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OPTIMIZATION OF LIGHTING POWER CONSUMPTION IN OFFICES

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ABSTRACT

In the frame of a research work aimed to analyze and optimize the lighting installations performances in offices, two papers are presented in this symposium.

In a first paper, various lighting sources with fluorescent tubes were experimentally tested in order to identify their performances, mainly their power consumption.

In this second paper, simulations are performed using the results of the first one in order to evaluate and to optimize the lighting power consumption in a typical office. Daylight regulation is the most effective strategy, but regulation based on presence detection is also considered. An economy of 50% or even more in energy consumption on a yearly basis can be obtained in the best situation.

1. INTRODUCTION

The tertiary sector, essentially composed of buildings, represents more than 40% of the total energy consumption in Europe. A decrease of the European energy demand requires thus a better energy performance of buildings. Lighting installations represent a significant part of this consumption (about 35% of the total primary energy consumed in buildings like offices and schools). This justifies the aim of this work which is to analyse and optimize lighting installations performances in offices. Only lighting with fluorescent tubes (the main light source in use in this type of buildings) is addressed in this work.

Our study is twofold. In a first paper [1], various systems were experimentally tested in order to identify their performances, namely their power consumption, in function of their using mode. The tube performances under reduced luminous flux with dimmable electronic ballasts (DEB) were especially evaluated.

In this second paper, simulations are made using some results of the first paper in order to evaluate the lighting energy consumption (on a yearly basis) in a typical office according to different strategies. These simulations use a various choice of control systems (daylight dimming, dimming or extinction according to room occupancy etc.). They can be centralized or not. Moreover, different room configurations (position of luminaires and sensors, use of blinds, fixed or variable presence etc.) are considered.

Hereafter, we detail the parameters considered and the methodology for taking these parameters into account in the consumption analysis.

2. PARAMETERS AND METHODOLOGY

2.1 Room under study

The room under study is a rectangle parallelepiped of about 6.5 m long, 3.0 m wide and 3.0 m high. A southward oriented window, 3.0 m wide and 1.0 m high is transversally placed across a small wall with its lower edge at 1.0 m from the soil. The reflection coefficients (supposed diffuse) of the walls are: $\rho_{wall} = 0.57$; $\rho_{ceiling} = 0.79$; $\rho_{soil} = 0.36$. Furthermore, the visual transmission factor of the window (taking into account the frame obstruction) is 0.65. The total illuminance at every place in the room is of course at each moment the sum of the statistical natural light and the artificial light. The computation will be made on 13 spots (‘test points’) at 80 cm high, disposed along the great central axis of the room.

2.2 Natural light penetration

Simulations were made for evaluating the penetration of natural light in the room for our country latitude. These simulations in function of the hour and the period of the year, take into account the statistic of the sky type (clear with sun, clear without sun, overcast). The file contains for each ‘test point’, the natural illuminance value E_{nat} (lx) averaged on each hour during one year from data available for every 5 minutes. The basic tool for these computations is *DAYSIM*, a day-lighting analysis software (developed at the Lighting Group of the National Research Council, Canada and at the Fraunhofer Institute for Solar Energy Systems, Germany) that calculates the annual daylight availability in buildings.

The possibility of using an attenuation blind is provided. The chosen blind (supposed perfectly diffusing) has an attenuation factor of 8.Two configurations are considered: without blind and with blind. The two data files are nevertheless not identical except for the factor 8 because, without blind, we have to take into account the solar spot in the room by clear sunny sky. As this solar spot can have a discomfort effect, we also used a file giving the time proportion P_{blind} (between 0 and 1) during which the blind is closed (on a manual or on an automatic manner) during each hour. This file is also issued from *DAYSIM* according to a stochastic model which takes into account the indoor and outdoor illuminances for determining the blind action probability of the user. We thus apply the following formula for E_{nat}:

$$E_{nat}(h,i) = P_{blind}\, E_{closed}(h,i) + (1 - P_{blind})\, E_{open}(h,i)$$

where E_{closed} and E_{open} are respectively the illuminance with blind closed and open at hour h and ‘test point’ i.

