Calculation of energy performance indices of daylight linked control systems by monitored data

Marco Beccali[1], Marina Bonomolo[1], Valerio Lo Brano[1] and Gaetano Zizzo[1]

[1]Università degli Studi di Palermo, Dipartimento Energia, Ingegneria dell'Informazione e Modelli Matematici, Palermo (Italy)

Abstract

The actual performances of Building Automation systems are often lower than the ideal ones. In order to investigate the actual performance of a Building Automation system for lighting control, a large stock of collected data, including indoor illuminance and absorbed electric power, have been presented and analysed in this paper. The measures have been taken during one year, in a laboratory located at the University of Palermo, where different lighting control systems, produced by two different manufacture companies, have been installed. As demonstrated in literature, many factors affecting energy savings' evaluation in lighting control systems are the position and the typology of the sensors and their configuration. Furthermore, using the collected data, a set of indices has been calculated. It is able to test the performance of the systems in terms of energy efficiency and fulfilment of visual comfort tasks, according to different natural light availability, lighting system configurations and time scenarios. Finally, the performances of the two above lighting control systems have been compared.

Keywords: Daylight control system, Building automation system, lighting, indices, daylight.

1. Introduction

The benefits of Building Automation and Control (BAC) systems are well-known and, for this reason, their application in both residential and commercial buildings and become very common. In several studies, potential energy savings due to BAC systems have been assessed (Ferrari and Beccali, 2017) and calculated by conventional methods sometimes suggested by technical standards, or by using simulation software.

Parise and Martirano (Parise and Martirano, 2009) proposed a methodology to calculate energy consumption for lighting systems and the impact of the BAC systems promoting a comprehensive eco-design. In particular, the above-mentioned method allows to satisfy in selected subareas lighting and energy performances and to provide design elements a basic efficient control system suitable for a manual or automatic regulation.

Asif ul Haq et al. (2014, a) developed a new method that is easy to apply but comprehensive at the same time, and gives a good indication as to the potential of energy saving from daylight utilization. They gave a detailed description for applying it basing on a simulated test project as an example. The same authors (Asif ul Haq et al., 2014, b) investigated the various control system types, the development of their associated technologies, the savings obtained from their application and the factors affecting their performance. Authors doing a literature review, demonstrated that lighting control systems can provide significant energy savings and result in reduction in electricity costs. Other researchers are beginning to study also the problem of an accurate and reliable calculation of these figures. Bellia et al. (2015) investigated the factors that influence the performance of Daylight-linked controls (DLCs) and did a review of the several aspects that must be considered during the design, installation, configuration and operating steps. P. Valíček, et al. (2015) explained the complexity setting the system due to the usual different position of the task surface and of the sensor commanding the system. Chen et al. (2016) carried out a cost-benefit evaluation method for building intelligent systems underlining that the problems, like sensor faults and control strategy flaws, may result in low performance and that high energy consumptions and maintenance costs are needed as well.

Doulas et al. (2014) presented a decision-making method capable to estimate the best position of a photosensor on the ceiling and its proper field of view (FOV) based on multiple criteria analysis, using three criteria:

- the correlation of the lighting levels between the working plane and the ceiling;

- the corresponding energy savings and the lighting adequacy (defined as the percentage of occupied time with total illuminance exceeding design illuminance 3)
- it is strongly affected by the control algorithm.

Their work is based on a great number of simulations with variable FOV and position of photosensors, performed in order to clarify the calculation procedure of the proposed methodology and on measurement taken form a prototype photosensor with variable FOV through the use of a telescopic cylinder. This paper presents an application of an original method carried out by the same authors and presented by Bonomolo et al. (2017). The method is based on the calculation of a set of indices and has been developed for the assessment of the energy performance of DLC systems, starting from monitored data and aiming to consider both the influence of systems characteristics and the daylight availability in the room. In particular, the index named Over illuminance Avoidance Ratio (OAR) takes into account the excess of light that could be caused by the position of the detector. On the contrary, the index named Under illuminance Avoidance Ratio (UAR) takes into account the defect of light. The Artificial Lighting Demand (ALD) index is defined to evaluate the rate of lack of natural lighting and, therefore, the rate of required artificial lighting to achieve appropriate illuminance values on the working plan. Finally, the Energy Ratio of Illuminance (ERI) index, being the ratio of the electrical consumption for lighting and the above-mentioned ALD, is useful to assess how close the performance of the real DLC system is to the one of an ideal system. In this paper, the application of the above-described method is presented using a large set of data, collected during about a one-year-long period in order to test the methodology with different DLC systems and daylight contribution.

2. Lighting system and daylight control systems

The measurement campaign has been carried out at the Solarlab laboratory (Figure 1), located at the third floor of the building hosting the DEIM (Department of Energy, Engineering of the information and Mathematical Models) of the University of Palermo (Italy) and described in detail in the work presented by Beccali et al. (2015). The laboratory has been equipped by a measurement instrumentation set. For measuring the indoor illuminance six indoor probes Delta Ohm HD 2021T (measuring range 0.02-20 klx) have utilized. Two of them have been placed on two different point of the ceiling, two on opposite walls and, finally, two at a height of 0,80 lx or 0,6. Furthermore, in order to measure apparent, active and reactive power, current and voltage a SIEMENS SENTRON Power Monitoring Device PAC3200 has been used. Data have been collected through the platform LabVIEW System Design.

