A CRITICAL REVIEW OF SIMULATION TECHNIQUES FOR DAYLIGHT RESPONSIVE SYSTEMS

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ABSTRACT

Application of lighting control technologies has increased the public interest. Although these technologies have been promoted during the last years their successful use in buildings has been accomplished in a small percentage of new projects. One reason is the difficulty in quantifying the energy savings and thus the subsequent payback period.

The majority of existing simulation tools (which are embedded in building energy codes) –needed during initial design- are based on the estimation of the potential energy savings due to daylight. The paper focus on the limitations of current simulation approaches comparing their results, in order to assess their accuracy. For this, special test cases have been developed exploiting their domain of validity.

Keywords: daylight, energy savings, simulation

1. INTRODUCTION

As the cost of energy has continued to rise, increasing effort has gone into minimizing the energy consumption of lighting installation. This effort has evolved along three major directions:

1. The development of new energy efficient lighting equipment
2. The utilization of improved lighting design practice
3. The improvement in lighting control systems

While saving energy is of a great importance, there are some other associated benefits, which should be considered. These are productivity and quality. However, it is quite difficult to quantify their influence. Lighting controls perform functions like on-off operation, time scheduling, dimming, dimming due to presence of daylighting, lumen depreciation and demand control. They can also be grouped into two general categories: centralized controls and local controls. Centralized controls are used in buildings where it is desirable to control large areas of the building on the same schedule. Localized controls are designed to affect only specific areas.

Daylighting can be considered as a very important strategy to substitude electric energy for the artificial lighting. It can reduce not only the lighting (and cooling as well) consumption but it can be very efficient in reducing peak electrical loads. A variety of results in relation to energy savings due to daylighting are presented to literature. Based on simulation results Szerman [1] found 77% for lighting energy savings and 14% for total energy savings. Embrechts and Van Bellegem [2] measured that an individual lighting dimming system can offer 20-40% of lighting consumption savings. Opdal and Brekke [3] compared measurements and calculation results and obtained 40% of lighting savings (calculation) and 30% of lighting energy saving (measurements). The indicative values presented are quite difficult to compare because they refer to a particular climate, building and daylighting system.

A typical daylighting control concept usually consists of at least two components:

- Integrated lighting control zones equipped with one or a number of photosensors
- Automatic control strategy for each zone (which is controlled by photosensor's signal)

The integrated lighting control zones are areas in the building that use daylight and electric lighting jointly to provide task, background or general illuminance. The size of a zone depends upon aperture configuration, sky condition and solar location. Measurements or results from simulation procedures (for a minimum of four different months representing winter, spring, summer, fall) are needed in order to establish the illuminance of the lighting zones. In order to establish the usual minimum/maximum range of performance, only winter and summer need to be analyzed.

Lighting zones link areas, which have similar daylighting distribution characteristics. Within a zone the light at the station point of maximum illuminance should not be more than about three times brighter than that at the station point of minimum illuminance. This guarantees a reasonable contrast ratio within the zone. A ratio of maximum to minimum illuminance greater than 9:1 is somehow the limit and the area should be divided into more zones [4].

In general, the greater the number of zones is in a space, the greater the opportunity for energy savings is. When there is a small number of zones in a room, the reduction of initial costs is often offset by the reduced performance characteristics of the integrated lighting system. Consequently the combination of performance, initial, operational and maintenance costs should be appraised to determine the optimum control strategies.

Once the lighting zones have been chosen, the one station point in the zone that will be used to establish the lighting control strategy for the zone must be selected. Usually neither the highest nor the lowest illuminance point in the zone should be chosen to represent the zone. If the station point with the highest illuminance value is used, the rest of the space will be under lighted when the illuminance on that point is equal to or larger than the design illuminance. Therefore the station point should be place somewhere between the high and the low.

Daylight responsive dimming systems consist of three major components; photosensor, lighting controller, and electronic dimming ballast. The basic algorithms for daylight control are “open-loop” and “closed-loop” indicating whether close or not (open) information is fed back to the system to achieve control objectives. Open loop systems cannot compensate for electric light losses (lumen maintenance strategy) but afford greater flexibility in calibration than most closed-loop systems. They are also more forgiving to errors in sensor placement or field of view.

2. CONTROL STRATEGIES AND TYPES

2.1 Basic daylighting control strategies

The basic control strategies are the following:

- *Simple on/off switching*

When daylight illuminance in the station point is reached, the electric lights are switched off and switched on again when the daylight illuminance drops below the control value.
A problem with the automatic on/off photoelectric switch has been the user reaction to its operation. Especially, people do not like automatic controls, which switch lights on when they could have been off under manual control. A special problem with the photoelectric switch is the rapid switching of lights on and off on occasions when daylight levels are fluctuating around the switching illuminance. This can annoy occupants and reduce lamp life. Various techniques have been developed to reduce the number of switch offs such the differential switching control (with introduction of dead bands) and switching with time delay.

- *Photoelectric dimming*

This is a more sophisticated method. If the illuminance Ex on the sensor which is located in the station point is greater than the target illuminance Es then the lights will be switched off. However if Ex is less than Es the control of the system is making the artificial lighting to provide an extra illuminance Es-Ex. In this case the fractional power saving from an ideally efficient control is given by the ratio Ex/Es.

2.2 Typical control types

Typical control types are:

- *Continuous Dimming, Constant Setpoint –*

This control type for continuously dimmable fixtures allows a single input signal to be set, then tries to maintain that signal at all times. If the signal is lower than this setpoint, the luminaires will be on at maximum output, and if it is greater, they will be on at their minimum output. The times between these end conditions, the luminaires will be dimmed accordingly to maintain the single signal setpoint with a combination of electric light and daylight. Figure 1 illustrates the relationship between the luminous dimming of the electric lighting system and the sensor response for this type of system.

