USING A PATTERN SEARCH ALGORITHM TO IMPROVE THE OPERATION OF A DAYLIGHT HARVESTING SYSTEM

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ABSTRACT

Daylight exploitation represents the cornerstone of any strategy aiming at reducing energy consumption in office buildings. On the level of design , this can be achieved by adjusting the properties and dimension of the façade openings together with a possible increase in the daylight zone, while on the equipment level, mainly by adopting daylight harvesting systems . The structure of these consists of a photosensor (which is usually placed on the ceiling) and a controller regulating the operation of the luminaires based on a control strategy (usually closed loop). Its main objective is to maintain the lighting levels on the working at the design value. The position of the sensor on the ceiling presents a problem. The ratio of the ceiling sensor illuminance to the one at a corresponding point on the working surface is not constant during daytime, and this may result in an erratic operation. Increasing the distance of the photosenor from the opening (in side-lit spaces) and/or reducing its field of view (FOV) the control strategy approximates the ideal operation but energy savings are reduced.

Usually, manufacturers provide some recommendations regarding the distance of the photosensor from the opening in an effort to avoid the opening being in the sensor's FOV (closed loop control algorithm). However, in many cases, the exact positions of the furniture are not known during the design phase and thus the sensor is placed at the center of the controlled zone in an effort to increase the area with total illuminance larger than the design one (i.e 500 lux). Does this position represent the best option? Such a question can be answered through a parametric analysis for a number of variables, using simulation, a tedious and time-consuming process. In the present work an optimization methodology is examined , combining Genopt and Radiance using very basic information for the sensor, investigating if it can ensure a better solution than what is suggested by common practice. Inputs are the photosensors' FOV, their orientation and their position. The methodology is trying to minimize an objective function which depends on a) the lighting energy achieved and b) the percentage of the working surface with total illuminance more than the design one, for 90% of the working hours (spatial Lighting Adequacy). Results show that the optimization procedure concerning photosensor placing is time consuming without results differing greatly from those achieved through common practice.

Key words: Daylight, Dimming, Lighting

INTRODUCTION

Lighting energy consumption represents a significant percentage of a building's energy balance [1, 2] and daylight exploitation is an essential strategy for increasing energy savings in office buildings. Among various existing daylight dimming systems, a closed-loop one using the integral reset algorithm [3] is quite simple in its use and in a number of systems a single photosensor can be directly connected to a number of proper ballasts, making the solution cost effective. Since achieving the design illuminance in the space with maximum energy savings is antagonistic, the proper position of the photosensor has to be estimated. Usually the sensor is placed at the center of the controlled zone. Integral reset is quite a common algorithm adopted by many manufacturers. The signal produced by the photosensor which is located on the ceiling is kept constant and equal to the signal during the night-time calibration procedure. The operational equations of this algorithm are the following [4] :

$$S_T(t)= S_{Edesign} \qquad (1)$$

Where $S_T(t)$ is the time dependent signal produced by the photosensor while $S_{Edesign}$ is the signal produced during night-time calibration. During day-time operation the photosenor signal is the sum of daylight $S_D(t)$ and electric $S_E(t)$ light components . Thus

$$S_T(t)= S_D(t)+S_E(t)= S_D(t)+\delta*S_{Edesign} \quad (2)$$

Where δ is the fractional output of the lighting system. $\delta=1$ represents full light output and δ_{min} the minimum one. Combining the above equations, the fractional output can be calculated as follows:

$$\delta=1-(S_D(t)/S_{Edesign}) \qquad (3)$$

For this study a linear relationship between fractional input power f_P and fractional light output δ was used. When the minimum lighting output is achieved (δ_{min}), there is a minimum power input f_{Pmin}. Both values depend on the type of the ballast. The relation between power f_P and δ is described by the following equations :

$$\text{If } \delta<\delta_{min} \text{ then } f_P=f_{Pmin} \qquad \text{else} \qquad \text{If } \delta_{min}<=\delta \text{ then } f_P=(\delta+(1-\delta)*f_{Pmin}-\delta_{min})/(1-\delta_{min}) \quad (4)$$

For the present calculation, a value of 0.1 was selected for f_{Pmin} while a value of 0.05 for δ_{min}.

The lighting levels on the working surface, when daylight is present, is given by the relationship

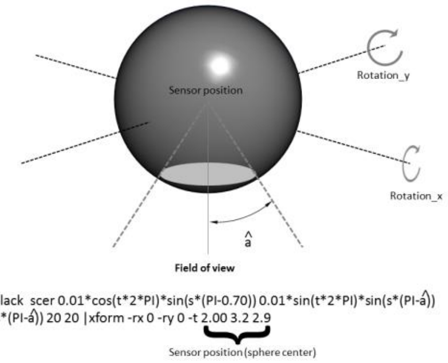
$$I_T(t)= I_D(t)+ I_{Edesign} * (1- S_D(t)/S_{Edesign}) \qquad (5)$$

Where I_T is the total illuminance, I_D is the illuminance due to daylight and $I_{Edesign}$ the design illuminance. Sensor position and FOV affect $S_D(t)$ and $S_{Edesign}$ and hence lighting (δ) and power (f_P) fraction. The aim of the paper is to present an optimization framework capable of estimating a near optimum position for a given sensor using as criteria the maximization of energy savings together with the working surface area with $I_T(t)>= I_{Edesign}$.

