421: Lighting control system: energy efficiency and users' behaviour in office buildings

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Abstract

Efficient daylight-responsive systems for illumination of buildings, including installation of automatic lighting control systems, can provide a significant contribution in order to set up design and intervention strategies towards energy saving and environmental protection. Moreover it is becoming increasingly important to establish a realistic baseline of the actual lighting energy consumption in buildings for the different scenarios nowadays used (both manually and automatically operated) which incorporates occupant's behaviour.

Analysis of energy saving potential of automated lighting scenarios have been carried out in real use conditions instead in controlled laboratory environment, in order to test the automation systems efficiency in operating time.

The analyzed building is a 6 floors office block each with almost 35 units. Different automation scenarios (for number, typology and location of installed devices) have been implemented in 2007during the renovation activity.. The building configuration, characterized by the same number and offices distribution for each floor, allows the simultaneous comparison of the operation systems implemented. The monitoring activity will be carried out for 2 years, starting from February 2008.

Mainly the following devices and automation strategies have been implemented: light sensors (to have a continuous dimming of the artificial light depending on the intensity of the natural one); occupancy sensors; weather station (to detect the outside illuminance conditions); power consumption meters (to monitor separately the energy demand for each floor); shatter control actuators and a supervision system (for the data monitoring to implement a statistical study of the human behaviour and systems performance).

Keywords: lighting automation system, energy efficiency, user control action

1. Introduction

Lighting has a substantial impact on the environment: the commercial sector counts more than 25% of energy consumption in EU for the lighting sector [1]. Considerable savings could be achieved even by application of intelligent control technologies in existing buildings [2].

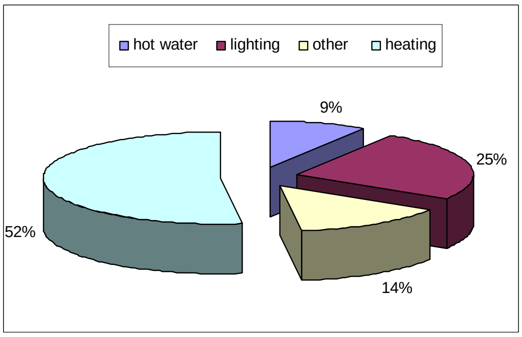

Fig 2. Energy consumption distribution in commercial buildings in UE [2]

Thus it is important to establish a realistic efficiency baseline of the actual lighting system in buildings for the different scenarios nowadays used (both manually and automatically operated), which incorporates occupants behaviour.

The features of lighting simulation tools currently available emphasize the importance of defining suitable reference cases for benchmarking the performance of automated lighting control.

Multiple studies have been internationally developed to collect data concerning the interaction between final users and lighting/shading control systems [3-4-5]. These results can provide a better understanding of control-oriented user behaviour in buildings and thus support the development of corresponding behavioural models for integration in building performance simulation applications.

Some studies have been developed focusing on the calculation of the potential energy saving obtainable in office building using automation devices (occupancy sensors, light sensors, dimming actuators).

The calculated results estimate an energy saving from 28% to 70%, starting from the basic solution to the more complex one. These results have been developed in a computational way [6-7].

Other studies refer about the application of the same technologies in lecture halls, measuring in real use conditions the efficiency of the automation system applied [8-9].

The study presented in this paper refers about a measuring campaign, carried out for the specific case study of an office building. In this analysis new scenarios have been implemented, introducing different control operability functions in the dimming regulation scenario.

2. Method

The research activity has been carried out by the CUnEdI (University Center for Intelligent Buildings – Centro Universitario Edifici Intelligenti) at the University of Trento (Italy), in collaboration with the APE (Provincial Energy Agency - Azienda Provinciale per l'Energia) with the aim of setting up a new approach for the design of lighting systems in office building using smart devices in order to achieve:

- higher energy saving,

- better visual comfort conditions,

- user's satisfaction for smart technology utilization modality.