Fig. 1: Some picture of the laboratory, of the sensors used to measure indoor illuminance and the section with the sensors location.

In order to test the DLC systems, four suspended luminaires equipped by LED (each one with a power of 54 W) have been installed. They are characterized by a power supply unit with DALI interface and are equipped with micro-lens optics in a polycarbonate cover. The nominal luminous is 3600 lm and the initial LED luminaire efficacy is 92 lm/W. Also four mono optic LED luminaires have been installed, with initial luminous flux of 700 lm and with an efficacy of 50 lm/W. Both types of luminaires have a colour temperature of 3000 K and a colour rendering index ≥80. The lighting power density is 1.86 W/m^2 for the whole area and 2.9 W/m^2 for the zone considered in this work (where the three dimmable suspended luminaires are installed).
Two different daylight linked control systems, produced by two manufactures have been tested. The first one ("System A"), has been installed, in a first period, on the ceiling at about m 1.60 away from the window, close to one of the two photosensors Delta Ohm installed on the ceiling utilised for the measurements. This latter is

characterized by an angle view of 180° longitudinally and 360° horizontally and, as in most lighting control systems, its positioning was not optimized with a precise method but was installed simply following the manufacturer's suggestions. It is designed for being easily usable by anyone, also by not skilled personnel; indeed, its interface is very user-friendly. It was composed by a closed loop photosensor, a scenario programmer, a touch dimmer, 3 manual actuators and 4 basic controls (common switches).
The second system ("System B") is equipped with a look-out open loop photosensor. It has been installed on the ceiling, following the installation manual guidelines. This photosensor has been linked and managed by a DALI electronic control ballast able to send the signal to the luminaires. In Figure 2 the pictures of the two photosensors are shown.

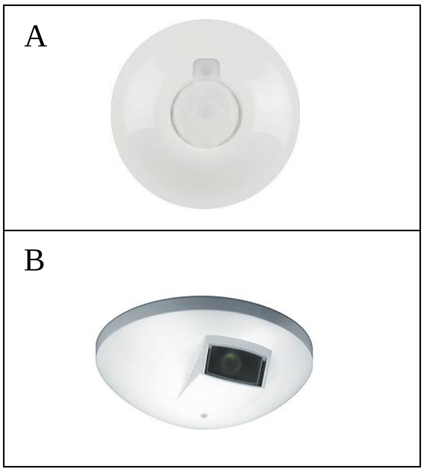


Fig. 2: Pictures of the closed loop sensor (A) and of the open loop sensor (B).

In the first case, a target illuminance value can be set on the software menu after a "rapid" calibration of the photosensor, which is made with a remote-control device. After the measurement of the desired lighting level on the task area with a luxmeter, the device sends a "calibration" command to the photosensor. This procedure has been made once with only artificial light and once with only daylight (without direct solar irradiance). This was the only option allowed by the software and obviously led to an approximate calibration of the system.
Generally, it can be observed that with only artificial light or with diffuse daylight, a certain correlation between illuminance measured on ceiling and on workplane is reliable only in case of low daylight levels (Bonomolo et al., 2017). The calibration of the second system has been shorter and easier. It is based on the "memorizing" of "twilight points" (dimming the lamps to have task illuminance in absence of daylight) and "daytime points" (dimming the lamps to have task illuminance in presence of daylight). An accurate performance assessment of lighting and energy figures of a DLC system can be fulfilled by handling separate sets of natural and artificial illuminance data which together are present in the target area. This problem is easily solved in case of use of simulation software, which is able to separately calculate both the series. When data come from a real monitored space, a photosensor is no longer able to split the two contributions to the total illuminance. Moreover, provided that only an "ideal" system is able to ensure a constant illuminance set point over time, the actual contribution of artificial light becomes variable over the time. In order to assess the artificial lighting contribution, it is possible to assume that the luminous flux is proportional to the power absorbed by the lighting system. The amount of artificial light has been calculated by applying a W/lx factor derived from measures made during the night-time. Natural lighting contribution has been estimated as the difference between the measured total illuminance and the calculated artificial illuminance.

3. Scenarios and configurations

During the measurement campaign an office end-use has been tested. According to these case, as already said, several scheduled occupancy times, task level on the work-plane, configurations and setup have been tested for each system.
For the first part of the study, the installed luminaires have been controlled by the system A. In the last part, the System B has been tested. The electricity consumption has been calculated for two different control strategies: dimming and on-off. For the first case, consumption has been calculated simply using the measured power. In the second case, the energy consumption has been calculated assuming that the luminaires turn on

when the illuminance value, due to the daylight contribution, is lower than the set-point value. Therefore, it has been taken into account the same time when the luminaires were turned on during the dimming case, but considering the absorbed power always at 100%.
All the illuminance values have been calculated using the average of the measures taken by two pairs of photosensors (two in the ceiling and two on the work-plane). They have been placed in the task area where a good uniformity is observed.
In total, 47 scenarios have been considered:

- 26 testing office scenarios with the system A;
- 21 testing office scenarios with the system B.

