Investigation of Daylight Redirecting Systems and Daylight Responsive Lighting Control Systems

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ABSTRACT

THE CRUCIAL QUESTION WHEN LOOKING at daylighting systems and daylight responsive lighting control systems is how to assess the systems' ability to maintain or improve the lighting conditions in a room and to reduce the energy consumption for lighting. This article gives two new definitions and shows how they can be applied in practice.

INTRODUCTION

Daylight is regarded to be a very promising option when talking about the use of solar energy. On the one hand there is no need to store it because it is used when it is available and on the other hand light is very tolerant against losses because of the logarithmic sensitivity of the eye. A loss of 50% which would be prohibitive for solar energy conversion is hardly noticeable to the eye. (Goetzberger 1996)

There are many systems who promise to use daylight in an optimised way, but up to now only few measures have been established to assess either the possible energy savings or the visual performance of a given system. This article will describe a new approach to define quantities with the emphasis on daylight responsive lighting control systems according to measurements at the Institute of Electronics and Lighting Technology (ELLI) at the Technical University of Berlin.

DAYLIGHTING COMPONENTS

Daylight redirecting systems

Generally daylight redirecting systems can be subdivided into movable and fixed systems. The light redirecting component of many movable daylighting systems is a modified aluminium slat whose daylighting capability is based on the differing reflecting and transmitting ability of each slat.

Fixed systems take advantage of the reflecting and transmitting abilities of special glasses and synthetic materials. The redirection by transmission is achieved by refraction (-prisms), by glasses with holographic optic elements (HOE) or by applying short, bent optical fibres between two glasses. A special characteristic of prisms is the total reflection of the incoming light (especially of the direct sunlight) under certain angles of light incidence.

Daylight responsive artificial lighting control systems

More daylight in interior spaces only leads to electrical energy savings if the artificial lighting is switched or dimmed according to the amount of daylight penetrating the room. Principally there are two different ways of controlling the artificial light: feedback control (closed loop) and feedforward control (open loop). For a feedback control the sensor must not receive direct daylight and for a feedforward control the sensor must not receive artificial light. (Rubinstein et al. 1988, Knoop et al. 1996)

The market for daylight responsive artificial lighting control systems can generally be subdivided into one section of simple stand-alone solutions with mostly one sensor per luminaire whose advantages are the low cost and the easy possibility to retrofit. The other section contains all products based on building management systems which are very flexible and offer the chance to create integral solutions for lighting and blind control.

Daylight responsive daylight control systems

Daylight responsive daylight control systems can be described as systems which try to guide as much daylight in the room as possible while maintaining or improving the lighting situation of the room using the existing blinds or movable daylighting systems. There is a great variety of systems which use different input parameters such as time, sun position and different illuminance values but also wind, humidity and temperature. The range begins with simple systems moving up or down curtains or conventional blinds and ends with bussystems controlling both artificial light and daylight.

Generally it is possible to apply closed loop and open loop strategies as well. The problem with closed loop strategies is the sensor position. The sensor has to measure a certain luminance of the window plane at eye height, which may cause installation problems.

THE ASSESSMENT OF QUALITY PARAMETERS

Lighting parameters

When thinking about how to assess the quality parameters of a daylighting system or daylight responsive lighting control system it is obvious that one has to agree on quantities and related values when a system can be called working. The next paragraphs will deal with the definitions for daylight responsive artificial lighting control systems and its application.

Regarding daylight responsive artificial lighting control systems it is clear that the system should not fall short of a horizontal illuminance distribution given in the tuning period while achieving the highest possible energy saving. Due to this fact two numbers have to be given for each system: one related to the energy saving which is described in the next paragraph and one describing the performance with respect to the illumination.

It is important to stress that a daylight responsive artificial lighting control system cannot be expected to maintain a given illuminance but to top up the lacking luminous flux. Therefore the authors established the relative lacking light exposure H_{LLE} [%] which takes into account both the difference ΔE between the measured illuminances E_M and the tuning values for each sensor E_{Set} as well as the period of time in which the illuminance values are not achieved (Equ. 1). The tuning values E_{Set} are given by the night-time illuminances at 100% output levels.

$$H_{LLE} = \frac{100\%}{n_{Sensor}} \sum_{n_{Sensor}} \left(\frac{\int_{t_M} \xi(t)\,dt}{E_{Set} * t_M} \right), \quad t_M = \text{measurement period}$$

Equ.1

$$\xi(t) = \begin{cases} \Delta E = (E_{Set} - E_M) & \text{if } E < E_{Set} \\ 0 & \text{if } E \geq E_{Set} \end{cases}$$

Equ. 2

In case of several sensors n_{Sensor} the H_{LLE} is the arithmetic mean calculated from the integral over the measurement period t_M. The measurements leading to this value should be done under different daylight conditions in order to be able to calculate the annual H_{LLE} by applying a specific sky model e.g. the average sky.

