

Chapter6:Lightingcontrolsystems

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6 Lighting control systems

6.1 Introduction

A building can be compared to a system with a variety of other and with the environment. From the control point of view, it is considered as having multi-variant dynamic subsystems showing linear or non-linear behaviours. Environmental and occupancy control operations. Occupants not only impose control functions of the different processes (HVAC, lighting, etc.).

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Due to the increase of environmental concerns, lighting control systems will play an important role in the reduction of energy consumption of the building without impeding comfort goals. As mentioned in the IEA Annex 31 (IEA 2001), energy is the single most important parameter to consider when assessing the impacts of technical systems on the environment. Energy related emissions are responsible for approximately 80% of most serious global environmental impacts and hazardous smog and particulates. Lighting is often the largest electrical load in offices, but the cost of lighting energy consumption remains low when compared to the personnel costs. Thus its energy saving potential is often neglected. According to an IEA study (IEA 2006), global grid based electricity consumption for lighting was about 2650 TWh in 2005, which was an equivalent of 19% of total global electricity consumption. European office buildings dedicate about 50% of their electricity for lighting, whereas the share of electricity for lighting is around 20-30% in hospitals, 15% in factories, 10-15% in schools and 10% in residential

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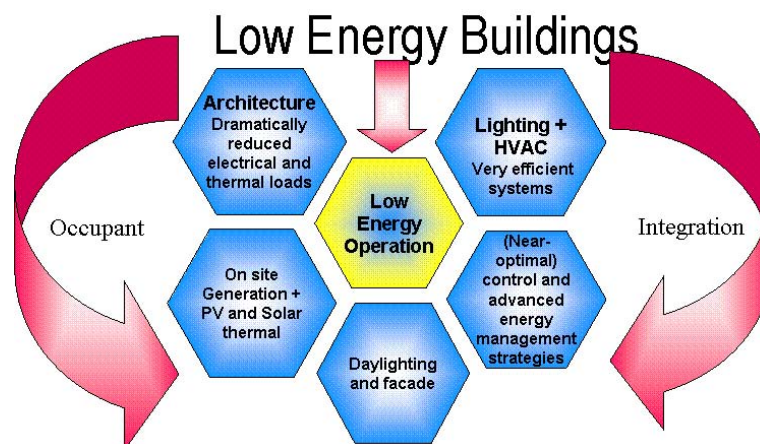


Figure 6-1. Low energy building concept.

The human requirements and the quality of the work environment are often expressed in terms of thermal and visual comfort. The optimal conditions of thermal comfort can be easily described as the neutral perception of the interior environment, where occupants do not feel the need for change towards warmer or colder conditions. Visual comfort, however, is not described easily. Rather than referring to a state of neutral perception of the interior environment, it is perceived as receiving a message. Aspects such as daylighting, glare, luminance ratios, light intensity and contact to the outside have their influences on our perception of visual comfort.

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To fulfill the requirements about comfort and energy efficiency, building managers have implemented programs to reduce lighting energy requirements by installing more efficient light sources and luminaires. However, this is not sufficient. Lighting energy management has to provide the optimal lighting level for the tasks being performed using the most efficient light sources suitable for the application, and providing light only when and where it is needed. This can be achieved by using lighting control strategies and lighting control system. The main purpose of these systems is to reduce energy consumption while providing a productive visual environment. This includes:

- Providing the right amount of light
- Providing that light where it's needed
- Providing that light when it's needed

In fact, lighting control will depend on the considered zone. Thus, it is necessary to define the following factors beforehand:

- The lighting needs (level of illumination, ambience, etc.)
- The task zone/area (position, size, disposition, etc.)
- The occupation time
- The control needs of the user

6.2 Identification of the lighting control needs

Development of a questionnaire for users

Lighting control is continuously evolving due to the constant evolution of requirements for visual comfort and the increasing demand for lighting energy savings. But there is often a lack of a clear identification of the needs. Annex 45 proposes here by a questionnaire in order to help the designer to identify the needs so that optimized solutions can be adopted. Note that the identification of the person answering the questionnaire is useful to understand the needs: a building energy manager pays more attention to the energy consumption and the energy savings than the occupant. The questionnaire available in appendix B should provide the following information:

- The different practices within the building
- The perception of the control barrier's
- The needed control type
- The controlled area
- The flexibility and modularity of the lighting control system

For example, the identification of the usages helps the designer to understand the way he has to design the installation. In a school, an On/Off system coupled with daylight dimming may be adequate but in some offices, it could be necessary to go one step further by integrating more advanced techniques. Similarly, asking the perception of the people on the barriers of lighting control may give information about the type and quality of lighting control system that can be applied (basic On/Off switching system, advanced daylight dimming system, etc.). It is also important to collect information about:

- Flexibility and modularity of the lighting system which gives information about the future affectations of the building. For some buildings (e.g. rented offices) light structure walls are displaced and spaces are reorganized regularly. A change of the lighting control system then has to be possible and easy.
- Maintenance scheme and needs.

6.2.1 Specification book

The building owner needs an efficient lighting system

An objective evaluation of a system requires the definition of performance parameters. In addition, it depends on baseline conditions to which the performance should be compared. Performance parameters include:

- Visual performance and comfort
- Building energy use
- Cost effectiveness
- Ease of use
- Maintenance
- Flexibility (versatility)
- Existing building constraints
- System stability
- System integration

An optimal system performance needs not only to reach a good performance with respect to saving electrical energy, but also to be accepted by the end-user. The end-user may be disturbed by the operation of the system and disable it. A high user acceptance guarantees undisturbed operations and consequently energy savings. Existing buildings have specific constraints and requirements. There is a need to analyze the existing lighting system and to determine the upgrade possibilities considering the technical and economical constraints. Therefore, an audit of the existing lighting installation is necessary. Advanced control requires elements such as electronic dimmable ballasts and distributed electric indoor grids. Similarly, the use of wireless technologies (switches, sensors, etc.) is a suitable solution for retrofit so that the replacement and exploitation costs can be limited.

The occupant needs to control the system

Within the limits of comfort, it is difficult to define exactly what the needs and priorities of the occupant are. They vary from one occupant to another, and also with time for the same occupant. For instance, some occupants may be concerned by energy savings, and some prefer better algorithmic lighting scenes even if it requires more energy and generates higher costs. Therefore, it is recommended that the occupant should have the possibility to change the system's behaviour according to his will.

The occupant needs to understand the system

The user acceptance of a lighting control system is better if the system and its working principle have been explained. On-site visits by practitioners and informal discussions with end-users showed that about 90% of them accept the system operation if they know/understand what its aims and working principles are. It has also been demonstrated that occupants react to a need (a specific condition) but not necessarily to the disappearance of this need. For example, if an occupant switches on the lights due to a sudden obstruction of the high daylight level, the probability that he will switch off when the level has returned low.

The lighting control system must be easy to use

The usability of the system must be defined to address all the types of users (building operators, occupants, facility managers, maintenance teams, installers, etc.). Usability expresses the quality of the experience of a user when interacting with a system.

It is the combination of factors affecting the experience of the user with the product or system:

- a. Ease of learning
 - How quickly can an untrained user learn to operate the system sufficiently well?
- b. Efficiency of use
 - How well and fast can an experienced user carry out tasks using the system?
 - What about the required time for servicing and maintenance?
- c. Error frequency and severity
 - How often do users make errors when operating the system?
 - How severe are these errors and how easily can they be detected and corrected?
- d. Subjective satisfaction
 - Does the user feel comfortable with the system?
 - Does the user feel that using the system brings any advantages?
 - In what way does he interact with?
- e. Maintenance
 - What about determination and implementation of the maintenance schemes?

6.3 Suitable Lighting Control Strategies

6.3.1 Introduction

Lighting and lighting control represents a significant contribution to the energy consumption of a building. In order to estimate the lighting energy consumption and related impact of controls the simplified equation from the European standard EN 5193 could be used:

$$W = W_{L,t} + W_{P,t} \text{ (kWh)} \quad (6-1)$$

Where

W - Total energy used for lighting - the amount of energy consumed in period t , by the luminaires when operating, and parasitic loads when the luminaires are not operating, in a room or zone, measured in kWh.

$W_{L,t}$ - Energy consumption used for illumination - the amount of energy consumed in period t , by the luminaires to fulfill the illumination function and purpose in the building, measured in kWh.

$W_{P,t}$ - Luminaire parasitic energy consumption - the parasitic energy consumed in period t , by the charging circuit of emergency lighting and by the standby control system controlling the luminaires, measured in kWh.

$$W_{L,t} = \sum_n \frac{\{(P_n \times F_c) \times [(t_D \times F_o \times F_D) + (t_N \times F_o)]\}}{1000} \text{ (kWh)} \quad (6-2)$$

Where

t_D - Daylight operating hours.

t_N - Non-daylight operating hours.

P_n - Total installed lighting power, measured in watts.

F_D - Daylight dependency factor - factor relating the usage of the total installed lighting power to daylight availability in the room or zone.

F_o - Occupancy dependency factor - factor relating the usage of the total installed

lighting power to occupancy period in the room or zone.
 F_c - Constant illuminance factor - the factor relating to the usage of the total installed power when constant illuminance control is in operation in the room or zone.

The estimation of the parasitic energy ($W_{p,t}$) required to provide charging energy for emergency lighting and for standby energy for lighting controls in the building is established using the following equation:

$$W_{p,t} = \sum \frac{\{P_{pc} \times [t_y - (t_D + t_N)]\} + (P_{em} \times t_e)}{1000} \quad (\text{kWh}) \quad (6-3)$$

Where

t_y - Standard year time - time taken for one standard year to pass, taken as 8760h.
 t_D - Daylight hours - the operating hours during the daylight time.
 t_N - Non-daylight hours - the operating hours during the non-daylight time.
 t_e - Emergency lighting charge time - the operating hours during which the emergency lighting batteries are being charged in hours.
 P_{pc} - Total installed parasitic power of the controls in the room or zone - the input power of all control systems in luminaires in the room or zone, measured in watts.

A detailed description of these equations is given in Annex 4: EN15193.

The reduction of the energy consumption is possible by playing on the different elements of the equations, for example:

- The installed power can be reduced by using low consumption light sources and efficient control gear (electronic ballasts, electronic DC transformer, etc.).
- Daylight dimming can lead to an important reduction of the energy consumption by adjusting the light flux smartly according to the daylight level. This is what is done by the F_D parameter.
- Operating hours can be reduced by adjusting lighting according to predicted or real occupation strategies through the F_O parameter and the amount of working hours (t_N and t_D). In fact, only a fraction of a building's lighting system is required at any given time. Lights frequently are left on in unoccupied places where there is no need for lighting. Through the reduction of the t_N , t_D and F_O values, energy savings can be calculated.

The first lighting controls level, also the most widely used, is the manual switch to put on or off an individual luminaire or a group of luminaires. This type of control is not robust enough with respect to energy efficiency as it relies solely on the behaviour of the occupants who are not necessarily concerned by energy savings, especially in the tertiary sector buildings. Lighting control strategies provide additional cost-savings through real time pricing and load shedding. Reducing lighting power during electricity peak-use periods when energy rates are at the highest can also be achieved through a Lighting Management System (LMS).

Lighting Management Systems allow building operators to integrate lighting systems with other building services such as heating, cooling, ventilation, in order to achieve a global energy approach for the whole building, in particular for green building or an energy-producing building.

Energy efficiency of lighting control systems depends on the strategies implemented as presented in figure 6-2.

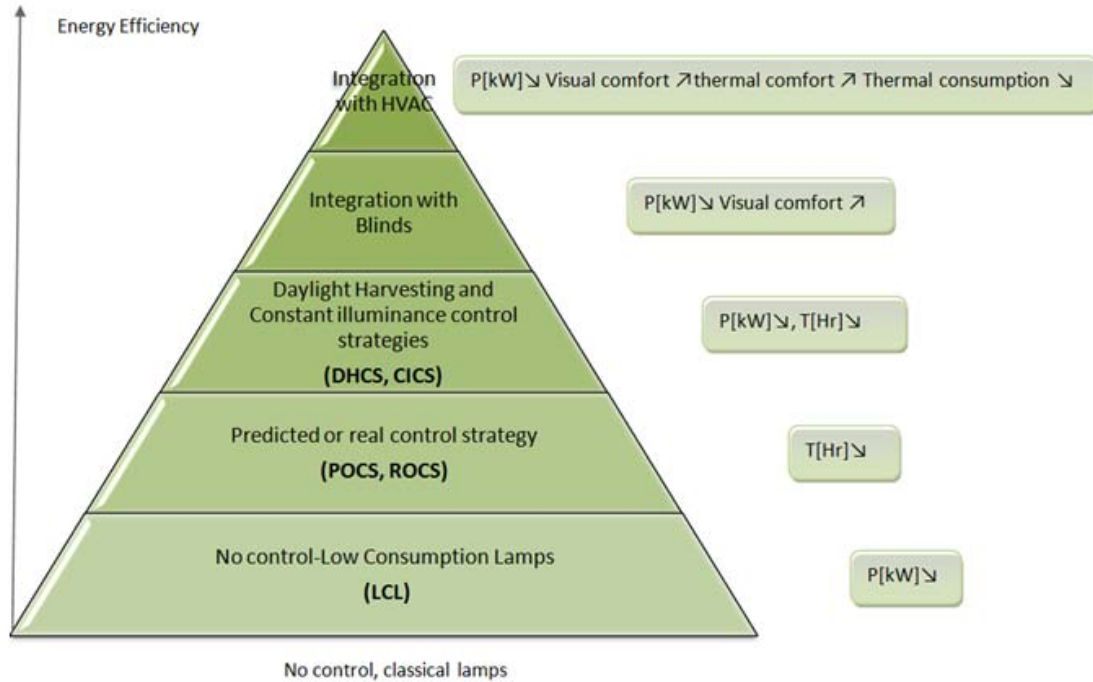


Figure 6-2. Relation between control strategy and energy efficiency.