The analysis of these three topics has being developed in real use conditions and not in controlled laboratory environment. In this way it is possible to test the potentialities and limits of technological solutions currently available on the market, the comfort perceived by human and performed by the system, the interaction between users and partially/completely automated systems.

In order to quantify the difference between energy performance of conventional lighting systems and each automated control scenarios, the energy demand of each case has been considered separately and a pairwise comparison has been performed.
In this research the manual lighting system is assumed as operated by an on/off switching; the automated Scenarios are defined at paragraph 2.1.

In order to test Scenarios so to reduce the energy demand and guarantee at the same time visual comfort improvement, the following factors have been considered:
- control of the user's presence in office, as a necessary condition to turn on the light;
-regulation of the artificial light, in relation to the natural light level;
- possibility of a manual regulation of the light, forcing the automatic regulation, in order to better meet the user's needs.
The balance between manual and automatic regulation is a crucial point in order to evaluate the realistic usability to the analyzed technology.

To carry out this analysis it is necessary to compare homogeneous or normalized environments (by specific factors) simulating the same boundary conditions.

For the evaluation of these aspects it is necessary the monitoring of the following data:

- user' s presence in the office, in order to make a scientific analysis of the energy consumption, normalized through the real occupation time
- inside illuminance level with and without intelligent devices, in order to evaluate the natural light contribution

- verification of the user's behaviour using the automation system, even if its regulation has been forced by a manual regulation, in order to evaluate the visual comfort for the users in a building automation system.

2.1 Case study

A specific case study has been analyzed: an office building in Trento (Northern Italy) in which a total refurbishment of electrical system and informatics net have been curried out recently.
The building has 6 floors, each of 1200 m^2 , with a similar indoor distribution.
The two main expositions are north and south. The building is characterized by 4 different and modular office typologies, each with the same power density installed and with the same natural light condition, even if with different surface and occupants number [Table 1].

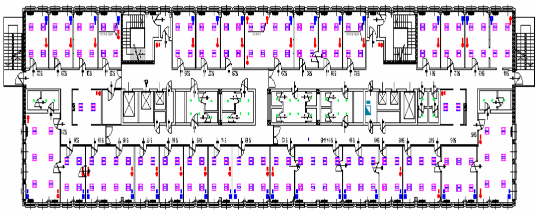

Fig. 3: floor type

There is the same windows typology (dimension 1.15m x 1.20m) with a constant inter-axis belong both the façades. The same shading system is present: internal Venezian blind, manually operated.
The artificial light is provided by lamps (1/55 W each, tubes T5). They have been designed in order to maintain 500 lux at the end of the luminaires life, by night. In the first utilization period they produce an over-density of luminous flux.
In the central part of the building service spaces are positioned: corridors, bathrooms, stairs and elevators.

Table 1: office typology

OFFICE TYPOLOGY	DEPTH (m)	WIDTH (m)	SURFACE (m^2)	WINDOWS SURFACE (m^2)	ELECTRICAL POWER (W/m^2)
A	5	3,5	17,5	2,76	12,57
B	5	5,25	26,25	4,14	12,57
C	5	7	35	5,52	12,57
D			40 - 56	6,9	11,00 - 9,82

The D type office represents a peculiar situation regarding:
- *utilisation modality*: not office but meeting room , with different occupancy level;
- *exposition:* not only one but two façade with South East/ South West windows;

- *surface*: the meeting rooms can be different floor by floor;
- *power density:* could by different in relation with the surface area.

Excepted from D type, the other office types can be homogeneously compared, distinguishing only by façade expositions. In this paper we will refer about S_xyy or N_xyy office where:
S = south façade
N = north façade
x = floor
yy = office progressive number
If there is no office number the code refers to the overage data for a specific floor (e.g. S_1, N_1; etc.).