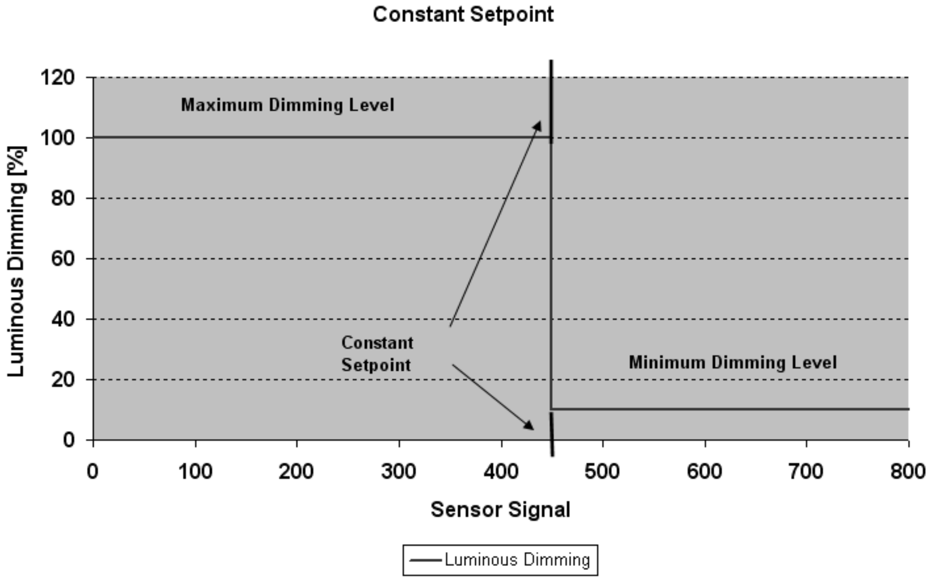

Figure 1. Constant setpoint control algorithm.

- *Continuous Dimming, Sliding Setpoint*

This control type for continuously dimmable fixtures allows two input signal to be set as a high setpoint and a low setpoint. The low setpoint gives the point at which the luminous dimming will begin to occur and it will occur linearly with the sensor signal until the high setpoint is reached and the system reaches its maximum luminous dimming. Figure 2 illustrates this control type showing the relationship between the luminous dimming of the system and the sensor response.

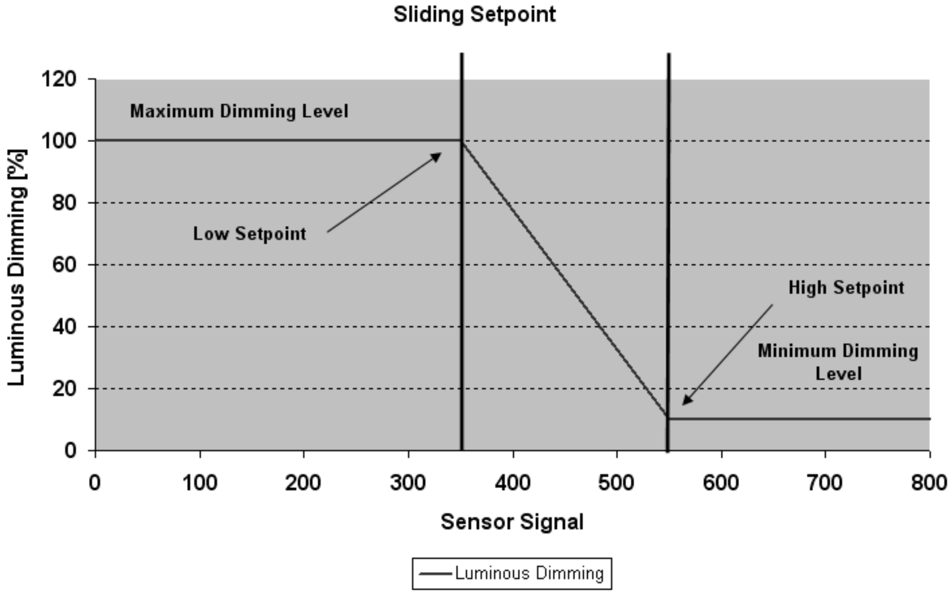

Figure 2. Sliding setpoint control algorithm.

Dimming controls are more expensive than on-off switching and more difficult to install. However they should save more energy, both through daylight linking and by dimming lamps at the start of their life to compensate for their increased output. The problems that have been encountered include poor operation of the system when a single photocell controls a wide area of the building with different daylight levels in different locations.

In typical photosensor-based lighting control systems the photosensor in located on the ceiling. Performance of the lighting system and hence the associated lighting energy savings strongly depended on the photosensor's spatial and spectral response and its control algorithm as well. This is presented in Figure 3.

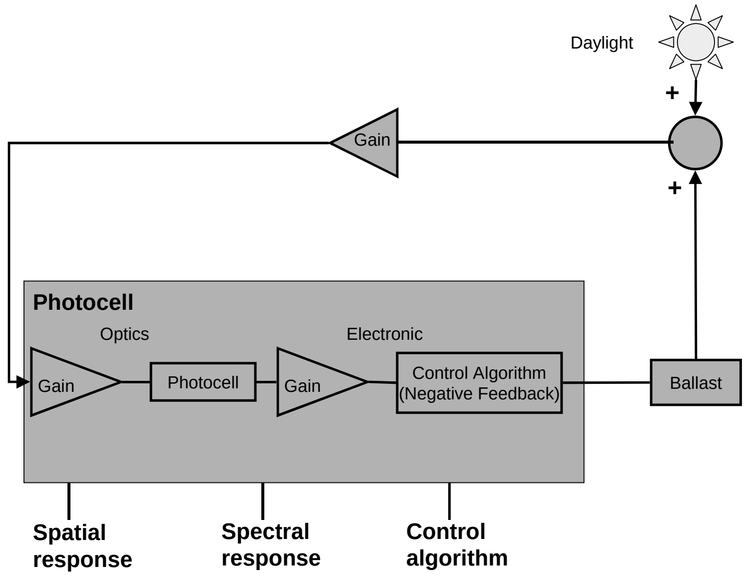

Figure 3. Factors that influence the performance of a daylight-control lighting system.