6.3.2 Predicted occupancy control strategy

The Predicted Occupancy Control Strategy (POCS) is used to reduce the operating hours of the lighting installation. It generates energy savings by turning lighting on and off on a preset daily time schedule. Schedules usually vary on a daily basis according to the building occupancy. By automatically turning off lights at a preset time, the systems assist building operators / facility managers to avoid having the lighting be on during unoccupied hours, mainly at night and at weekends. Different schedules can be programmed for different areas of the building based on the occupant needs.

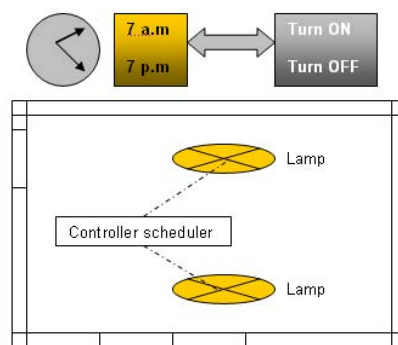


Figure 6-3. Time scheduling control scheme.

The time scheduling control strategy enables switching on or off automatically based on time schedules and occupancy patterns for different zones. Twenty-four hour timers allow the occupants to set certain times for lighting. The timer is set to switch lighting on during occupancy. Measurements have shown that the best energy efficiency solutions are combining the use of a cutoff system with a manual switch on system; potential gains are between 10 and 15% (without

daylighting)(Floyd et al. 1995, Rundquist et al. 1996). Note that the gain may be more than 50% in case of 24 hours lighting (Maniccia et al. 1999, NBI 2003). This strategy is used most widely in applications where building occupancy patterns are predictable and follow daily and weekly schedules like classrooms, meeting rooms and offices.

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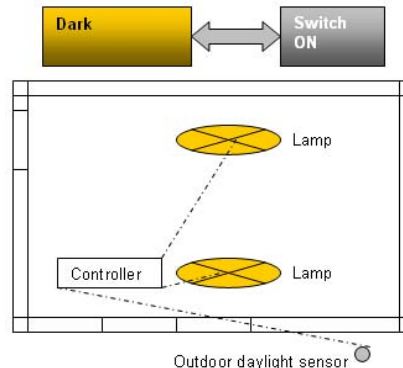


Figure 6-4. Dusk/dawn control scheme.

The *Dusk or Dawn control strategy* is a type of predicted occupancy strategy based on sunrise and sunset which can be calculated for every building location. Light is switched on automatically when it gets dark, and off when there is enough daylight. This control type is not often applied for indoor lighting but is very efficient for atriums with good daylight availability or for glazed corridors linking buildings. This strategy is not necessarily achieved with an outdoor daylight sensor. The on and off hours can be provided by a scheduler.

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6.3.3 Real occupancy control strategy (ROCS)

Real Occupancy Control Strategy limits the operation time of the lighting system based on the occupancy time of a space. In opposition to the predicted occupancy control, it does not operate by a pre-established time schedule. The system detects when the room is occupied and then turns the lights on. If the system does not detect any activity in the room, it considers the room as unoccupied and turns the lights off. To prevent the system from turning the lights off while the space is still occupied, a delay time (ranging typically from 10 to 15 minutes) can be programmed.

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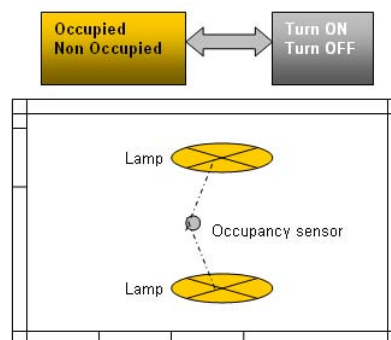


Figure 6-5. Occupancy control scheme.

Real Occupancy Control Strategies are best used in applications where occupancy does not follow a set schedule and is not predictable. Classic applications include private offices, corridors, stairwells, conference rooms, library stack areas, storage rooms and warehouses. The savings potential of real occupancy control varies widely from 20 to 50% (system combination) (Maniccia

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et al. 2000, NBI 2003). It depends on the level of detection, the place of the sensor, the coupling with daylight-harvesting and of course the movement of the occupants.

6.3.4 Constant illuminance control strategy

The Constant Illuminance Control Strategy (CICS) takes into account the ageing of the lighting system in the room. It compensates the initial oversizing of the lighting system introduced by the use of the maintenance factor (MF) at the design stage.

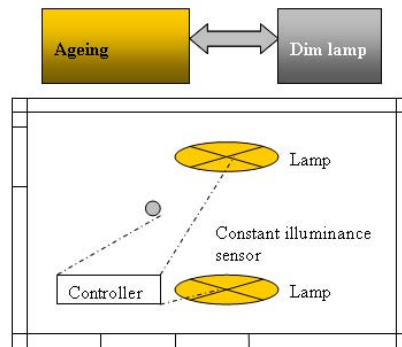


Figure 6-6. Constant illuminance control scheme.

The constant illuminance control strategy uses a photocell to measure the lighting level within a space or determines the predicted depreciation (ageing) of the lighting level. If the light level is too high, the system's controller reduces the lumen output of the light sources. If the light level is too low, the controller increases the lumen output of the light sources. The result is a system that minimizes lighting energy use while maintaining uniform and constant lighting levels.

6.3.5 Daylight harvesting control strategy

The Daylight Harvesting Control Strategy (DHCS) allows facilities to reduce lighting energy consumption by using daylight, supplementing it with artificial lighting as needed to maintain the required lighting level.

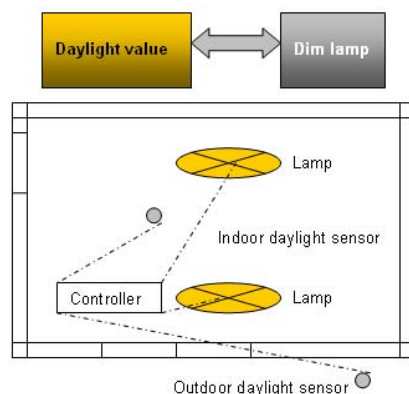


Figure 6-7. Daylighting harvesting control scheme.

The *Daylight harvesting control strategy* uses a photocell to measure the lighting level within a space, on a surface or at a specific point. If the light level is too high, the system's controller reduces the lumen output of the light sources. If the light level is too low, the controller increases the lumen output of the light sources. Sensors are often used in large areas, each controlling a separate group of lights in order to maintain a uniform lighting level throughout the area. The result is a system that

minimizes lighting energy use while maintaining uniform lighting levels. This system can also provide the constant illuminance strategy.

Daylight harvesting systems are generally used in offices and skylights. Typical applications include classrooms, high-rise office buildings and retail facilities. The savings potential varies from 20% (daylight-harvesting alone) to more than 50% (daylight-harvesting plus real occupancy). (NBI2003)

To illustrate the potential gain obtained with these different strategies an office building has been simulated according to the energy calculation method described in French regulation RT2005. Tests have been done for two climatic zones - Paris and Nice - on a 600m² office building. The results are shown in Figure 6-8.

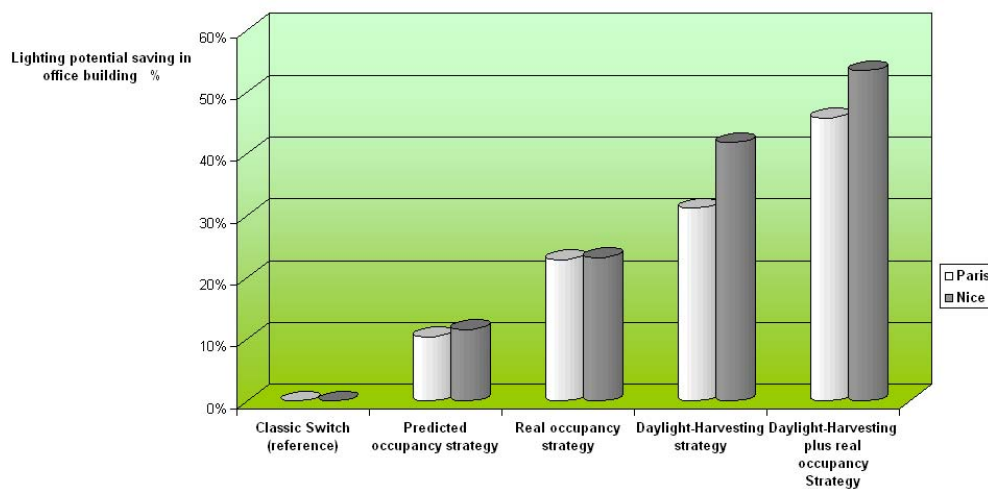


Figure 6-8. Estimation of energy savings according to the French thermal regulation calculation tool "method ThCE".

In office buildings, predicted occupancy control strategy (based on scheduler) allows 10% gain whereas real occupancy (based on presence detector) allows 20% gains. We can notice that Daylight-harvesting impact depends on the climatic zone. So, in office building potential gains vary from 30% (Paris) to 40% (Nice). Coupling of different strategies should result in more energy gains, for instance, daylight harvesting and real occupancy achieves up to 50% gains. These gains are a function of the room and window sizes, building orientation and sensor(s) position(s).

6.3.6 Lighting management system and building management system

All the strategies described above can be applied in almost any building. They can be stand alone systems or part of a fully interoperable lighting management system (LMS). With LMS one can schedule the light operations in any area within the building, or monitor occupancy patterns and adjust lightings schedule as required. The LMS gives facility manager the ability to remotely control building lighting energy consumption. It also enables the facility manager to perform load shedding strategies in case of high electricity demand in the building. The utilization costs is thus reduced as the control strategy has turned off or dimmed some lights or lighting components during peak-use periods.

Moreover, thanks to LMS, building operators will be able to record lighting scenes or predefined scenarios. For instance, a simple push on a button could select a *video projection* scenario which would consist of dimming light level, lowering blinds and setting down the screen.

LMS also give a finest way to control lamps. Building operators will be able to manage lamps in one zone independently. The lighting rows close to the windows (usually less than 4m as best practice) will be controlled with daylight strategy whereas the others will not be. An additional advantage of LMS is their ability to monitor the operation of the lighting systems such as the number of operating hours in a given area, the number of times the lights are switched on. Using this information, maintenance operation like relamping (action to replace a burned out lamp) can be scheduled.

In case of implemented Building Management System (BMS), the management of the lighting system can be combined with heating, ventilation, and air conditioning, security, etc. This type of integrated management system will allow sharing actuators and sensors. Some examples of integration are given below.

6.3.7 Lighting control integration levels

Three levels of integration can be distinguished for the indoor lighting control. These are listed below:

- The first level takes into account the artificial lighting alone.
- The second level takes into account artificial lighting and its control by external information like daylighting, occupancy, ..
- The third level takes into account artificial lighting dealing with artificial lighting plus external interaction with external elements like HVAC systems and blinds.

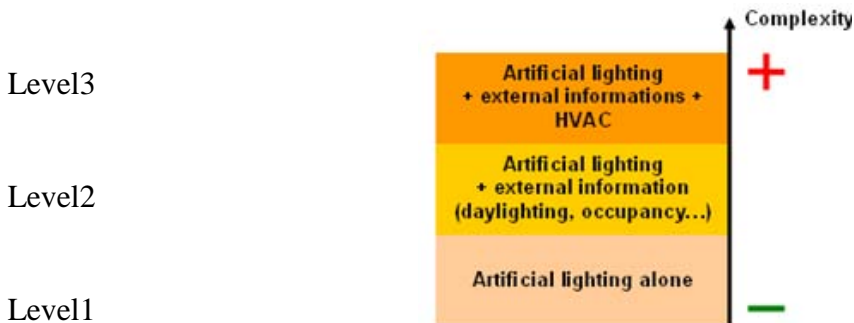


Figure 6-9. Levels of integration strategies.