2.3 Contribution of artificial light

The room is supposed illuminated by monotube luminaires model *R2600/158 Isolum (60°)* from the Belgian manufacturer *ETAP* (www.etaplighting.com) (see photometric curve in figure 1) equipped with tubes *Philips Master TLD super 840 58W*. Two placement configurations were chosen (figure 2) :
- ‘parallel configuration’: 4 luminaires placed parallel to the window and distributed on one row along the great central axis of the room
- ‘square configuration’: 4 luminaires perpendicular to the window, in two rows.

Figure 2 gives also the iso-lux curves at 0.80 m high at nominal flux.

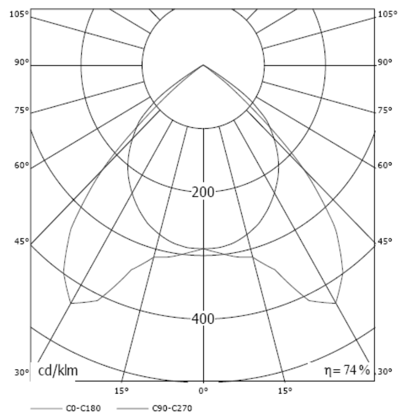
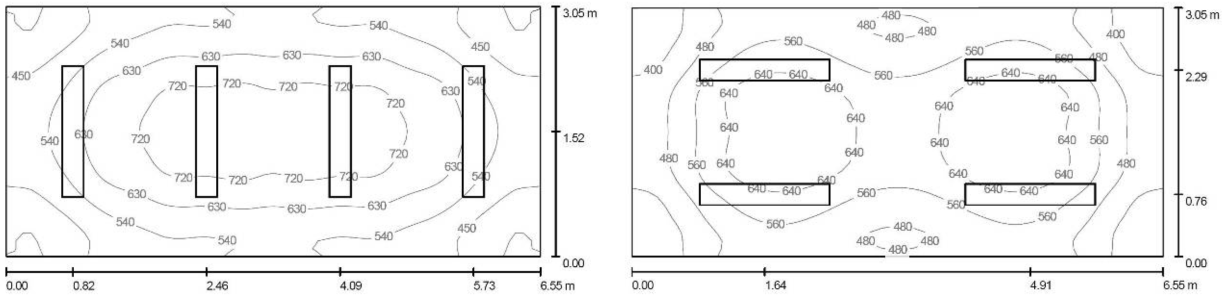


Figure 1. *ETAP R2600/158 Isolum (60°) photometric curve*



parallel configuration *square configuration*

Figure 2. *Luminaires placement configurations and iso-lux curves at full flux*

2.4 Lighting control systems

Beside the power consumption evaluation without any light control, we are interested to know the incidence on this consumption of the following light control systems (all from *ETAP*):

- *ELS* : Regulation in function of the daylight ('*ETAP* Lighting System')
- *MDD* : Movement Dependent Dimming
- *MDS* : Movement Dependent Switching

plus combinations *ELS*+*MDD* and *ELS*+*MDS*.

2.5 Night time switch

Generally, the light control systems consume some energy in the standby mode (typically during night). To prevent this wasting, a night time switch is of course recommended: it is systematically considered in this study. As only one central item is usually provided for all the rooms of the building, the own consumption of this switch will be neglected.

2.6 Room occupancy

Three configurations are analyzed with the *MDD* and *MDS* systems:

- permanent occupancy between 8h and 18h
- idem except a lunch pause between 12h and 13h
- random presence between 8h and 18h.

If we note $P_{presence}$ the time proportion (between 0 and 1) of the room occupancy during the hour considered, we apply the following formula for determining the illuminance due to artificial light at hour h and test-point i

$$E_{artif}(h,i) = \sum_{n=1}^{4} [P_{presence} E_{funct,n}(h,i) + (1- P_{presence}) E_{standby,n}(h,i)]$$

where $E_{funct,n}$ is the illuminance of luminaire n when it is in its functioning mode (full flux) and $E_{standby,n}$ the similar situation when the luminaire is in its standby mode (= 0 with *MDS* system and typically 3% of full flux - full dimming - with *MDD* system).

