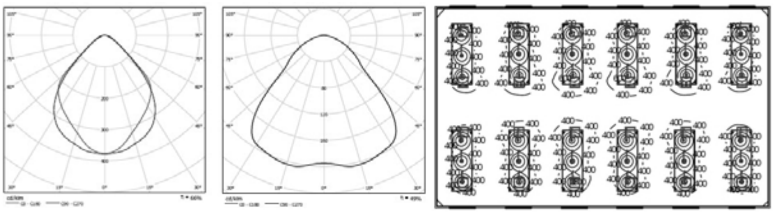

Figure 4: (a) Curve photometric GL luminaries; (b) Curve photometric individual luminaries; (c) Isolux curves

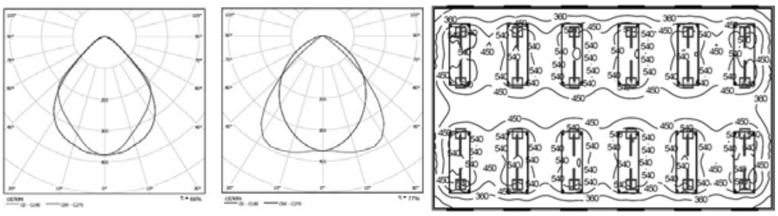

Figure 5: (a) Curve photometric GL luminaries; (b) Curve photometric LL luminaries; (c) Isolux curves

For each proposed system lighting distribution at workplane, installed lighting power and lighting energy efficiency value are obtained (Table 2). The Lighting Energy Efficiency Value (LEEV) is calculated by the following equation, based on installed lighting power (P), lit space area (A) and average illuminance obtained (E_a):

$$LEEV=P\cdot 100/(A\cdot E_a)$$

Table 2: Energy characteristics of each lighting system proposed

Lighting system	Name	Installed lighting power density	Ea	LEEV
01_General lighting	GL	16’20 W/m2	483 lx	3’35 W/m^2/100lx
02_General localized lighting	LL	11’80 W/m2	479 lx	2’46 W/m^2/100lx
03_General + Local lighting 1	(G+L)1	15’45 W/m2	429 lx	3’60 W/m^2/100lx
04_General + Local lighting 2	(G+L)2	13’70 W/m2	469 lx	2’92 W/m^2/100lx

4.2. Lighting Control

Considering that the case study hasn’t got blinds or any dimming element in windows, following lighting controls are studied:

- energy-efficient (off) occupancy sensor (O1): a perfectly located occupancy sensor with 5 minutes delay time. The lighting system can only be activated manually through the switch. It is switched off either manually by the user or automatically by the occupancy sensor. The occupancy sensor consumes a standby power of 3W when the lighting system is switched on.

- on/off occupancy sensor (O2): an automatically controlled lighting system with an ideally located occupancy sensor with 5 minutes delay time. The occupancy sensor is permanently in standby mode and activates the lighting whenever occupancy is detected. The occupancy sensor permanently consumes a standby power of 3W.

5. Results and analysis

5.1 Reference model

DAYSIM provides results for DA_{500} and also for Daylight Factor (DF). These results are shown in Table 3. To visualize graphically these results the ECOTECT software has been used (Figure 6).

Table 3: Daylight statictics of open-plan office workplane

Daylight metric	Maximum	Average	Minimum	Median	Min/Ave	Ave/Max	Min/Max
DF	24’71%	3’83%	0’98%	2’18%	26%	16%	4%
DA_{500}	66’00%	61’58%	30’00%	62’00%	49%	93%	45%

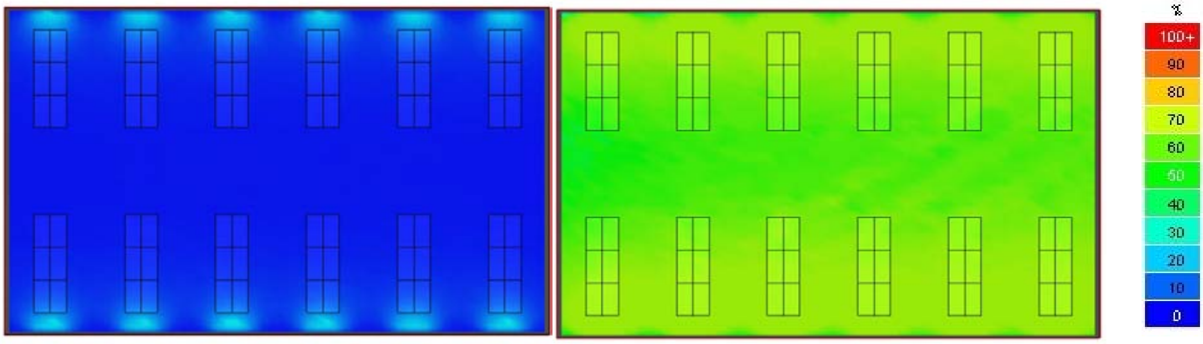

Figure 6: Visualization of distribution of daylight metrics on the workplane (a) DF; (b) DA_{500}

The central value for DA_{500} is 62%, which indicates a significant potential of daylighting contribution in this office (1524 hrs/yr during the considered time range), with a relative high uniformity distribution on the work plane.

If the space had no daylight contribution, the lighting system will be switched on during all working hours (2458 hrs). The energy consumption in this case will be 35’30 kWh/m^{2}yr. This scenario represents the worst energy consumption scenario. To calculate cost and environmental implications related with this electricity use, it is supposed an equivalency of 0’170783 €/kW_{electr} (0’138863 £/kW_{electr}) and 0’21 $kgCO_2/kW_{electr}$ (Table 4), as published by Spanish Ministry of Industry.