2.2 Technology applied

The lighting system of the 5° floor is still manually operated, as required in the previous installation system (switching on/off the office luminaires by two channels: right table zone, left bookshelves zones).
In each of the other five floors a specific scenario has been applied, using automation systems with different type and number of controlled parameters and increasing complexity level, as described in the following.

Scenario 1 (6° FLOOR): requires that the IR occupancy sensor installed [Fig.4] switches off the light if nobody is detected in the office for more than 15 minutes.
The used devices also have the light level detection function, in order to turn off the light if unnecessary, but their sensitivity is not high enough (the illuminance threshold is manually selected) and it can suddenly and improperly control the lighting operation.
With this technology is not possible to monitor and record the value read by the devices; thus it is difficult to give a functionality diagnosis of these sensors. Asking the users, errors in the presence detection have been complained.

Fig. 4: LU 360 PE / 360 PE2- Theben

Scenario 2 (4° FLOOR): implies in addition that lights are switched off, if the daylight-based task illuminance level exceeds 500 lx.
It is possible as well to manually dim the luminaires. Technology by KNX (www.knx.org) has been used; digitally sends on the bus the communication telegrams, enabling the monitoring action.
These devices [Fig.5] give more accurate measures (higher number of switching segments), and moreover their application program allows the maintenance of a constant illuminance level, even not enabled in this application, in order to investigate this specific activation modality. In this application the user decision ability is higher, using a dimming regulation modality: the light intensity is manually selected and maintained until the absence is detected. Defects in brightness reading depend on the surface colour corresponding to the detection direction (vertical line) that could describe a different condition compared to that one on the working surface.
Because the KNX installation flexibility, in the future this configuration could be changed just downloading a new device parameterization.

Fig. 5: ARGUS 630592 – MERTEN (brightness and presence sensor)

Scenario 3 (3° FLOOR): the luminaires are switched on when occupancy is detected and dimmed (by two separately controlled circuits, depending on the windows distance) so as to provide predefined minimum illuminance levels (500 lux). It is moreover possible to force the automated regulation in compliance with the users' preference, maintaining this value until the absence is detected.
The smart devices applied in order to detect the presence are the same used for the scenario 1. Two luminance sensors have been installed for each façade in order to detect the natural light level incoming from the windows. The two reference rooms have been chosen in order to avoid the use of shading system for the detected windows, and to get in this way the higher level of natural light contribution for the two expositions façades.
Obviously it is possible to have lower inside illuminance level and probably lower dimming value in offices where the venetian blind are partially closed.
The installation position and direction of these devices is a crucial point in order to manage a correct measure. It is strictly related to its internal position in correspondence with the window. For the specific case study there is an homogeneous distribution in façade of the transparent surfaces.
The dimming percentage required is selected by the electrical engineer during the commissioning process, operating directly by a manual regulation, using the manual calibration of each dimming channel.
The installation in each office of both this specific light sensor and the presence detector was evaluated a too expensive solution. It is not

possible to record the illuminance level detected by these sensors because it is a internal variable to the system functionality.
The communication protocol, applied to control this lighting control system, is the DSI. In the installed configuration is not possible to record the dimming percentage as a digital value.

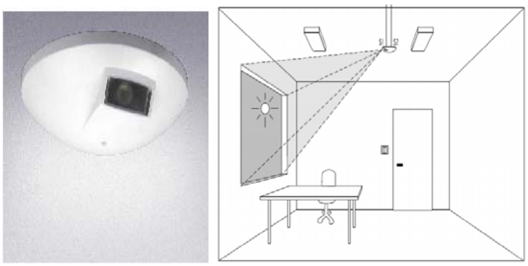

Fig.6: LUXMATE-Daylight LDS-Zumtobel (light sensor and its installation modality)

Scenario 4 (FLOOR 2): the activation modalities are the same of the scenario 3 (possibility to switch between the automatic and manual control of the artificial light). The procedure and the number of the inside illuminance measures are different. In this case there is one light/occupancy sensor for each office, with a specific artificial light level required. The detection point is positioned in the middle of the room, on the working desk.
The communication protocol is KNX, as for scenario 2. The regulation actions of the devices for this scenario can be recorded (occupancy, inside illuminance, dimming percentage, manually forced command).

