Interreg CENTRAL EUROPE
Dynamic Light
European Union
European Regional Development Fund

DYNAMIC LIGHT—TOWARDS DYNAMIC, INTELLIGENT AND ENERGY EFFICIENT URBAN LIGHTING

DELIVERABLE D.T1.2.1

WP T1 – Baseline Inventory

Dynamic Lighting Technology

- Inventory of existing experiences and knowledge -

11/2016

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Chapter – 1: Luminaire Technology

A standard LED luminaire consists of a number of components which work in cohesion to provide the desired lighting scenario. The following are few of the most typical components of any standard LED luminaire:

a. Basic LED unit
b. Primary optics
c. Secondary optics
d. LED driver
e. LED circuit board

The new size and shape of the basic LED technology has once again shifted the focus back onto the design of optics and reflectors, making it a crucial component of the LED luminaire. Light distribution is a very critical and important property that not only influences light output and efficiency but more importantly the visual comfort and glare characteristics in a LED luminaire. [1]

1.1 LIGHT DISTRIBUTION: LED CHIP

A standard LED chip without any accessories can have three different types of light distributions. These distributions govern the design of optics and reflectors to achieve a desired light distribution in a luminaire.

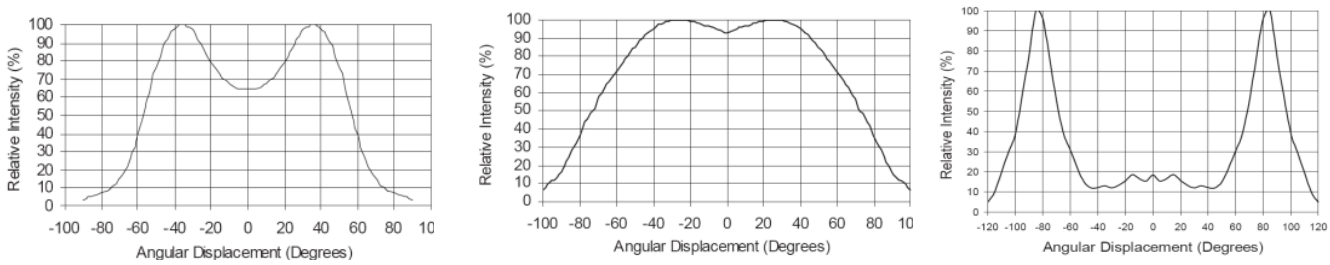


Fig.1: a. Batwing; b. Lambertian; c. Side-emitting. [1]

With these three basic light distributions it is possible to create hundreds of different light distributions. Most commonly used light distribution is the lambertian distribution, wherein the LED producing such a distribution is combined with an optical system to produce the common light distributions used in road and street lighting.

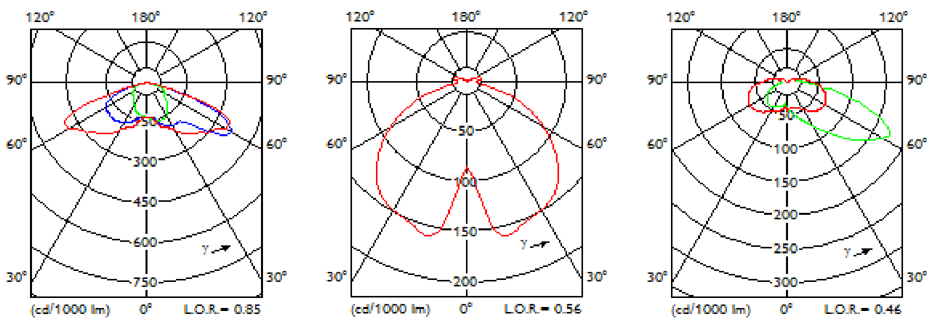


Fig.2: Typical light distributions in street lighting applications. [1]

1.2 LED OPTICS

The primary function of the LED optics is to gather as much light as possible from the LED chip and shape it to the desired distribution. Many a times a combination of primary and secondary optics are used to obtain the required light distribution.

1.2.1 Primary optics

The purpose of the primary optics is to collect the light from the chip and reshape it the requirements of the subsequent optics and also to protect the light emitting diode itself. Hence the Primary optic is:

- Integrated into the LED package
- Optimised for light extraction
- General beam shaping

Optical concentrators are ideal elements for this purpose. Optimisation is done for different evaluation criteria like maximum transmission, minimum residual divergence and homogeneous near and/or far field. The common primary optic is as explained earlier the lambertian type. The primary optics controls the luminous flux as much as possible and provides it to the secondary optics.

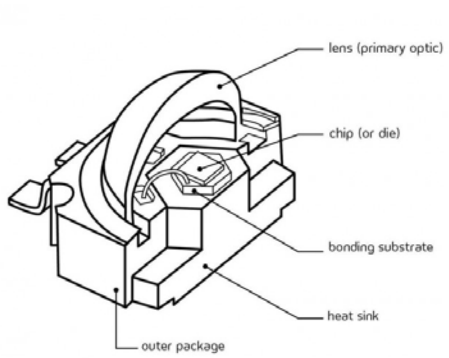


Fig.3: Typical LED package. [2]

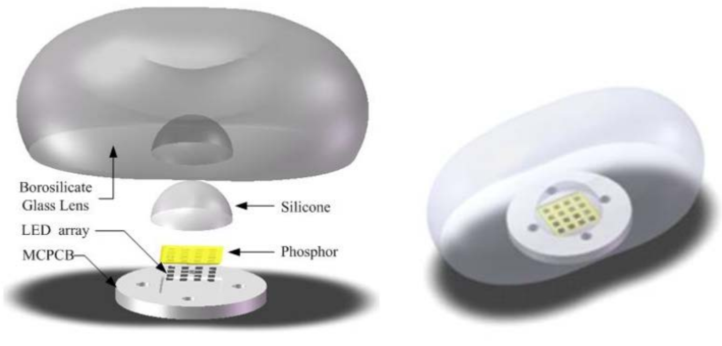


Fig.4: Primary optical system of LED chip array module. [3]

1.2.2 Secondary optics

Since a primary optic is limited in the amount of beam control it can achieve, secondary optics are required to meet the objectives of a particular application. Secondary optics send the light in a desired direction and obtain the required brightness by controlling and directing the light output from the primary optic.

Secondary optics are usually separate from the LED package. Typically separated by an air gap, this gap can also be filled with a material with a similar refractive index to reduce the Fresnel losses.

Secondary optics are characterised by the width of the light beam they produce. The angular width is specified by measuring the angular serration between the directions, at which the intensity has fallen to half its peak value. This value is called the Full Width Half Maximum (FWHM) divergence.

Fig.5: Secondary optical systems. [4,5]

There are two primary categories of secondary optics, diverging and collimating optics.

1.2.2.1 Diverging optics

Diverging optics spread the incoming light into a wider beam of light. Pillow lenses are the most popular diverging optics used mostly in automotive signal lamps. Other diverging optics include diffuse lenses, faceted lenses, rod lenses etc.

