Energy Conversion and Management 84 (2014) 623–632

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

An economic perspective on the reliability of lighting systems in building with highly efficient energy: A case study

F. Salata *, A. de Lieto Vollaro, A. Ferraro

DIAEE, Area Fisica Tecnica, University "Sapienza" of Rome, Italy

ARTICLE INFO

Article history:
Received 25 February 2014
Accepted 17 April 2014
Available online 21 May 2014

Keywords:
Efficiency
Reliability
Lighting system
LED
MTTF
Energy

ABSTRACT

The performance of lighting system must be calculated in order to determine the energy requirements of the building. In the normative [EN 12464-1] are established lighting requirements which have effects on energy needs. The European standard [EN 15193] provides guidance on that evaluation. The easiest way to comply with reduction of energy requirements leads to the replacement of traditional lamps with LED ones, but if we calculate also the reliability parameters, the economic return is not guaranteed.

Using bibliographic data, we have compared lighting's results for a museum (LED lamps versus CFL and halogen lamps). The objective function of the study is to optimize the energy consumption of lighting systems, but at the same time to assess the reliability (MTTF of the lamps) of these systems. Without accurate information about this last parameters, the right choice of the lamps cannot be done successfully.

1. Introduction

In order to respect the energy saving normative established by the building sector regarding the field of lighting-technique [1–4], the best solution is to substitute those systems characterized by low efficient light sources with systems which, with the same luminous flux, consume less energy [5]. The most recent data show how the 7% of primary energy resource, in the developed countries, is consumed only for the lighting [6].

Recent studies show that we could have an energy saving of two-figure percentage with a technological transition from currently used lighting systems, to more highly energy efficient systems (depending on the field we are interested in, whether the residential or business sector). Such data should be taken into consideration both by the scientific community and by those engineers working in the energy management area.

For the right evaluation of the incidence of energy consumption related to the lighting requirements in the developed countries, the statistics data furnished should be examined. According to the US Department of Energy [7] the energy used for lighting has an incidence of the 7% of the whole energy consumption and reaches the 18%, if we just take into consideration the electric energy. In Canada [8] the energy consumed for the lighting system in commercial buildings has an incidence of the 10% of the whole of this consumed energy and reaches the 24% of the electric energy. The commercial building section in turn has an incidence of 33% of the whole energy required from the civil building section.

In Sweden the Swedish Energy Agency furnishes percentages which correspond to the 23% of the whole electric consumptions [9]. In Italy the energy consumption for lighting systems has an incidence of 16.4% of the whole of the energy requirements [10].

Globally, according to some studies, the lighting is responsible for the 7.2% of the worldwide energy consumptions; while the electric energy consumed for illuminating engineering purposes has an incidence of the 19% of the electric energy consumed [11].

Particularly, in commercial buildings the lighting system has an incidence on the electric energy required with percentages that go from 20% to 45% [12].

Tackling such consumptions, by optimizing and operating in the lighting systems, in conditions where all requirements are fulfilled, can bring to enormous amounts of energy savings. [13–16]. Many studies claim that it can be possible to have reductions until two-figure number. For example, according to Trifunovic [13] such savings could stabilize between the 27% and 30% of the present consumptions. Whereas according to Mortimer [14] we could have the 25% saving by substituting the tungsten lamps for the halogen ones, or we could have a 75% by replacing the tungsten lamps with the compact fluorescent ones and a 10% by substituting the fluorescent lamps, characterized by a 38 mm tube, for lamps which have a diameter of 26 mm [15].

In a more general way, Santamouris [16] says that if the most *énergivore* lamps currently used were substituted for light sources

* Corresponding author. Address: Via Eudossiana, 18, 00184 Rome, Italy. Tel.: +39 0644585661.

E-mail address: ferdinando.salata@uniroma1.it (F. Salata).

http://dx.doi.org/10.1016/j.enconman.2014.04.063
0196-8904/

with a specific efficiency of 80 lm/W, the energy saving obtainable would be approximately the 35%, whereas if we use light sources even more efficient (at least 117 lm/W) energy savings could reach a percentage of 55%.

What has been previously said concerns the direct energy consumptions for the lighting. Then some other elements should be added, such as the energy saving determined by minor heating loads of the lighting systems related to the air conditioning systems during the summer [17].

Therefore it is important, to pay attention to those peculiar environments where an advanced lighting performance is required, in order to obtain savings in terms of economic management of such spaces [18].

This was the perspective from which the case study of a museum centre was analyzed, whose special lighting demands were satisfied thanks to *énergivore* systems [19].