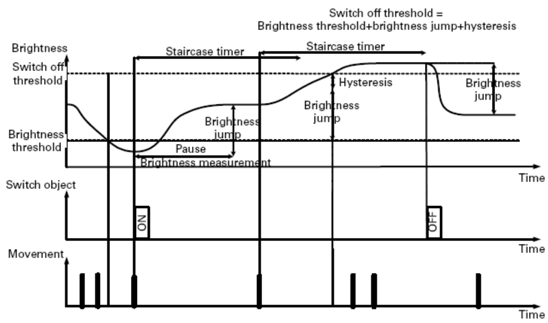

Fig. 7: Functionality system for the presence/light sensor: constant illuminance level maintenance

Scenario 5 (FLOOR 1): requires the unlocking function of the occupancy sensors by switching in each office. This allows that when the occupancy detector is enabled the light is automatically dimmed in order to maintain a minimum illuminance level of 500 lux.
The user can autonomously decide to have only the light turn on or off but with the dimming level directly calculated by the system, with any possibility to be manually changed.
The used technology is still the KNX protocol (gateway DALI), and all the parameters controlled by the bus system are simultaneously recorded. This was the last floor to be built, so an additional function for the installed devices, was available, concerning the occupancy detection: the detection area can be divided in 4 sectors. With this application B sector could be excluded, preventing the switch on of the light in one office with the open door even if somebody walks in the corridor closed to the detected area.

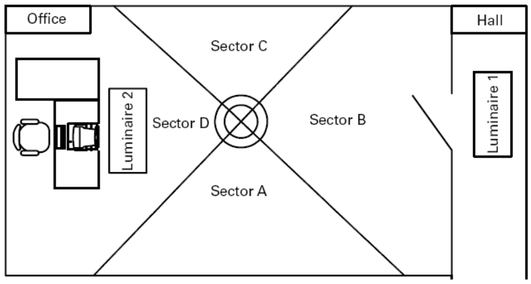

Fig. 8: Detection area subdivision: MERTEN 6309

Scenario 6: applied in four reference offices on the first floor, two for each façade, this scenario requires the manual control of the shading system by means of buttons connected to the bus: the position and the rotation angle of the slates are data monitored by the supervision system.
In a second research step, the position of the shading system will be implemented as a function of the outside illuminace conditions and exposition. At the same time the automatic control of the artificial light intensity will be applied, as described in Scenario 5.
In order to monitor the outside climate conditions a weather station is used, able to measure not only outside illuminance, to optimize and balance the glazing and illuminace conditions, but also outside temperature, wind speed and raining.

2.3. Monitored parameter

KNX installation devices, that belong to the same functional group, are "logically wired" by means of group addresses.
A particular attention was paid to the definition of the structure for the codes (group address) for different functions.
A general structure (Table 2) was defined considering:
- *macro-categories* of functions (n_1);
- *sub-functions* for each macro-category, describing its specific applications (n_2);
- *a progressive number* (max value 255), for each single detected variable (n_3)

The complete group address has been defined as composition of these 3-value code (n_1-n_2-n_3).
For this specific project were active the group address with grey background, as shown in Table 2.
This structure was built considering general purposes for a flexible use in future projects, involving a considerable number of parameters, and to control many main functions (macro categories) in automation systems.
In particular "Lighting", "Temperature" and "Control" macro-categories are present three times (A, B, C) respectively for a total of 255*3=765 devices. There is also a table for establish a correlation between the sequential number "n_3" and the spatial position (floor, office) of each single device.