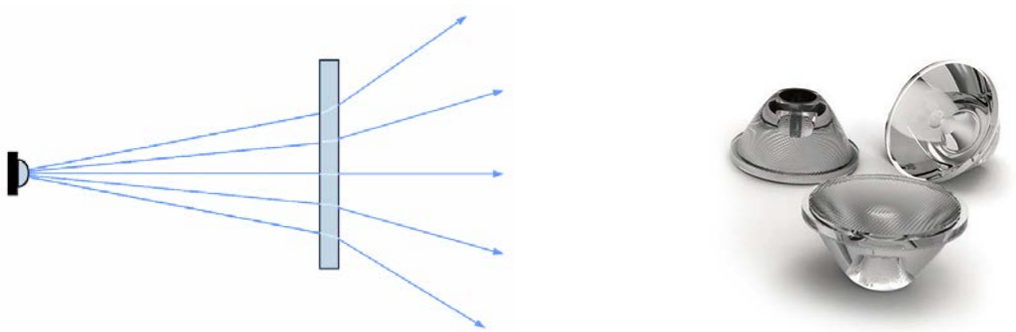


Fig.6: Diverging optics. [4,6]

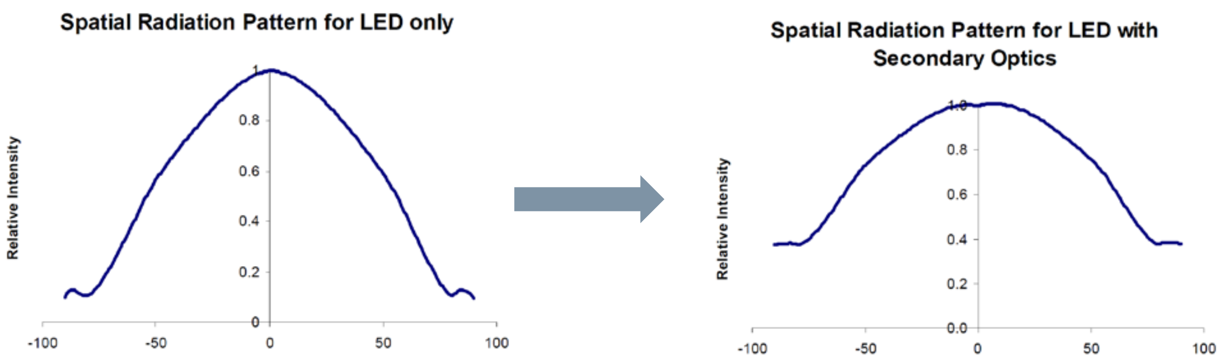


Fig.7: Change in light beam width using diverging optics. [4]

1.2.2.2 Collimating optics

Collimators focus the incoming light into a narrower beam of light. Collimating optics come in two main types: reflecting and refracting. LEDs using collimating optics are more efficient and produce a more uniform appearance.

Reflecting elements are typically metallic coated cavities with a straight or parabolic profile. They serve two main functions: to redirect the light from the LED into a useful beam and the final appearance of the luminaire.

Refracting collimating optics typically used in LED lamps include planoconvex, dualconvex and collapsed planoconvex (Fresnel Lenses).

A study by Andreas Bielawny [8] showed that small reflectors are able to control luminous flux far more than large reflectors but as a result small reflectors produce far less lumen output.

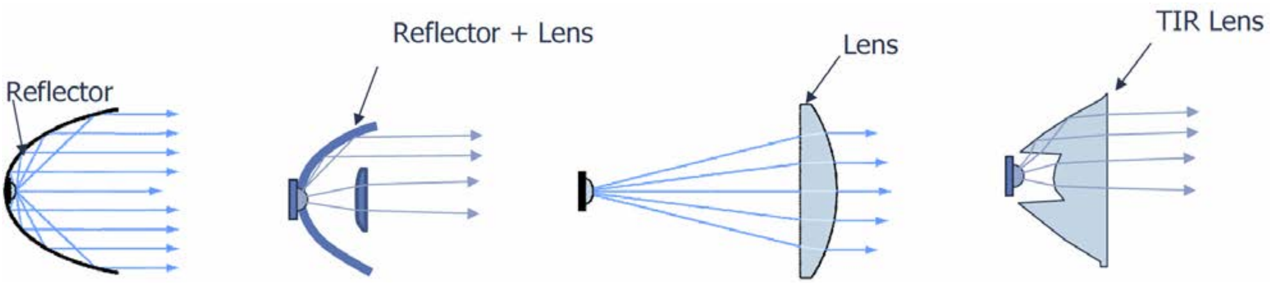


Fig.8: Collimator optics. [4]

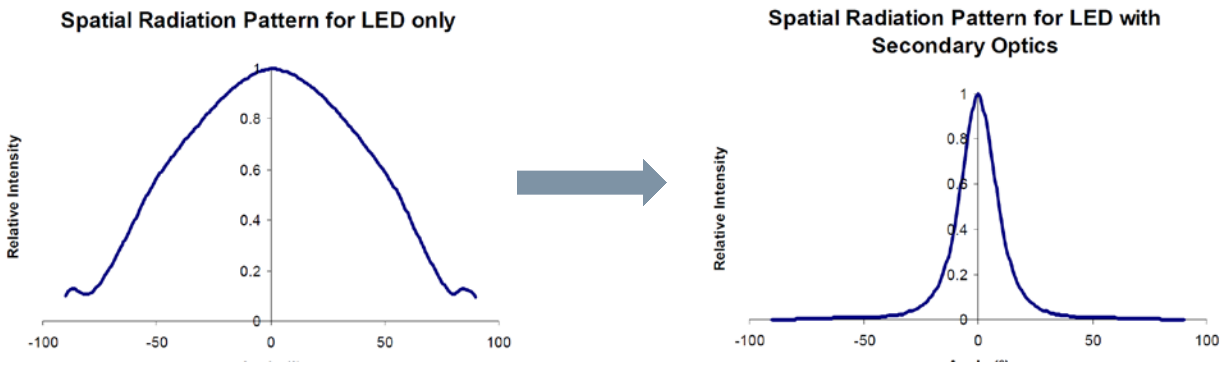


Fig.9: Change in light beam width using diverging optics. [4]

1.2.3 Luminous Flux control

All LED applications can be divided into two groups: direct and indirect. The term direct and indirect describes the relation between the LED and its secondary optic component. The term direct is also used to emphasise that the LED luminaire uses the flux from the primary optic of the emitter to create the light distribution.

A. Direct: a direct optical configuration is characterised by the alignment of the optical axix of the emitter with the main optical axis of the light. The emitter in this case is directly visible to the observer.

B. Indirect: In contrast to the direct configuration, an indirect optical configuration will always prevent the emitter from being observed directly. Indirect solutions offer better light control.

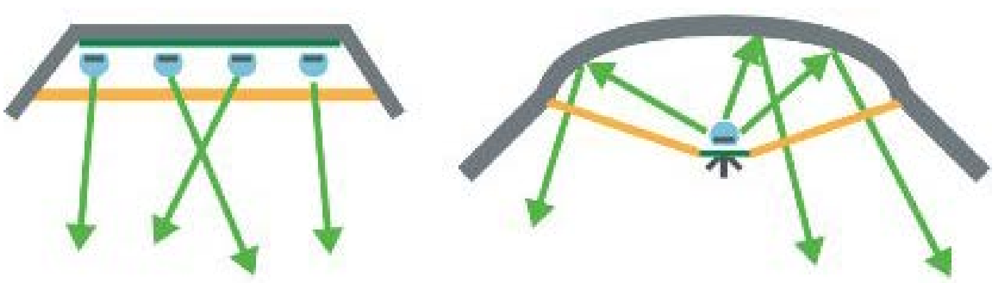


Fig.10: Change in light beam width using diverging optics. [4]

1.2.4 Material for optical systems

a. Polycarbonate: These materials are characterised by low cost, excellent mechanical properties, resistance to yellowing/ ageing due to exposure to high flux and short wave blue light, high temperature performance high internal transmission and excellent moulding characteristics.

b. PMMA: It is widely used in optic solution as an alternative to glass. It is less dense than glass, softer and easily scratched than glass, higher transmission.

c. Silicone gel: High performance but extremely expensive.