Since it is very likely that users are disturbed more by a large illuminance drop over a short period than by a small one over a long period acceptance studies might show that it is useful to add an exponent higher than 1 the function ξ(t) in Equ. 2. As to this parameter, further information on how a system is able to cope with different daylighting situations in terms of user acceptance can just be found out in an acceptance study.

Another possibility to differentiate between the influence of illuminance and time is to give another measure just related to the time in which the control system does not meet the requirements.

Regarding daylighting systems and daylight responsive daylight control systems it is very difficult to assess the quality parameters because this is a question of visual comfort on which luminances from window have an important impact. One possible measure is the increase of the light exposure referenced to uncontrolled conventional blinds.

Energy parameters

The most important aspect regarding possible electrical energy savings due to daylight responsive artificial lighting control systems is to make sure that only the system's contribution to the energy saving is measured. When just looking at the percentage of saved energy one has a measure depending very much on room parameters such as window size, obstruction and orientation as well as artificial lighting parameters such as the illuminance level, uniformity and luminaire positions. In order to be able to differentiate between these parameters the authors established two quantities, the room potential *RP* and the system potential *SP*, whose product equals the potential energy saving. The room potential describes the daylight attributes of a given room and the system potential characterizes the effectiveness of a certain system. (Ehling et al. 1996)

The room potential RP is determined by calculating the mean value of the annual relative usable light exposure $H_{use,a,rel}$ over the area of the room. (Aydinli et al. 1987)

For the measurement of system potentials it is necessary to be able to measure absolute illuminance values and the related daylight contributions, which can easily be done by calculating artificial light levels from the power consumption of the luminaires.

The first step is to calculate the illuminance levels by artificial lighting $E_{Artificial}$ which is theoretically necessary to maintain an illuminance distribution given by the artificial lighting installation for each sensor. Knowing the illuminances caused by daylight $E_{Daylight}$ this can be done by integrating the difference between the tuning illuminance values E_{Set} and the daylight illuminances $E_{Daylight}$ over the measurement period t_M (Equ. 3).

It is only useful to define system potentials for time intervals in which the system is actually working, i.e. in which $E_{Artificial} \neq 0$ (Equ. 4). The illuminance values $E_{Artificial}$ are calculated from the dim levels. Furthermore the time intervals have to be taken into consideration in which the system is switched on although it would not be necessary.

It is important that only those time intervals contribute to the calculation in which $E_{Artificial} \geq (E_{Set} - E_{Daylight})$ since otherwise systems which do not provide enough light would be rated better than they are. The system potential for several sensors *SP* is given as the arithmetic mean of the system potentials at each sensor position (Equ. 5).

For the measurements it is important to choose the artificial light level according to the room potential (e.g. daylight factor) in order to have the system working in the complete dynamic range.

Meaningful results can only be achieved by proper installation of the control system. The authors propose to tune the system in a way that H_{LLE} does not exceed 4% for each sensor as a rule of thumb resulting from numerous tuning procedures.

For predicting energy savings of a given system on any place of the world the annual relative system potential considering the probability of daylighting conditions has to be calculated according to the definitions for $H_{use,a,rel}$ in Aydinli et al. 1987. The product of the room potential and the systems potential equals the possible energy saving.

$$\chi(t) = \begin{cases} \dfrac{E_{Set} - E_{Daylight}}{E_{Artificial}}, if E_{Daylight} \; E_{Set} \\ and\left(E_{Set} - E_{Daylight}\right) \; E_{Artificial} \\ \dfrac{E_{Set} - E_{Artificial}}{E_{Set}}, if E_{Daylight} \geq E_{Set} \end{cases}$$

Equ. 3.

$$SP_i = 100\% * \frac{1}{t_M} \int_{t_M} \chi(t)dt \text{ for all } \boldsymbol{dt}\text{, which have } \boldsymbol{E}_{\text{Artificial}} > 0$$

Equ. 4.

$$\boldsymbol{SP} = \frac{1}{n_{Sensor}} \sum_{n_{Sensor}} SP_i$$

Equ. 5.