To maintain target lighting levels at the workplane in response to changes in the amount of available daylight, a signal is measured by photosensors, which represent workplane illuminance values. But, this is very difficult in practical situations because the photosensor reacts to the luminous distribution of all surfaces seen by the photosensor.

3. Predicting lighting energy use

The prediction of the daylight potential to save energy is quite critical in order to design the correct automatically controlled lighting system since this system has high initial costs. Energy saving is strongly related to the climatic conditions of the countries and the available daylight levels in the interior of buildings.

Prior to the prediction of energy savings due to daylight a feasibility study should be performed in order to estimate the potential for energy savings. Four techniques can be used:

1. Estimation of perimeter zone of the building. This zone is extended to ~2-2.5 the window head. In this zone which normally has adequate daylight all day long, switching may be acceptable, since the lighting system may adjust its flux only once or twice during stable daylight hours.

2. Estimation of average daylight factor (ADF). ADF 2%- 5% indicates a strong potential for energy savings due to daylight.

3. Estimation of feasibility factor (Eq.1) is as follows:

$$FF=WWR * T_{vis} * OF \qquad \text{Eq. (1)}$$

Where WWR is the Window to Wall Ratio, T_{vis} is the visible transmittance of the opening and OF is the Obstruction Factor. OF equals when less than 50% of the opening is shaded and it is equal to 0.4

when the shaded part exceeds 90%. If FF is grater than 25% then daylight is expected to have significant energy savings [5].

4. Each side lit space can be divided in three areas [6], the daylight area, the mixed light area and the artificial light area namely. Daylight area has a depth of approximately two times the effective window height and strong daylight savings potential. Mixed light area is extended 1.5 times the effective window height next to daylight area. The rest area represents an artificial lighted area. Effective window height is the effective window area divided by the width of the façade. Effective window area is the actual glass area above 0.9 m from the floor in the façade multiplied by the transmission of the window pane.

For the prediction of the performance of the electric lighting control system and its effect on energy use and other performance characteristics, the following parameters are required:

1. Accurate computation of daylighting
2. Accurate simulation of the sensor perfomance
3. Reliable simulation of the artificial lighting system output in relation to the control voltage.

The difference between the photosensor signal and workplane illuminance is the major problem for any inaccuracies observed between estimated and measured lighting energy consumption. This difference in a real installation is determined by the daytime or nighttime calibration, the photosensor placement, and the photosensor's field of view. Although it is easier to consider a linear relationship between the photosensor signal and the workplane illuminance this is not the case in real world.

3.1 Accurate computation of daylighting

For the accurate computation of daylighting two methods are used: Radiosity [7, 8, 10] and ray tracing [11] (either forward or backward).

In radiosity all surfaces are assumed perfectly diffuse. Thus means that all surfaces have constant luminance independent of the viewing direction (not true in many real world situations). Each surface is subdivided into a mesh of smaller patches. During the calculation process the amount of light distributed from each mesh patch to every other patch is calculated.

The advantages of this method are:

- Calculations of diffuse intereflections between surfaces

The disadvantages include:

- 3D mesh requires memory
- Does not account for specular reflections or transparency effects

The ray tracing technique tracks the path of a light ray as it bounces off or is refracted through a surface.

The ray tracing algorithm has the following advantages:

- Accurate estimation of direct illumination, shadows, specular reflections and transparency effects.
- Memory efficient

The disadvantages are:

- Computationally expensive
- If the point of calculation is changes the whole process should be repeated.

However, as internal illumination has to be calculated in a dynamic way to take into account sky variability, the above methods require a quite high computational effort, since intereflection calculations have to be performed for each time step. Thus there is a need for models that can calculate, in an accurate way, illuminance levels in complicated geometrical environments without the need to repeat time-consuming intereflection calculations at every time step.

A simple approach is the use of the "split-flux" method. In this method the daylight transmitted by the window is split into two parts a downward-going flux (Φ_F) which falls on the floor and portions of the walls below the imaginary horizontal plane passing through the center of the window and an up-ward going flux (Φ_C) which strikes the ceiling and portions of the walls above the window midpane. A fraction of (Φ_F) and (Φ_C) is absorbed by the room surfaces. The remainder, the first reflected, F_1, is approximated by (Eq.2):

$$F_1=\Phi_F * \rho_F + \Phi_C * \rho_C \qquad \text{Eq. (2)}$$

where ρ_F is the area-weighted average reflectance of the floor and those parts of the walls below the window midplane, and ρ_C is the area-weighted average reflectance of the ceiling and those parts of the walls above the window midplane.

To find the final average internally reflected illuminance, Er, on the room surfaces (which in this method is uniform throughout the room) a flux balance is used. The total reflected flux absorbed by the room surfaces (or lost through the windows) is $AEr(1-\rho)$, where A is the total inside surface area of the floor, walls, ceiling and windows in the room, and ρ is the area-weighted average reflectance of the room surfaces, including windows. From conservation of energy (Eq 3):

$$AEr(1-\rho)=F_1 \quad or\ Er= (\Phi_F * \rho_F + \Phi_C * \rho_C)/ A(1-\rho) \qquad \text{Eq. (3)}$$

A more accurate procedure for the estimation on internally reflected daylight can be performed using the daylight coefficient approach, developed by Tregenza and Waters [12]. The daylight coefficient d_k is defined as the ratio between the luminance of a patch of sky and the illuminance in the building due to light from this patch (Eq.4):

$$d_k=E_k/L_k a_k \qquad \text{Eq. (4)}$$

Where L_k is the luminance of the sky patch, E_k is the illuminance at a point in the room and a_k is the solid angle subtended by the sky patch. The sky is divided into zones of altitude and azimuth, and a daylight coefficient can be assigned at each zone. Then, total illuminance at one point in a room can be calculated using the formula (Eq. 5):

$$E_k = \sum_{145}^{k=1}\left(d_k * L_k * a_k\right) \qquad \text{Eq. (5)}$$

Following the daylight coefficient approach [13,14], the intereflection calculation is carried out once for each sky zone, and it does not have to be repeated if the sky luminance distribution changes. The advantage of this approach is that hourly calculations of interior lighting in a building, for a whole year, can be performed faster without repeating intereflection calculations. Since the sky is treated a s number of discrete sources, the contribution of direct and reflected sunlight in the interior lighting can be assessed by adding, to the sky zone where the sun is located, an additional luminance equal to the normal illuminance divided by the solid angle of the zone.