The illuminance target value has been set to around 500 lx on the work-plane at a height of 0.85 m.

4. The performance indices

The set of indices that are utilized to analyse and compare the DLC systems has been previously presented and commented in detail in another work (Bonomolo et al., 2017)., therefore here are described only synthetically. The first index is the Artificial Light Demand (ALD) (Eq. (1)) which is defined as the sum, during the operation time, of the differences between the illuminance target value on task area (E_{set}) and illuminance due to available natural light (E_{nat}), when this one is lower than the set point itself, times the hours:

$$ALD = \Sigma_{\text{operation time}} (E_{set} - E_{nat}) \times \Delta t \qquad \text{if} \quad E_{nat}<E_{set} \qquad \text{(eq. 1)}$$

This definition ensures that ALD changes according to the sky conditions for a given set point and a given period (for instance a day). Figure 3 shows this concept for two different days.

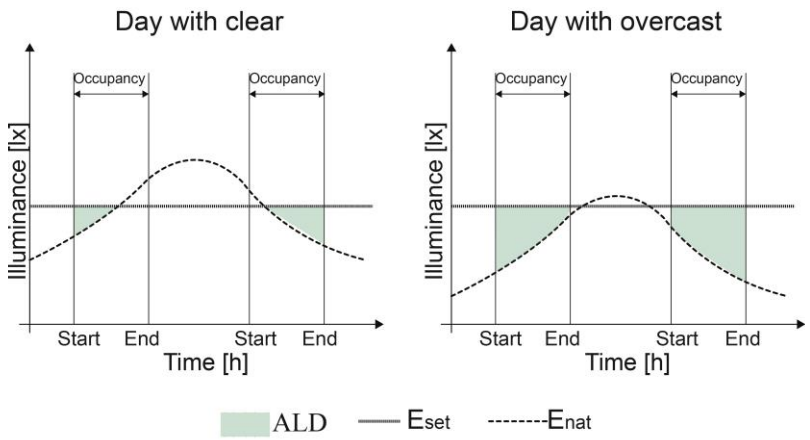


Fig. 3. Graphic scheme of ALD for two different days.

A normalization of energy consumption with respect to the actual artificial light demand (ALD) is useful in comparing a DLCs operation with different hardware-software configurations (e.g. photosensors position) and calibration (Doulos et al., 2017). Moreover, it would be possible to make a comparison between different lighting systems. They would consume different amounts of energy according to their lighting efficiency and ability to control the illuminance on the task area over time also according to the measured ALD. In this way, the second adopted index is the Energy Ratio of Illuminance (ERI) (Eq. (2)) as the ratio between the electricity consumption (ELEC measured in Wh) and ALD (lx·h) as follows:

$$ERI= ELEC/ ALD \qquad [Wh/lx\cdot h] \qquad \text{(eq. 2)}$$

If we look at an ideal system, the consumption due to lamps operation will be strictly proportional to the ALD by a factor k (Wh/lx·h) that can be intended to be a characteristic of the observed system and also a target value for the ERI of a real system. Indeed, in a real system, measured consumption could result in higher (or lower) than k·ALD and ERI will have a different result from k. In the tested systems the k value is 0.246 Wh/lx·h.
Anyway, it must be noted that when a system is not able to fulfil over the operation time the minimum E_{set} value (under-illuminated space), its electricity consumption is not related to the expected operating conditions

and its low value is not reached thanks to its energy efficiency. At the same time, it is necessary to consider energy waste due to the quantity of “excess” of illuminance, which are highlighted by higher ERI values.
Two more indices are able to account also for values and times when the system provides an “excess” or a “deficiency” of illuminance for a given target value of illuminance on the task plane.

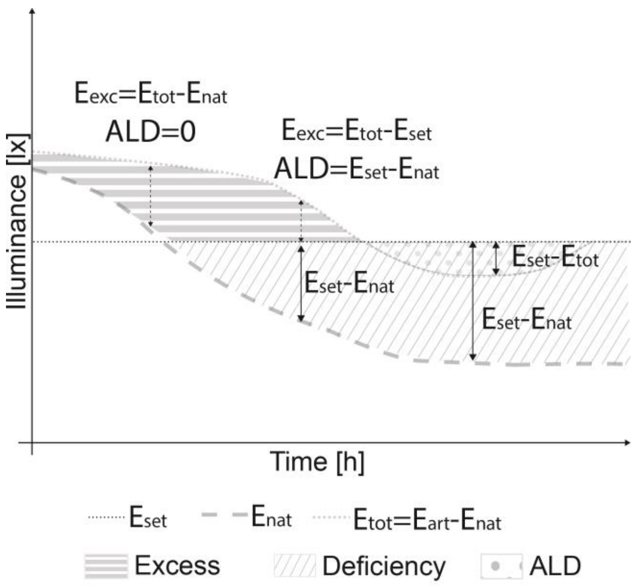


Fig. 4: Graphic scheme of the excess or the deficiency of illuminance compared to the illuminance target value on work-plane or area.