MEASURED RESULTS

The ELLI is examining all components for a sensible use of daylight and artificial light with the focus on systems which are able to integrate all components into a building management system. Therefore three identical testrooms with different building management systems and removable daylighting systems were established (Ehling et al. 1996). Measurements are conducted according to a monitoring protocol which was established by the IEA Task 21 *Daylight in buildings*. (Velds and Christoffersen 1997)

The next figures show the measured results of a daylight responsive artificial lighting control system applying an open loop strategy from 30.04.1997.

Since it is the task of a daylight responsive artificial lighting control system not to fall short of the illuminance value set in the tuning procedures this is one parameter to be recorded. Figure 1 shows the relative illuminance values referred to its night time values. It also displays a vertical exterior illuminance EV to give an impression of the daylighting conditions ($E_{V,max}$ = 42 klx). For clarity reasons

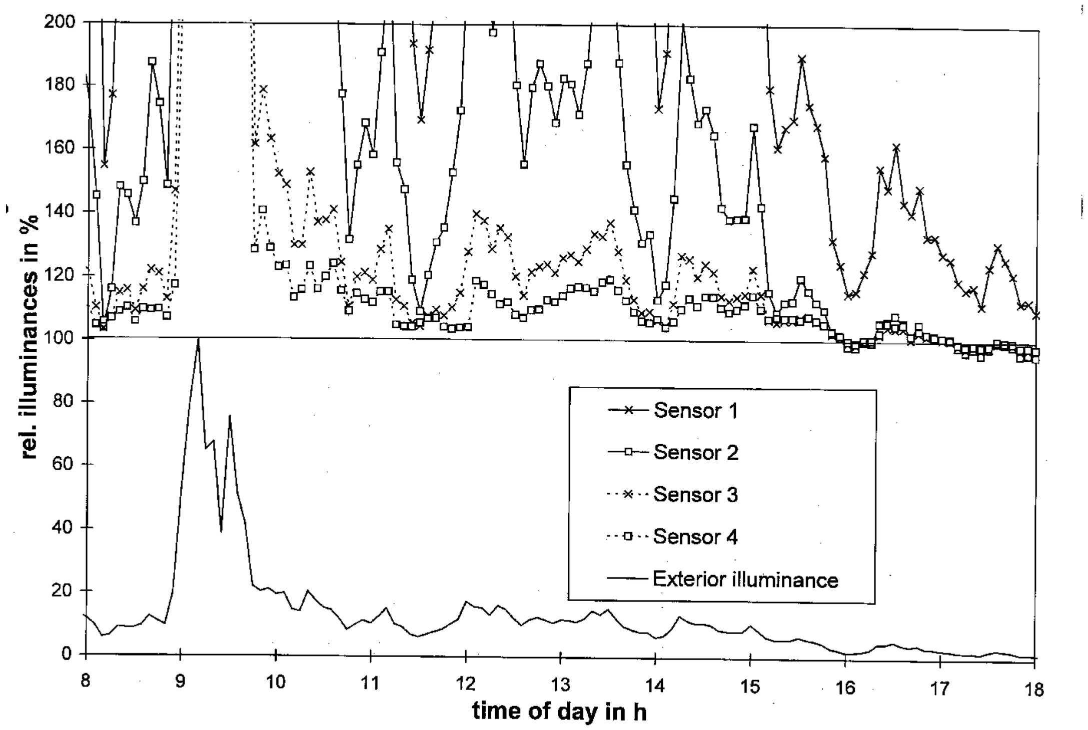

Figure 1. Relative illuminance values (referred to the night time values), vertical illuminance.