Computation of daylight coefficient using a backward ray tracing engine can be performed as follows: Rays are emitted from the reference plane towards directions fitting the propability function of the light reflection.

The rays are recursively tracked through reflections and transmissions, and if their weight is greater than the threshold ray-weight they are accounted for to the sky patch corresponding to the specific direction. The ratio between the sky patch score and the total number of rays emitted determines the daylight coefficient between this patch of the sky and the considered point. The part of the calculation dealing with intereflection is presented in Figure 4.

DAYSIM [15] uses RADIANCE as calculation engine in order to estimate daylight coefficients. Contributions from direct sunlight are modeled by some 65 representative sun positions, which are a subset of all possible sun positions throughout the year. These positions were generically chosen, as they generate an evenly spaced grid across all possible sun positions throughout the year for median latitudes.

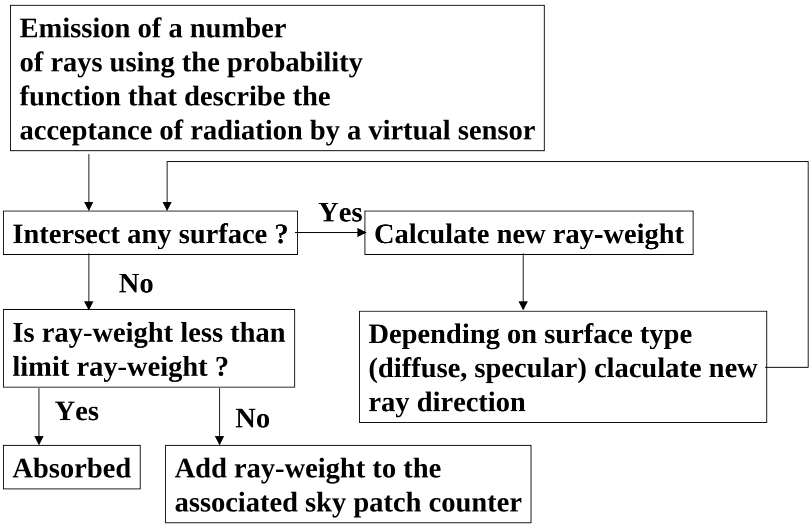

Figure 4. Flow diagram concerning the stochastic calculation of indirect illuminance.

3.2 Accurate simulation of the sensor behaviour

Bierman and Conway [16] reviewed different photosensor models with different acceptance angles and varying spatial and spectral sensitivity and they have provided the data necessary to improve the accuracy of simulations of the actual performance of photosensors. C. Ehrlich et al. [17] have presented a method to simulate the photosensor behaviour. The method is based on the concept of multiplying two fisheye images: one generated from the angular sensitivity of the photosensor and the other from 180 or 360^0 fisheye image of the space as “seen” by the photosensor (Figure 5). Analyzing the final image photosensor illuminance can be calculated accurately.

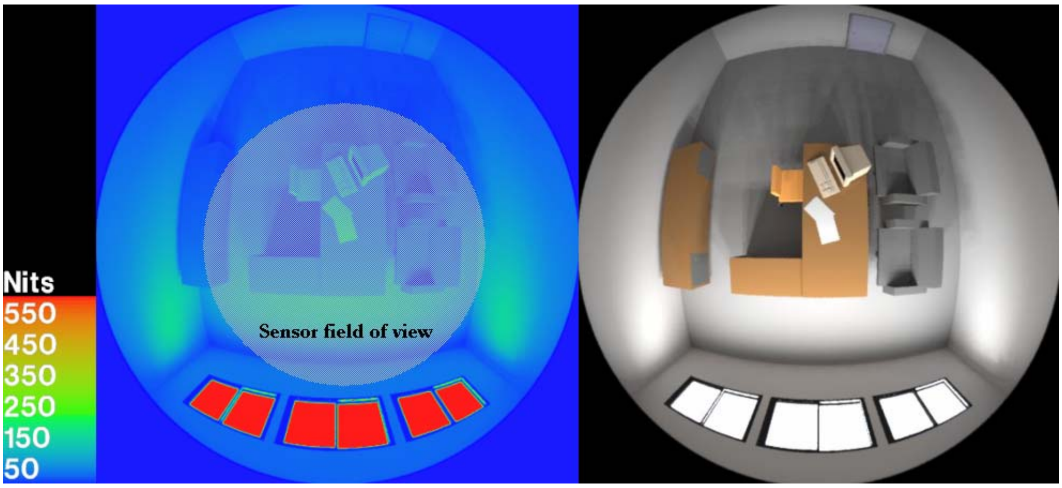

Figure 5. Fisheye images. Angular sensitivity of the photosensor (left) and space as “seen” by the photosensor (right).