1.3 LED CONFIGURATIONS

Predominantly three different LED chip configurations are used in street lighting applications which are as follows:

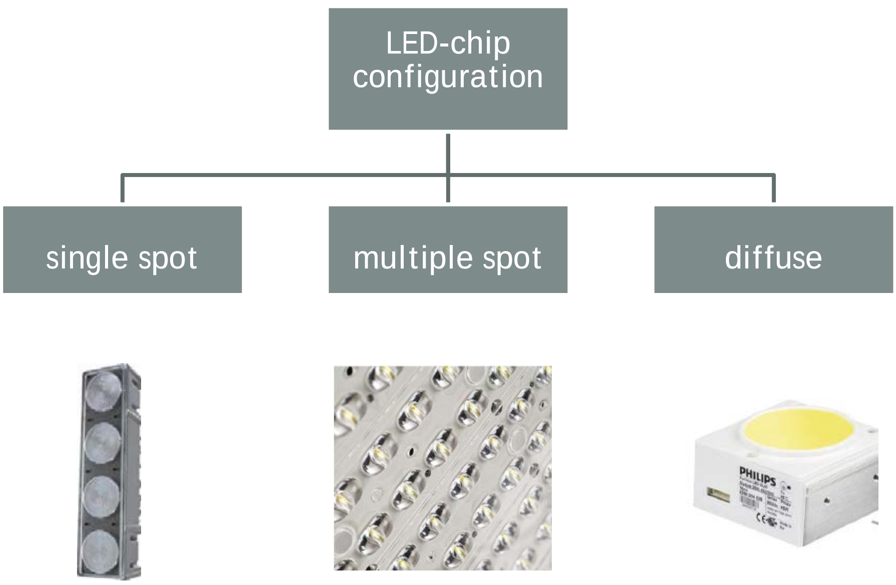


Fig.11: LED chip configurations. [1]

	Single spot	Multiple spot	Diffuse
Optical system	lenses	lenses	Reflector
efficacy	Very high	Very high	High
Appearance on the luminaire	Single small very bright spots	Many small bright spots	Bright field with shining reflection of the reflector
Visual glare appearance	high	acceptable	low
Effect of damaged LEDs on light distribution	Dark holes on the road	Reduced brightness on the road	Reduced brightness on the road
Visual effect of damaged LEDs on the luminaire	LEDs without function	Some clusters on the LED panel are dark	No relevant differences
LED replacement	Not so easy, mostly single way luminaries	Replace the LED-panel very easy mostly	Replace the LED-module very easy

Table.1: Comparison of LED chip configurations. [1]

1.3.1 Single spot LED configurations

Single spot LEDs have a very high efficiency when considering the Utilisation factor. With single spot LEDs it is possible to bring the light directly to the place where it is actually needed. At the moment single spot LED can be the best solution to reduce spill light. However this is achieved using single spot LED with their own optic systems, but in case there is any damage to the LED, there will be no light produced from that part of the luminaire. This "dark area" can have an influence on the uniformity of the light distribution adversely affecting the safety of road traffic, which is not anymore acceptable. [1]

1.3.2 Multiple spot LED configurations

Multiple spot LEDs also have very high efficiency when considering the Utilisation factor. There are many solutions available in the market with different light distributions using multiple spot LEDs. A wide range of light distributions are available for various types of applications. Spill light created from similar light distribution from different manufacturers is not always the same. Spill light depends on the quality of lenses and hence has an effect on the efficiency. Each LED on the panel has a similar light distribution, in this case if one cluster of LEDs are damaged, there are no "dark areas" on the road, only a drop in the brightness levels. The panel itself would have some dark patches but not adversely affecting the safety of the road traffic. The visual appearance of such luminaires is also better than in case of single spot LED luminaires. [1]

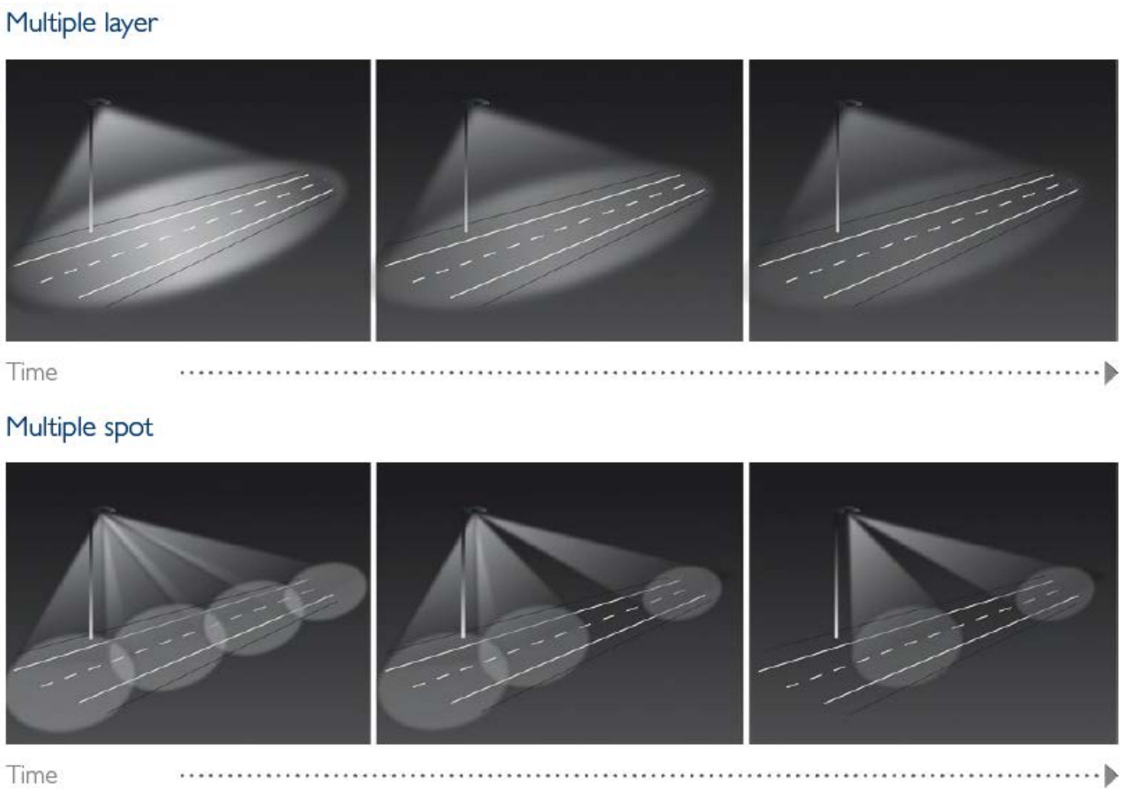


Fig.12: Dimming strategy: Multi-layer and Multi-spot. [1]

1.3.3 Dynamic lighting control- Multiple spot LED

Multiple spot LED-systems tend to have more possibilities in terms of lighting control. Any changes in the requirements or changes in road layouts or structuring can be easily taken care of by changing the LED-panel. This is however only possible when the system has been defined for easy replacement of LED-panels and the thermal management has been designed for higher power usage. In case of construction works or temporary changes in the layout of roads, it is possible to modify the LED-panel to target different area or even bring light to additional areas like pedestrian areas. The old panels can be used as spare parts or can be used in other roads. The old LED-panels can be used in other various ways, which are still open to study and investigation. [1]

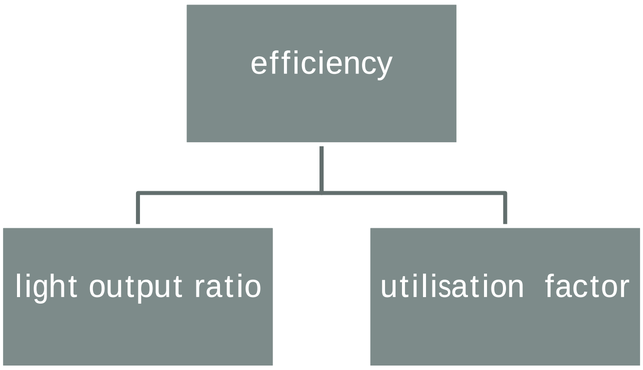
1.4 EFFICIENCY

The efficacy is better when the dimension of the lamp is smaller. Small lamps like LED need a small lens or reflector to create the desired light distributions. But such a small design requires high precession connections and circuitry.

However, as the study from Andreas Bielawny [8] showed that small reflectors are able to control luminous flux far more than large reflectors but as a result small reflectors produce far less lumen output. A small lamp combined with high light output levels need to have a good light distribution to keep the glare within limits.

1.4.1 Factors influencing efficiency

The efficiency of a luminaire thus depends upon the type of LED, the light distribution of the LED and the requirements of the lighting application.