Level 1 (artificial lighting alone)

In this integration example, the user controls the artificial lighting through a manual switch/dimmer.

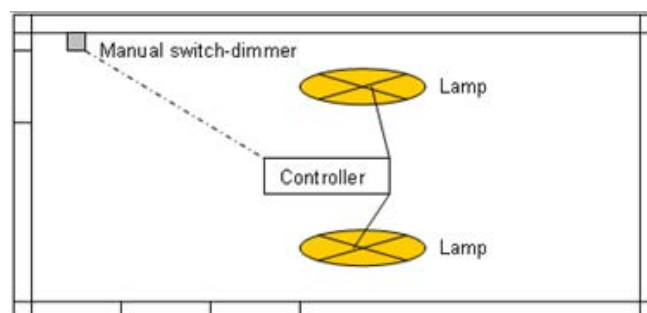


Figure 6-10. Simple strategy.

This allows artificial lighting control according to a manual switch (ON/OFF or dimming). This solution is one of the most used systems in buildings consisting of only a switch for a lamp or a group of lamps.

Level 2 (artificial lighting control based on external information)

In this integration example, an illuminance sensor and an occupancy sensor have been combined to the manual switch-dimmer in order to increase the visual comfort of the occupant. For each sensor, a priority level is set.

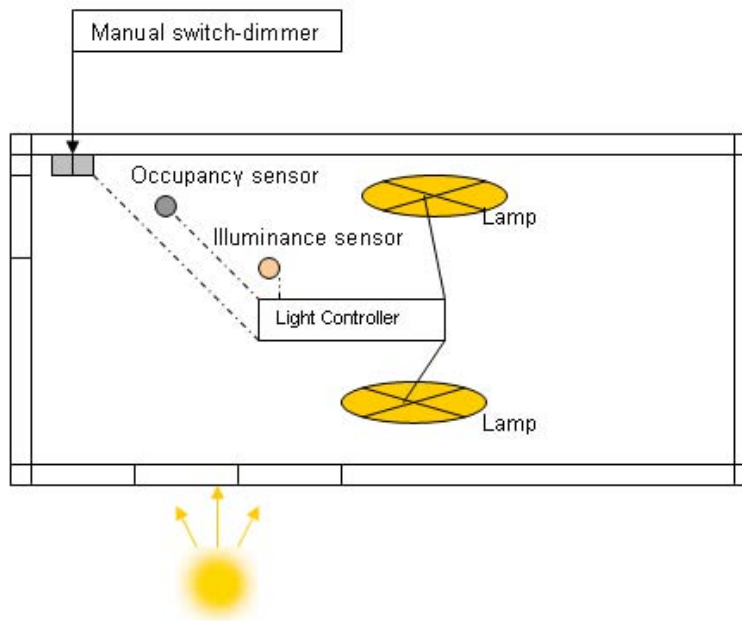


Figure 6-11. Coupling between Artificial lighting, daylighting and real occupancy.

This system allows artificial lighting control according to:

- A manual switch (on/off) or dimming with a high priority level
- An occupancy sensor with an intermediate priority level
- An illuminance sensor (in order to assume a constant light level) with a low priority level

We can notice that the plan becomes rather more complicated when we want to share sensors. The saving potential of this solution is quite the same as daylight harvesting plus occupancy sensor.

Level 3 (artificial lighting and daylight and HVAC system)

In this integration example, there is a full integration of the lighting system with the HVAC systems and the blinds system in order to increase the visual and thermal comfort of the occupant.

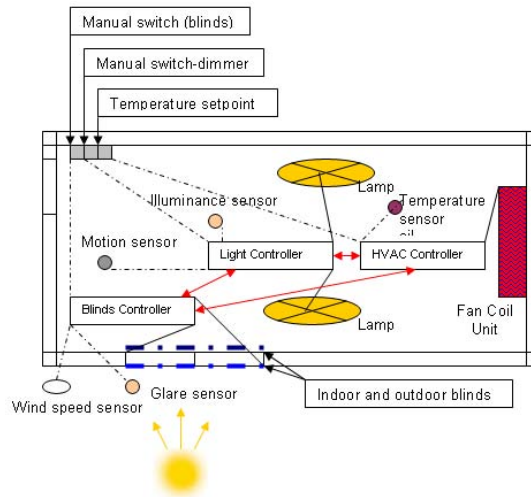


Figure6-12. *Coupling betweenartificiallighting,daylighting andHVAC.*

This system allows control of artificial lighting, daylighting (with blinds) and HVAC. Supplementarysensorsare representedwiththeir own prioritylevel,such as:

- Amanualtemperaturesetpointbuttonwithahigh prioritylevel
- Amanualswitchblindbuttonwithahighpriority level
- Anindoortemperature sensorandwindspeed sensor withanintermediate prioritylevel
- Aglarsensorwithalowprioritylevel

The communication scheme of this third integration level is complicated because of the multiple interactions between the sensors and the controllers (red double-arrow). In this system, the sharing of equipmentsandsensors isnecessary as shown in Figure6-13.

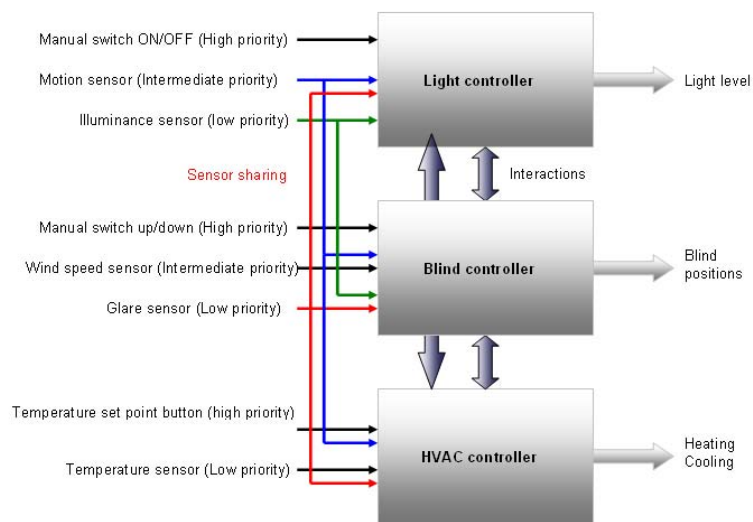


Figure6-13. *Interactionofthesensors onthedifferentcontrol lertypes.*

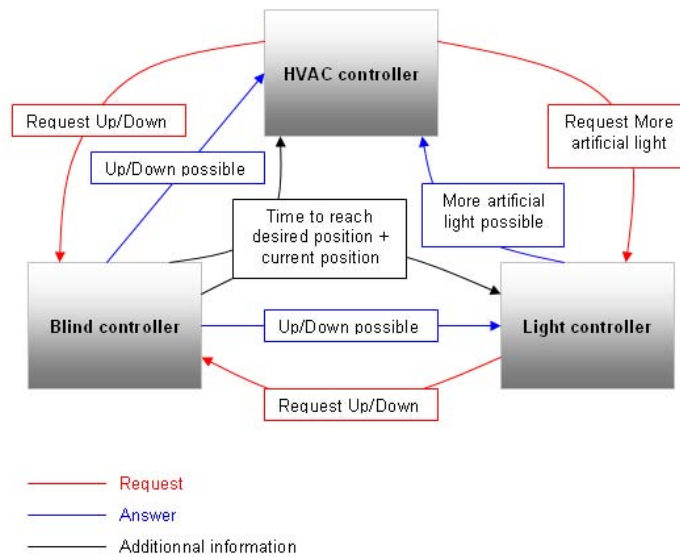


Figure 6-14. Example of interactions between controllers.

Figure 6-14 represents the possible interactions between the different controllers. Contradictory situations may lead to problems. A blind-up request from the HVAC controller and a blind-down request from the light controller have to be solved by an arbitrations system to adapt the best solution in function of predefined priorities. If correctly implemented, the energy saving potential of this 2 integration level is more significant than a level 2 integration solution with daylight harvesting alone.

It is important to note that this kind of integration is not designed for buildings which consume large amount of energy (other cheaper solutions are, most likely, more relevant and less expensive). Nevertheless, it seems to be a real challenge to reach the requirements of new building generations (Green building and in positive energy building).

Sharing of equipment and sensor

The equipment sharing is an important issue to achieve a proper integration of the control strategies (level 1 to 3). In order to maintain a good indoor climate, the control system can generally act on the applications as shown in Table 6-1.

Table 6-1. Equipments and sensors involved in the control strategies – impact classification.

Equipment	Sensor			
	Temperature sensor	Indoor illuminance sensor	Outdoor illuminance sensor	Occupancy sensor
Solar protection system	Visual comfort SA Thermal comfort MA	Visual comfort MA Thermal comfort SA	Visual comfort MA Thermal comfort SA	-
Artificial lighting system	-	Visual comfort MA	Visual comfort MA	Visual comfort MA Thermal comfort MA
Heating system	Thermal comfort MA	-	-	Thermal comfort MA
Cooling system	Thermal comfort MA	-	-	Thermal comfort MA

MA implies a main actor, SA implies a secondary or minor actor.

6.3.8 Lighting control strategy analysis

Table 6-2. Lighting control strategy analysis 1.

Strategy	Predicted occupancy	Real occupancy	Constant illuminance	Daylight harvesting
Main Advantages	-Low costs -Easy to install and use -10 to 20% gain	-Relatively low costs -High rate of energy saving for space with intermittent occupation for example when people regularly go through (20 to 50% ¹).	-Constant light level considering aging. -5 to 15% gain	-Constant light level. -Possibility to couple with Blind and HVAC -20 to 50% gain.
Main Disadvantages	-Setting of clock has to be changed if operating hours change.	-Ultrasonic sensor can be fooled by HVAC systems (vibration of air flow) -Low precision sensors will cause uncomf for the occupant.	-Sometimes high costs. -Not easy to configure.	-Sometimes high costs. -Not easy to configure.
Main Usages	-Classrooms, -Meeting rooms -Offices (open space). -Store, supermarket -Museum	-Corridors, stairwells -Library stack areas, -Storage rooms -Warehouses -Toilet.	-Offices (open space), -Classrooms, -High-rise office buildings -Retail facilities.	-Offices (open space), -Classrooms, -High-rise office buildings -Retail facilities.
Basic Components	-Scheduler -Time clock -Switch -Dimmer	-Occupancy sensor (Infrared or/and ultrasonic) -Switch -Dimmer	-Photosensor -Dimmer	-Photosensor -Dimmer -Multi-switch

Table 6-3. Lighting control strategy analysis 2.

Strategy	Level 1 : Artificial lighting alone	Level 2 : Artificial lighting control based on external information	Level 3 : Artificial lighting and daylight, and HVAC system
Complexity	-Low	-Intermediate	-High
Potential of energy saving	-Intermediate	-High	-High
Control strategies involved	-Predicted occupancy -Real occupancy	-Predicted occupancy -Real occupancy -Constant illuminance -Daylight harvesting (main)	-Predicted occupancy -Real occupancy -Constant illuminance -Daylight harvesting (main)
LMS	-No LMS or BMS needed	-LMS -BMS (optional)	-BMS needed

¹ 60% is considered for Real occupancy plus Daylight harvesting

6.4 Lighting control architecture

The lighting control architecture supports the implementation of the defined strategies. It can be organized in four levels:

- Lighting service
- Lighting plant
- Lighting zone
- Lighting device

The lighting service level deals with the overall lighting management system, it could also be called the lighting backbone. Lighting *plant* as an analogy to HVAC central plant deals with the control of central technical areas. It often appears at each building floor. Lighting zone deals with the different interactions in a zone (zone = a room or a set of rooms). Finally, lighting device is the terminal device, which controls the visual comfort of a specific area.

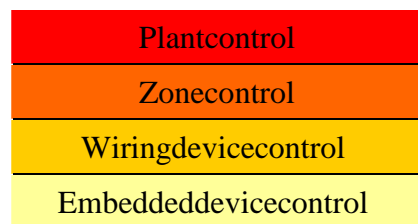


Figure 6-15. Level structure of the lighting control architecture.

These levels have been established thanks to a study of the various lighting systems. These systems are described with generic components listed in Figure 6-16.



Figure 6-16. Lighting components.

The key point of lighting architecture definition is the position of the actuator. We can consider any lighting fixture as one or a mix of these architectures.

6.4.1 Lighting control levels

Plant Control Architecture

The Plant Control Architecture (PCA) is an architecture where actuators and controllers are placed in one panel board at the lighting plant level. This type of architecture is usually used for on/off control in buildings like industrial buildings, supermarket. It could also be used for specific zones, for example, a complete storey in an office building, or even for individual corridors or staircases. This architecture is simple and robust and thus widely used.