3.3 Reliable simulation of the artificial system light output in relation to the control voltage

As mentioned before the photosensor signal is processed through a ballast controller and sends a dimming control voltage to the electronic ballast forcing them to reduce power. Although there are a variety of control algorithms, a closed loop proportional control system offers the most adjustments to the user and accommodates to some degree the different response characteristics of the photosensor to daylight versus electric light. In order energy consumption to be estimated accurately functions of control voltage and light output ratio is needed (Figure 6). Unfortunately this can be estimated using experiments or using manufacturer’s data [18, 19, 20, and 21]

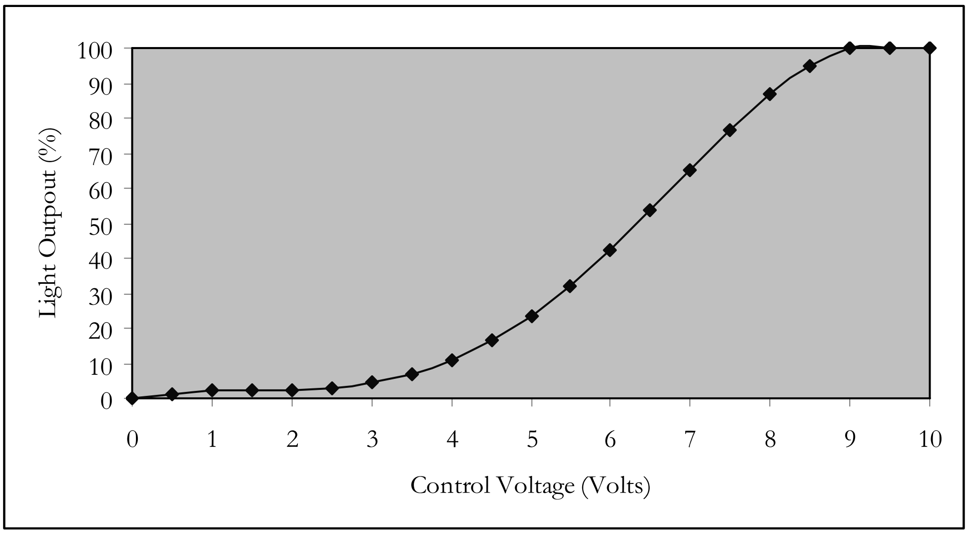

Figure 6. Control voltage and corresponding light output ratio for a ballast.

3.4 Capabilities of existing software tools

3.4.1 RELUX

RELUX is one of the most common used simulation programs in lighting planning in Europe. RELUX can simulate interior and exterior spaces with lighting applications using RADIANCE but also can simulate daylight for interior spaces and gives results that can help a daylight designer. RELUX calculates daylight factors according to DIN 5034 [22] and CIE clear or overcast sky and can calculate energy savings from daylight (for diffused or clear sky conditions). The latest version of RELUX can be downloaded from www.relux.ch [23].

3.4.2 SPOT

SPOT (Sensor Placement and Orientation Tool) [24] is a simulation tool that intends to assist a designer in quantifying the existing or intended electric lighting and annual daylighting characteristics of a given space. Also, SPOT helps the designer to establish the optimal placement of the photosensor inside the space relative to annual performance and annual energy savings.

Namely, this simulation tool can calculate on daily and hourly basis the average light output, electrical savings, additional heating loads, cooling load savings, average workplane illuminance, minimum and maximum illuminance, as well as, the time that the minimum and maximum illuminance occurs. These calculations are strongly related with the placement and the type of the photosensor. A “wrong” placement or choice of the type of the photosensor can result in smaller energy savings.
The latest version of SPOT can be downloaded from www.archenergy.com/SPOT.

3.4.3 DAYSIM

DAYSIM [15] is a RADIANCE-based daylighting analysis tool that has been developed at the National Research Council Canada and the Fraunhofer Institute for Solar Energy Systems in Germany. Windows TM and Linux versions of DAYSIM can be downloaded from www.daysim.com. In order to calculate annual illuminance profiles, one could in principle also use the standard Radiance programs and start thousands of individual raytracing runs for all sky conditions of the year. This approach is not practical as a Radiance simulation for a single sky condition can take hours so that an hourly annual simulation would literally require years of calculation time. To keep simulation times short, Daysim uses the Radiance algorithm coupled with a daylight coefficient approach. A unique feature of the Daysim is a *user behavior control model*, called Lightswitch [25, 26]. The model can be used to quantify the energy saving potential of automated lighting controls, e.g. of an occupancy sensor over a standard on/off wall switch. It combines annual illuminance profiles and occupancy profiles with behavioral patterns that are based on field studies in buildings throughout the Western world. Further input quantities are, a description of the lighting control system (manual wall switch, occupancy sensor, dimmer), blind control (manual, automated) and the type of occupant (energy-conscious/active or passive). For example, the model predicts when users will lower window blinds in response to glare, or when they will switch on the electric lighting.

3.4.4 Esp-r

During the time-step simulation, Esp-r [10] can adjust various model parameters according to a predefined (by the user) law. Artificial lighting control algorithm then initiates the daylight simulation, coordinating RADIANCE to carry out several tasks as follows:

- Transfer of data defining current solar position
- Generation of sky model
- Re-building of the scene model
- Calculation of internal illuminance for defined sensor locations
- Transfer back of illuminance data to luminaire controller. Integral reset and closed loop proportional controllers can be simulated

3.4.5 Energy Plus

The EnergyPlus [9] daylighting calculation is derived from the daylighting calculation in DOE-2.1E [8]. There are two major differences between the two implementations:

- In EnergyPlus daylight factors are calculated for four different sky types—clear, clear turbid, intermediate, and overcast; in DOE-2 only two sky types are used—clear and overcast.
- In EnergyPlus the clear-sky daylight factors are calculated for hourly sun-path sun positions several times a year whereas in DOE-2 these daylight factors are calculated for a set of 20 sun positions that span the annual range of sun positions for a given geographical location.