Table 4: Energy use avoiding daylighting within the office

Hours of lighting use	Energy use	Cost		CO_2 emissions
hr/year	kWh/m^{2}year	€/year	£/year	kg CO_2
2458,30	35,30	1447,74	1177,16	1780,19

5.2 Analysis of proposed lighting systems and controls

Proposed lighting systems are now compared with the worst scenario. Figure 7 (a) shows a comparison between installed lighting power density and annual energy consumption for lighting considering a manual switch on/off control lighting. Figure 7 (b) compares costs and CO_2 emissions for each lighting system.

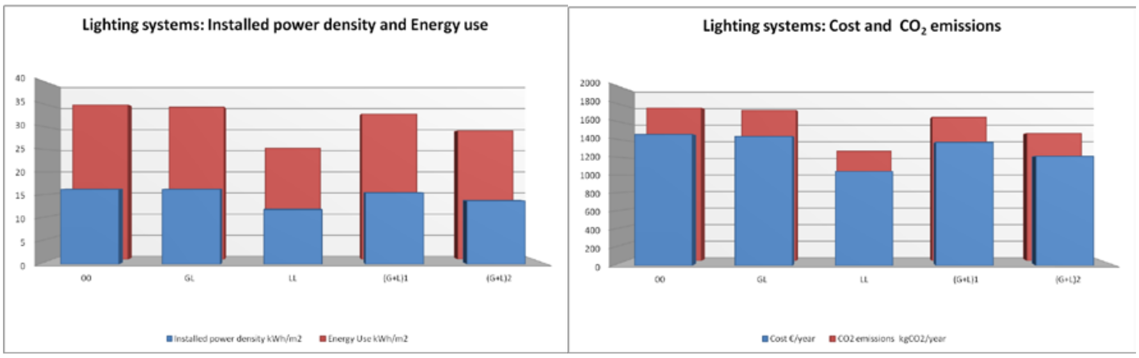

Figure 7: (a) Lighting system comparison: Installed lighting power density and electricity use; (b) Lighting system comparison: Cost and CO_2 emissions

To study lighting control effect, every lighting system has been simulated with each control sensor. The energy consumption related to these calculations is shown in Figure 8, and values are exposed in Table 5.

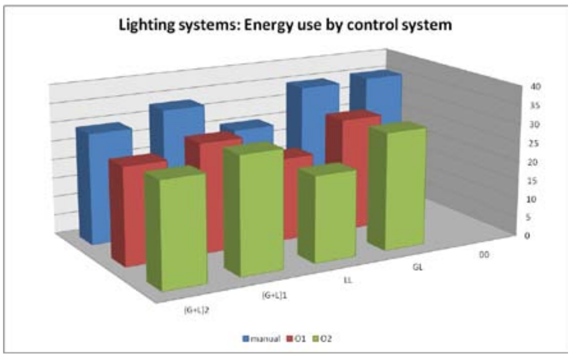

Figure 8: Lighting system comparison: Energy use by control system

These results show that the LL system is the system with lower installed lighting power density, lower energy consumption and one of the systems that provides higher average illuminance levels at the workplane with a lower LEEV.

Table 5: Lighting systems comparison

Name	% lighting use hrs	Installed power density kWh/m^2	Energy Use kWh/m^{2}yr	Cost €/year	Cost £/year	CO_2 emissions kgCO_2/year
00	100%	16,20	35,30	1447,74	1177,16	1780,19
GL	95%	16,20	34,80	1426,48	1157,43	1754,05
LL	95%	11,80	25,40	1039,10	844,89	1277,70
(G+L)1	95%	15,45	33,20	1360,17	1105,95	1672,50
(G+L)2	95%	13,70	29,40	1206,43	980,95	1483,46
GL+O1	76%	16,20	29,90	1227,31	997,93	1509,14
LL+O1	76%	11,80	21,80	894,46	727,28	1099,85
(G+L)1+O1	76%	15,45	28,80	1180,14	959,57	1451,14
(G+L)2+O1	76%	13,70	25,60	1047,34	851,59	1287,85
GL+O2	77%	16,20	30,80	1260,69	1025,06	1550,18
LL+O2	77%	11,80	22,50	920,59	748,53	1131,98
(G+L)1+O2	77%	15,45	30,50	1249,47	1015,94	1536,38
(G+L)2+O2	77%	13,70	27,20	1113,52	905,40	1369,22

Daylight contribution and the substitution of the GL system for a LL system imply an energy saving about 27%. Respect to occupancy sensor use, the energy-efficient (off) occupancy sensor (O1) seems to be the lighting control system that provides greater energy savings, but the results obtained are very similar to on/off occupancy sensor (O2).
The incorporation of occupancy sensors for lighting control provides an energy saving about 15% whatever the lighting system is studied. Mixture of improvement of lighting systems and incorporation of lighting controls can give energy savings about 38% respects to worst scenario.

6. Discussion and Conclusion

In this work, the effect of different lighting systems and lighting control systems has been analysed related to potential energy and cost savings and CO_2 emissions reduction.

Usual practise in lighting for offices had been the implementation of general lighting systems. Recommendations suggest the use of individual luminaries in workstations to achieve a higher comfort visual and energy savings related to lighting. The results show that, to achieve the defined lighting criterion, is possible reach higher energy savings (27%) using a suspended luminaries lighting systems that provide a general lighting but with a lower distance between the lighting source and the workplane, and considering daylight availability.

The additional incorporation of lighting control systems based on occupancy sensors allows adjust the hours of lighting use to operational working hours. This adjustment provides cost and energy savings about 15% whatever the lighting system was installed. Lighting control system is a cost-effective way to provide cost and energy savings in offices.

But these results don’t assure an adequate luminous comfort of workers, so it is necessary consider other aspects to evaluate the lighting system like glare or non-visual effects.

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