Review of methods used to predict lighting energy savings due to daylight

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Abstract: The paper presents a review of current methodologies to estimate the lighting energy savings due to daylight. Although simplified approaches are described, state of the art computational techniques are presented together with future developments.

Key words: lighting energy use, daylighting

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

The technologies and systems used to control lighting are of a great importance in the process of design and construction in accordance with the energy saving criteria. The selection and/or the practicability of the control system can permit optimum use of the design decisions. In addition good control systems can also provide appreciable economic benefits in existing buildings not designed properly.

One of the most well known lighting control strategies is the use of daylighting. This type of strategy employ a photosensor-controller device, linked to a switching or dimming unit that varies electric light power in response to daylight.

2. Daylighting Control strategy

Providing daylight in a building does not by itself lead to energy efficiency. Even a well daylit building may have a high level of lighting energy use if the lighting controls are inappropriate. Case studies [6] have shown that in a conventionally daylit commercial building the choice of control can make 30-40% difference to the resulting lighting use. A typical electric lighting system control concept appropriate for a daylit building usually consists of at least two components that are often not part of non-daylit buildings:

- Integrated lighting control zones
- Automatic control strategy for each zone

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. In order to establish the lighting zones illuminance measurements are needed or results from simulation procedures for a minimum of four different months representing winter, spring, summer, fall). In order to establish the usual minimum/maximum range of performance, only winter and summer need to be analysed.

The data sets should be for at least two time periods. Usually, noon is used for one while the other period is at least three hours before or after noon. Many daylighting systems function in such a way that some time other than noon provides the maximum performance characteristics; if the daylighting concept performs considerably differently in the morning than in the afternoon at the same station point, both cases should be reviewed. Finally data sets should be established for the two sky conditions: clear and overcast.

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.

In general, the greater the number of zones in a space, the greater the opportunity for energy savings. First costs may increase as the number of zones increases. When a small number of zones are present in a room, the reduction of first costs is often offset by the reduced performance characteristics of the integrated lighting system. Consequently a combination of performance, first costs and operating and maintenance costs should be appraised to determine the optimum control strategies.

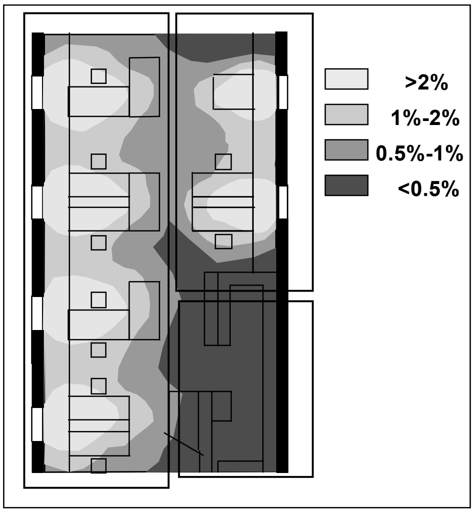

Figure 1. Distribution of daylight factors in a space and separation of this space in three control zones.

Some sensors come with sun shields for cases where the cell cannot be placed far enough from the window. For switching systems the sensor is located so that it views the external daylight source with minimal view of the electric lights.

Photosensor location is less critical with open - loop systems and can be compensated for during commissioning. Manufactures have specific recommendations as to where to locate the photosensor.

In practical terms, daylighting control systems do not use models to calculate the effect of daylight inside the spaces as a function of the external variables. In fact they merely measure ambient conditions in real time. The various control systems adapt to varying needs in different ways depending on the type of the plant and set comfort levels. American standards call for high lighting levels, whereas the general European level and the present trends tend to concentrate on other parameter (contrast, uniformity, colour, etc). The purpose is to obtain good comfort levels with lower lighting levels. In defining the minimum parameters for the control units, the following factors should be kept in mind:

- Uniformity in relation to the daylight factor.
- Current and future use of the spaces.
- Possible need to build-in local human adjustment to the parameters.
- Different visual needs and consequent different lighting levels.