Once the final daylight illuminance (direct plus intereflected using the split flux method) value at each reference point has been determined, the electric lighting control is simulated. The fractional electric lighting output, f_L, required to meet the setpoint at reference point i_L is given by Equation 6:

$$f_L(i_L) = \max\left[0, \frac{I_{set}(i_L) - I_{tot}(i_L)}{I_{set}(i_L)}\right] \qquad \text{Eq. (6)}$$

Here, *Iset* is the illuminance setpoint and *Itot* is the daylight illuminance at the reference point. This relationship assumes that the electric lights at full power produce an illuminance equal to *Iset* at the reference point.
The fractional electric lighting input power, f_P, corresponding to f_L is then calculated. The relationship between f_P and f_L depends on the lighting control type. For a continuously-dimmable control system, it is assumed that f_P is constant and equal to $f_{P,min}$ for $f_L<f_{L,min}$ and that f_P increases linearly from $f_{P,min}$ to 1.0 as f_L increases from $f_{L,min}$ to 1.0 (Figure 7). This gives (Eq. 7):

$$\begin{aligned} f_P &= f_{P,\min} && \text{for } f_L < f_{L,\min} \\ f_P &= \frac{f_L + (1-f_L)f_{P,\min} - f_{L,\min}}{1-f_{L,\min}} && \text{for } f_{L,\min} \le f_L \le 1 \end{aligned} \qquad \text{Eq. (7)}$$

4. SIMULATIONS

4.1 Description of the reference room

The room that was used for all the simulations is a typical space in office buildings. In addition, the dimensions and the data that were used are given in the next figures (Figures 8 and 9). The windows are located on the south facade of the building. The optical properties of the elements inside the office room are presented in Table 1.

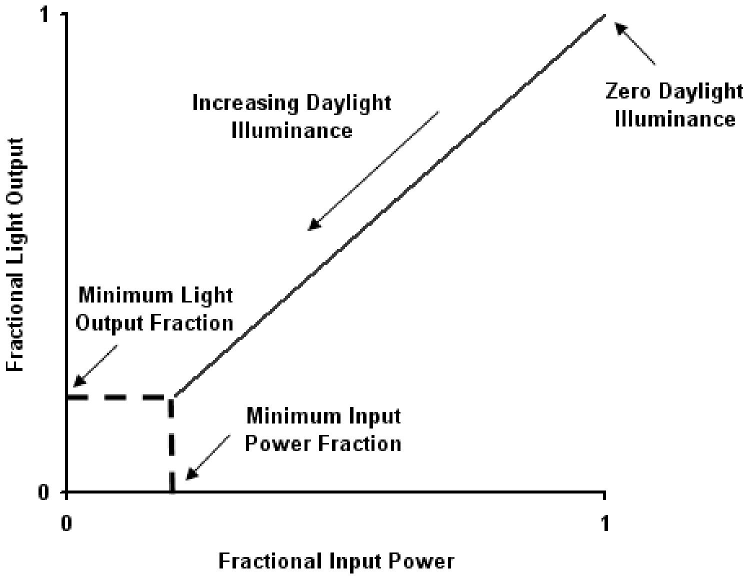

Figure 7. Fractional electric lighting input power f_P, corresponding to fractional electric lighting output f_L.

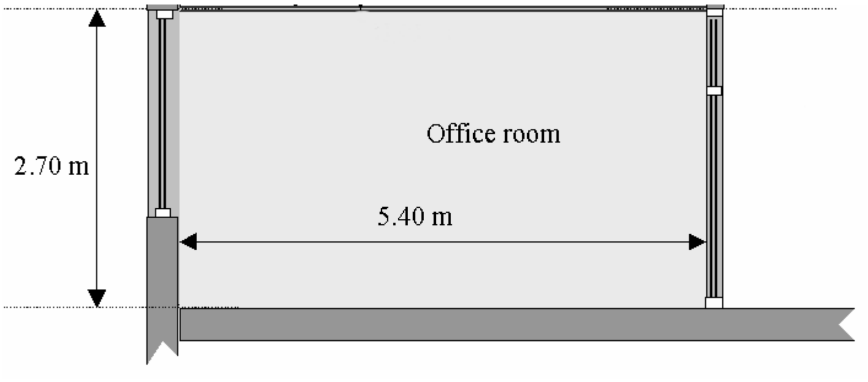

Figure 8. Vertical cross section of the office room.

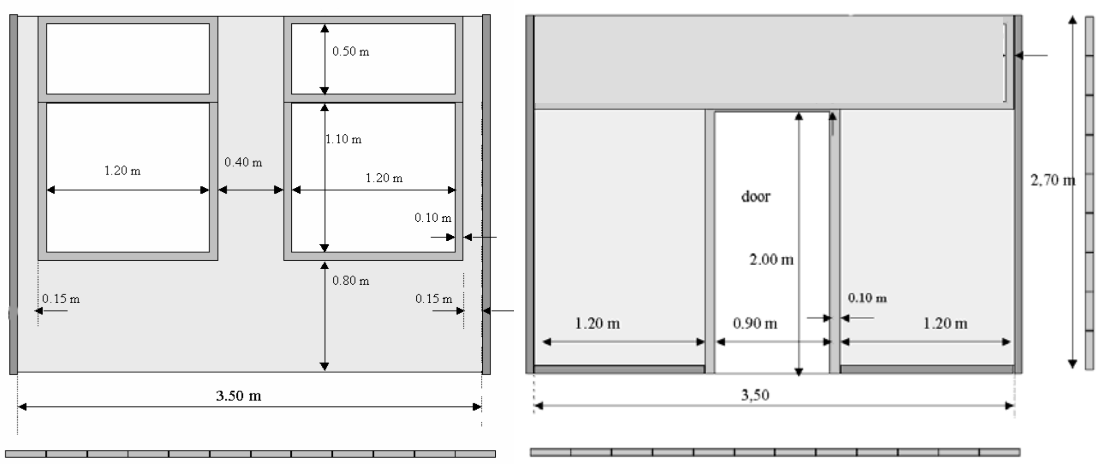

Figure 9. Layouts of south façade (left) and north façade (right).

Table 1. Optical properties of the elements inside the office room.