The index named OAR (Over illuminance Avoidance Ratio) is defined as the ratio, evaluated for an observed time period, between the minimum requirement of artificial light (ALD) and the sum of it plus the artificial light eventually provided in excess (E_{exc}).

$OAR = ALD / (\Sigma_{operation\ time}\ E_{exc} + ALD) = \Sigma_{operation\ time}\ (E_{tot} - E_{nat})^{*} \times \Delta t$ *(only when $E_{tot} > E_{set}$) (eq. 3)

where E_{tot} is the total illuminance due to the contributions of natural and artificial light.

Therefore, for a given ALD, the higher the over-lighting (low values of OAR) the lower the capability of the system to fulfil the maintenance of the illuminance target value on task area and thus the higher the related energy consumption.

If we want to account the “deficiency” of light, an UAR (Under-illuminance Avoidance Ratio) (Eq. (4)) index can be calculated. It can be defined as follows:

$UAR = 1 - \Sigma_{operation\ time}\ (E_{set} - E_{tot}) \times \Delta t / ALD$ (eq. 4)

So, when a system does not cause much “under-lighting”, E_{tot} results most of the time close to E_{set} and UAR will be close to 1. At the same time the closer E_{tot} to E_{nat} (when $E_{nat} < E_{set}$), the closer UAR to 0 which indicates that an insufficient contribution of artificial light has been provided by the system.
As a result of previous considerations, in order to give a more complete response on the performance of an observed system during the monitoring exercise, ERI, UAR and OAR indices must be considered together.
The scheme in Figure 5 shows how several combinations of the indices values can be interpreted for a system diagnosis.

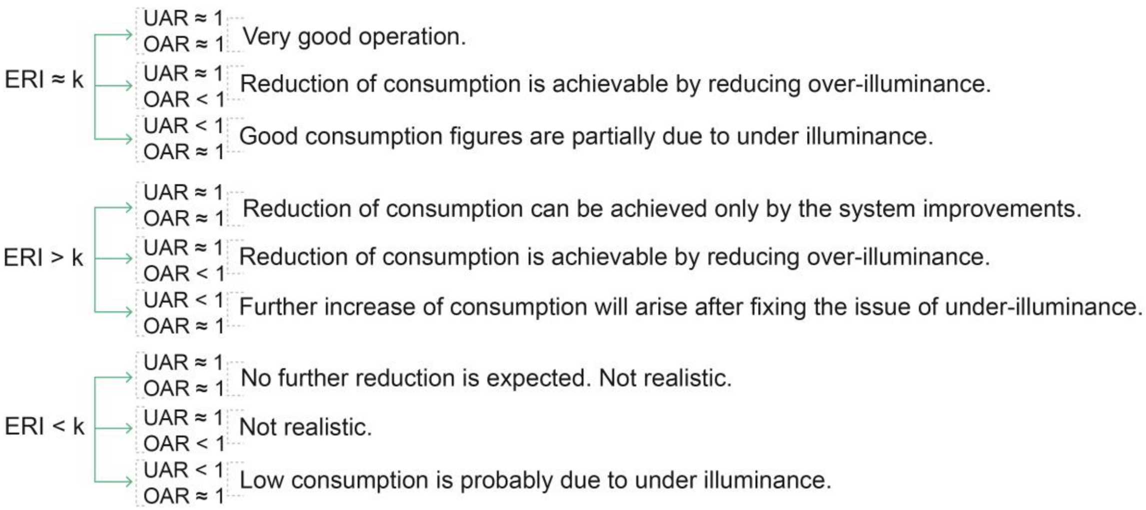


Fig. 5: Possible combinations of ERI, UAR, OAR and their meaning (Bonomolo et al. 2017).

5. Result and discussion/Data analysis

Two monitoring campaigns has been conducted from April 2016 to December 2016 and from May 2017 to July 2017. All the collected data have been analysed and the above indices has been calculated to test the actual performance of the systems for the different set-up, configurations and scenarios. In Table 1 some results of this calculation have been reported.

Tab. 1: Results for selected tested scenarios with dimming and on-off control.