OPTIMIZATION SCHEME

The use of global optimization methods, though not suitable for every case, can explore large regions of possible solutions when trying to find the best values for a set of variables which will minimize an objective function. There is a large number of optimization methods (pattern search, genetic algorithms etc), but when these are used in building design problems [5] there are some requirements that have to be met, such as the existence of the non-analytic expression of the objective function together with time consuming simulations. In the present paper, the optimization problem was solved using a hybrid approach, with Particle Swarm Optimization for global search and Hooke-Jeeves for its proved convergence properties. This approach can handle local minima problems more efficiently, since Hooke-Jeeves is strongly depended on the smoothness of the objective function.

While many studies [6-9] have been realized when examining techniques and systems in an effort to increase lighting energy savings, there is a small number of studies dealing with the photosensor, which are focused on the optimization of these systems’ performance [10]. The aim of this paper is to examine if an optimization method can be used during the early design of the building’s systems in order to optimize the position of a photosensor for an integral reset dimming system. A theoretical model of the system is used but the same methodology can be utilized for real systems as well. The simulated photosensor has an ideal cosine spatial sensitivity and is located at a centre of a small black sphere with an opening. The size of the opening determines the sensor’s field of view while the direction can be altered by adjusting rotation around two axes as presented in the following graph.



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!gensurf black scer 0.01*cos(t*2*PI)*sin(s*(PI-0.70)) 0.01*sin(t*2*PI)*sin(s*(PI-â))
0.01*cos(s*(PI-â)) 20 20 |xform -rx 0 -ry 0 -t 2.00 3.2 2.9
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Figure 1. Schematic representation of the examined photosensor.

It is evident that the sensor’s FOV is geometrically modified by adjusting the solid angle formed by the hole. Implementation of the optimization procedure was straightforward using Genopt [11]**.** Genopt is designed to minimize the value of an objective function by using user-selected parameters. This function was defined as follows:

$$OF=2-ESP - sLA \qquad (6)$$

Where ESP is the energy savings percentage while the parameter sLA (spatial Lighting Adequacy) is similar to spatial Daylight Autonomy representing the percentage of the working surface where the lighting levels (from daylight and artificial lighting) is larger than the designed value (i.e 500 lux) by at least 90% for the period of the analysis. The parameters used are the coordinates of the sensor on the ceiling together with its axis rotation and field of view. Operation schedule is between 8:00-18:00 totaling 3650 hours annually, for Athens, Greece climatic file. In side lit spaces, any increase in the distance between sensor and opening reduces ESP and increases sLA.

A batch file was created and used as the simulation program. Its output is a delimited file with ESP and sLA values which is used by GENOPT to evaluate the objective function. The batch file contains commands: a) for reading the input file (sensor position, rotation, FOV) b) for creating sensor radiance files c) for running a simulation with artificial lighting to calibrate the sensor, d) for running the three phase method [12] e) for elaborating the simulation results and for writing the results in the output file. Calibration is performed by calculating the average illuminance over a grid on the working surface, together with the sensor illuminance. Depending on the design illuminance selected (500 lux in our case), sensor illuminance ($S_{Edesign}$) is adjusted accordingly.

The room that was used for the simulations is a typical space in an office building with dimensions of 4 x 5.5 x 2.8 m with one external façade**.** The electric lighting system consisted of four ceiling recessed fluorescent lamp (T26 2x36W) luminaires in a uniform layout. The installed power was 12.9 W/m^2 while the average maintenance lighting levels on the working surface (0.8 m height) were 579 lux with 0.7 uniformity (minimum to average value). Since the lighting system is inside the perimeter zone as this is defined by EN 15193-2007 [13], it can be controlled with one sensor. Wall, ceiling and floor reflectances are 0.55, 0.8 and 0.3 accordingly while glazing transmittance is 0.73. External shading for the south oriented façade (overhang with dimensions 0.8 m x 4 m). Initially, hourly sensor illuminances from the batch simulation file were compared with results from DAYSIM [14] using the same geometry in an effort to tune radiance parameters. The following graph presents sensor illuminance (FOV 2x30^0) for south orientation at the center (x=2m, y=2.5 m) of the ceiling.