Elements of the room	Reflectance	Transmittance
Ceiling	0.85	-
Walls	0.65	-
Floor	0.20	-
Door	0.40	-
Window frame	0.80	-
Door frame	0.80	-
Window	-	0.771

4.2 Results

The results presented below were obtained with the following stand-alone programs: RELUX, SPOT and DAYSIM These results were obtained by using a given set of simulation parameters, therefore it is not excluded that the same programs would be capable of obtaining better accuracy if more accurate parameters were used, and vice versa. Since SPOT and DAYSIM use RADIANCE as calculation engine the same set of parameters have been adopted (ambient bounces =3, ambient divisions=1000).

Simulations have been performed on hourly basis for a typical year using Los Angeles TMY. Since RELUX uses a different approach, using the TMY monthly values of sunshine propabilities have been calculated.

The performed simulations took place during 12:00 LT on the 21st of March for overcast sky conditions. Only a single overcast sky was evaluated because the daylight distribution under any overcast sky has the same distribution, varying only in the magnitude of illuminance provided. The daylight factor varied from 0.5% to 11.3% and the average value was 2.8%. In sequence, giving the necessary inputs (schedule of the employees, average illuminance 520 lux, average daylight factor 2.8% and lighting loads 12.1W/m^2) was made the calculation for the energy savings.
Figure 10 presents monthly energy saving due to daylight for the examined space using photosensor control.

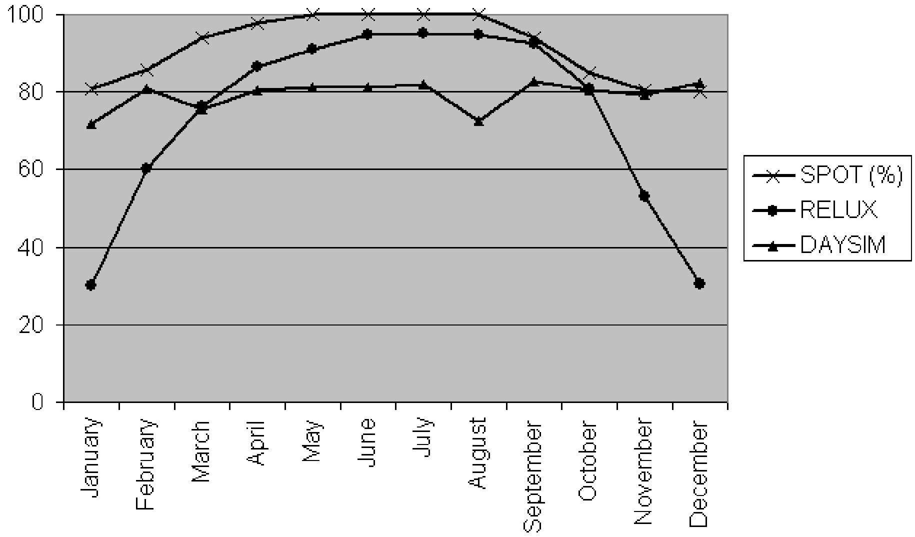

Figure 10. Comparison of the estimated monthly daylight savings for Los Angeles City using SPOT, RELUX, DAYSIM simulation programs.

SPOT values are 15% on the average more than DAYSIM ones while RELUX underestimates lighting energy considerably especially during winter months.

RELUX calculations are extremely fast while SPOT and DAYSIM calculations are computationally expensive.

SPOT presents functionality over sensor spatial response while it can perform correlations between photosensor and work plane illuminance. This is crucial relationship since a 100% correlation (ideal) means that the ratio between the average workplane illuminance and the photosensor signal is always the same. Two sets of simulations have been performed in an effort to present the above-mentioned correlation. As presented in Figure 11, five (5) sensors have been placed on the working surface while other five, representing photosensors have been place on the ceiling.

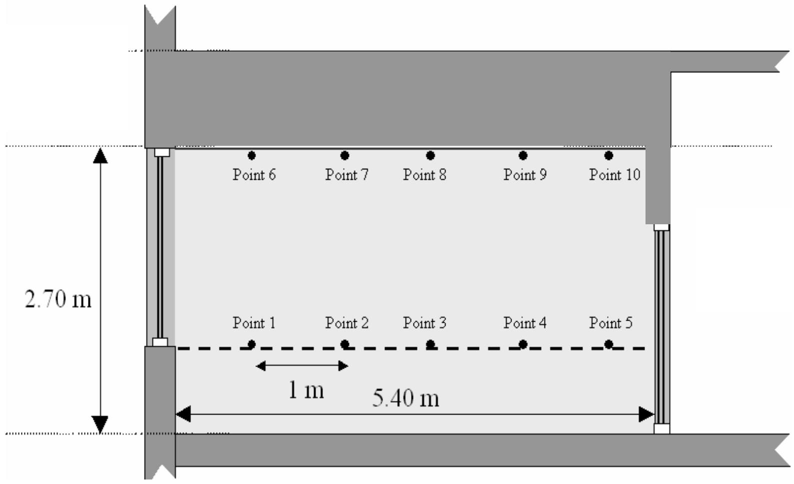

Figure 11. Schematic representation of the sensor location.

The correlation graphs is shown in Figure 12 (a and b) and represent the variation in sensor readings that the selected photosensor / luminaire zone combination experiences throughout a year for sunny and cloudy conditions. The ideal correlation graph will be very linear between the cloudy, sunny, and electric lighting conditions.