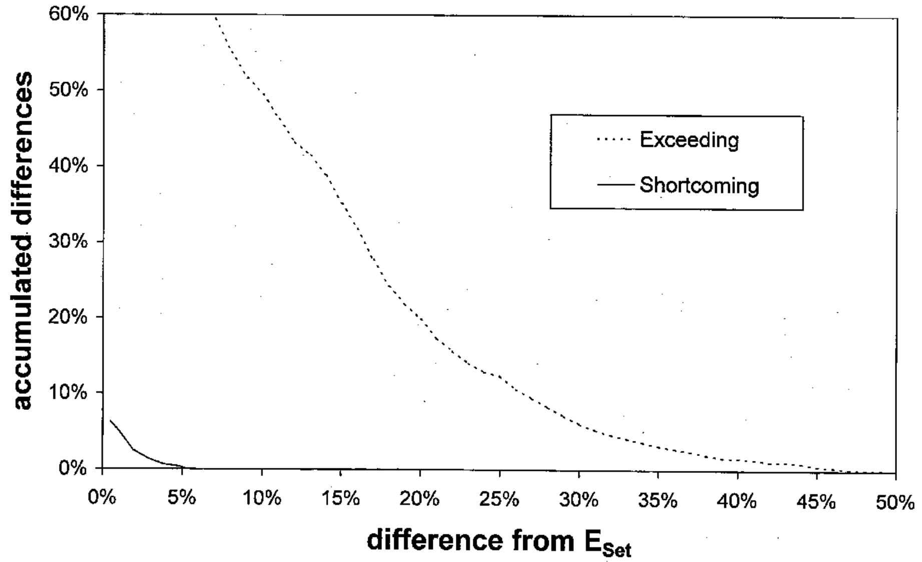

Figure 2. Accumulated exceedings and shortcomings of the illuminance

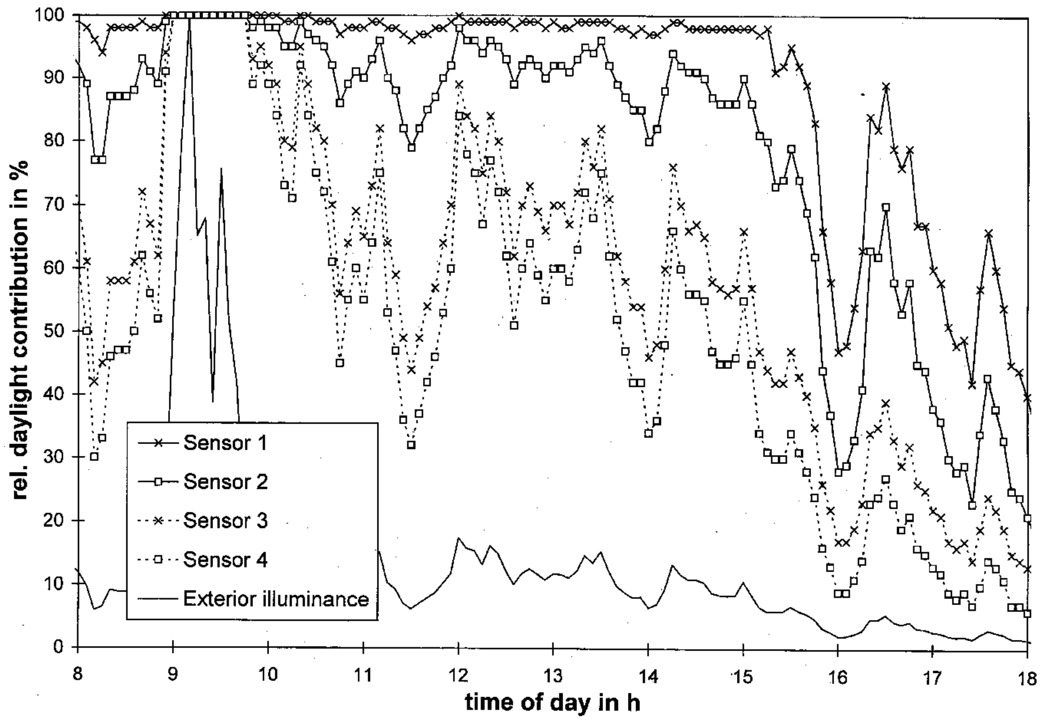

Figure 3. Daylight contribution to the total illuminance, vertical illuminance

the values of only four of twelve sensors are displayed, the first is closest to the window.

Figure 2 displays the accumulated exceedings and shortcomings of the illuminance taking all twelve illuminance sensors into consideration. (Figure 2)

The second important parameter is the system's ability to use the available daylight (Figure 3). It is necessary to know the percentage of daylight contribution to the total illuminance for the calculation of the system potential.