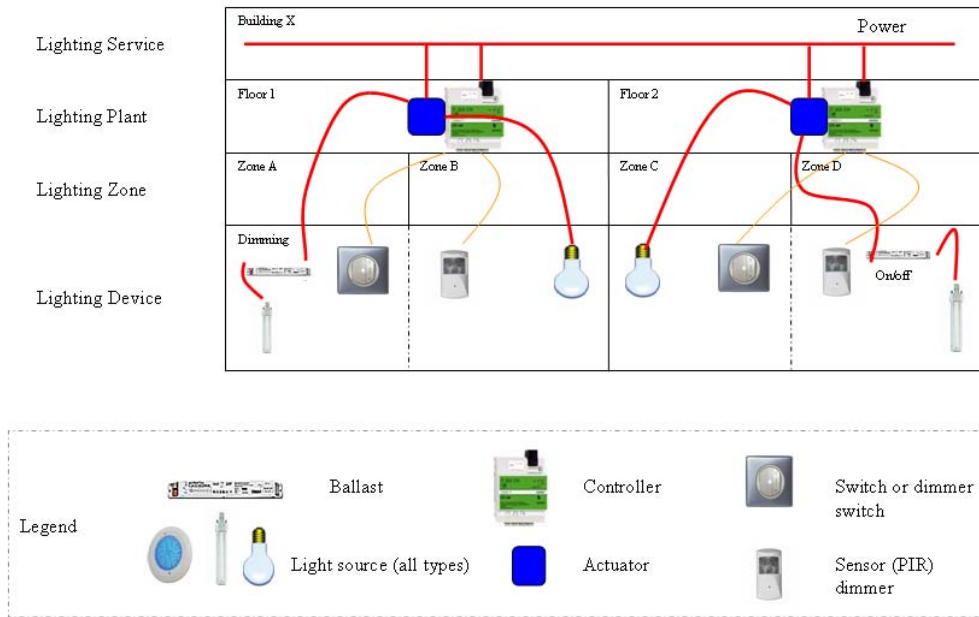


Figure6-17. Plantcontrol.

ZoneControlArchitecture

The Zone Control Architecture (ZCA) is an architecture where the actuator and controller act on a defined area of the building floor. This architecture is widely used for offices with open spaces, schools and hospitals because it enables easy change of the control strategy.

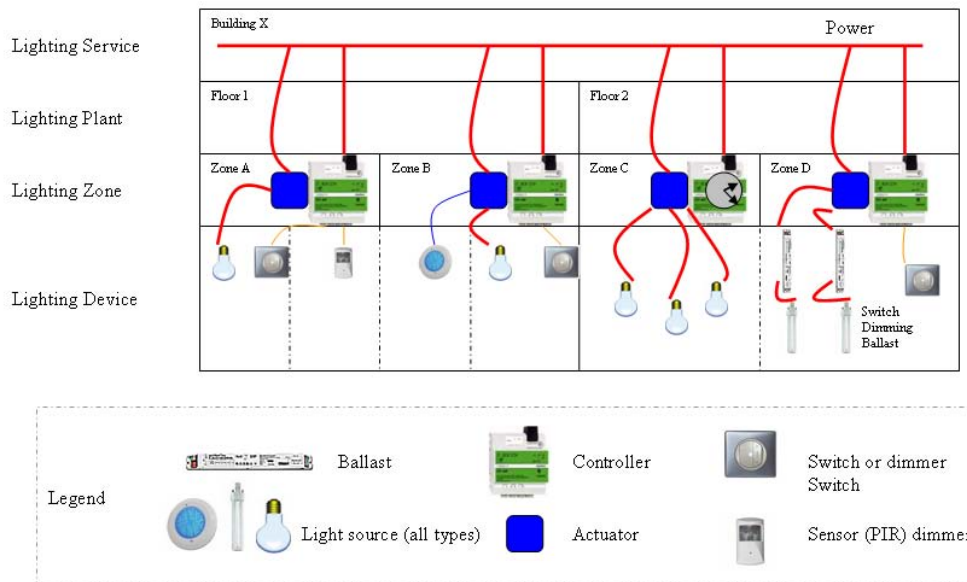


Figure6-18. Zonecontrol.

Wiring Device Control Architecture

In the Wiring Device Control Architecture (WDCA), the actuators are located at the wiring device level. It can be a wall, ceiling or floor wire. The actuator is usually embedded with the sensors. This kind of architecture is most popular for residential buildings, small offices and hotels because commands are distributed in the room to allow the occupant to perform fine control. This architecture is commonly used for simple control. Nevertheless, there exists more integrated dimming applications. Moreover, WDCA can easily be combined with plant control architecture.

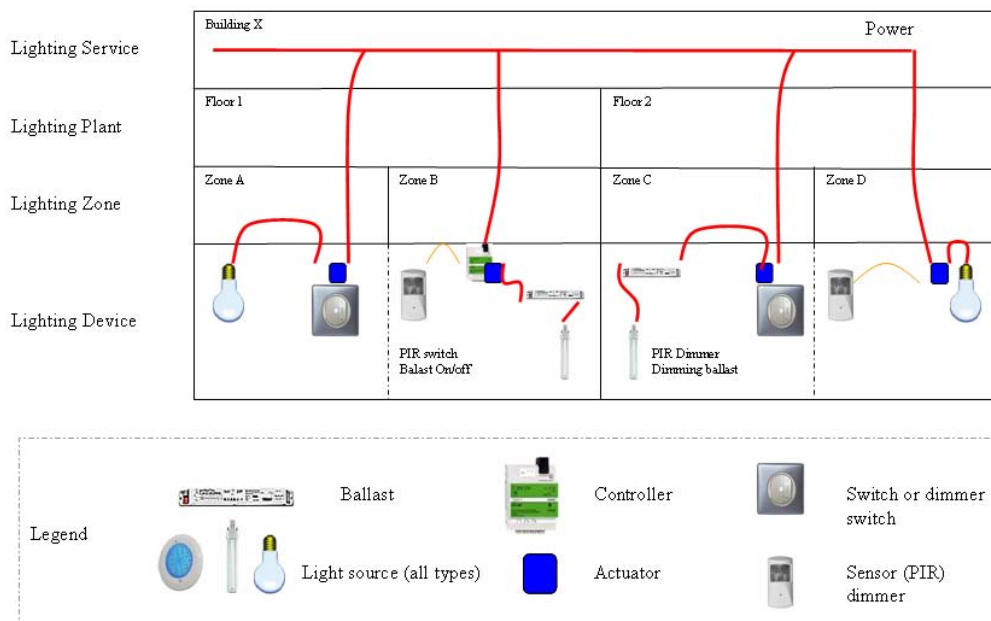


Figure 6-19. Wiring device control.

Embedded Fixture Control Architecture

The Embedded Fixture Control Architecture (EFCA) is an architecture where actuators and controllers are repositioned in the lighting device, usually in the ballast. Most of the EFCA systems are connecting all control gears through a BUS system. They provide individual or mutual control thanks to controllers that are commonly placed at the floor panel board, in the false ceiling or in a device. On one side the binding between device is physical through, for example, wiring. On the other side, the binding is logical, through for instance, links between the push buttons, sensors (PIR) and the actuators are set by the controller. The logic behind the binding and the programming makes configuring the system really flexible and versatile. This kind of architecture uses proprietary or open network protocols² like KNX, LON, Zwave and of course the well-known DALI.

In Figure 6-20 protocols are represented with a blue line. Some BUS system can directly provide power to the lamp (like LED), they are called Power Over BUS.

²See 1.4.4 Networks

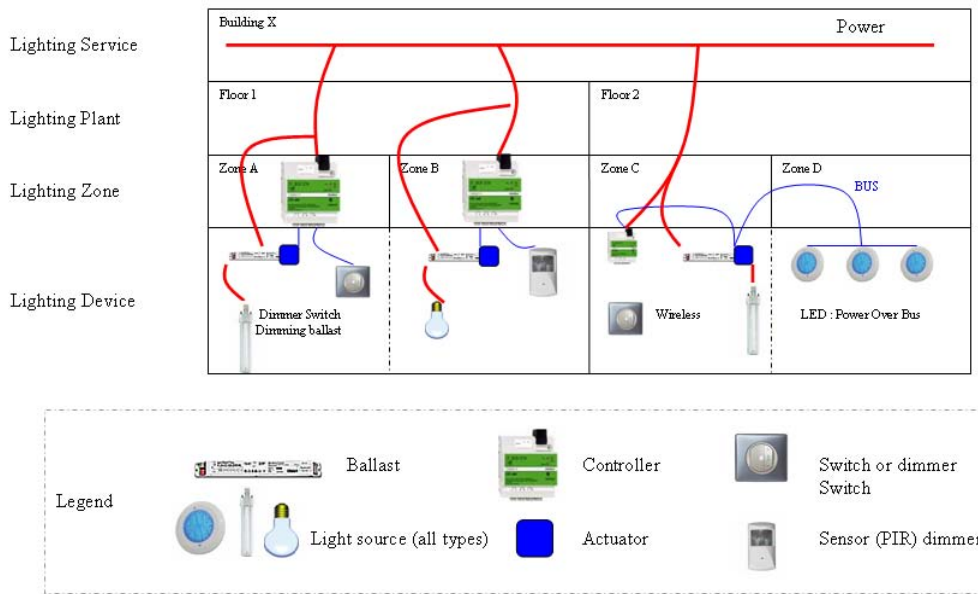


Figure6-20. EmbeddedDevicecontrol.

ArchitectureSWOTAnalysis

Table6-4 presents the SWOT Analysis of the lighting control architecture. (The SWOT analysis is a strategic planning method used to evaluate the Strengths, Weaknesses, Opportunities, and Threats of elements or strategies).

Table6-4. SWOT analysis of lighting control architectures.

Architecture	Costs	Flexibility	Easy to install	Mixing with BMS	Visual performance and comfort
Plant Control	Intermediate	Intermediate	Quite easy	Possible	Low
Zone Control	Intermediate	Intermediate	Easy	Quite easy	Intermediate
Wiring Device Control	Low	Low	Very easy	Difficult	Intermediate
Embedded Fixture Control	High	High	No expert is needed	Easy	High

6.4.2 Lighting control components

Controllers

A lighting controller is an electronic device used in building to control the operation of one or multiple light sources at once. Majority of lighting controllers can control dimmers which, in turn, control the intensity of the lights. Other types of controllers can also control lighting, according to specific scenarios. Lighting controllers communicate with the dimmers and other devices in the lighting system via an electronic control protocol (DALI, DMX, ZigBee, KNX, etc.). The most common protocol used for lighting today is Digital Addressable Lighting Interface which is commonly known as DALI. Controllers vary in size and complexity depending on the types of buildings (from small residential buildings to big tertiary one). For most of the time the purpose of lighting controllers is the same: to combine the control of the lights into an organized, easy-to-use system, and to reduce lighting energy consumption.



Figure 6-21. Lighting controllers.

Sensors

A sensor is a device that measures or detects a real-world condition, such as motion or light level and converts the condition into an analog or digital representation. The sensor specifications include performance factors (range, accuracy, repeatability, sensitivity, drift, linearity and response time) and, practical and economical considerations (costs, maintenance, compatibility with other component and standards, environment and sensitivity to noise).

Illuminance sensor

Illuminance sensors indicate the illuminance level in the sensor detection area. They are used to measure indoor illuminance (e.g. on a working plane) and outdoor illuminance (e.g. on the roof of a building). Illuminance sensors are mostly used to switch or to dim luminaires. Some basic illuminance sensors enable day/night detection. They can also be used in integrated control strategies, particularly if solar protections are involved.

Illuminance sensor commands the lighting control system to dim or to switch on/off according to the daylight level. Illuminance sensors have to be placed so that they measure the light levels which are representative of the space. It is useful to mark the illuminance sensor position in the lighting control panel so that building operators can find them in the future.



Figure 6-22. Example of indoor illuminance sensor.

Outdoor illuminance sensors measure the outdoor illuminance level. They can be combined with the lighting controls so that indoor luminaires can be controlled by dimming or switching.

Table 6-5. Illuminance sensor–Input/Output and applications.

Component	Information Inputs/Outputs	Applications in buildings
Indoor illuminance sensor	Input: Illuminance on the workplane Output: Analogue or/and digital signal to controller	Visual comfort Energy consumption
Outdoor illuminance sensor	Input: Outdoor illuminance Output: Analogue or/and digital signal to controller	Energy consumption.

Particular case of day/night sensors

This device enables the comparison of outdoor illuminance with a predefined threshold in order to trigger actions on outdoor lighting (street lighting) or closing of shutters. They were developed primarily for street lighting and are generally very robust.

