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Lighting Optimization for Efficiency, Cost, and Carbon Emissions Reduction: Overview, Methodology and Case Studies

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Abstract:
All buildings owners tend towards lighting with high energy efficiency, great performance, low carbon emissions, easy maintenance, and at reduced costs. Several parameters determine the choice of lamp: luminous efficiency (in lumens per watt), economic life (in hours), colour rendering index (CRI), colour temperature (in kelvins, K) and the power (in watts, W). This paper analyses the possibilities of lighting optimization trough an overview of the current literature, methodology definition and real case studies.

Keywords: Lighting efficiencies, LED, Movement and presence sensor

INTRODUCTION

On a daily basis, light plays an essential role: it contributes to our health, our safety and our dynamism, improves our working conditions and increases our performance, but it also participates in the beautification of spaces, the enhancement of interior architecture.

Since the Kyoto agreements, the impact of lighting on the environment has been recognized: in non-residential buildings, it can represent up to 30% of electricity consumption. Nevertheless, up to 70% of this consumption could be saved by replacing old luminaires with more efficient modern systems [1]. In most cases, such investments are quickly profitable, and they often improve the quality of lighting.

Less bulky, more efficient, more energy-efficient, the products are constantly being renewed, always offering more possibilities: long-life lamps with high luminous efficiencies, more efficient and smarter luminaires thanks to simple automation, electronic control systems that now allow to benefit from more flexible installations, and programmable lighting scenarios according to the desired effects and atmospheres.

It is therefore through a judicious choice of materials, associated with compliance with lighting standards, that the quality of lighting can be improved, and that savings can be made, provided that the return on investment is calculated in terms of overall cost and to use products with high energy efficiency.

For example, for teaching premises, quality lighting is sought for improving school performance. If lighting alone is not enough to stop the academic difficulties met by children from kindergarten to university, it can nevertheless greatly contribute to improve their environment, their comfort, their visual perception, and this, at a cost of reduced operation (consumption and maintenance) thanks to the use of high-performance equipment and in compliance with the requirements of national or/and international standard such as European standard EN 12464-1 [2].

Another example, offices require efficient lighting for good working conditions.
Working in good conditions serves the interest of both the business owner and his Employees. Poor quality lighting makes visual tasks more difficult, slows down the pace Workload, increases fatigue and generates excessive operating costs.

Fig. 1 is an example of results of luminance distribution measurements and the corresponding street pictures [3].

Fig.1. Left picture shows the street picture, and the right picture shows the luminance distribution

METHODOLOGY

Audit

The methodology is based on audit that allows to identify, test, and describe solutions whose characteristics will be as follows [4,5]:

- adequate luminosity in quantity (illuminance level) and quality
- rapid return on investment thanks to the energy savings obtained
- adaptation to existing supports
- maximized saving of daylight depending on the contribution of natural light [6]

Adequate Brightness:

It is necessary to carry out brightness tests in different configurations, comparing the illumination obtained under the existing conditions and with the different solutions considered.
In relation to the brightness levels obtained, the objective is to provide the right lighting with regard to the recommendations in order to optimize energy savings.

Return on Investment:

Due to the general requirement given for a rapid return on investment on the one hand and that the locations of the lighting devices cannot be modified on the other hand, field solutions are relatively limited, with the imperative of working on modifying existing devices to find adaptation solutions.

Indeed, solutions such as the replacement of complete devices as well as the rewiring of devices to introduce electronic ballast or LED driver technology sometimes prove to be complicated: Firstly because of the cost of supply and secondly second because of the labour time work necessary for the operation.

***Adaptation to Existing Supports*:**
The objective is to find simple solutions that do not require a major modification of the internal lighting system, both in terms of optics and electrical equipment.

Use of Daylight Supply:
The contribution of daylight available in the circulations can make it possible to carry out savings in daylight hours, the installation of cells to automatically manage turning off superfluous electric lighting [7].

Qualitative Lighting Criteria
The quality of environment lighting (example: workplace) is assessed according to various criteria:

The Amount of Light Available:
The quantity of light or level of illumination is measured in lux - by means of a luxmeter.

For a given task and/or type of room, the level of illumination must never be lower than at a reference value (a national or international norm for example).

This value depends on the precision of the task and the size of the pieces worked (example: a minimum brightness of 150 lux for workshop work).

In a lighting renovation situation, it is important to take a margin in relation to the minimum illuminances required to consider the effects of lighting dimming in the time.

Lighting Uniformity:
The level of illumination is never identical at all points in a room. It is important that there are no too large differences in brightness that prevent correct accommodation when the operator moves [8]. A good homogeneity is obtained by a judicious choice and installation of lighting devices in the room and around the workstation.