2.7 Number and place of the sensors

When we wish to control the light in function of the daylight, it is needed to install sensors measuring the light level in some places in the room. Their number and location influence the visual comfort and the consumption. This point will thus be examined. For our convenience, the possible sensor locations will be restricted on the 13 test-points mentioned above.

At *ETAP* (and other companys), the sensor, fixed on the tube, is fundamentally a luminancemeter as it delivers a signal (the ‘set-point’ of our regulation) proportional to the luminance of the surface viewed. This quantity is at turn proportional to the illuminance received by this surface (still depending on its reflection factor and its tilt versus the direction line from the sensor). For a defined situation, we can thus calibrate this signal in value of illuminance at the surface aimed by the sensor.

2.8 Recommended illuminance value

We consider an illuminance value of 500 lx at 0.80 m high, which is the recommended value for a permanent ‘standard’ work in an office, according to the European standard *EN 12464-1 (Lighting of indoor workplaces).* The iso-lux curves of figure 2 confirm that our choice of illuminating equipment is adequate for reaching this objective.

2.9 ELS modelisation

The *ELS* system is among our selected control systems the only one which is true regulating. It thus requires the use of the dimming mode of the lamps to cope with the contribution of natural light. We suppose that one sensor is associated to each luminaire. The objective is, for each natural light situation, to dim the 4 lamps adequately in order to obtain the set-point illuminance (500 lx) on each of the spots aimed by the sensors. We note:

- SP the set-point
- $E_{i,j}$ the illuminance due to the luminaire i at full flux at the spot aimed by the sensor associated to the luminaire j.
- $E_{natur.j}$ (h) the natural illuminance at hour h at the spot aimed by the sensor associated to the luminaire j
- τ_i (h) the dimming rate of luminaire i (proportion of full flux) at hour h, which is the quantity of interest (all the other quantities being known)

The following formula is thus of application in the general case, for each spot j

$$\sum_{i=1}^{4} \tau_i(h) E_{i,j} = SP - E_{natur,j}$$

Except the situation of only one sensor controlling the four luminaires (identical value for each τ_i), the extraction of τ_i requires an iterative process. Consider the case of two sensors (and thus two pairs of luminaires, each pair being associated to one sensor). Note $\tau_{i,k}$ the rate τ_i of the k^{th} iteration. One has for each hour h:

$$\tau_{1,k} = [SP - E_{natur,1} - \tau_{2,k-1} E_{21}] / E_{11}$$
$$\tau_{2,k} = [SP - E_{natur,2} - \tau_{1,k} E_{12}] / E_{22}$$

The first iteration requires thus an initial value $\tau_{2,0}$ to be chosen rather arbitrary between 0 and 1.

We can easily generalize this algorithm for the general case of 4 sensors.

The algorithm will converge to the set-point for each sensor, only if the full fluxes of the luminaires allow it: a dimming rate value higher than 1 is indeed forbidden. It is also the case for rate value lower than the full dimming rate (typically 0.03). The possibility of convergence of this iterative process and the speed of it depend thus on the over-sizing degree of the installation and the number of sensors. For the concrete situation of concern, we observe that 3 iterations are sufficient with 2 sensors for both 'parallel' and 'square' configurations, while the convergence does not completely succeed with 4 sensors though the result is quite acceptable.

2.10 Computing of the energetic consumption

Referring to the result obtained in the first paper [1] with the *Philips* material (tube + dimmable electronic ballast), the total power consumption of the luminaire n can be approximated by the linear law :

$$P_{tot,n}(h) = 46\ \tau_n(h) + 9.0\ \ (W).$$

The yearly energetic consumption (in W.h) for this luminaire is therefore the sum of its power consumption for each hour in the year.

To this value, we have in principle to add the parasitic consumption of the controller, sensors included. The sensors consume typically 0.5 W which is low and thus negligible. The controllers have a typical consumption of 2 W depending of the dimming regime. We can thus also neglect this, at least at full flux. At deep dimming, their contribution can become significant (in relative value). Let us cite in this context the *DALI* controller which maintains its consumption even with the tubes cut-off.