The Light output ratio (L.O.R) is a necessary property to define the efficiency of a luminaire. As the L.O.R approaches to one, more light will come out of the luminaire. This factor is the ratio between the luminous flux produced by the lamp to the luminous flux coming out of the luminaire. The differences between the two are termed as losses. Losses can be:

- Transmission losses caused due to the material properties of lenses.
- Reflection losses caused due to the material properties of the reflectors.
- Transmission losses of the housing (glass or polycarbonate)
- Losses inside the luminaire housing, depending upon the place and shape of the reflector.
- Thermal conditions for the LEDs (higher temperatures reduce luminous flux)

The utilisation factor provides information about the percentage of light produced from the luminaire which is available on the application area. This factor is influenced by factors like geometrical conditions, height of the pole, aiming of the luminaires, dimension of the illuminated area and the lighting distribution of the luminaire. The higher are these factors the better is the efficiency of the light installation. The utilisation factor gives better information about the efficiency of an luminaire than the light output ratio. In practice the information about the utilisation factor is not easy to calculate, specific software needs to be used to calculate the utilisation factor. [1]

1.5 LED TECHNOLOGY AND DYNAMIC POTENTIAL

LED technology has for the first time provided the possibility to digitalise light. LED's in many ways can be considered as an entirely new dimension of software controlled intelligent light source. [13]

The LED technology today makes it possible to have various different LED light sources with different characteristics and functions combined in one single luminaire. These features make the LED technology truly multi-functional, performing different functions at the same time and being able to fulfil different requirements not only in long term but also on short term.

This combination of various LEDs with different function in one single luminaire offers the possibility to design complex control scenarios that can dynamically change the characteristics of the lighting with changing requirements, uses or needs.

The possibility to have different LED groups and layers in one luminaire gives the opportunity to:

- achieve required light output and intensity
- ability to be dimmed seamlessly on demand
- dynamic white lighting with varying colour temperatures
- achieve dynamic colour lighting
- intelligent light management and interface systems
- integration with sensors and other systems
- easier and faster communication and data exchange
- possibility to be operated through renewable sources of energy
- remote monitoring

In the state of the art luminaire technology today we are able to control and change, to name a few, the following light characteristics:

a. Light distribution / Light direction
b. Colour temperature
c. Light spectrum
d. Light quantity
e. Timing
f. Duration

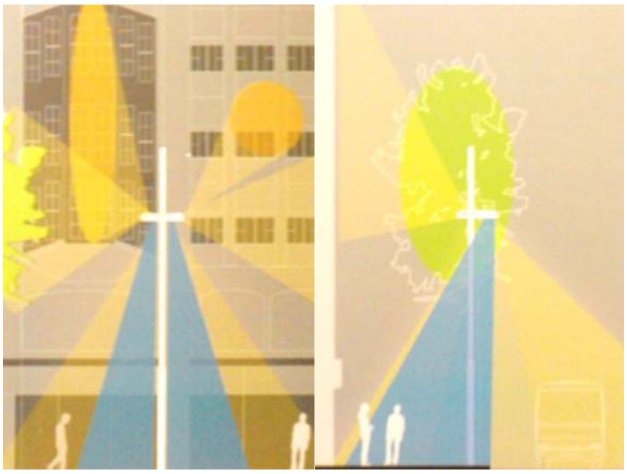


Fig.12: Multi-functional luminaires. [14]

1.5.1 Light Distribution

The small size of the light source makes it possible to have a number of lighting solutions combined into a single luminaire. Using various optics or lenses, different light distributions can be integrated in one source, making it possible to control light on surfaces, illuminating certain vertical elements, creating accents and highlights and generating visual fields that help in reading the city.

A single luminaire can provide solutions for various functions, for example a busy commercial area can have office spaces, restaurants, eating joints, places to socialise and relax, entertainment and event spaces all compacted into one space.

Earlier, the conventional lighting solutions can only provide a specific light distribution curve only giving flexibility in adjusting the height of the light point or the lumen output based on the wattage of the lamp, but today, with LED technology it is not only possible to have the desired light distribution as required by the two different situations, but it is also possible to control the luminous intensity, spill light, have precise focussing and aiming.

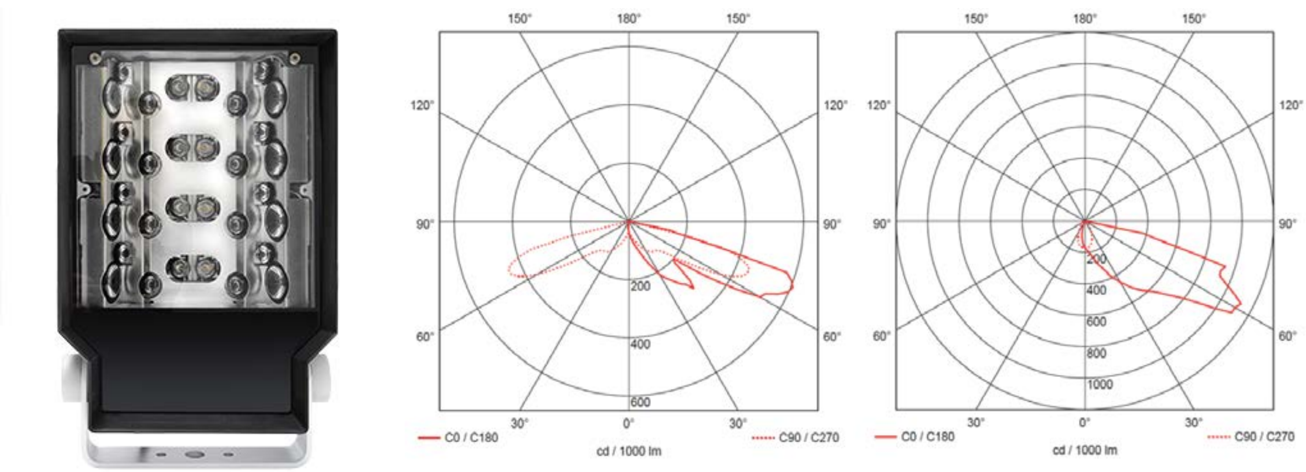


Fig.13: Different light distributions in a single luminaire. [15]

1.5.2 Colour temperature

Light has a stronger influence on living systems than only transmitting information about the space and the subjects to the eye; its influence is holistic and immediately connected with time and temporal rhythms [11]. Our contemporary human behaviour and our 24 x 7 lifestyle, days, month and seasonal time cycle are losing their significance. The ever-connected society, late-night shopping, round-the-clock public transportation, shift work and an attractive night-life are liberated us from the day/ night rhythms.

LED technology along with control systems can assist in supporting the time cycles, dynamic white light with varying colour temperatures can mark the different times in a day, giving a visual clue to the individual about the time of the day.

Dimming and luminous control can be used to signify seasons, with brighter surfaces during winter than summer or vice versa.

A. Sant Cugat, Spain

For the illumination of the City hall square, the designers programmed these secondary lights to follow a colour gradient based on four main hues which vary with the seasons. Each gradient is animated in turn so that individual tints from each gradient travel along the length of the promenade.

The visitors’ sensation thus changes with their position, the time of year, and their movement across the space. [12]

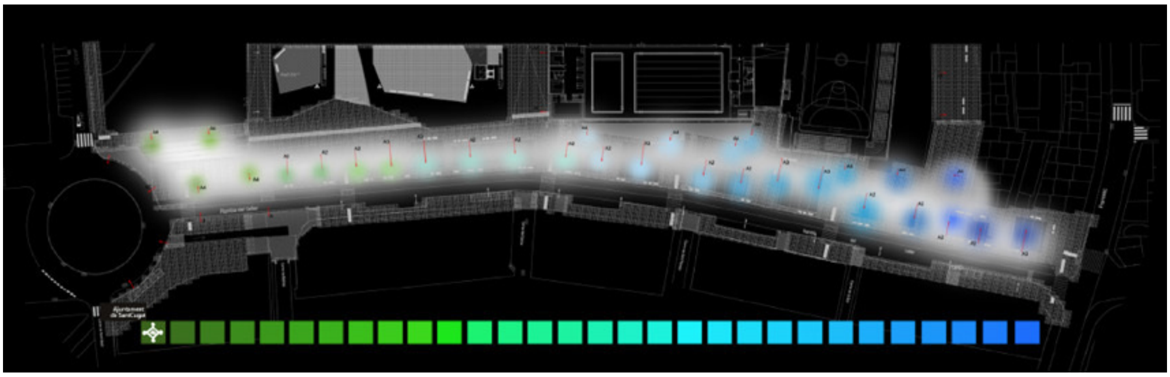


Fig.11: Sant Cugat, Spain. Lighting Designers: artec3 Studio. [12]

B. Optics with complex facetted surfaces for dynamic colour temperature

Due to the extremely small size of LED chips both the reflectors and the lenses can now be equipped with LEDs of different colour temperatures. The colour mixing and variation is done in the optic itself. [10]

1.5.3 Light Spectrum

LEDs for the first time provide the opportunity to design not only with white light, but with different colour spectrums of light.