System	Schedules	Date	ALD [luxh]	Dimmer control				On-off control			
				OAR	UAR	ELEC [Wh]	ERI [Wh/lxh]	OAR	UAR	ELEC [Wh]	ERI [Wh/lxh]
System A	09:00-13:00 14:00-18:00	04/10/2016	874	0.36	0.97	653.7	0.75	0.02	1.00	961.3	1.11
	09:00-13:00 14:00-18:00	05/10/2016	704	0.19	1.00	875.5	1.24	0.01	1.00	996.3	1.42
	09:00-13:00 14:00-18:00	06/10/2016	1221	0.52	0.97	622.8	0.51	0.03	1.00	824.0	0.68
	11:00-15:00 16:00-20:00	10/10/2016	1394	0.47	0.93	729.8	0.52	0.03	1.00	874.3	0.63
	8:00-12:00 13:00-17:00	12/10/2016	315	0.18	0.01	743.1	2.36	0.02	1.00	996.3	0.67
	8:00-12:00 13:00-17:00	13/10/2016	449	0.16	0.97	715.3	1.59	0.01	1.00	996.3	2.22
	10:30-14:30 15:30-19:30	17/10/2016	322	0.22	1.00	428.5	1.33	0.01	1.00	764.5	2.38
	07:00-11:00 12:00-16:00	18/10/2016	180	0.17	1.00	351.1	1.95	0.01	1.00	529.2	2.94
	07:30-11:30 12:30-16:30	20/10/2016	766	0.29	0.96	679.5	0.89	0.02	1.00	996.3	1.30
	07:00-11:00 12:00-16:00	21/10/2016	1114	0.61	0.82	460.1	0.41	0.03	1.00	779.3	0.70
	07:00-11:00 12:00-16:00	23/10/2016	1638	0.62	0.93	704.3	0.43	0.03	1.00	996.3	0.61
	10:00-14:00 15:00-19:00	25/10/2016	919	0.66	0.93	425.3	0.46	0.03	1.00	745.7	0.81
	09:00-13:00 14:00-18:00	26/10/2016	561	0.36	0.96	460.2	0.82	0.01	1.00	807.7	1.44
	8:00-12:00 13:00-17:00	27/10/2016	458	0.38	0.91	300.7	0.66	0.02	1.00	457.5	1.00
	07:00-11:00 12:00-16:00	31/10/2016	553	0.59	0.84	317.4	0.57	0.02	1.00	710.1	1.28
	07:00-11:00 12:00-16:00	02/11/2016	973	0.74	0.79	373.5	0.38	0.02	1.00	633.4	0.66
	8:00-12:00 13:00-17:00	04/11/2016	1797	0.99	0.85	410.5	0.23	0.07	1.00	488.0	0.28
	09:00-13:00 14:00-18:00	13/11/2016	653	0.37	0.98	520.5	0.80	0.02	1.00	797.6	1.22

	07:00-11:00 12:00-16:00	15/11/2016	1615	0.64	0.92	661.7	0.41	0.04	1.00	926.7	0.58
	09:00-13:00 14:00-18:00	18/11/2016	1057	0.58	0.91	482.0	0.46	0.03	1.00	650.7	0.62
	8:00-12:00 13:00-17:00	28/11/2016	1151	0.49	1.00	653.9	0.57	0.03	1.00	872.3	0.76
	07:00-11:00 12:00-16:00	30/11/2016	936	0.24	0.96	840.6	0.90	0.02	1.00	996.3	1.06
	07:00-11:00 12:00-16:00	01/12/2016	1569	0.64	0.94	618.2	0.39	0.04	1.00	813.3	0.52
	8:00-12:00 13:00-17:00	03/12/2016	1138	0.71	0.85	458.1	0.40	0.04	1.00	668.0	0.59
	8:00-12:00 13:00-17:00	04/12/2016	1481	0.83	0.85	493.2	0.33	0.04	1.00	745.7	0.50
	09:00-13:00 14:00-18:00	05/12/2016	1300	0.66	0.87	527.4	0.41	0.03	1.00	799.1	0.62
System B	09:00-13:00 14:00-18:00	31/05/2017	569	0.65	0.70	222.82	0.39	0.16	0.80	817.4	1.44
	09:00-13:00 14:00-18:00	01/06/2017	733	0.87	0.68	149.97	0.20	0.51	0.65	280.7	0.38
	09:00-13:00 14:00-18:00	02/06/2017	726	0.84	0.87	204.24	0.28	0.33	0.99	514.8	0.71
	11:00-15:00 16:00-20:00	03/06/2017	1613	0.73	0.82	465.18	0.29	0.39	0.95	780.9	0.48
	8:00-12:00 13:00-17:00	04/06/2017	854	0.89	0.42	112.26	0.13	0.67	0.40	792.7	0.22
	8:00-12:00 13:00-17:00	05/06/2017	469	0.62	0.97	195.60	0.42	0.21	1.00	792.7	1.10
	10:30-14:30 15:30-19:30	07/06/2017	1468	0.90	0.76	304.08	0.21	0.48	0.85	677.0	0.46
	07:00-11:00 12:00-16:00	06/06/2017	852	0.77	0.95	309.20	0.34	0.33	0.96	612.6	0.72
	07:30-11:30 12:30-16:30	08/06/2017	929	0.92	0.30	76.15	0.08	0.79	0.23	115.5	0.12
	07:00-11:00 12:00-16:00	09/06/2017	703	0.99	0.23	115.33	0.05	0.77	0.18	87.4	0.12
	07:00-11:00 12:00-16:00	10/06/2017	493	1.00	0.20	72.54	0.07	0.60	0.28	116.4	0.24
	10:00-14:00 15:00-19:00	11/06/2017	1431	0.71	0.61	317.53	0.22	0.58	0.73	457.3	0.28
	09:00-13:00 14:00-18:00	15/07/2017	457	0.71	0.58	187.70	0.41	0.51	0.53	320.5	0.44
	07:00-11:00 12:00-16:00	13/06/2017	1072	0.80	0.57	208.77	0.19	0.61	0.56	300.0	0.28
	07:00-11:00 12:00-16:00	05/07/2017	445	1.00	0.10	142.45	0.22	0.87	0.10	126.1	0.18
	8:00-12:00 13:00-17:00	06/07/2017	444	0.55	1.00	246.07	0.55	0.26	1.00	792.7	1.00
	8:00-12:00 13:00-17:00	12/07/2017	387	0.78	0.46	150.85	0.39	0.51	0.47	792.7	0.53
	09:00-13:00 14:00-18:00	13/07/2017	576	0.66	0.58	227.06	0.39	0.55	0.54	338.2	0.39
	07:00-11:00 12:00-16:00	17/07/2017	438	0.47	0.48	140.39	1.42	0.11	0.86	850.5	1.94
	09:00-13:00 14:00-18:00	18/07/2017	323	0.52	0.88	214.96	0.67	0.26	0.77	320.5	0.99
	09:00-13:00 14:00-18:00	21/07/2017	645	0.70	0.57	233.43	0.36	0.16	0.96	947.7	1.47