3. RESULTS CONCERNING THE YEARLY ENERGETIC CONSUMPTION

For comparisons purpose, we will consider as our <u>reference situation</u> the situation without control: full flux for the 4 luminaires for each working day during the working hours (8h-18h managed by night time switch). Yearly performance: 570 kWh. This value will thus be considered as the reference to which we will compare the energy consumption of the other situations in order to evaluate the 'kWh economy'.

For each situation considered, we observed that there is no significant difference according to the centralized control system in use (no system; analogue *'Control-it' ;* digital *DAL* from *ETAPI*). Let us however mention that if a *DALI* controller is used at the individual level (one system for each luminaire as it is often the case), the economy related to the reference situation decreases of about 3% by comparison to the same system without controller.

Through a *VisualBasic* application, we studied various situations by changing different parameters. The summary of the results obtained in these simulations is sketched in Table1 (see also comments which follow).

situation	Luminaire configur.	Control	Sensors number	Blind	occupancy	Economy (%)
1	Parallel	ELS (500 lx)	1	Open	n.a.	63
2	Parallel	ELS (500 lx)	1	Closed	n.a.	38
3	Parallel	ELS (500 lx)	1	manual	n.a.	57
4	Parallel	ELS (500 lx)	1	automatic	n.a.	60
5	Parallel	ELS (500 lx)	2	Closed	n.a.	42
6	Parallel	MDD	4	n.a.	permanent	7
7	Parallel	MDD	4	n.a.	random	17
8	Parallel	MDS	4	n.a.	permanent	9
9	Parallel	MDS	4	n.a.	random	22
10	Square	ELS (500 lx)	1	Closed	n.a.	30
11	Square	ELS (500 lx)	2	Closed	n.a.	42

Table 1. *kWh economy by comparison to the reference situation*

Comments on this table

- Effect of number of sensors

For situations with a single sensor, this one, placed in the centre of the room, controls the four luminaires in the same way. When there is no centralized control unit, it is advisable to have 4 sensors (one for each luminaire, at the vertical of each) because the sensor controls directly the ballast. An intermediate situation is 2 sensors (on the grand axis of the room, centred on the left and right pair of luminaires respectively). How more the number of sensors how more comfortable the light situation in the room but how more difficult to converge to an optimal dimming control of the luminaires. The situation with 2 sensors seems to be the best compromise between illuminance repartition and consumption.

In the case of one sensor, the 'square configuration' of the luminaires gives a higher consumption than the 'parallel configuration' but the light repartition in the room is more favourable. With two sensors, the situation is quite similar for the two configurations, both concerning the power consumption and the light repartition.

- Systems with occupancy detection

Two systems are studied: the *MDD* system (full dimming – typically +/- 3% of the full flux - in case of no occupancy) and the *MDS* system (cut-off of luminaires in case of no occupancy).

Two occupancy modes are considered:
- permanent occupancy except during lunch pause (between 12h and 13h)
- random occupancy, which is typical for conference room.

Use is here made once again of the software *DAYSIM* according to a standard model validated by Fraunhofer Institute

These figures correspond to no cut-off delay. For reason of comfort, it is advisable to introduce a temporization to avoid a cut-off when a person present in the room is relatively immobile. Of course, a delay implies an increased consumption, especially in random occupancy mode. A value of 10 minutes seems to be acceptable.

We also studied the mixing of *ELS* regulation with occupancy detection (*MDD* or *MDS*). The progresses by comparison to *ELS* without such a detection are obviously only significant in random occupancy : an increasing in 'kWh economy' of the order of 10% is achievable.

4. CONCLUSIONS

- Dimming in function of daylight availability combined with a central (night) time switch is the most effective way to reduce the energy consumption: an economy of about 50% (or even more) is possible on a yearly basis for south oriented rooms, compared to an installation where the only light control is to switch-off the lamps outside the office working hours.
- Regulation laying on presence detection has of course a modest effect for rooms with permanent occupancy (only active during lunch pause) but is more effective for rooms of random occupation as conference rooms (up to 20% economy)
- The advantage of a centralized control system (analogue or digital) was not evidenced in our study concerning the power consumption economy. Their interest is elsewhere, namely in the easiness to modify a lighting installation according to a change of room configuration (e.g. transformation of individual offices in a "landscaped office").

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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