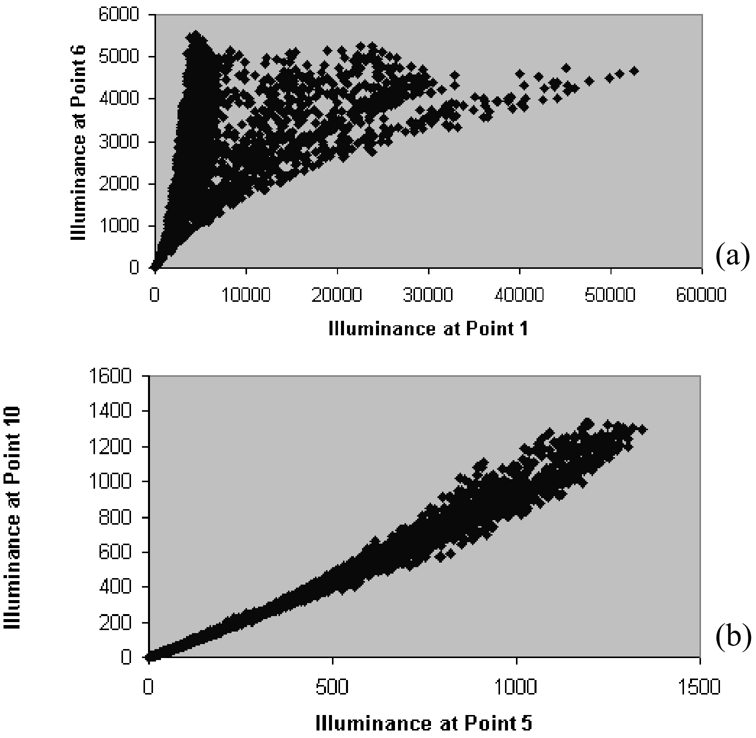

Figure 12. Photosensor illuminance (vertical axis) versus workplane illuminance (horizontal axis). (a) Point 6 versus 1 and (b) point 10 versus 5.

It is evident that as the point is moving away from the façade the correlation between photosensor and workplane illuminance is improved but this is not the optimum position since due to low daylight levels all lights in the zone will be on.

Unfortunately none of the examined software offers an optimisation capability. On the other hand DAYSIM presents a unique feature, occupancy modelling. The energy savings due to occupancy modelling is presented in Figure 13.

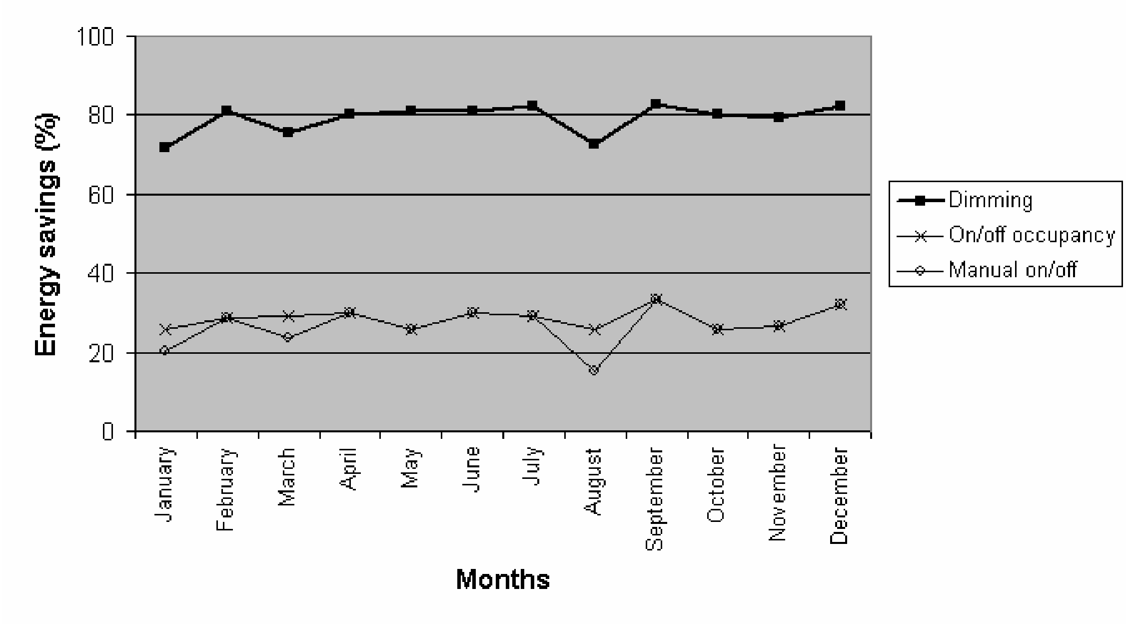

Figure 13. Energy savings due to daylight for various control strategies for Los Angeles City.

From the estimated monthly energy savings (Figure 13), it was found that continuous dimming could result in greater energy savings than the manual on/off or the on/off occupancy control strategies. The monthly energy savings with a dimming control strategy reached almost 80%, while the estimated energy savings with the other two control strategies rarely exceeded 33%.

5. DISCUSSION

Lighting control systems are a complex technology that changes rapidly. A variety of controllers, software, sensors and devices are currently available, but there is a lack of information concerning the actual performance of these systems and control strategies. In order to fully exploit their capabilities and implement the most energy efficient control strategies, simulation softwares are needed during the initial design phase. This will improve the design parameters such as optimal ceiling or wall positions for the photo sensor, shielding configurations from electric lighting and daylighting sources and the control algorithms to be defined accurately.

In the present paper three stand-alone programs have been tested while the analysis of the results revealed that simple and basic scenarios are capable of identifying weak areas in a given program.

Recently new simulation tools have been developed aiming at the calculation of energy savings due to daylight (SPOT, DAYSIM). Nevertheless the user should have an experience with daylight simulation since using default values for various parameters results can vary considerably. What is really needed is the use of a well defined case study as benchmark. Daylight coefficient approach seems to be the only alternative in order to achieve a short time step yearly analysis. The problems associated with this approach are:

1. Long pre-processing time
2. Dynamic link with a user defined schedule for shading operation is not possible thus integrated design can not achieved in full extend . Only DAYSIM offers different shading control strategies.

Necessary developments in algorithms must be done in the following sections:

- Optimisation algorithm for the best position of the photosensor
- Control optimisation of various types of shading systems
- A data base with control functions for voltage and lighting output ratio for a large number of ballasts

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