Lighting Atmosphere: Colour Rendering and Colour Temperature:
A good lighting atmosphere is essential for staff satisfaction and a good productivity in their work environment. This lighting atmosphere depends essentially on the type of light source (or lamp) used for lighting.

It is essential that the lamps used allow faithful reproduction of the colours – of the furniture, of the worktop, of the worked pieces – to give a good perception of details and avoid errors, especially during the control phase for example.

The degree of colour restitution called CRI (colour rendering index) is measured on a scale of 100. A minimum of 80 is required for workstation lighting, regardless of its nature [8].

On the other hand, the lamps must have an apparent colour that is both in harmony with the work environment and in correlation with the level of illumination (example: tint of warm colour for the reception hall, offices, cooler colour shade for brightly lit rooms requiring a toned light suitable for precision work).

Protection Against Glare:
Independent of the amount of light, this is an essential criterion, especially for workstations requiring strong visual concentration (work on a display screen, monitoring or work of fine parts...).

Glare is caused either directly by the presence of lighting (natural or artificial) in the field of vision of the operator, either indirectly by the reflection of the lighting on bright or shiny surfaces or a display screen.

The limitation of glare is obtained:

- by the implementation of qualitative lighting devices equipped with optics (reflectors and so-called scroll grilles) masking the view of the lamps
- by properly positioning the lighting fixtures in relation to the workstation and the position of people
- by an adequate location of the workstations in relation to the walls diffusing natural lighting (windows, overhead lighting).

Lighting Standards:
Many organizations have established standards that address lighting design, safety, performance, mounting, and testing, as well as illumination levels [9]. Below, some examples:

- IEC 62504:2014+A1:2018 ➔ Light emitting diode (LED) products and related equipment
- NEMA SSL 1-2016 ➔ Electronic Drivers for LED Devices, Arrays or Systems
- ANSI C82.11-2023 ➔ American National Standard for Lamp Ballasts—High Frequency Fluorescent Lamp Ballasts

RESULTS - CASE STUDIES

This section contains different relevant case studies among the literature on lighting efficiency.

Case Study #1: Street Lights [10]
Outdoor lighting can be defined as the lighting of roads, pedestrian and bicycle ways, parks, and other areas during the night times. Outdoor lighting is needed for safety and comfort. Energy Agency (IEA) statistics, where lighting has been estimated to account for approximately 19% of global electricity consumption. Outdoor lighting devices consume 15 to 20% of global lighting consumption.

This case study is about the possible energy saving for outdoor lightings on a university campus in Turkey.

Various scenarios have been developed in order to save electrical energy used for outdoor lighting and four scenarios have been built for this purpose. The first scenario is to switch off some lightings after 23:30; the second scenario is dimming the lamps; the third scenario is to replace the current LED lamps with energy efficient ones and the fourth scenario is to use the last two scenarios together.

Table 1 contains a summary of the savings for each scenario.

Table 1: Energy consumptions, savings and CO2 emissions for all scenarios

	Installed power (kW)		Energy consumption (MWh/year)	CO2 emission (tCO2/year)	Energy saving (MWh/year)	CO2 saving (tCO2/year)	Energy-saving (%)
	Before 23.30	After 23.30					
Current Status	302.92	302.92	1290	426	_	_	_
scenario 1	302.92	65.40	656	216	634	209	49%
scenario 2	302.92	151.46	886	292	404	133	31%
scenario 3	180.58	180.58	769	254	521	172	41%
scenario 4	180.58	90.29	528	174	762	251	60%

The cost of installation of LED lighting systems is more expensive than other lighting systems. But, the wide usage of LED lighting systems is inevitable due to the long lifetime, the decrease in purchase prices compared to the previous years, increasing efficiency factors, and the increasing electricity prices [11, 12]. The analysis demonstrates that it is possible to save up to 60% of electricity consumption with the improvements required in the lighting systems proposed in this study.

Case Study #2: Industrial Buildings [4]

The site of this case study is an industrial site of a famous manufacturing/mining holding in Zimbabwe.

A walk-through audit was conducted. The main objective of the walk-through energy audit was to assess the illumination requirement of the plant and scope of improvement of illumination quality and level.

The light levels in the plant and selected offices were measured during daytime by using a lux/light meter. Measurements were taken at a number of points and averaged.