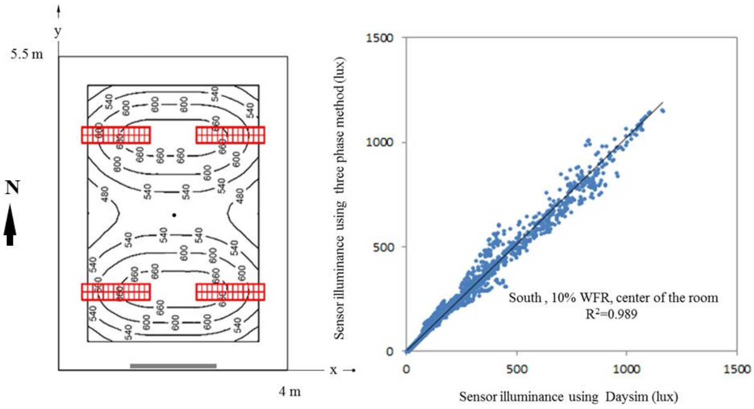
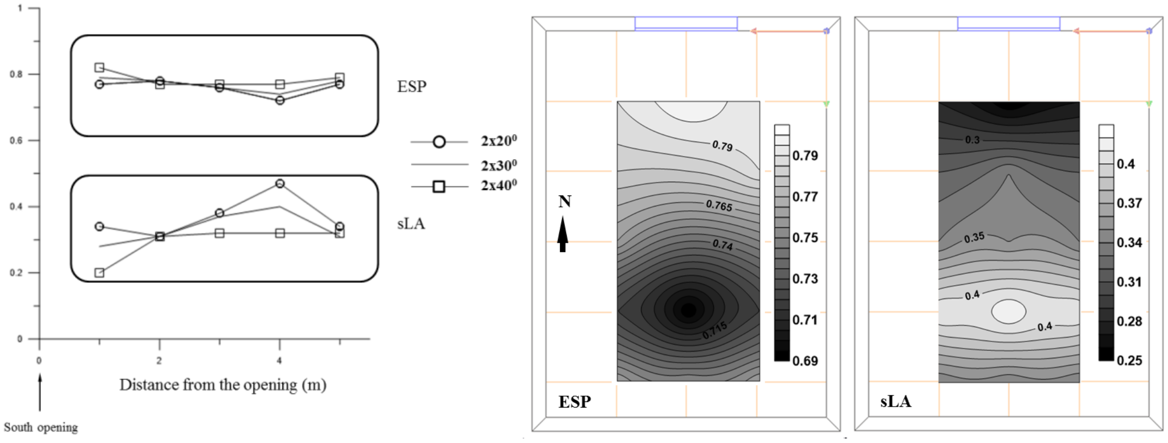


Figure 2. Comparison between sensor illuminance using three phase method against Daysim.

RESULTS

A problem that may affect optimization results is due to the stochastic nature of radiance calculation. Relaxing Radiance parameters, in an effort to speed up simulation, may result in an increase in the variability of calculated lighting energy saving values making the optimization algorithm's convergence harder. Another issue is that set point sensor illuminance as this is estimated during night time calibration can be easily achieved by daylight only, increasing calculated lighting energy savings. It seems that by moving the sensor position away from the opening there is a relatively small decrease in ESP parameter (maximum difference 7% for the narrowest FOV 2x20^0 and south orientation while the difference increases to 21% for north orientation).



a) b)

Figure 3: ESP and sLA as a function of the distance from the opening. a) Section, south oriented room 10% WFR. b) bottom view, north oriented room , 10% WFR.

On the other hand, sLA increased with the sensor's distance from the opening and this change is more pronounced for the south oriented room with narrow FOV (2x20^0), reaching 34%. Nevertheless, the estimated energy saving percentage is quite increased for both south and north orientation, a characteristic strongly associated with an integral reset algorithm. The objective function (OF) shows limited variance over sensor position since ESP and sLA are antagonistic. The optimization method was used for the south oriented room using a sensor with FOV 2x30^0 pointing downwards.

A solution was found after 203 simulations indicating that the sensor's optimal position is 4 m away from the window achieving 75% lighting energy savings and 40% spatial lighting adequacy. When the sensor's aiming is considered as a simulation parameter, OF is minimized when the sensor is located 3.5 m and 10^0 tilt along east-west axis, away from the opening. The tilt angle is using a north oriented room (10% WFR) , the optimal solution (ESP=0.78, sLA=0.34) was achieved when the sensor's position is located 2 m away from the opening with 15^0 tilt. Along east –west axis the optimization process took approximately 45 mins in an Intel core i7-3520M processor.

CONCLUSIONS

Optimization methods can be used during the design phase so as to identify and estimate the parameters involved with the dimming system's performance. The definition of the objective function is quite crucial and some expert judgment is needed to simplify the optimization problem and reduce the size of the solution search space. The following main observations could be made:

1) The simulation program has to ensure the smoothness of the objective function. Since Radiance three phase method was used, proper selection of its parameters is crucial as they affect accuracy, processing time and convergence.

2) The optimization process was time consuming using approximately 200 discreet simulations. Judging from the results achieved, the solution that is suggested by common practice (sensor placement in the center of the controlled zone) differs in terms of energy savings by less than 3% from the optimal one (south oriented room). The optimal sensor position varied between 2 m (north oriented room) and 3.5 m (south oriented room) with 10^0 and 15^0 sensor tilt respectively and 2x30^0 FOV.

3) Spatial lighting adequacy (sLA) can be used to characterize dimming systems' performance and complements energy savings.

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