**Figure 6-23.** Example of day/night sensor.**Table 6-6.** Illuminance sensor–Input/Output and applications.

Component	Information Inputs/Outputs	Applications in buildings
Day/night sensor	Input: Outdoor illuminance Output: Analogue or/and digital binary signal (on-off)	Visual comfort (outdoor lighting, shutters, etc.) Energy consumption (blinds, heating, etc.)

Presence sensors

Presence sensors detect the presence of occupants by detecting their movements. The most common sensors used in the building sector are passive infrared (PIR) sensors that react to variations of infrared radiations due to movement of persons.

Table 6-7. Presence sensor–Input/Output and applications.

Component	Information Inputs/Outputs	Applications in buildings
PIR sensor	Input: Movement Output: Analogue or/and digital binary signal (occupied/not occupied)	Security Visual comfort Energy consumption

Passive InfraRed (PIR) sensor

These sensors are usually equipped with Fresnel lenses that define the zone of detection. Two kinds of PIR are usually distinguished: the movement sensor and the occupancy sensor. They have the same working principle but differ on the number of scanned areas.

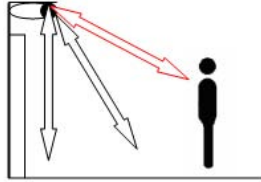


Figure 6-24. PIR sensor.



Figure 6-25. Multi-function PIR sensor.

Multi-function PIR sensor can integrate up to 4 functions listed below:

- Occupancy detection
- Indoor illuminance sensor (level of illuminance for the switch on of the lamps)
- Infra-red sensor
- A timer (turn the lamps off after a certain delay)

The PIR sensor has some inconveniences, such as:

- Some human activities are achieved without any movement, e.g. watching television, reading book, sleep, etc.
- They are position sensitive and may be irrelevant if looking to a dead zone

Active InfraRed (AIR) sensor

Active InfraRed devices use infrared technology consisting of an infrared diode which constantly or episodically sends infrared rays into the controlled area. A receiver monitors the reflected wave modification of its properties (wavelength or amplitude) indicates a change occurred in the detection zone.

consisting of an infrared diode which constantly or episodically sends infrared rays into the controlled area. A receiver monitors the reflected wave modification of its properties (wavelength or amplitude) indicates a change occurred in the detection zone.

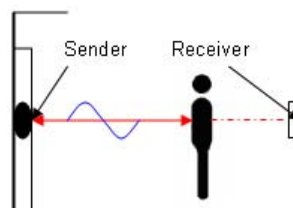


Figure 6-26. Infrared sensor.

Ultrasonic Presence (UP) sensor

Ultrasonic devices send out inaudible sound waves. At the same time, a device is scanning for sound waves which are reflected at a specific rate. If a change in the reflected wave is detected, it indicates that something or someone has moved in the detection zone.

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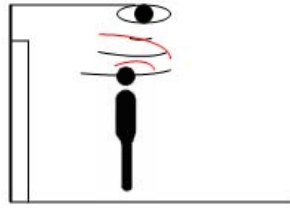


Figure 6-27. Ultrasonic sensor.

There are products combining the two technologies, for example, the PIR and the ultrasonic presence detections. They are called Passive Dual Technology sensors. They see and hear the occupants so that presence is detected even if there is no movement.

Windspeed sensors

Cup or propeller anemometers are adapted to wind and air flows in duct measurements. They are the most common sensors for wind speed in systems integrating this data for management of external shadings. They are useful for the control of blinds.

Table 6-8. Windspeed sensor—Input/Output and applications.

Component	Information Inputs/Outputs	Applications in buildings
Windspeed sensor	Input: windspeed Output: Analogue or/and digital signal (wind speed)	Security Visual comfort Energy consumption

CO₂ sensors

CO₂ sensors can in certain cases where advanced ventilation control strategies are applied be used as presence detectors. Particularly when sharing sensors among applications is being considered.

Table 6-9. Windspeed sensor—Input/Output and applications.

Component	Information Inputs/Outputs	Applications in buildings
CO ₂ sensor	Input: CO ₂ concentration Output: Analogue or/and digital signal (CO ₂ concentration)	Thermal comfort Visual comfort Energy consumption

Sensor Position

Positioning the sensors cannot be neglected. For example, to get a relevant indication of the illuminance level on the work plane, the illuminance sensor should be installed on the work plane. For obvious practical reasons, sensors are never actually placed on the work plane. Similarly, to have a proper evaluation of the thermal comfort level, the temperature and humidity level should be measured at the centre of the room. This is hardly possible in practice in an occupied space. It is highly important for movement sensors to have a good view of the space so that they correctly can detect the movement in the area.

Actuators

Actuators are used for the automation in all kinds of technical process plants. They are used in wastewater treatment plants, power plants and even in refineries. This is where they play a major part in automating process control. Depending on their type of supply, the actuators may be classified as pneumatic, hydraulic or electric actuators. They measure or detect real-world conditions, such as displacement or light level and converts the condition into an analog or digital representation.

Switch

The switch is the most common interface between the lighting system and the occupant. The switch can integrate several modes:

- On-off switch
- Timer for switch-off



Figure 6-28. Manual switch.

Switching hardware are relatively simple and generally very cost effective. Switching is appropriated in singly occupied spaces where light level changes are generated by the behaviour of that occupant (when the occupant switches the lights on or when the lights are switched on by an occupancy sensor). For multiple-occupant spaces, automatic on/off switching must be used with care. An automatic control that causes unexpected changes in light level, while a space is occupied, may confuse or annoy occupants.

Switching systems that automatically change lights according to daylight, should only be used in spaces where the daylight levels are very high during most of the day. In this case lights will be off most of the day. Switching may also be acceptable when occupants are transient or performing non-critical tasks. Switching systems are often appropriate for atria, corridors, entryways, warehouses and transit centres, especially when there is abundant daylight.

Dimmer

Dimming systems adapt the light levels gradually, and thus reduce power and light output gradually over a specified range. Dimming can generate important energy savings. However, dimming hardware/devices are more expensive than switching devices. The dimming can be achieved through two modes:

- Continuous dimming
- Step by step dimming



Figure 6-29. Dimmer.

Continuous dimming is a continuous adaptation of the luminous flux of the light source(s) in function of external information. Most of the time, this kind of dimming is achieved through a DC control command on the ballast of the luminaire (discharge lamp) or through the transformer (halogen lamp). Some manufacturers have adopted a standard analogue 0-10 V dimming protocol that allows ballasts from different manufacturers to be used with compatible systems.

Step by step dimming is a way to control the light output of the luminaires based on a limited number of configurations. The rated dimming levels are based on information generated by the controller, received by the actuator and transmitted to the light source. The number of dimming steps is defined by the protocol used. DALI-based dimming system is an example of this kind of step by step dimming (256 dimmed levels). Switching systems perform very well in climates with stable sky conditions, such as south of France, while dimming systems is predisposed to save more energy in climates with variable sky conditions, such as Brussels.

Wireless sensors and actuators

Wireless sensors (Presence sensor, illuminance sensor, etc.) and actuators (dimmers, switches, etc.) are based on old existing concepts what their intrinsic functionalities concern. It is the way the control is achieved that makes them now attractive: wireless. Their main advantage is their flexibility (no need for cabling). Thus, both installation and operational costs can be reduced significantly. That is why they are used more and more in refurbishing and open space area.

Wireless sensor networks in commercial and industrial buildings are exposed to an increasing number of interference sources, like WiFi nodes, microwaves, Bluetooth devices, RFID, and other wireless sensor networks. Most wireless sensor networks perform well in a *clean* RF environment after initial installation. The challenge is to maintain good performance when there is another deployment of supplementary RF source.

Other components

The building shell can be integrated in several types of active or passive components that impact directly on heat/cool energy or illuminance level. These components can be placed in roof or in facade. See IEA task 31 and IEA task 21 on daylighting for more details. The visual comfort may be influenced by the daylight availability. We can identify a large list of components influencing the daylighting of the buildings such as the dynamic glazing systems or the blinds, louvres and shutters family.

Dynamic glazing systems

Electrochromic, gazochromic and crystal-liquid glazing (EC, GC and CL) are color changing glazing (through voltage control). These windows belong to a new generation of technologies called switchable glazing or smart windows. Switchable glazing can change the transmittance, transparency, or shading of windows in reaction to an environmental signal such as sunlight, temperature or an electrical control. Smart windows alter from transparent to tint by applying an electrical current. Potential uses for these technologies include daylighting control, glare control, and sky lights. By automatically controlling the amount of light and solar energy that can pass through the window, smart windows can help save energy.

Blinds, louvres and shutters family

Generally, louvres and shutters are opaque, rigid, operable blades or panels with manual or automatic controls such as clocks, timers, illuminance sensor or thermostats. Flexible and translucent designs are also available. Louvres reduce heat gain and can transmit, disperse, reflect or reduce daylight. Automatic blinds coupled with blind controllers and combined with lighting control can significantly reduce the need for electric lighting during the day.

Networks

The evolution of building automation and direct digital control in the 1980's has favoured the development of communication technologies in buildings. Today building automation systems offer two main possibilities to integrate the control of different equipment/applications in a building, namely:

a. Proprietary systems

b. Open systems

- Standard system (which comes from a standard)
- De facto standard (which comes from industry best practice)

A *proprietary system* is a closed system that is developed by a single manufacturer/contractor. The manufacturer holds the knowledge underlying the development of the system. In such systems, the initial costs might be relatively low and easy to set up, but the building owner is locked into products of a single manufacturer and cannot take advantage of innovative technologies easily.

An *open system* is one where standards are developed, published and maintained by an independent recognised organisation body (CEN, ISO, ASHRAE/ANSI, etc.) or an industrial alliance (de facto standard). Any change to the system requires the comments of users, industry, professionals before being approved by the standards/organisation or the alliance. Open communication protocols are now becoming used for the integration of equipment from different manufacturers. This offers the following benefits:

- Media sharing. In this system, different products from different manufacturers run on the same communication cables
- Vendor independence. This applies for initial purchase of different equipment and/or system extension

Standardization of protocols

The CEN TC247 WG4 has been working on standardisation of data transmission methods between products and systems for HVAC applications. This working group has divided the communication within a building automation system into three types of communication requirements:

- The Management net. It is used for workstation to workstation communication
- The automation or control net. It is used for plant controllers and workstations
- The field net. Used for terminal unit controllers, sensor devices, drives etc.

The work of CENTC247 is to enhance the implementation of Building Automation System (BAS) by supporting a number of standards. To bring down cost, the standardization work promotes open systems architecture.

Table 6-10 gives a list of communication protocols and the media that are required:

Table 6-10. Communication protocols and media. (Adapted from: BCG group-UK)

Level	Protocol	Transmission Media
Management	BACnet (ISO14684-5)	Ethernet, PSTN/dialup modem, IP, MS/TP
	WorldFIP (EN50170)	Twisted Pair
Automation	BACnet (ISO14684-5)	Ethernet, LONtalk, PSTN/dialup modem
	KNX (ISO14543)	Ethernet
	LONtalk (EN14908)	Twisted pair, RF, CPL, IP
Field	KNX (ISO14543)	Twisted pair, Main signalling
	LONtalk (EN14908)	Twisted pair, RF, CPL, IP

Some commonly used open standards have not been recognised by CENTC247, but are in use, for example:

- MODBUS which is often used to attach HVAC plant modules such as a chiller to a BAS.
- IT standards such as Microsoft COM, DCOM or internet standards (TCP/IP, HTTP, etc.) which is used at the management level.

Proprietary systems and protocols

ZWAVE (Will become a de facto standard)



Z-Wave is a new technology in wireless remote control developed by Zensys (<http://www.zen-sys.com>), from Denmark. Z-Wave is a next-generation wireless ecosystem that lets all home electronics talk to each other, and to the customer, via remote control. It uses simple, reliable, low-power radio waves that easily travel through walls, floors and cabinets. Z-wave uses a sharp Mesh network

topology and has no master node. Therefore, a Z-wave network can span much further than the radio range of a single unit.

ENOCEAN



The EnOcean company (EnOcean 2007) has developed a technology that is based on the efficient exploitation of slightest changes in the environmental energy using the principles of energy harvesting. In order to transform such energy fluctuations into usable electrical energy, electromagnetic, piezoelectric, solar cells, thermocouples, and other energy converters are used.

The products (such as sensors and radio switches) from EnOcean are batteryless and were engineered to operate without maintenance. The most pervasive example of a product stemming from the proprietary RF protocol is the battery-free wireless light switch. This product is marketed with the argument that it requires less time and wire to install because no wire is required between the switch and the light fixture. They also avoid the need to run switched circuits as the actual power switching is performed locally at the load itself. The above list is not exhaustive. In fact there are many other proprietary protocols for Home and building automation (and especially

for lighting) such as system from Creston, Legrand, Wavenis, Lutron, Delta Dore, Schneider electric, Insteon and soon.