Research has shown the importance of facial recognition and colour recognition in increasing the feeling of safety and encouraging more public and social interactions. White light assists in quicker facial recognition, also providing a perception of greater brightness and is perceived as producing more illuminance.

The quality of LEDs to produce saturated coloured light can be used as a design tool to add new dimensions and layers to urban spaces.

Colour can be used to give special emphasis on certain design elements or features or could be used during celebrations or special occasions or certain times of a day to create interests or attract people and customers.

Colour can be used to enhance key features of the city or to create new identity for a space or to add character and interest to a space.

A. Southwark, London, UK

The installation has transformed a space that was previously dark and unattractive into bright and interesting route for people to enjoy and walk through.

The lights react to the volume of pedestrians passing underneath them, with the illuminations changing in intensity according to the flow of people.

The quiet phases will be marked with a twinkling star effect and when the area becomes busier, the firework effect will build up momentum reaching its most striking display in times of increased activity.

Fig.12: Southwark, London, UK. Designers: Halo Lighting. [12]

1.5.4 Light quantity

The LED technology today allows for much more than simple dimming and changing light levels; the concept of "dimming on demand" ensures a better quality of public lighting that responds and reacts to the needs to the society by controlling light to when, where and how it is needed.

A. Dynamic Street Lighting, Wellington, New Zealand

Using a passive infra-red (PIR) sensor attached to each pole light can be turned up from a dimmed setting when a pedestrian, cyclist or motorist approaches and then after a programmed time the light will return to its dimmed state. A central management system can enable lights to be configured in a way that increases lighting outputs progressively with movement and collectively greatly increases the energy savings potential for the city.

The sensors are connected to web-based software for remote monitoring, management and control of street lighting infrastructures. The software is directly coupled to sensors through the internet and features remote programming and modification of settings of individual and groups of streetlights, context-specific lighting levels to reflect local conditions such as weather changes, special events and emergency situations as well as analytical tools to allow the use of exact data for energy savings/consumption, detection patterns and lamp failure detection.

Like more basic systems it is also capable of reporting faults. As the system is based on an open platform it can be developed to allow an interface with hardware from other providers (e.g. traffic and local weather monitoring). [16, 17]

	Totals	Severn	Priscilla	Black Rock	Duthie	Fitzpatrick
Total Operation (minutes)	27,329	5,940	4,560	5,250	6,330	5,250
Minutes on Full	7,281	2,174	1,235	807	2,280	785
Minutes dimmed	20,048	3,766	3,325	4,443	4,050	4,464
Dimmed %	73.4%	63.4%	72.9%	84.6%	64.0%	85.0%
Vehicle count (#)	12,367	4,229	1,754	1,011	4,394	979
Consumption (kWh)						
70w (HPS)	1,913.1	415.8	319.2	367.5	443.1	367.5
30w (LED)	819.9	178.2	136.8	157.5	189.9	157.5
25w (LED)	683.2	148.5	114.0	131.2	158.2	131.2
30w LED with Tvilight	278.6	76.5	47.0	37.5	80.5	37.0
14w LED with Tvilight	152.1	39.8	25.6	22.4	42.0	22.2
Savings						
HPS to LED (30w)	57.1%					
HPS to LED (25w)	64.3%					
30w LED with Tvilight	85.4%	81.6%	85.3%	89.8%	81.8%	89.9%
14w LED with Tvilight	92.1%	90.4%	92.0%	93.9%	90.5%	94.0%

Fig.13: Effects of LED and adaptive lighting in Wellington on sample streets. [16, 17]

Chapter – 2: Sensor technology and control applications

2. 1 PRESENCE SENSORS IN MODERN LED STREET LIGHTING

The primary device needed to adjust light levels of urban street lighting to the current need is some kind of sensor which detects movement of people and vehicles in a given area. Technically, there is a wide range of different sensors available on the market, but only a few of them are used in conjunction street lighting. This has mainly to do with system costs.

Using modern LED street lights with sophisticated light guidance – mainly by using lenses, but also reflectors – will reduce energy consumption by up to 75% or 80% compared to conventional street lights with gas-discharge lamps. The energy consumption can even be reduced further by using sensor-controlled LED street lights. There is only one problem: The sensor solution has to be rather cheap, otherwise such systems will never amortize over the lifetime of the street light. This means that most probably not the most sophisticated technical solutions will be used, but the one which offers acceptable performance at a reasonable cost.

This leads to three main types of sensors which are currently established on the market: passive infrared (PIR) sensors, Radar Sensors and camera-equipped systems. Due to very low systems costs PIR sensors are the mainly used sensors at the moment. Radar systems start profit from the increased use of this type of sensor (e.g. automotive industry) which brings down system costs to an acceptable level. Camera systems might be the most sophisticated solution at the moment, but extensive software development costs make solutions with this type of sensor rather expensive.

2.1.1 Passive Infrared (PIR) Sensors

PIR sensors are classical movement and presence detectors, used in many applications in- and outdoors. They can detect the levels of infrared radiation of objects within their detection area. Every object emits at least a low level of infrared radiation. The hotter an object is, the more radiation it emits. Basically these sensors detect movement of heat fields compared to the background.

Figure 1: Schreder Teceo streetlight with integrated PIR sensor

Figure 2: Tvilight Citysense Plus – external PIR sensor solution

Pros:

- PIR sensors are the cheapest solution on the market for presence and movement detection.
- They have very low power consumption.
- They are very small in size and can be easily integrated in all different kinds of street light designs.
- They are rather easy to integrate. For a very simple setup, there are even LED drivers on the market with integrated PIR sensor support, hence no further components are needed (the LED driver has the programmable logic integrated).
- A wide range of street light manufacturers offer an option for an integrated PIR sensor solution. This means little to no additional cabling and installation efforts.

Cons:

- Limited range of only 6-10 m in the area below the street light.
- No differentiation between different types of moving objects (people, bikes, cars,…) possible
- Prone to reduced detection during winter as people packed in coats and caps will emit lower levels of infrared radiation.
- Prone to reduced detection due to weather conditions as rain or snow might overlay a moving objects infrared radiation.

2.1.2 Radar Sensors

Radar sensors send out electromagnetic radio waves in the microwave range which are reflected by (moving) objects. The frequency shift between the sent and received wavelength is used to determine the presence of moving objects. Radar sensors used for lighting and traffic applications mainly use a carrier frequency of 24 GHz. Depending on the type of sensor and technique used, different kinds of information can be gathered. In regard to applications in street lighting and traffic, there are three main techniques which may be used:

Figure 3: lixtec 90W LOD – street light with integrated radar sensors

Figure 4: Comlight Motion Detection – external radar sensor solution

1) Continuous wave (CW) / Doppler radar

Rather simple and most commonly used technique. Allows the detection of moving objects, their speed and (optionally) the direction of movement (approaching to / receding from the sensor).

2) FSK radar

FSK stands for Frequency Shift Keying, as this technique switches between two discrete carrier frequencies close to each other. The advantage of FSK radar over CW radar is that it allows distance measurement of moving objects. This is very helpful as is opens up the possibility to differentiate between different types of moving objects (e.g. persons, bikes, cars, trucks). This information might be used to establish different light levels for different road users.

3) FMCW radar

FMCW radar stands for Frequency Modulated Continuous Wave. The carrier frequency is changed linearly by applying a triangle or saw tooth waveform. More complex than FSK, but also allows the measurement of distances to stationary objects.

Systems using radar sensors consist if the sensor itself, most probably an op-amp to amplify the signals and a microcontroller or digital signal processor to process the raw data of the sensor.