Table 2: Structure of group address

Macro-categories	n_1	Sub-Function	n_2	Group address n_1-n_2-n_3
Lighting A	0	On/Off	0	0-0-n
		Feed-back value (on/off)	1	0-1-n
		Dimmer	2	0-2-n
		% dimmer	3	0-3-n
		Feed-back value (dimmer)	4	0-4-n
Lighting B	1	(as above)	…	1-0-n …
Lighting C	2	(as above)	…	2-0-n …
Temperature regulation A	3	Current internal temperature	0	3-0-n
		Arrange temperature (set-up)	1	3-1-n
		Fan Coil (speed)	2	3-2-n
		F.C. command	3	3-3-n
		Efficiency	4	3-4-n
		Antifreeze	5	3-5-n
Temperature regulation B	4	(as above)	…	4-0-n …
Temperature regulation C	5	(as above)	…	5-0-n …
Shading system control A	6	Stop/step by step control	0	6-0-n
		Move (up/down)	1	6-1-n
		% inclination of venetian blinds slates	2	6-2-n
		% height venetian blinds	3	6-3-n
Shading system control B	7	(as above)	…	7-0-n …
Shading system control C	8	(as above)	…	8-0-n …
Control A	9	Internal illuminance	0	9-0-n
		Occupancy	1	9-1-n
		Automated and manual switch	2	9-2-n
		Manual dimmer control	3	9-3-n
		Manual on/off control	4	9-4-n
Control B	10	(as above)	…	10-0-n …
Control C	11	(as above)	…	11-0-n …
Monitoring	12	Timer	0	12-0-n
		Weather station	1	12-1-n
		Energy counter	2	12-2-n
		FB current meter	3	12-3-n

3. Data elaboration tool

The supervision software used in the case study is Gefasoft – Graphpic 7.1. In order to let communicate it with KNX devices, the EIB OPC-server has been used.

The monitoring results are stored in a databank; for each day is generated a file ("MeasArvyymmdd.TXT") containing the data recorded on contingency at different delay time.

Each single message is labelled with a distinctive "ID number" related to each specific monitored parameter; in this case study we have defined an *absolute* correspondence between the group address and the ID number.

The research team of CUnEdI has created an appropriate program for an automatic data processing.

The main goal was to relate different events occurring in a specific room at the same time interval finding relations between the employed parameters (presence and use of artificial light, energy use and external lighting level, dimmer percentage and internal lighting level, etc.)

The tool was structured in order to be flexible also for different future applications.

From the main page user can select between two types of conversion data: the first related with the daily recorded data and the second with monthly pre-elaborated data.

3.1 Daily data conversion

It's possible to select multiple files created by Gefasoft.

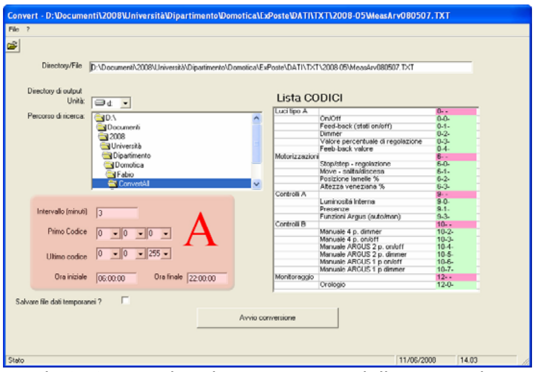

Fig 9. Conversion data program – daily conversion

With our program (Fig 9-A) it is possible to:

- define a specific time interval (min.) for compute a standard average of data (in our specific application we used a 3 minutes interval);
- define the initial and final ID variable and initial and final time (hour) to be considered; we have considered from 6:00 AM to 10:00 PM;

The program will convert data from raw to a new optimized format.

3.2 Monthly data conversion

User can select multiple files created with the previous conversion. It is possible to exclude by the computation the files concerning holidays (Fig 10-A) and also every other kind of day selecting its number (Fig 10-B).