Open systems and protocols (*standard system and de facto standard*)

BACnet



BACnet (<http://www.bacnet.org/>) stands for The Building Automation and Control network. It was developed by ASHRAE and is now published as an ASHRAE/ANSI standard, a CEN standard and an ISO standard. BACnet is a communications protocol for building automation and control networks. It is equally suitable for both the automation and management levels, especially for HVAC, lighting control and fire alarm equipment. It is recognized as an ANSI and CEN standard as well as ISO standard 16484-5. The protocol is based on four layers of the OSI model.

LonWorks



LonWorks (<http://www.echelon.com/>) was developed by Echelon in the USA. It is a general purpose network using the LonWorks protocol and the Neuron chip. It is most suitable for device-level integration and widely used in buildings on twisted pair cable using a transceiver known as FTT-10. The use of Standard Network Variable Types (SNVTs, pronounced *snivets*) contributes to the interoperability of LonWorks® products from different manufacturers.

MODBUS (De facto standard)



MODBUS (<http://www.modbus.org>) designed by Gould Modicon Company is not an official standard and is supported by most Programmable Logic Controllers (PLC). It relies on a Master/Slave serial protocol. Modbus is considered to be very simple and easy to implement and use, and has been adopted not only by the industrial manufacturing milieu but also by many manufacturers of building equipments. Modbus has become extremely popular for the reason that it is free, inexpensive to implement both in hardware and software. It is however limited to simple data exchange and is not used for more sophisticated requirements.

KONNEX



Konnex (<http://www.knx.org>) results from the formal merger of the 3 leading systems for Home and Building automation (BatiBUS, EIB and EHS) into the specification of the new Konnex Association. The common specification of the KNX system provides, besides powerful runtime characteristics, an enhanced *toolkit* of services and mechanisms for network management. On the Konnex device network, all the devices come to life to form distributed applications in the true sense of the word. Even on the level of the applications themselves, tight interaction is possible, wherever there is a need or benefit. All march to the beat of powerful interworking models with standardised data-point types and *Functional Block* objects, modelling logical device channels.

X10 (De facto standard)



X10 (<http://www.x10.com>) is an industry standard for communication among devices used for home automation. It primarily uses power line wiring for signalling and control, yet now a radio-based transport is also defined. X10 was developed in 1975 in order to allow remote control of home devices and appliances. It was the first domestic automation technology and remains the most widely available. X10 was the first home automation technology and remains the most widely available. However, now it seems obsolete. Data rates are very low (around 20 bit/s). To summarise, with its tiny command set and poor reliability X10 protocol is simply too limiting for today's home environment control.

ZIGBEE



The ZigBee (<http://www.zigbee.org>) Specification describes the infrastructure and services available to applications operating on the ZigBee platform (ZigBee, 2004). ZigBee is a published specification set of high level communication protocols designed to use small, low power digital radios based on the IEEE 802.15.4 standard for wireless personal area networks (WPANs). ZigBee's current focus is to define a general-purpose, inexpensive self-organizing mesh network that can be shared by industrial controls, medical devices, smoke and intruder alarms, building-automation and home automation. The technology is designed to be simpler and cheaper than other WPANs such as Bluetooth. The most capable ZigBee node type is said to require only about 10% of the software of a typical Bluetooth or Wireless Internet node, while the simplest nodes are about 2%. There are currently discussions between the ZigBee commission and BACnet commission to set up a bridge between the *wired* and *wireless* open protocols.

Communications systems and protocols specific to lighting systems

DALI



DALI (DALIa, DALIb) is a digital communication protocol designed specifically for lighting systems. DALI is effective for scene selection and for getting feedback regarding faulty light sources. This makes it very useful to use together with building automation systems where remote supervision and service reports are required. DALI was originally introduced in 1999 by ballast manufacturers who wanted to introduce a standardized digital ballast control protocol. It is designed to be very easy to install and to (re)configure. All actuators, controllers and sensors are connected to one single control cable. A DALI-system consists of load interfaces (electronic ballasts), control panels (push buttons), sensors (occupancy sensor) and control interfaces (controller) and gateways (1-10V converter). Example of possible DALI operations:

- Individual, group or broadcast messaging
- Request status data from an individual luminaire
- Assigning of addresses to luminaires using a discovery algorithm which makes the need for hard addressing obsolete
- Selection of lighting scenes

It is important to note that DALI is not a new Building Management System (BMS), DALI is only available for lighting. However, it can be an easy add to existing BMS like BACnet, Lonworks or KNX thanks to gateway.

Building Management System (BMS), DALI is only add to existing BMS like BACnet, Lonworks or

DMX512/1990

DMX 512/1990 is a Digital Multiplex Data Transmission standard for Dimmers and Controllers operating in simplex mode (unidirectional). It can control up to 512 channels. Data is transmitted in packets. Each packet updates all the devices installed. Each packet consists of up to 513 frames. After a start frame (consisting of zeros), up to 512 frames can follow containing the data for each device connected. The devices are not directly addressed. The information sent to them is defined by the frame position within the packet.

Conclusions

The main issue for the success of integrated solutions in buildings is to define the appropriate communication protocol and the media for the information transfer. It is most likely that BACnet, Konnex and LonWorks will be the major actors in this field as there will be integrating HVAC, lighting, fire safety, security functions. However, DALI and wireless low power technologies have a certain future regarding lighting control. On the one hand, DALI has been established worldwide as the standard for digital lighting control. It is an open non-proprietary standard that makes genuine freely addressable lighting control a reality (individual, group, and all together). DALI seems to be much easier to install, extremely versatile and much more cost-effective than any lighting control systems already on the market, despite its greater functionality.

On the other hand, wireless technologies (low consumption or battery less) may present a new solution to bring the installed cost down and to ensure energy efficiency. Over the past 10 years many new RF solutions have been developed into our every-day life. It is expected that soon a reliable, robust, easy-to-install and secure wireless network technology for connecting devices in buildings will gain market acceptance and substantial shares of new and retrofit installations soon. ZigBee and Zwave are heading in this direction. Nevertheless they are still not well defined on a semantic point of view. Moreover it doesn't exist efficient tools to design, install, commission and troubleshoot this kind of technologies.

Internet Protocols (IP)

IP is said to be among the most important technologies for our industry. IP networks are deployed in the Internet, in extranets, and in intranets. Numerous different media are concerned, for example fiber optics, cables and wireless. IP is a powerful vehicle for enabling communication but it does not specify the content of messages in such detail that is needed e.g. to make two systems exchange a temperature value.

Today, IP serves as the intermediary network technology. It is principally found in building backbones and access networks to the field-area network. Technologies that provide mechanisms to be transported over IP include LonWorks (EIA-852), BACnet/IP and KNX/IP.

Table 6-11. Standard and nonstandard networks for building automation Communication protocols and media.

Network protocol	Media/Option	Standard	Applications for lighting	Sector of application	Main Advantages
BACnet	IP, Ethernet, PTP, ZigBee, MS/TP, LonTalk, Arcnet	Yes ISO 16484-5	***	Building automation	Norm Many networking options
LonWorks	IR, PLC, TP, RF, IP	Yes EN 14908	***	Building and home automation	Norm
KNX	IR, PLC, TP, RF, IP	Yes ISO 14543	****	LBandHA	Norm
PROFIBUS	IP, TP	Not a norm but an industrial standard	*	Industrial	Robustness
MODBUS	IP, PTP, MS/TP	Defacto	**	Industrial	Robustness Simplicity
WorldFIP	IP, TP	EN 50170	*	Industrial	Robustness
X10	PLC, RF	OPEN not a norm	***	HA	lot of products
Bluetooth	RF	IEEE 802.15.1	*	Electronics	low cost
ZigBee	RF	Based on IEEE 802.15.4	****	LBandHA	low consumption
DALI	TP	IEC 62386	*****	Lighting control	Dedicated to lighting
DMX	MS/TP	YES	*****	Theatre lighting	Dedicated to lighting
Zwave	RF	Not a norm but Industrial standard	****	LBandHA	Low consumption Many applications in USA
INSTEON	RF, PLC	Proprietary	***	HA	Robustness Simple to use
Wavenis	RF	Proprietary	***	HA	Simple to use
INONE	RF, PLC	Proprietary	***	HA	Simple to use Simple to install
EnOcean	RF	Proprietary	****	HA	Batteryless Many products

Very few lighting applications:

Few lighting applications:

Some lighting applications exist:

Many lighting applications exist:

Dedicated to lighting:

* IP: *Internet Protocol*, RF: *Radio Frequency*
 ** IR: *Infra Red*, PLC: *Power Line Communication*
 *** PTP: *Peer to Peer*, TP: *Twist Pair*,
 **** MS/TP: *Master Slave/Token Passing*
 ***** LB: *Little Building*, HA: *Home Automation*

Component analysis

Table 6-12 below gives an overview of the typical use of the different components.

Table 6-12. Components application overview.

Components	Simple strategies				Integrated strategies	
	Predictable Occupancy Control Strategy	Real Occupancy Control Strategy	Constant Illuminance Control Strategy	Daylight Harvesting Control Strategy	Integration with blinds	Integration with HVAC
Sensors						
Scheduler	✓		✓		✓	✓
Clocks	✓				✓	✓
Illuminance sensor			✓	✓	✓	✓
Presence sensor		✓			✓	✓
Temperature sensor						✓
Wind sensor					✓	
Actuators						
Switch	✓	✓		✓	✓	✓
Dimmer			✓	✓	✓	✓
Others						
Skywells				✓	✓	✓
Smart windows					✓	✓
Automatic blinds					✓	✓
Networks						
Proprietary	✓	✓	✓	✓	✓	✓
Open	✓	✓	✓	✓	✓	✓

6.5 Recommendations

General Recommendations

This section suggests a generic analysis scheme to design lighting control systems for new and existing buildings. The *first step* is to collect the building owner needs and the expectation of the different users of the building (facility manager, building operator, occupants). This step is crucial to design lighting installation as it will:

- enhance the acceptance of the system by the users (expected visual comfort level, adapted human interface, etc.),
- facilitate the overall management of the system by providing relevant information and tools like fault detection, energy monitoring, dashboard etc.

This may be difficult in case of new building especially when the owner is not the end user. The *second step* is to achieve the functional analysis in order to translate the needs into technical terms,

that is, to choose the relevant control strategies, network architectures, systems and equipments. It includes the definition of a commissioning (Cx) plan corresponding to the above mentioned functional analysis.

The *third step* is to produce user guides for:

- The building operator to understand the system and optimise its operation (fault detections, maintenance, etc.)
- The facility manager to understand the performance indicators of the dashboard (energy consumption, running cost, payback time, etc.)
- The occupants to understand the control strategies (predicted occupancy control strategy, real occupancy control strategy, constant illuminance control strategy, daylight harvesting control strategy, etc.) and how to use the control system to optimize his visual comfort with an eco friendly behaviour (e.g. remote control, dimmer, task lighting, etc.)

Specific Recommendation for existing buildings

Installing lighting control system in existing building requires, in addition to the user needs analysis, an audit of the existing lighting installation in order to get a detailed description of the existing strategies, architectures, systems and components.

This audit allows to determine the control potential of the lighting installation (e.g. presence of separated lighting circuit for different zones, presence of electronic ballasts, possibility to install and use a wireless network, electrical network quality, etc.) and to design a relevant system for this building.

For example, wireless networks or power line communication system (PLC) seem very attractive as they are flexible and less expensive to install. However these solutions have limitations when the lighting system is very large (in building over 10,000 m²) due to signal attenuation, electromagnetic compatibility disturbance, etc. Figure 6-30 presents a general scheme to design an energy efficient lighting installation with specific consideration for the control system.