It must be clarified that ALD values characterize the days when the systems worked. It ranges according to the season, the hours of the occupancy schedules and of the daily time. The scenarios reported in Table 1 are characterized by ALD values that ranges between 315 lx·h and 1797, for the System A, and from 322 and 1613 lx h, for the System B.

Starting to compare how the two systems worked, it can be noted that in some case, they worked in different way during scenarios with ALD very similar. For instance, for the scenarios with ALD of about 322 lx·h an OAR of 0.22 and an UAR of 1 have been calculated for the System A and an OAR of 0.52 and an UAR of 0.88 for System B. Also, for scenarios with ALD of about 703 lx·h an OAR of 0.19 and an UAR of 1 have been calculated for the System A and an OAR of even 0.99 an UAR of 0.23 for System B.

The graphs in Figure 6 shows the relation between OAR and ALD indices for the two systems operated by the two control strategies. In general, high values of OAR corresponded high values of ALD. It means that the systems worked better when there was low contribute of daylight. So, in general, the greater the ALD, the lower the possibility of having over-lighting problems. The same is for the ON-OFF control case.

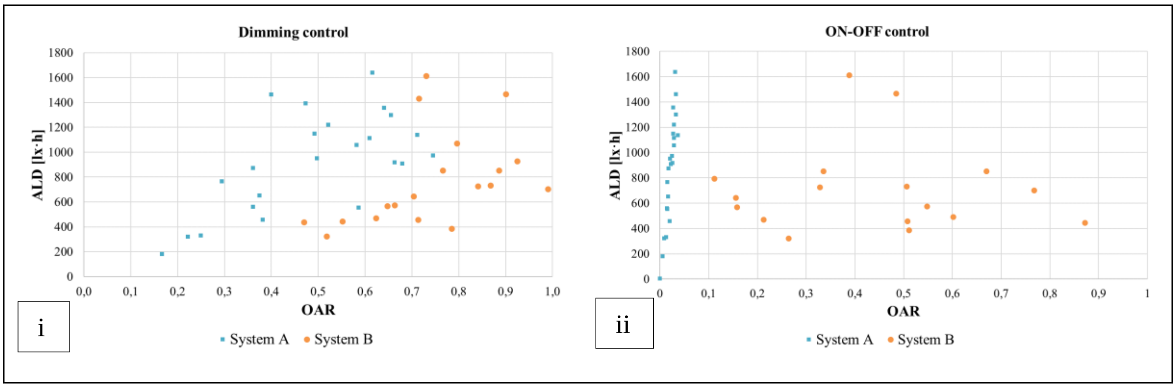


Fig. 7: Relationship between A.L.D index and OAR index calculated in dimming control and ON/OFF control for the two systems.

Generally, in dimming operation system A had OAR lower than System B. For both systems a certain linear correlation with ALD can be observed. In ON-OFF operation (Figure 7ii) System A had a maximum of OAR equal to 0.07 (very poor result), while figures of System B are generally better, even if not well correlated with ALD.

Also, observing figure 8i and 8ii, it can be noted that the higher ERI the lower OAR values. It means that the system wastes energy over-lighting the room. On the other hand, low ERI values are coupled to low values of UAR (Figures 8iii and 8iv), because such energy “saving” is affected by an excessive under-lighting. The reason why correlations OAR vs ERI and UAR vs ERI are not very robust lays on the fact that the system can perform in under and over-lighting in the same day of operation.