Once the minimum control levels have been defined on the basis of these parameters and needs, the sensors will be positioned in the light of these needs. Lighting controls cost quite a lot, thus reliable tools for the prediction of their associated energy savings should be used in order to verify their selection and estimate the payback period.

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 climate conditions of the countries and available daylight levels in the interior of the buildings.

Prior to the prediction of energy savings due to daylight a feasibility study should be performed in order to estimate the possible 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 > 5% indicate a strong potential for daylight savings.
3. Estimating the feasibility factor (1) as follows:

$$FF = WWR \times T_{vis} \times OF$$

Where WWR is the Window to Wall Ratio, T_{vis} is the visible transmittance of the opening and OF is a factor, which is called Obstruction Factor. OF equals 1 in case where less than 50% of the opening is shaded while its value decreases to 0.4 when the shaded part exceeds 90%. Values of FF larger than 25% present a case that daylighting have the potential for significant energy savings.

4. Each side lit space can be divided in three areas [1], 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 artificial light 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 windowpane.

The simplest method to predict energy savings due to daylight is to assign a single annual figure for lighting energy use. This is accomplished by estimating a cumulative frequency distribution of illuminances for a point (or on average) in the interior. This is difficult to be performed on hourly basis for the typical meteorological year. Thus a more simplified procedure is followed, using a cumulative frequency distribution of the exterior horizontal illuminances (figure 2). This can be obtained either by using the local TMY or by using Satellite server [3].

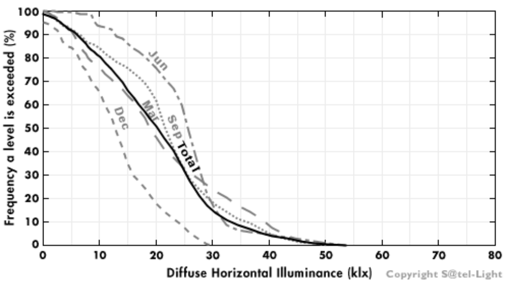

Figure 2. Cumulative frequency distribution for horizontal diffuse illuminance

By multiplying the above values by the daylight factor [4, 5], interior cumulative frequency distribution can be estimated. Although the method is simple, the multiplication implies that the sky is considered as overcast all year long thus the result somehow represents a worst-case scenario. Of course sunlight is excluded.

This method is recommended by the Swiss Lighting Association [7] and provides for a rated task illuminance and a given daylight factor the minimum operating hours (%) during which a workplace can sufficiently and exclusively be lit with daylight.

A more refined method (based again on daylight factors concept) was proposed by M. Szerman [8]. His method estimates the lighting switch-on hours based on daylight factor and local weather data.

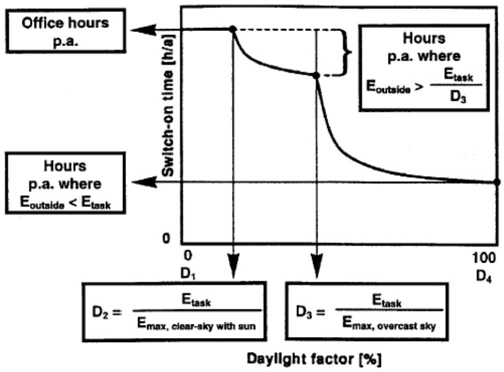

Figure 3. Calculation of daylight autonomy (Report "Simple Design Tools", Annex 29, Task 21, IEA, May 1998)

If a more detailed estimation of daylighting levels in needed for all possible sky conditions (at least the conditions that included in the TMY) computer techniques should be used. Detailed lighting simulation began in the late '70s with the introduction of Lumen II and around 1980 a daylight feature was added. In the mid 1980's Supelite emerged as a powerful daylighting simulation tool, which could analyse complex spaces. Today there are more tools available (see forthcoming CIE TC 3-33 publication). Basically two methods are used: Radiosity and raytracing (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.