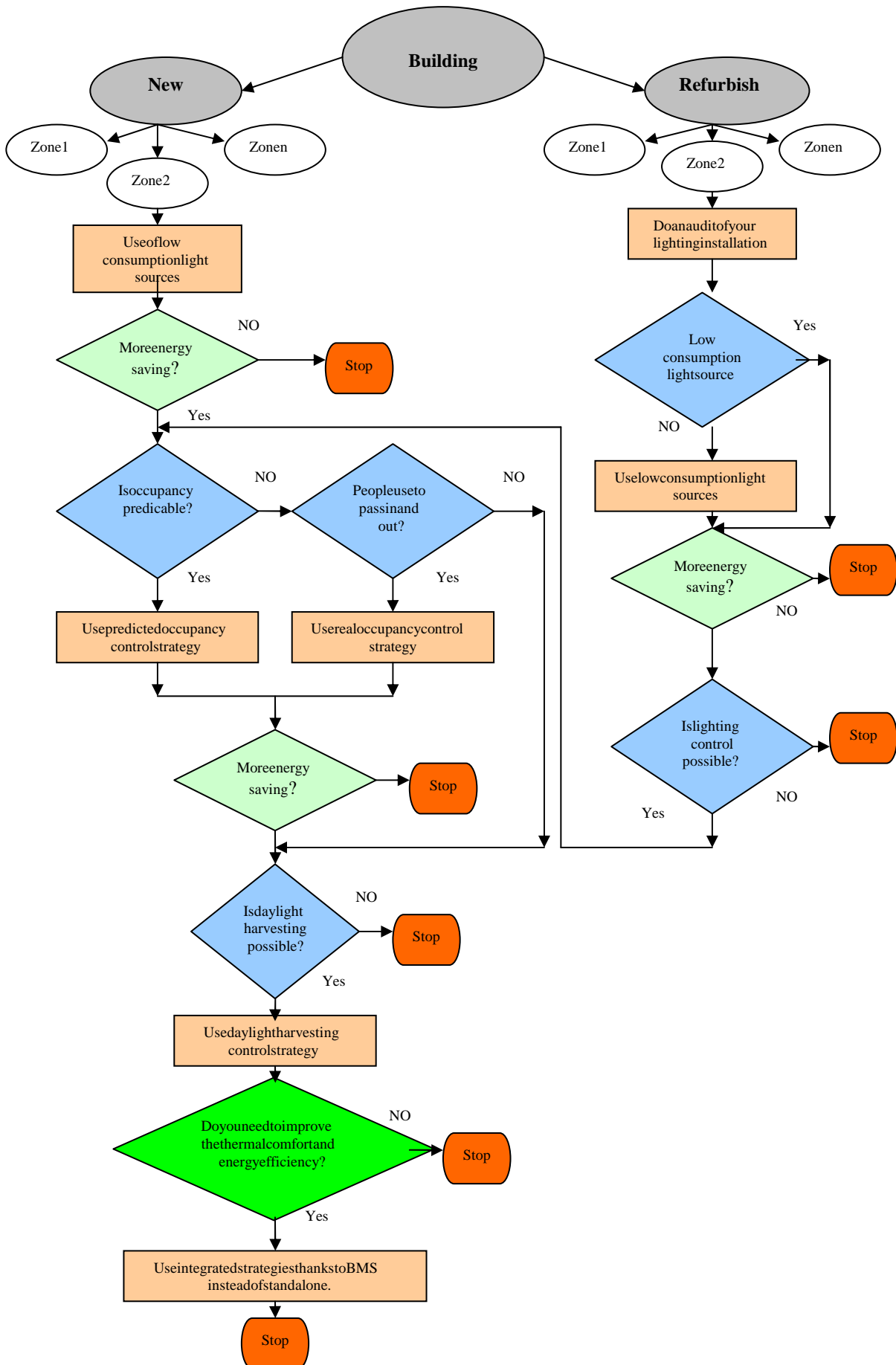


Figure 6-30. General scheme for energy efficient design of lighting control.

6.6 Illustrations

6.6.1 Illustration 1: NOSS National Office for Social Security – Belgium



This case study is an example of a very simple lighting control system working in a very efficient way. The building is organised in landscape offices (open plan) of about 20 work stations.

Control and management of the daylight

There is no advanced daylight control system in the NOSS building. The users have vertical lamellas that they can manually control in order to assume their visual comfort.

Figure 6-31 . NOSS building.



Figure 6-32 . Landscape office at daytime

Figure 6-33 . Luminaire with daylight sensor.

Figure 6-34 . Landscape office at nighttime.

Control and management of the artificial light

Landscape offices

The artificial lighting is controlled by:

- A manual switch in each local (landscape office) in order to switch lights manually on or off
- Two rows of luminaires (near to the windows and deeper in the local) are connected to a daylight dimming system based on the individual measurement of the luminance of the area under the luminaire.
- A central clock cut the luminaires off at 19:00. A second cut off command is sent at 21:00.

Circulation areas



The artificial lighting is automatically switched on at 7:00 in all corridors (day time mode). At 19:00, the artificial lighting of the circulation areas is set on night time mode. Two luminaires out of three are switched off in order to save energy. But one luminaire out of three stays on for the movement of night workers (for security, cleaning, etc.). A cycle of three days is used to avoid non-uniform ageing of the luminaires. This is done through special cabling so that the luminaire that stays on for the night changes each night.

Figure 6-35 . Circulation area.

Restrooms

During daytime, the artificial lighting of the restrooms is controlled by a presence PIR sensor with a delay set on 15 minutes.

rooms is continuously On. During nighttime, the artificial lighting of the rest rooms is controlled by a presence PIR sensor with a delay set on 15 minutes.

Table 6-13. *NOSS building-lighting control system properties.*

Features	System properties
Strategy	Predicted Occupancy Control Strategy Real Occupancy Control Strategy (Time Scheduling Control Strategy) Daylight Harvesting Control Strategy
Integration level	Level 2
Architecture	Zone Control Architecture
Network	Open systems-Standard system

Building Information

Architect: Régie des Bâtiments

Building owner: Régie des bâtiments (occupant: NO SS)

Location: Place Victor Horta, nr 11, B-1060 Brussels, Belgium

6.6.2 Illustration 2: The Berlaymont Building-louvres façade-Belgium

The concept of Ventilated Double Skin Facades (VDSF) is increasingly often applied in new office buildings or retrofittings. For common VDSF equipped with parallel glazing panes, a link can easily be made between the amount of daylight penetrating the building and the total glazed area of the facade. Louvres facades are a particular concept of Ventilated Double Skin Facades equipped at the outside with inclinable glazed lamellas. They offer a dynamic behaviour, which is function of many elements: slope of the lamellas, climatic conditions (diffuse or direct light), incidence angle of the sun, control algorithm, etc. Such a louvre facade concept has been applied on the Berlaymont building, the new retrofitted building of the European Commission in Brussels (Belgium).

The multi-storey louvre ventilated double skin facade of the Berlaymont presents a cavity that is partitioned neither horizontally nor vertically and therefore forms a single large volume. Metallic floors are installed at each storey in order to allow access for cleaning and maintenance.



Figure 6-36. *View of the large cavity and the louvres in vertical position.*



Figure 6-37. *Louvres in horizontal position.*



Figure 6-38. *Shadow on the Building-10 December-14:00*

The difference between this type of facade and the outdoor facade is composed exclusively of inclinable louvres.

classical multi-storey facade lies in the fact that the outdoor facade is composed exclusively of inclinable louvres.

Façade description

The Berlaymont building is a louver VDSF building. Its external skin is made of fixed glazed plates (200 cm out of 50 cm), of the facade and 12 mm on the top of the facade and

Its interior skin is composed of traditional of a whole of suspended frameworks on which within-uniform thickness (8 mm on the bottom) to their dimensioning with the wind.



Figure 6-39. Cross-section of a lamella.



Figure 6-40. View through the louvres.



Figure 6-41. View of the building.

The glazed lamellas of the exterior skin are made of perforated film presenting a white face to the exterior side, the louvres present a dark face so as to allow brightness being positive, view is possible from the way.

of two glass leaves which enclose a multi-layer internal side to better reflect the light. On the interior with the seeing them. Indeed, the contrast of the inside to the outside but impossible the other

Control and management of the daylight

The slope of the lamellas is ensured by engines, which are ordered from a central processing unit. The control of the slope is done according to various parameters, such as:

- The position of the sun (date and hour)
- The position of the lamellas on the facade (orientation and height)
- The information collected by the outdoor sensors (horizontal illumination, wind speed, rain, outside temperature)

When the outdoor horizontal illuminance is higher than 25000 lx, the lamellas are positioned according to their position on the facade.

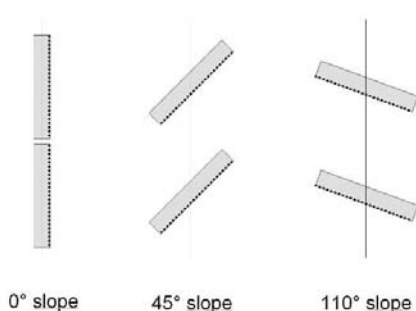


Figure 6-42. Different louvre positions.

If the lamellas are located in a sunny zone (which is a function of the date and the lamella's position on the facade), so as to be perpendicular to the rays of the sun. Thus, their slope lies between 0° and 80° , in order to work as solar protection; If the plates are located in a shaded zone and if the external horizontal illumination is higher than 25.000 lx, they are placed in position of luminous penetration (slope with 110°), to work as reflectors of light.

When the horizontal outdoor illuminance is lower than 25000 lx, all the lamellas are set in position of luminous penetration (110° of slope) to allow the daylight penetration in the building. Other modes are also integrated into the control algorithm, such as maintenance mode and alarm mode in case of fire.



Figure6-43 . Louvresinhorizontalposition–90°slope.



Figure6-44. Louvresinlightpenetration mode–110°slope.

The control strategy of the lamella is structured a Figure6-45.

an open-loop system organized as presented in

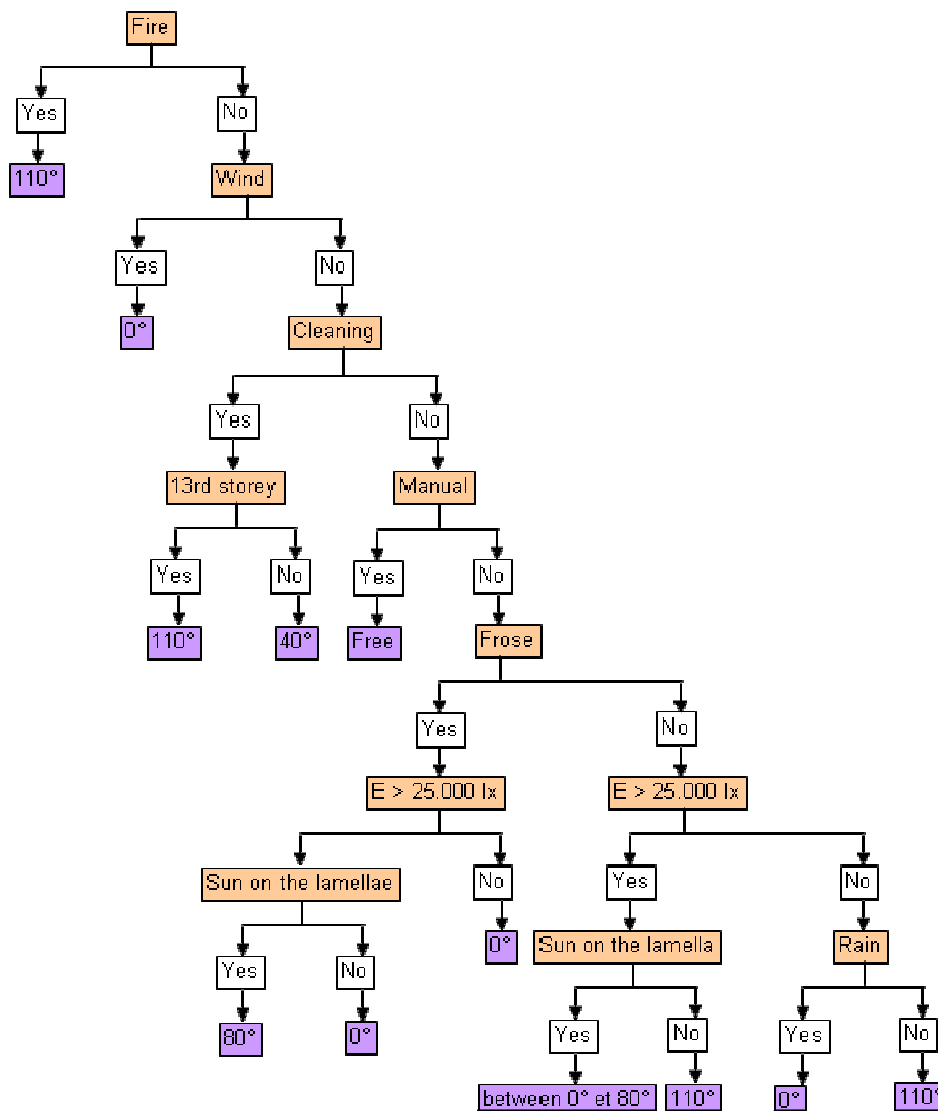


Figure6-45. Structureofthecontrolstrategyofthedaylightin oftheBerlaymontBuilding.

Control and management of the artificial light

The control of the artificial light in the individual offices of the Berlaymont Building is a function of:

- An individual switch. An individual switch controls the luminaires for each local (Manual On and Manual Off)
- The absence detection. If there is nobody in a local (office), the light switch off after a delay (that can be adjusted)
- The daylighting level. The illuminance level of the artificial lighting is automatically set to 300 lx or 500 lx in the local (office) in function of the outdoor illuminance level (daylighting level). This control of the artificial lighting is function of general settings for each wing in the building.