After the energy audit survey and detailed data analyses, the energy audit team put forward the following recommendations to implement:

- Switching of lights: The calculations show that the company would save US$614.40 per day per flood light by making sure that each flood light is switched OFF.
- There is need for the responsible personnel to remind personnel or office occupants to switch OFF office lights and utilize daylight [13]. This can be done by putting stickers at the doors of each office as shown in fig.2.
- Replacing T8 and T12 fluorescents with LEDs and Replacing HPS (high pressure sodium) lights with LEDs

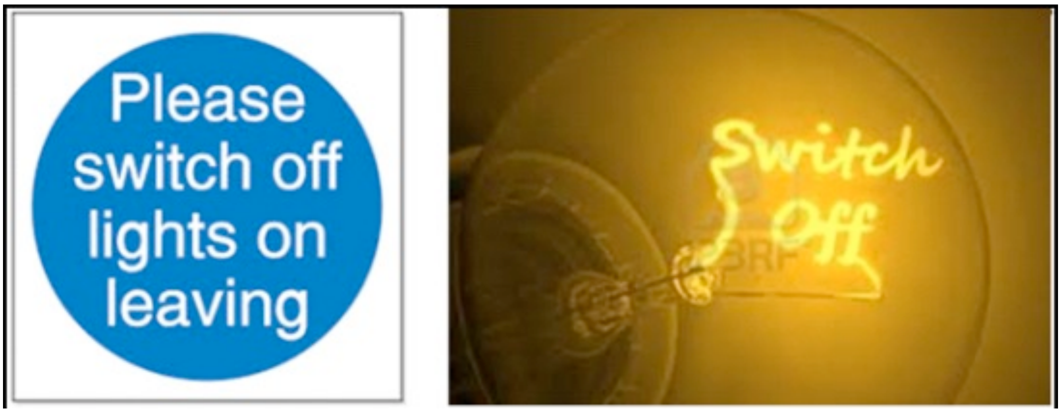

Fig. 2. Poster on doors of each office

It has been demonstrated in this specific case study that the improvement of lighting technologies can determine a significant reduction of electricity consumption. Savings are shown in table 2.

Table 2: Simple Payback period (spp) results

Existing type	Recommended Actions	No. Of replaced bulbs	Fixtures changed	*AES (kWh)*	*ADS (kVA)*	*ACS (US$/year)*	*Implem. Cost*	*SPP (year)*
400W HPS	bulb 80W LED	130	130	364 416	499.2	48 677.0	*37 700*	*0.77*
58W T8 Flu. bulb	20W T8 LED	357	0	158 784	217.5	21 209.3	*24 804*	*1.2*
36W T8 Flu. bulb	15W T8 LED	54	0	9 934	55.4	1 496.5	*2 268*	*1.5*
18W T8 Flu. bulb	8W T8 LED	13	0	1 139	1.6	152.3	*351*	*2.3*
TOTAL				*534 273*	*773.7*	*71 535.1*	*65 123*	0.91

AES - annual energy savings; ACS annual cost savings

Case Study #3: Residential Buildings [14]

This case study presents an energy audit study of two commercial buildings in Dhaka (Bangladesh) and a tool that has been developed to facilitate energy audit of commercial buildings. The tool is developed using Microsoft Visual Basic Application and named "EnergyWise".

The study showed that the present electrical energy usage of the commercial buildings in Dhaka are quite inefficient and up to 8-15% in electrical equipment and 28-45% in lighting section of energy consumption can be appreciably reduced. Subsequently, the cost reduction can be achieved by feasible replacements.

Fig. 3 shows the percentage of total energy cost due to different types of lights. The chart is obtained using EnergyWise.