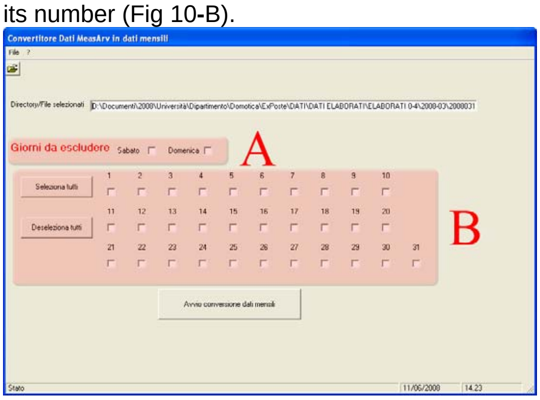

Fig 10. Conversion data program – monthly conversion

4. Elaboration data

Data analysis will be executed on an annual, monthly and daily base, valuing the differences between the results for different events.

A "*typical day*" data analysis has been carried out in order to understand and model user's behaviour in traditional offices and to quantify the energy saving potentialities of an automation system for lighting control,. In this way it is possible to perform also an hourly data analysis, instead of a daily overview of the system functions and user interactions.

The first results regard the period from April to May 2008. The energy saving measured is included between the 36% and the 58%, with the hourly trend shown in Fig. 11. The other data recorded are described in the following.

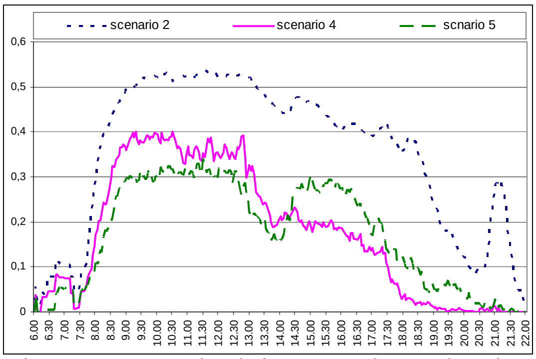

Fig. 11: Occupancy levels for 3 scenarios monitored as function of working hour time

4.1 Energy use

The energy saving percentage for each scenario has been calculated in comparison with a reference level of energy demand considering the manual control of the lighting system (5° floor).
For each floor the energy use is available as a global value including corridors and elevators.

4.2 Presence detection

This value is registered for each office in different floors in order to get a representative sample to estimate the occupancy trend of the building. The recorded values for the scenarios are different, so that they will be evaluated in the energy saving calculation.
The occupancy time of users in each room has to be recorded and monitored in order to normalize the energy consumption by the necessity and the effective use of the lighting system in a space. A period shorter than 6 minutes is not considered as an absence.
A complete monitoring for 3 floors will be avaliable and these data will be compared with the presence period of users certified by their time cards.
So it should be possible to find relationship functions available also for the other floors.

4.3 Internal lighting

This value is registered for each office at 1° floor and for 6 offices at 2° and 4° floor.
In order to evaluate different levels of lighting system performances, concerning visual comfort conditions as function of the illuminance level maintained on the task area, the lux detected by the luminance sensors have been analyzed.
Indeed the intelligent light system is regulated and dimmed by means of this detected value in order to guarantee a minimum illuminance level (in compliance with the regulation UNI EN 12464-2/2004). Considerable differences between the two expositions have been detected, that clearly influence the required dimming percentage.

4.4 Dimmer percentage

In order to verify the effectiveness of the lighting automation system, the dimming percentage could be considered a crucial value.
This value shows the energy level use for each room.

5. Conclusion

Initial monitoring stage is started in April 2008 and will continue in order to get a complete analysis of energy saving during a whole year.
The next steps for the data analysis will consider the following factors:
- energy saving for each scenario for the whole period;
- efficiency of presence detector (possible wrong power off);
- iteration between users and automation system (manual or automatic power on probability related with internal parameters);
- shading system with implemented function (see scenario 6);
- evaluation of users satisfaction.

7. References

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