Pros:

- Depending on the sensor used very good ranges are possible (20-30 m for persons, 60 m and more for cars and trucks), much higher than with PIR sensors
- Hardly any distortion of the performance due to weather conditions (e.g. fog, rain, snow).

Cons:

- Even though the prices for radar sensors have decreased in recent times, overall costs of a radar system are still much higher than PIR systems.
- Energy consumption of a radar based system will be higher than a PIR sensor.
- Might need extensive software efforts

2.1.3 Camera Systems

Using camera systems for object detection offers a highly flexible solution for a wide range of applications. Most systems will use 2D CMOS cameras. Camera system use the detection of moving, connected pixels compared to the background to gain knowledge about speed and size of a moving object.

Figure 5: Philips LumiMotion – external camera solution

Pros:

- Very good detection of different objects possible.
- Surveillance area can be exactly configured in software.
- Surveillance area can easily be changed be the use of different lenses.

Cons:

- Extensive software efforts needed.
- Extensive computing power needed.
- Energy consumption higher than PIR sensors.
- Prone to reduced detection due to weather conditions as rain or snow might overlay a moving objects infrared radiation.
- Detection might be tricky at higher speeds.
- Needs a minimum light level or infrared lights at night (can be avoided by using a night vision camera).
- Needs active anti-shake in software as a moving lamp post (due to wind) might lead to movement detection.
- Might need higher installation efforts.

2.2 BRIGHTNESS CONTROL

The introduction of LED street lights also opened up the possibility of dimming the brightness to any desired level, as LEDs can be switched on and off without any delay even at a high frequency, in contrast to conventional street lights with gas-discharge lamps.

LED dimming is usually done using pulse width modulation (PWM). This means that the LEDs are switched on and off a few hundred or thousand times per second. By varying the difference between on and off times, the brightness can be set to any level between 0% and 100% (Note: Due to leakage current which will occur at 0%, the LEDs will still glow at a very low level and will not be completely off).

LED drivers are built into the street lights to power the LEDs. There are three different possibilities to control the brightness level of the LED. Most of the drivers use the DALI interface, which has become the de-facto standard for street light brightness control. Another interface which is used quite often is the 0/1-10 V interface. The third possibility would be to control the driver directly via a PWM signal, but this is rarely used nowadays.

1) DALI Interface

DALI (Digital Addressable Lighting Interface) is a two wire digital interface which was developed and is maintained by the DALI activity group, a consortium of lighting equipment manufacturers. It is specified in the technical standards IEC 60929 and IEC 62386. A DALI network consists of 1 controller and 1-64 slaves. Each slave has a unique address which allows different brightness settings for every slave. Sending commands to a group of slaves or all slaves is also possible. The communication protocol is based on a pre-defined set of commands which allows interoperability of equipment of different manufacturers. DALI has a nominal voltage of 16 V. 0 V to 4.5 V is a logical “0”, 16 V ± 6.5 V is a logical “1”. DALI systems in street lights will quite often use a voltage level of 12 V. In a demand-oriented street light the control unit attached to the sensor will also be the DALI controller, the LED driver is the DALI slave.

2) 0/1 – 10 V Interface

This interface is classical analog interface which was originally developed by Philips. It is also a two wire interface. The analog voltage on the interface determines the brightness of the street lights. Depending on the LED driver, 0 V or 1 V means 0% brightness, 10V means 100% brightness. Equivalent to DALI, the control unit attached to the sensor will control the LED driver via the cable connection.

2.3 COMMUNICATION

Communication between neighboring street lights in demand-oriented systems will allow creating lighting scenes. For example, a whole area can light up when a sensor detects a movement, or the enlightened area can move along with a moving person.

On the other hand, establishing communication of street lights to a backbone will allow the implementation of a management system. Broken lights can be detected instantly, the power consumption of each single light can be monitored, or emergency light scenes could be created.

2.3.1 Communication between street lights

Communication between street lights will almost exclusively be wireless. There might be some use cases, where a wired solution like e.g. power line makes sense, but generally a wireless connection is a much easier approach.

Most of the wireless connectivity solutions which are used in street light and sensor systems respectively make use of the technical standard IEEE 802.15.4, which defines the lower layers (OSI-model) of a low-rate wireless personal area networks (LR-WPAN). It uses transfer rates of only up to 100 KHz, but the emphasis of this standard is to focus on low cost and low energy consumption.

Three unlicensed frequency bands are supported by this standard:

- 868 MHz: Europe only
- 915 MHZ: North America only
- 2.4 GHz: worldwide

Most manufacturers of street lights and sensors currently use wireless solutions in the 2.4 GHz band, as it allows worldwide reselling of their products.

IEEE 802.15.4 is the basis for standards which define the upper layers of a WPAN. The best known solution in this connection is ZigBee, but there are many other solutions on the market, also quite a lot of proprietary ones.

2.3.2 Backbone communication

Regarding backbone communication, wired systems also come to play a role. As there is a mains cable available in every street light, power line communication might be an obvious choice. The existing power cable is also used as data cable – which is also the main source of possible problems with this solution. The mains cable was not designed for data transfer, hence its lacks any kind of shielding which makes it prone to interferences and malfunctions. Nevertheless, there are some solutions on the market (e.g. Swarco Futurlux with Powerline Communication) which were specially designed for street light applications.

Even though there is the possibility of power line connections, most systems will still use a wireless connection or a network cable connection to the backbone. Most lamp control systems on the market currently use a mesh network for the communication between the street lights, and some kind of gateway which collects data from the connected street lights and sends it to the backbone database or a cloud storage solution.

2.3.3 Operation of heterogeneous environments

One problem which occurs in practice is that most cities will not use street lights from one manufacturer only. There will be all different kinds of street lights from various manufacturers in use. And every manufacturer uses its own type of wireless connection between the street lights and its own gateway and backbone solution. This means that in a bigger city a lot of different control systems would be needed to manage the street lights. As this is not a very desirable solution, manufacturers started to think about a joined approach. This was the basis for the TALQ consortium. TALQ was founded by a number of manufacturers of street lights in order to establish a globally accepted standard for street light control interfaces in order to manage and monitor heterogeneous street light environments.

2.3.4 Example of a street light management system

As mentioned in the previous passage, there are quite a few different street light management systems from different manufacturers on the market. But in practice they are built up quite similar. The Swiss company esave AG has developed the system "slControl" which is sold them but also resold by street light manufactures under their own name.

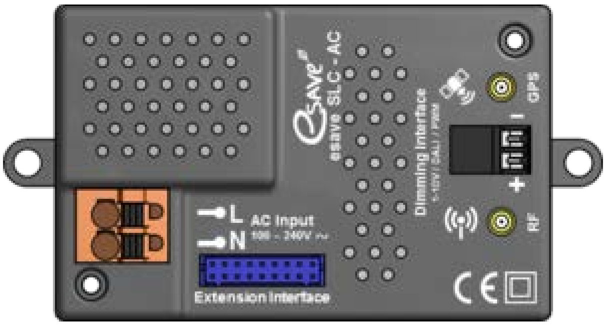


Figure 6: esave slControl – street light controller

The most important device is a small control unit called slControl which is build into every single street light which is desired to be monitored. It can control the light intensity, monitor the street lights function and automatically connects to a mesh network. Optionally the controller can also be equipped with sensors (PIR, radar) or a GPS module to be automatically positioned in the management software (this can also be done via GIS data). Up to 250 devices can be connected in a single mesh network. The network can be accessed and configured using an USB dongle and a laptop.

If you need a more centralized approach a gateway can be used. It connects to the mesh network, collects data from the network and sends it to a server solution via GPRS or a network cable. Figure 7 illustrates the different approaches. Per 250 street lights you will need one gateway. Several gateways can be connected to the backbone solution and allow you to manage and monitor all connected street lights. The database allows you to store all relevant information about each single street light like street light model, brightness, data sheets, contacts for spare parts etc.