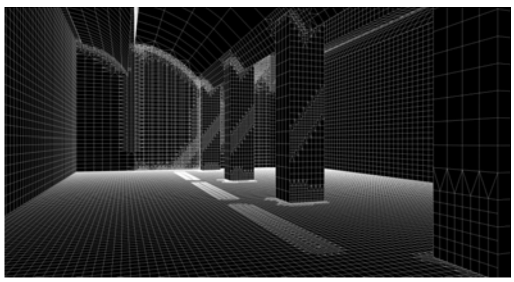

Figure 4. Radiosity meshing

Advantages of the method are:

- Calculations of diffuse intereflections between surfaces
- View independed solutions
- Immediate visual results

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

Disadvantages include:

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

ADELINE 's Superlink [8] and Radiance [12] are the representative tools for radiosity and raytracing techniques respectively as mentioned above.

Although the computational methods exist, it not straightforward that these methods are suitable to estimate accurately lighting energy savings due to daylight. The reasons for that:

1. Extremely long computational time. Normally 8760 hourly values are needed which means that the equivalent number of simulations is needed.
2. Normally photosensors are located to the ceiling while the calculation of daylight illuminance is performed on the working surface (figure 5).

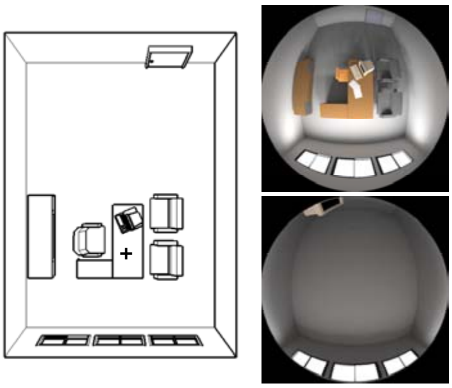

Figure 5. Sensors field of view from ceiling (top picture) and working surface (bottom picture)

This task-to-ceiling illuminance ratio is not constant during time. Thus estimating lighting energy use with task illuminance data (i.e. use of software) the results can be incorrect. Depending on the type of space task-to-ceiling illuminance ratios can range between 2/1 to 10/1 [9]

3. The presence of venetian blinds (or any other innovative daylighting system) on the façade can produce various luminance patterns in an area and this can cause unreliable performance of the system.
4. 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 the figure 6.

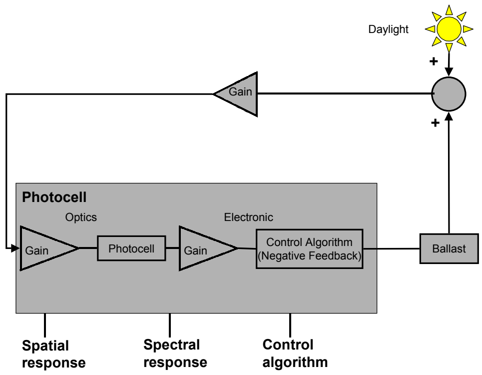

Figure 6. Factors that influence the performance of a daylight-control lighting system.

To overcome some of the reasons presented above various techniques have been introduced. For example the introduction of daylight coefficient approach, developed by Tregenza and Waters [15], will in principle, allow computer calculation to be used whilst keeping simulation times manageable. Various codes have been proposed based on this technique (Passport-Light by Tsangrassoulis et al [10] , DLS by Cropper et al. [11])

The most recent code is DAYSIM [13,14] which is a RADIANCE based dynamic daylight simulation method to calculate the short-time-step development of indoor illuminances in buildings based on hourly mean direct and diffuse irradiance values.

Consequently, there are some tools available for the calculation of daylight autonomy (percentage of hours that a design illuminance is exceeded due to daylight only). In order to estimate accurately the profile of lighting energy use, information of the hardware (sensor's properties, ballasts) and the control algorithm used is needed. Although some tools exist only for research reasons their future availability will help to examine new possibilities in sensing elements (CCD instead of a simple photosensor) in order to generate the relevant control parameters.

4. Conclusions

This paper has outlined various methods to estimate:

- the potential for lighting energy savings and
- the lighting energy savings themselves

Today work is currently in progress to extend the capabilities of existing algorithms for the estimation of lighting energy use. We hope that an interoperable algorithm will enable designers and researchers to not only design efficient daylit environments, but a whole host of user sensitive strategies.

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