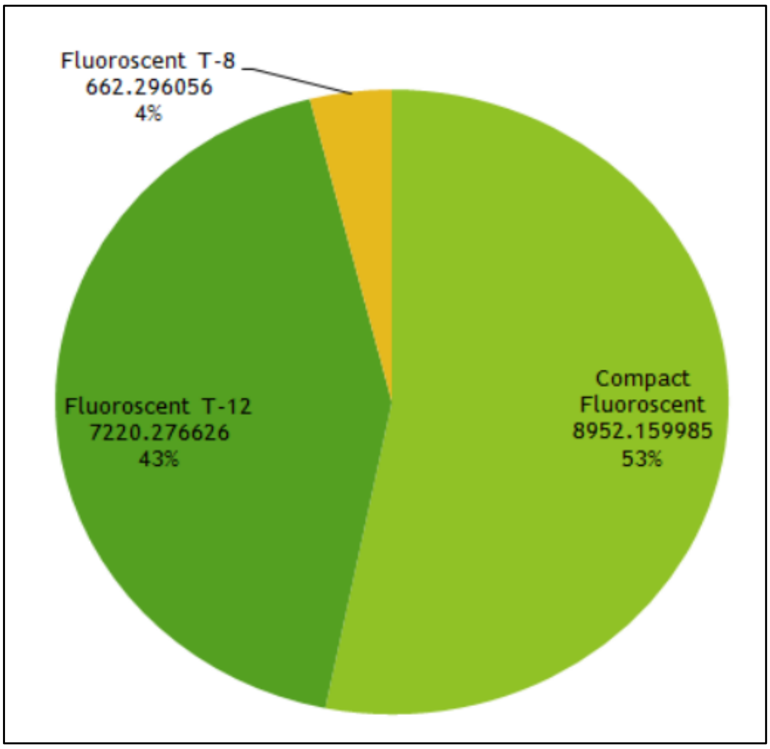

Fig. 3. Percentage of total energy cost due to different types of lights

Illumination level is measured using digital Lux meter which gives the output of light directly in Lux. Illumination level is required to determine if the present light level is adequate or more than necessary so that the auditor can reduce the number of lights to save energy. Measured light level is 743.02 Lux per room but for educational institutions recommended illumination level is 300 Lux per room according to Bangladesh National Building Code, BNBC (2011).

Replacement of T-8 (15 W), T-12 (36W), CFL (14W, 23W, 65W) by respectively LED Tube light (8W and 16W) and Led Lamps (9W, 14W, 33W).

Energy and Cost Saving After Replacement:
For building 1: 6,936.44 kWh and 67,977 BDT (Percentage Savings for lighting vs other equipment = 28,8%)

For building 2: 20,386.695 kWh; 199,790 BDT (Percentage Savings for lighting vs other equipment = 41,5%)

DISCUSSION

Manage To Reduce Losses

Below are 4 of the most common lighting management configurations [15]. Compared to a luminaire equipped with a conventional ferromagnetic power supply, energy consumption is reduced by 20 to 40%. Gains of 60% can be achieved with more complex setups.

1. Luminaire with electronic power supply: 20%
2. Luminaire with dimmable electronic power supply and light management cell or presence detection: 30%
3. Luminaire with electronic power supply manual dimmer OR with clock and time programming: 40%

4. Luminaire with electronic power supply manual dimmer AND with clock and time programming: 70%

Movement And Presence Detectors
They control the switching on and off of the lighting by infrared detection. The sensor detects the presence and movement of a person by the emission of heat it gives off. The signal is sent to the lights which turn on immediately. The detector ensures the automatic extinction of the premises as soon as there is no longer anyone and movement. Some systems provide for a gradual lowering of the level of illumination, step by step, down to a pilot level. To prevent lamps from failing prematurely, electronic ballasts should be of the "hot start" or "hot cathode" type.

Galitsky et al. [16] found that energy up to 10–20% can be saved with the use of occupancy sensors.

Level of Illumination Variation
The dimming makes it possible to adapt the level of lighting to the needs. It also offers the possibility of permanently maintaining the same level of illumination. A photoelectric cell measures the contribution of natural light and modulates the artificial lighting accordingly. This solution is particularly appreciated in teaching premises which generally have large bay windows. This prevents the teacher from moving around and guarantees constant visual comfort.

As the consumption of the tubes decreases when the level of lighting drops, the variation automatically generates energy savings.

Today, presence detection and dimming are frequently associated. This device is inexpensive from the point of view of the electrical installation (no more switches or vertical wiring).

Lighting Management System
Ambience management systems offer the possibility of saving and programming several lighting scenarios that the user can simply activate and modify according to his needs, at any time, using a remote control, a wall-mounted touch screen, or even via his computer [17, 18]. Presence detection functions, dimming of lighting according to natural light, and programming of scenarios can also be combined within a centralized system which makes it possible to manage several rooms in the building, and to easily modify the organization of the lighting of the space without having to intervene on the installation [19].

Maintenance
Over time, the average illuminance levels of a lighting installation decrease and this decrease results from four factors:

- drop in the luminous flux of the lamp during its lifetime,
- number of faulty lamps between two replacement operations system of lamps,
- dusting of light fixtures,
- fouling of the room.

According to Khalid et al. [20], maintenance is one of the important aspects of energy conservation. Maintenance includes both cleaning and re-lamping.

Electronic ballasts also have the advantage of eliminating the flickering of the lamps as well as their flashing at the end of their life, which is particularly unpleasant and costly in maintenance [21].

CONCLUSION

All buildings owners tend towards lighting with high energy efficiency, performance, and easy maintenance and at reduced costs. The flexibility of the installation must also allow rearrangements of the space according to the needs of the company, and the lighting must be able to be modified easily without leading to additional costs.

For employees, lighting must enable them to do their work in the best possible conditions: ergonomic lighting, quality of light that improves visual perception, and therefore performance, and simple use that allows everyone to intervene, for example by varying the levels of illumination.

Several parameters determine the choice of lamp: luminous efficiency (in lumens per watt), economic life (in hours), colour rendering index (CRI), colour temperature (in kelvins, K) and the power (in watts, W).

Machine learning approach to evaluate the energy and cost-saving opportunities (lighting included) should be subject to further research [24].

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