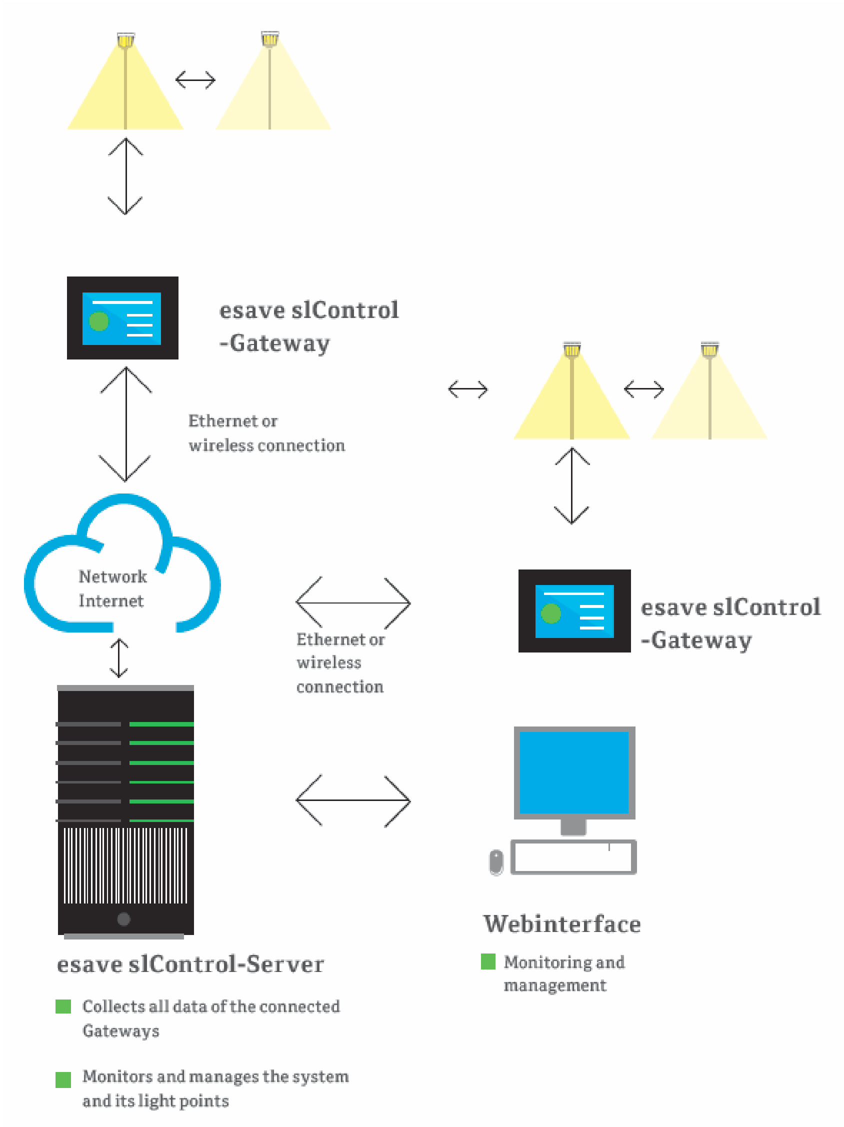


Figure 7: esave slControl – street light management solution

- **Sources**

a. Figures

Figure 1 Schreder S.A. (2014). *Schreder Teceo brochure.*

Retrieved from http://www.schreder.com/en-GB/products/teceo/

Figure 2 Tvilight B.V. (2016).

Retrieved from http://www.tvilight.com/citysense/

Figure 3 lixtec GmbH (2016).

Retrieved from http://abatec-group.stadtausstellung.at/lixtec

Figure 4 Comlight AS (2016).

Retrieved from http://www.comlight.no/technology

Figure 5 Philips N.V. (2016).

Retrieved from http://www.philips.es

Figure 6 esave AG (2016)

Retrieved from https://www.esaveag.com

Figure 7 esave AG (2016)

Retrieved from https://www.esaveag.com

b. Web Documents

Webpage RF Beam Microwave GmbH (2016). *What does Doppler sensor mean? What is FMCW Radar? What is FSK Radar?* FAQ-Section

Retrieved from https://www.rfbeam.ch

Manual DALI AG (2001). *DALI Manual.* Munich, Germany: Richard Pflaum Verlag

Retrieved from http://www.dali-ag.org/

Webpage Wikimedia Foundation (2016). *IEEE 802.15.4.*

Retrieved from https://de.wikipedia.org/wiki/IEEE_802.15.4

Brochure esave AG (2016). *esave slControl brochure.*

Retrieved from https://www.esaveag.com

Chapter – 3(a): Energy efficiency and lighting control

The energy efficiency of technical systems is defined as magnitude of energy consumption reduction to fulfill a task. The main influencing factors here are the effectiveness of the system for converting the energy used as well as the temporal optimization of the technical processes in order to achieve the result.

3.1 ENERGY EFFICIENCY AND DIMMING BY CONVENTIONAL LIGHT SOURCES

In conventional street lighting with primarily gas discharge lamps as light sources, the efficiency of the system is determined by the type of lamp and the luminaire materials used as well as the adaptation of the light output characteristics to the lighting task. The amount of the light (light intensity distributions) used to illuminate the visual tasks as well as the light output ratio of the luminaires form the essential parameters for the efficiency of lighting systems. Thus, the energy losses by generating of visible light (UV and IR components), the losses of ballasts and optical losses through filters and reflectors are essentially seen as system losses.

3.2 LIMITATIONS OF USABILITY OF CONTROL SYSTEMS BY CONVENTIONAL LIGHTING SYSTEMS

Conventional light sources permit only a limited use in dynamic control systems, because the lifetime and the technical characteristics of the gas discharge lamps are adversely influenced thereby. In addition in the case of reduced power operation (dimming) of gas discharge lamps, the lamp effiency is reduced compared to the full power operation. The losses of the impedances, which are mandatory used for the current limitation of the gas discharge, remain virtually at the same level like in non dimming mode.

Light sources based on gas discharge also require up to 30 minutes to achieve their full luminous flux. This is especially given for fluorescent and compact fluorescent lamps. A re-ignition of the metal halide lamps after short supply voltage interruption is only possible with voltages of more than 10 kV or after a cooling pause of approx. 3 - 10 min. Special sockets for high ignition impulses are necessary for this purpose.

About the above reasons, the conventional street lighting systems limit solutions to increase efficiency based on free adopting the light level to users needs. Therefore energy saving potentials are exploited by switching off lamps in multi-lamp systems or every second light point.
In single-lamp systems, especially in the case of high-pressure sodium lamps, which are still the most frequently used lamp types in street lighting, impedance transformers are usually used to achieve an increase in efficiency at times with low traffic intensity. In this case, the following fixed power reduction steps can be realised:

Lamptype	full power of system [W]	reduced power of system [W]	rel. reduction [%]
HPS 50 W	61	41	32,8 %
HPS 70 W	88	58	34,1 %
HPS 100 W	123	84	31,7 %
HPS 150 W	181	97	46,4 %
HPS 250 W	285	133	53,3 %
HPS 250 W	280	125	55,4 %
HPS 400 W	429	215	49,9 %

Fig.13: Table 1: dimm steps for HPS lamps by usage of impadance converter

Asides from these technical disadvantages of conventional lamps to use in intelligent control systems, the normative background did not motivate the dynamic adaptation of the lighting levels to the traffic intensity. After the publication of DIN EN 13 201 in 2004 the number of users was taken over as an influencing variable to determine of the recommended lighting level.

3.3 ADVANTAGES OF LED LUMINAIRES

In consequence of technical developments at the field of LEDs and their use in public lighting systems following advantages concerning energy efficiency are achieved:

- Increase of energy efficiency of led lamps
- Decrease of system loses of luminaires (decrease of visible light ratio, increase of ballast loses) Steigerung der Lichtausbeute der LED-Lampen
- Possibilities of continuously power adjustment
- No light output efficiency by dimming
- Further possibilities for optimizing the light distributions
- Possibilities of power reduction independent of electrical networks

Chapter – 3 (b): Energy management and "Energy Management Systems", ISO 50001:2011 in Municipalities

An understanding of energy use throughout the organisation can reduce the cost of energy. Generation technologies, fuels, energy measures, audits and contractual opportunities can be assessed and implemented as part of a comprehensive energy management approach. When combined with energy efficiency measures, the optimisation of supply and on-site generation technologies could yield dramatic improvements in performance (municipality's performance). Managing the use of energy, maximum demand, energy "self-generation", and other aspects of electricity contracts can yield substantial savings. The rising costs of energy have municipalities looking for opportunities to reduce costs.