There are different possibilities available when it comes to the reduction of energy consumptions, and modern technology suggests the use of LED lamps as a solution to these problems [20]. This solution enables the design engineers to achieve high performances both aesthetically and in terms of energy consumptions. Moreover, for what concerns the reliability, this solution is interesting since the energy source guarantees an MTTF (Mean Time To Failure, it describes time to failure for non-repairable components like an integrated circuit soldered on a circuit board and it is expressed in hour) [21] even higher than the one measured in incandescent or discharge (fluorescent) lamps.

The aim of this study was to examine the connections among different solutions for the energy saving and the problems aroused by the reliability issue. This is why two lighting system solutions, with the same lighting quality, were compared for the case study before mentioned.

The case study was a museum centre, and two systems were compared (traditional = incandescent + compact fluorescents; new = LED) keeping in mind several parameters such as: effectiveness, lifespan and reliability, plus all the expenses determined by all these factors.

2. The case study

The case study was a museum centre used for the exposition of canvas paintings kept in sealed glass cases characterized by anti-glare glass and anti-UV.

Such glass cases give the possibility to light the works of art obtaining the best lighting results without worrying about the perishability of the canvases.

During the design phase two types of different solution were taken into consideration (Type A, formed by incandescent and compact fluorescent lamps; and Type B, of LED sources only), although both of them have the same ability to fulfill the necessities established by the main lighting parameters.

A software [22] for the design and simulation of lighting systems was used in order to execute a proper designing phase and later on be able to compare the two solutions. The main rooms of the building were reproduced through 3D technique and exposed, afterwards, to simulations. The spaces used for the exposition were: the main hall, two big rooms and a little private room. The building also presented a public cafeteria and an administrative office.

In every room, as showed in Figs. 1 and 2, both the ceiling and walls were characterized by light colors and the parquet floor was made of light colored wood.

For the lighting systems used in these spaces the following results were assumed: 2477 h of lighting per year, that is 9 h of lighting per day of the systems for a whole of 6 days in an entire year, without forgetting the 20 days of closure per year.

The rules regulating these spaces expected a minimum amount of values both for what concerned the average lighting and the uniformity [23]. In this specific case, for the works of art kept in the museum, were established the following parameters: $E_{average} > 350$ lx on the horizontal surfaces and an accent lighting of $E_{average} > 500$ lx for vertical surfaces placed near the works of art. Regarding the uniformity the attempt was to maintain $E_{minimum}/E_{average} < 0.8$ on every surface monitored.

To be in line with the comparison carried out, the lighting values in both solutions (LED vs Fluorescent and Halogen) could not have too much difference between each other, thus a maximum value of 10% (representing the difference of the lighting parameters), for our scopes, was considered acceptable.

Both systems were equipped with all the accessories and plant design performances, both indispensable for the right functioning of the system; the specific purpose of this building required the necessity to furnish the systems a continuity in the service; it must be specified that the electrical wiring was not taken into consideration.

3. The light sources

The Type A lighting solution was formed by halogen incandescent lamps and compact fluorescent lamps (CFL). Whereas the Type B solution used LED lamps only.

The first solution took into consideration the demands determined by both the ID (index of chromatic performance) and costs control, thus using halogen incandescent lamps (conventionally with a 100 value) and compact fluorescent lamps for their major lifespan and specific efficiency (lumen/watt). The MTTF was of 4000 h, for the halogen lamps, and 12,000 h for the CFL [24–27]. The probability of failure rate was assumed with an exponential distribution.

The most recent LED sources unite excellent energy performances with good chromatic performances [28]. The specific global efficiency [28] of the system η_g was:

$$\eta_g = (\eta P_a \rho_o)/(P_a + P_c) \quad (1)$$

where η is the LED luminous efficiency ($\eta = \Phi/P_a$); Φ is luminous flux emitted by the LED [lm]; ρ_o is optical luminous output; P_a is electric power absorbed by the LED; and P_c is electric power absorbed by the power system, management system, control system and regulation system.

LED light sources usually function regularly over time, but the luminous flux emitted decreases later on reaching such low values that the light sources are not considered useful for their application anymore [29]. The lifespan of a LED coincides with the time during which the device produces a sufficient luminous flux. The LED production (for the lighting field) has its core in the realization of highly performance lighting equipments, whose effects have a bad influence on the electronic devices and on its service life [30].

Table 1 shows the characteristics, useful for this case study, of the lamps we took into consideration.

For what concerns the evaluation of the energetic and economic sustainability of a lighting system, it should be kept in mind all the extra costs which are not directly related to its operational phase. By calculating their Life Cycle Assessment (LCA) it could be possible to estimate the overall environmental impact. In other words we can calculate the rough consumption of raw materials and energy, both by estimating and monetizing the emission of GHG produced during the lifespan of the goods and the wastes produced by its stoppage as well [12].

Recently the U.S. Department of energy, through some studies, calculated the LCA of incandescent lamps, compact fluorescent lamps and LED luminous systems [7,31,32].