In order to assess the systems ability to maintain lighting situations set during the tuning procedures and for the calculation of possible energy savings it is necessary to measure the power consumption of the artificial lighting. Figure 4 shows an example of measured dim levels for the same day shown in Figure 1 and Figure 3.

The values for H_{LLE} and SP_i of this day can be calculated from Equ. 1 and Equ. 4 according to the values shown in the figures 1,2 and 3. There is also the mean value of the four sensors shown in the graphs and the mean value of all twelve sensors installed.

1. Sensor	H_{LLE} 1	= 0,00%	SP_1	= 91%
2. Sensor	H_{LLE} 2	= 0,24%	SP_2	= 86%
3. Sensor	H_{LLE} 3	= 0,14%	SP_3	= 77%
4. Sensor	H_{LLE} 4	= 0,09%	SP_4	= 86%

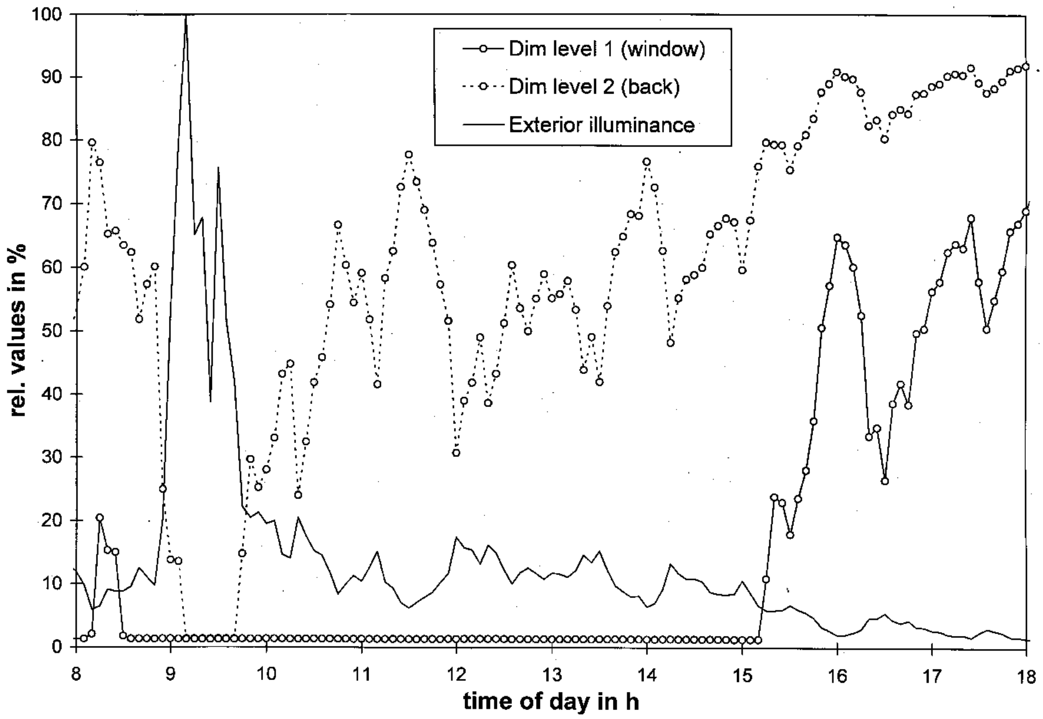

Figure 4. Dim levels of an open loop control system, exterior illuminance

Mean: (1. Sensors) H_{LLE} **= 0,12% SP = 85%**
Mean: (12. Sensors) H_{LLE} **= 0,14% SP = 84%**

Measurement of several systems under various daylight conditions have shown that the system potential of a dimming daylight responsive lighting control system is in the range of 80% and 90% for a standard office room.

CONCLUSION

When trying to evaluate daylight responsive artificial lighting control systems it does not make sense just to look at measured energy savings. The authors established two measures, the lacking light exposure and the system potential, in order to assess the systems' ability to cope with different daylight conditions and to save electrical energy. Furthermore it is shown that these definitions can be applied in measurement practice.

ACKNOWLEDGEMENTS

The authors thank Baumann, Hüppe Form, Krülland, Philips, Reko, Siemens, Warema and Zumtobel for equipping test rooms with daylighting systems and daylight responsive lighting control systems. T. Knoop wishes to thank Siemens for supporting his studies with an Ernst-von-Siemens fellowship. ●

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Session 11

Daylighting and Visual Quality