Table 6-14. Berlaymont building-lighting control system properties.

Features	System properties
Strategy	Constant Illuminance Control Strategy Daylight Harvesting Control Strategy
Integration level	Level 3
Architecture	Plant Control Architecture
Network	Open systems-Standard system

Building Information

Architect: P. Lallemand, S. Beckers, Berlaymont 2000
 Building tenant: European Commission
 Location: Rue de la Loi, nr 200, B-1000 Brussels, Belgium.

6.6.3 Illustration 3: Intecom project-France

The aim of the Intecom project was to develop smart systems to integrate the lighting control, blinds and HVAC applications to improve the indoor environment and reduce energy consumption. A good integration can be achieved through a limited data exchange. CSTB has focused on the interactions at the zone level among the three applications: HVAC, lighting and blinds. At the zone level, the different applications enable to reach the following goals during occupied period:

- Provide desired thermal comfort
- Provide desired illuminance level
- Avoid glare or provide requested contrast level

When the space is unoccupied, only the energy economy target needs to be met. The control strategies have been first assessed by simulation using the SIMBAD Building HVAC toolbox. The implementation has been carried out using the general-purpose simulation tool (MATLAB/Simulink/Stateflow). Two emulators have been developed, namely; a zone emulator and a building emulator. The communication between building and prototypes was supported by the Lonworks standard protocol.



The zone emulator consists of a single room with a fan coil unit, a luminaire with electronic ballast and a screen blind.

Figure 6-46. One zone sample.



The building emulator consists of a six-zone building with a VAV system for air conditioning and the same characteristics as the zone emulator for the light and blind equipments.

Figure 6-47. Six-zone sample.

The following facts can be considered on the communication among the controllers:

- The blind can answer to a request of the artificial light or HVAC system.
- The light controller can request blind for more daylight.
- The HVAC controller can request the blind to reduce solar gains or ask the light to switch on to bring more internal gains.
- The interactions among the applications will depend on the amount and type of data that is exchanged.

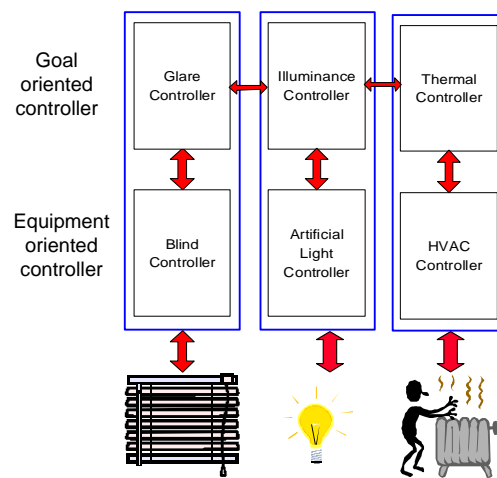


Figure 6-48. Communication between goal-oriented and equipment-oriented controllers.

The simulation studies have shown that:

- There is significant potential for energy savings and visual comfort with integrated control of light and blinds only if the lighting system possesses a dimming actuator.
- The integration of HVAC and blinds applications does not gain any major advantages.
- The integration of HVAC, light and blinds applications can bring up to 50% of energy savings during summer periods.
- In the case of integration of HVAC, light and blinds, there is a tendency of an increased number of blind movements during summer. This is usually not accepted by occupant.

Table 6-15. *Intercomproject-lighting controls system properties.*

Features	System properties
Strategy	RealOccupancyControlStrategy ConstantIlluminanceControlStrategy DaylightHarvestingControlStrategy
Integration level	Level3
Architecture	PlantControlArchitecture
Network	Proprietarysystem

6.6.4 Illustration 3: DAMEX project-Finland

The objective was to improve energy efficiency of a modern office building by maximizing daylight utilization. This was achieved by means of the integrated control system consisting of illuminance sensors, venetian blinds and electric lights, all interfaced to the DALI bus (Figure 6-49).

Short description of the characteristic features of the system:

- Both blinds and lights were controlled using only a vertical outdoor illuminance sensor without any indoor light sensors.
- According to measured vertical façade illuminance, and current date and time, the control system selects a predetermined lighting scene to be used. The scenes stored in the system memory contain all the information which is needed to control the devices.
- Only a little instrumentation is needed. The principle was to apply the daylight measurements and computer simulations in modelling the lighting process and then utilize the model in control.
- Individual light output levels for each luminaire or lamp and blind position were created and stored using DALI programming software. The predetermined scenes were created using real daylight measurements and lighting software. The DALI system is capable of storing 16 different scenes.

The measurements gave important information how indoor lighting and window luminances are changing in different daylight situations. Predetermined scenes were selected to minimize the glare, not to maximize the indoor light levels. The blind angles were selected to keep the luminance of the window within an acceptable range. Delays in control are short enough to prevent intolerable glare in dynamic daylight situations with high sun intensity.

Results showed that the described system can be effectively used to utilize the daylight in office building without causing glare to the users. The glare caused by the daylight reduces often the savings otherwise achievable through daylight.

An example of the results is shown in Figure 6-50 i.e., the shortest day of the year. Due to the glare the blinds shut at 10:51 AM when vertical illuminance exceeded 16000 lx, and opened again at 14:28 PM when the vertical illuminance falls

under 12000lx. The figure presents the vertical il
thehorizontalilluminance(middlecurves)andthe

luminance(highestcurve),indoorsensordataof
blinds(lowercurve).

The relative power of the lighting during one day i
noon was 43% and the average power 73% of the night
even in December it is possible to achieve energy s
whendaysarelonger,thesavingsareremarkable,b
electriclightisminimalduringnormalworkinghou

sshowninFigure6-51. The minimum power at
-time value. The main conclusion is that
avings in the Finnish climate. In summertime
ecausewithanoptimalblindcontroltheneedof
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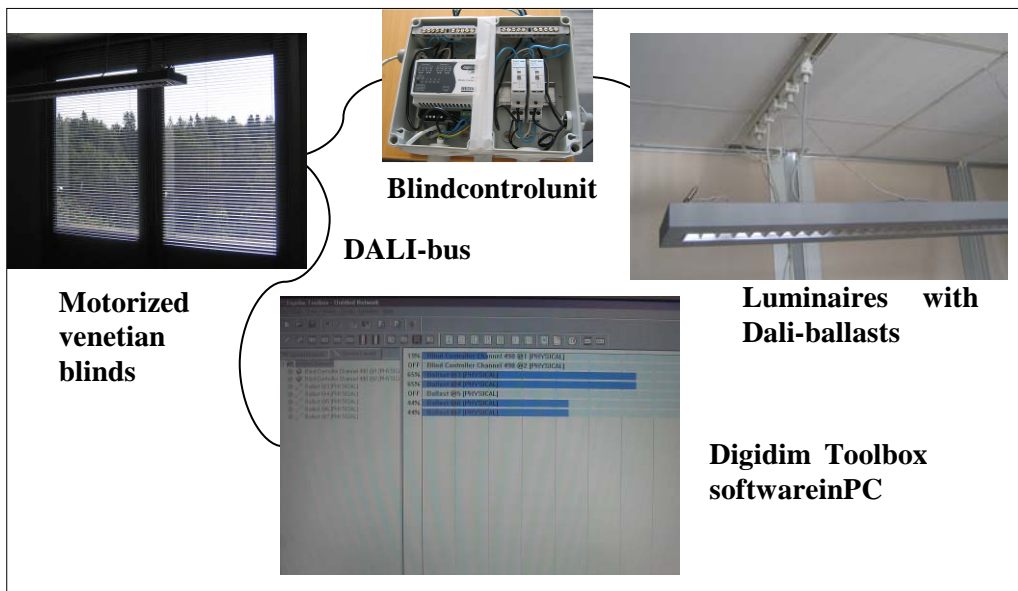


Figure6-49. TheintegratedcontrolsysteminterfacedtoDALI bus.

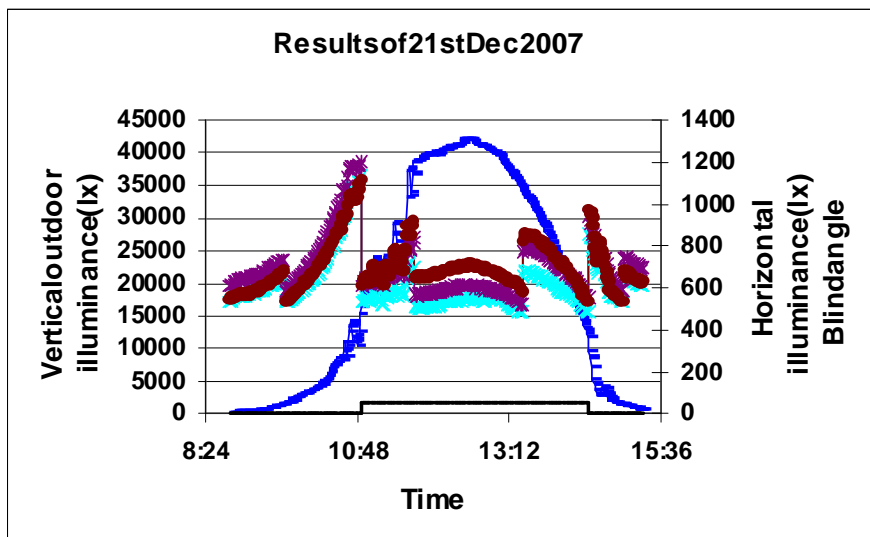


Figure6-50. Illustrationofthesensordataandoperationoftheblindsduringoneday.

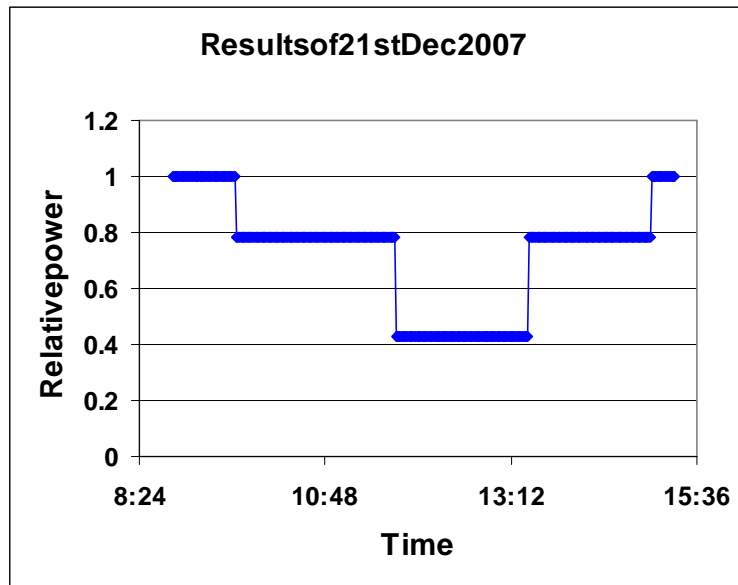


Figure 6-51. Electric power reductions during the day of Figure 6-50.

6.7 Conclusions

Lighting is an important part of the global building energy consumption. It can represent about 5 to 10 kWh/m².year in the residential sector and reach to more than 60 kWh/m².year in tertiary sector. Lighting consumption can be easily reduced with efficient light sources. Further energy gains can be achieved with smart lighting control strategies. Today, the most common form of control (the standard wall switch) is being replaced by automatic systems which are based on occupancy or daylight harvesting. Most common examples are occupancy sensors which turn the lights off when the area is unoccupied, time-based controls and the dimmer plus photocell combination. All are more effective than the standard switches in saving energy. Potential gains vary from 10% with simple clock to more than 60% with a total integrated solution (occupancy plus daylight plus HVAC). However, each sensor can be turned off by mistake if they are not well specified, installed and maintained. On the other hand, if they operate well they provide a direct benefit to the occupant in terms of energy saving, comfort and ease of use, in new buildings as well as in refurbish one.

Furthermore, today new components are coming on the market like smart windows and intelligent automatic blinds. The last component allow obtaining significant energy savings. However, no concrete study can actually show this. Finally, lighting management/control systems can easily be associated with BMS. Smart integration with other technical equipments (such as Blinds and HVAC) can be done to decrease energy consumption and improve general comfort. Such solution can allow building operator to provide the right amount of light where and when it is needed. On the other hand, it increases the complexity of the lighting system so that commissioning becomes essential for a good integration.

Lighting automation systems must be calibrated when installed, if possible after the building is occupied and the facility staff has to be involved in the commissioning process. The building sector is rife with anecdotes on lighting control systems which do not run as expected or do not work at all because they were improperly installed or because the facility managers or occupants do not understand them. The commissioning process will reduce these problems.

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