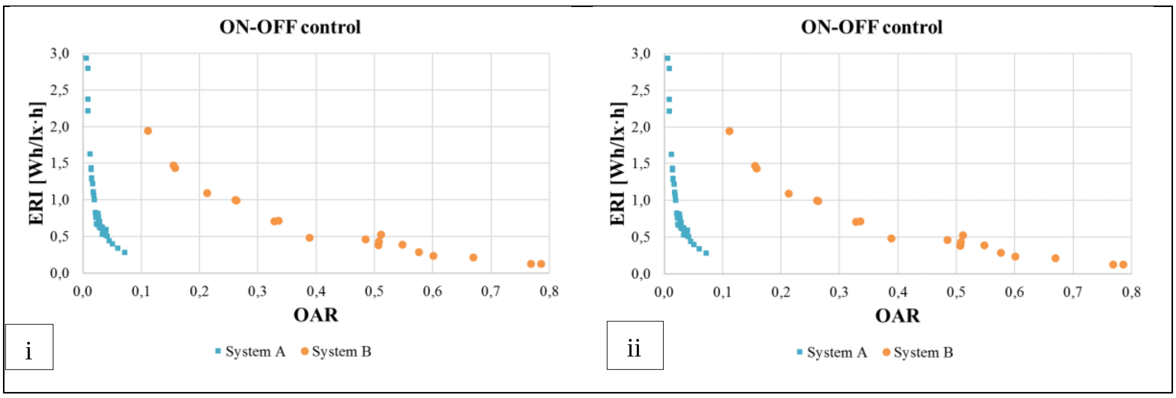
It can be noted that the System A in ON-OFF case had not problems of under-lighting (Figure 8iv), but it had serious problems of over-lighting (Figure 8ii).

As already noted looking at the calculated values, the System B had higher performances than the System A. Comparing the two control strategies, it can be observed that both system had higher performances with dimmer control. Anyway, the gap between the performances of the two control strategies is larger for System A.

Indeed, the cloud of points calculated for the System B with dimmer control shifted slightly to higher values of OAR (Figure 8i). In the case of ON-OFF control, it is much more evident (Figure 8ii). The OAR values are very low for the System A (the highest value is 0.07). On the contrary, in the case of System B they are higher reaching value of 0.87), while, UAR are almost every time equal 1.

In such a light it is useful to observe the ratio OAR/UAR vs ERI graphs. The higher the ratio the higher is the influence of the under-lighting during the system operation.

All the considerations related to the best performance of System B and of the dimming control for both the systems are confirmed also in graph 8iii and 8iv. Also, the predominant behaviour of System A to provide exceeds of lighting (OAR/UAR very low) is confirmed.



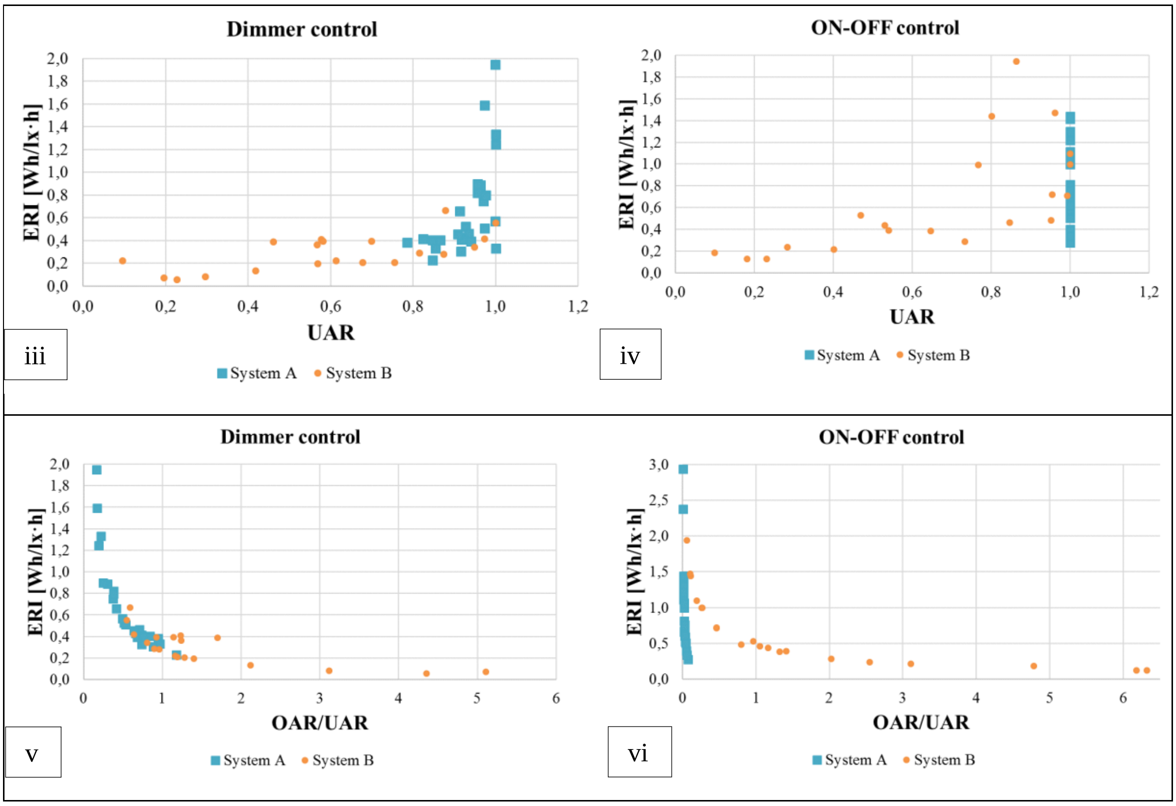


Figure 8. Relation between ERI index and OAR index calculated in dimming control and ON/OFF control for the two systems.

The correlation between electrical consumption and ALD values (Figure 9) is useful for analysing the ALD influence on the system performance. The ideal consumption has been calculated proportionally to the ALD. For this reason, the correlation is linear. On the contrary, looking at the actual consumption lines (both of System A and B), the correlation is not linear. It is because, as already said and observed, the control system did not work as expected in ideal cases and, in some cases, low values of UAR and the OAR have been found. The more the point are closer to the consumption line, the more the system worked good. The actual consumption lines shifted from the ideal one because the absorbed power of the control systems (around 18.3 W for the System A and around 10 W for the System B).

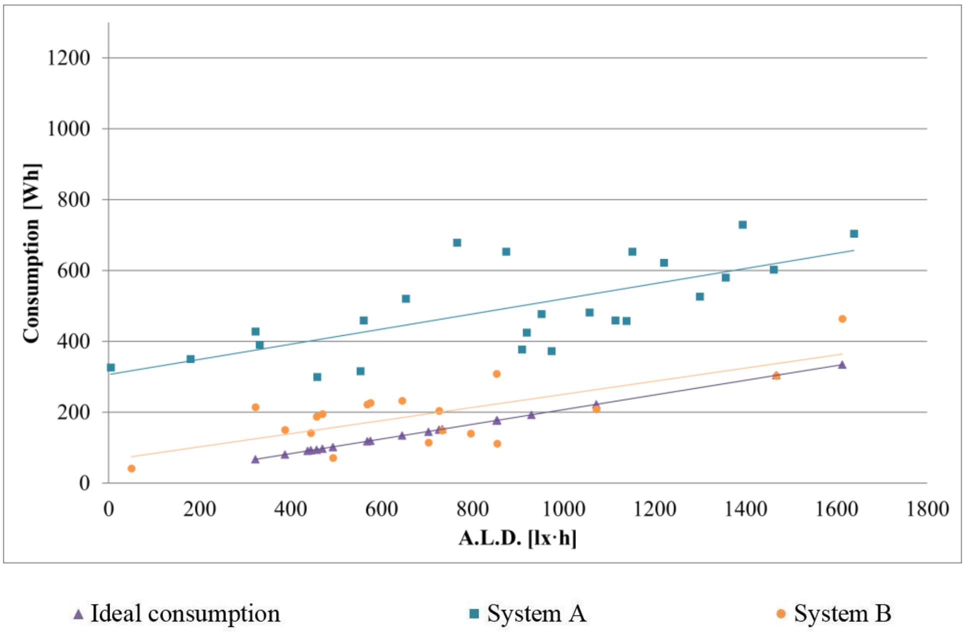


Figure 9. Comparison between the relation of ALD index and electrical consumption for the two systems and calculated for an ideal case.

6. Conclusion

This paper presents an experimental test of a new method developed by authors to evaluate the actual performance of two DLCs, based on the calculation of a set of indices. The index ERI has been used to account for the specific consumption *k* (Wh/lx·h) with respect to the artificial light demand (ALD). Generally, it depends on the lamps efficiency, on the luminaries, on the electric systems and on the control systems. The indices OAR and UAR have been used to account their ability to maintain the target illuminance on the task area. The two systems have been tested under different operating conditions and control strategies (dimming and ON-OFF). In general, the closer the ERI index to the *k* factor the more the system works properly with very high values of UAR and OAR.

The values of the indices have been calculated in different scenarios characterized by variable daylight availability and compared in order to have a picture of how each system performed. Furthermore, relationships between the indices have been carried out and analysed for large sets of data.

In general, it has been proven the ability of the indices to highlight situations where e.g. a low specific consumption is almost due to the inability of the system to fulfil the minimum target illuminance but only occasionally performing over-lighting. Likewise, it can be noticed that the highest ERI values correspond to the lowest OAR values i.e. system is performing in over-lighting conditions.

Anyway, low ERI values are also coupled to very variable values of UAR. For this reason, it is useful to observe it as function of OAR/UAR ratio. In this light, the higher the ratio the more prevalent is the under-lighting condition.

In almost all the observed conditions System A performed worse than System B with a persistent behaviour characterized by frequent and relevant over-lighting.

For both the systems the relationship between ALD and electrical consumption was only barely proportional because the control system did not always work as expected in ideal cases (with UAR and OAR both equal to 1). Anyway, also by this light it has been possible to confirm the higher efficiency of System B.

Therefore, it can be affirmed that such method can be utilised to assess the systems performance on different days and, consequently, with different daylight conditions as well as different systems operating in similar daylight conditions. Further work will deal with the test of other commercial systems aiming also at a comparison of their performances in different seasons.

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