"Energy management" is a term having a number of meanings but is mainly concerned with the one that relates to saving energy in businesses, public-sector/government organizations, and homes. In our case, this term is closely connected with its using in municipalities as the report debate about using of energy management in municipalities across the Danube region. The implementation of energy management provides support enabling municipalities (MU) to establish the systems and processes necessary to improve energy performance, including energy efficiency, control of energy use, consumption and – increasingly production of energy, mostly from renewables.

Energy management is the key to saving energy in every organization in the world. Much of the prominence of energy saving follows from the global need to save energy - this global need affects energy prices, emissions targets, and legislation, all of which lead to several griming reasons why municipalities should save energy at their buildings specifically.

Energy management is a system bringing many benefits through its effective implementation.

- Enabling significant savings – Municipalities that have taken a strategic approach to energy efficiency often find project opportunities with attractive payback periods and ongoing reductions in energy expenditure.

- Reducing exposure to future energy price increases – Energy efficiency improvements offset these costs, making municipality less vulnerable to future price increases.

- Reducing greenhouse gas emissions – managing energy use is the way to minimise greenhouse gas emissions.

- Reducing maintenance costs – Energy efficiency actions can foresee problems before they occur and therefore reduce the "one-off" costs.

- Ensuring corrective and preventative actions with workflow through to completion.

- Recording legal requirements, energy policy, Audit management – both energy and management system audits – with triggering of action through workflow.

- Controlling energy targets and objectives, management representative appointment, Nonconformities, corrective action, preventive action. Prepare basis for municipal energy audits.

Whilst energy management has been implemented in larger companies (and their buildings) for a long time, it has only started catching on in municipalities in previous decade mainly. Most municipalities aren't even aware of the term, and take more of a randomly, crisis approach (responding when the problems in buildings occurs, such as replacement of heating source and etc.) to reducing their energy consumption, mainly in Eastern Europe countries. But the monitoring and systematic approach used by energy management is just as effective in the municipalities as it is in companies.

In an effort to reduce energy costs and greenhouse gas emissions, many municipalities across the world have considered or implemented energy management in recent years seeing an use of alternative energy sources or generation technologies such as co-generation plants, solar systems (roof-mounted), heat pumps and many other technologies, off.

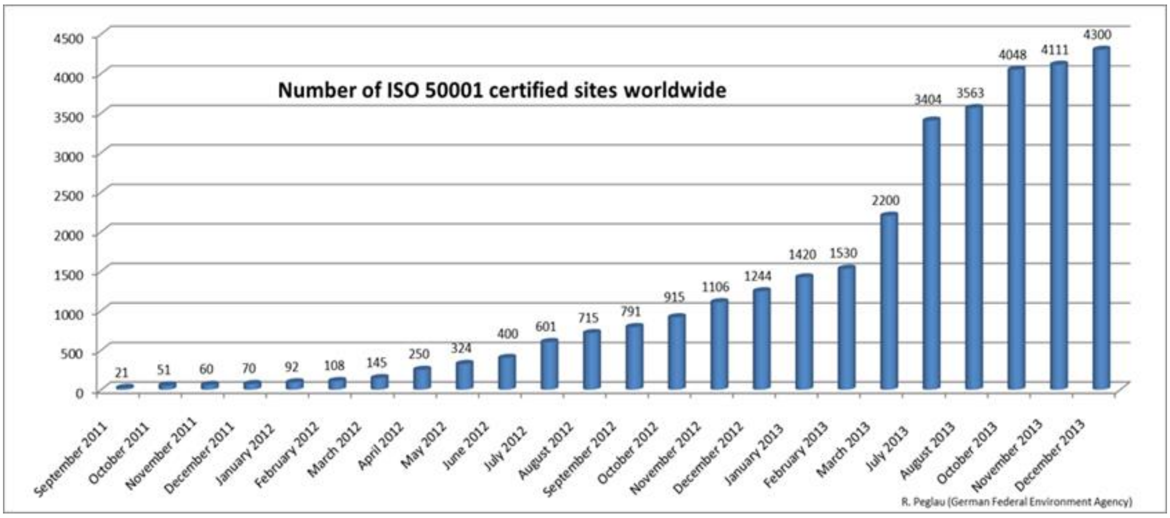
Public lighting is an indivisible part of energy management in every municipality. Without systematic approach and monitoring, public lighting will never be efficient from the economic and social point of view.

3.1 ENERGY MANAGEMENT SYSTEM

„Energy management system" – EnMS in accordance with ISO 50001 is based on the management system model of continual improvement also used for other well-known standards such as ISO 9001 or ISO 14001. This makes it easier for municipalities to integrate energy management into their overall efforts to improve environmental/energy management.

The EnMS is a proven framework for industrial facilities, commercial facilities, or entire organizations and municipalities to manage energy—including all aspects of energy procurement and use. An EnMS establishes the structure and discipline to implement technical and management strategies that cut energy costs and greenhouse gas emissions—and sustain those savings over time.

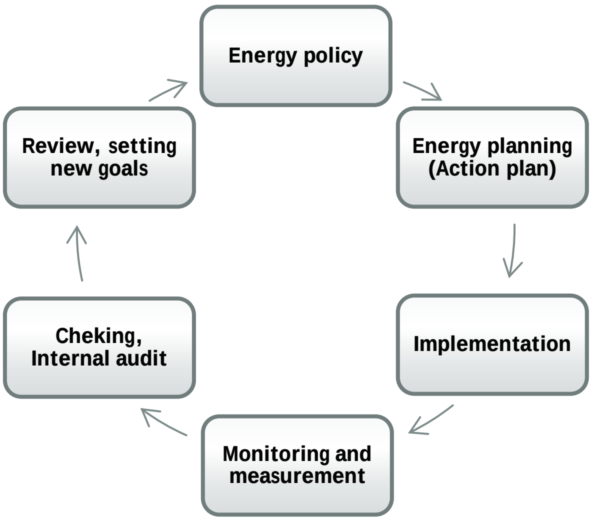
The number of ISO 50001 certifications are raising steadily, as illustrated in figure below.



Source: Online, https://dqsus.com/what-is-the-iso-50001-energy-management-standard/

It is important to mention, that figure above states the implementation of ISO regardless type of the organization (covering companies, municipalities as well). In case of municipalities, the share is rather low (reaching 10 %) and the implementation of EnMS in municipalities across the Europe is about 80 implementations in 2014.

The purpose of EnMS is to enable organizations to establish the systems and processes to improve energy performance, including energy efficiency, use and consumption. This International Standard is applicable to all geographical, cultural or social conditions. EnMS specifies and guarantees requirements, upon which an organization can develop and implement an energy policy, and establish objectives, targets, and action plans which take into account legal requirements and information related to significant energy use. EnMS can be tailored to fit the specific requirements of the organization, including the complexity of the system, degree of documentation, and resources and etc. The International standard is based on the Plan-Do-Check-Act (PDCA) continual improvement framework and incorporates energy management into everyday organizational practices.



Plan	Conduct the energy review and establish the baseline, indicators, objectives, targets and action plans, as well as energy policy.
Do	Implement the energy management action plans.
Check	Monitor and measure processes and the key characteristics of operations determining energy performance, report the results.
Act	Take actions to continually improve energy performance.

Based on these principles relevant for each organization/municipality (appropriately public lighting or every single pole/luminaire) energy management can be set up distinctively to ensure energy savings, reduce of maintenances or other important characteristics (e.g. security, social acceptance and etc.).

Measurement and monitoring of key parameters is an integral part of energy management, including public lighting. In chapter below, the issue of measuring and monitoring is detailed explanation with regard to public lighting.

3.2 MONITORING AND DATA MINING FOR DYNAMIC LIGHTING

Data mining (or measuring of consumption) and monitoring of key parameters is an element expectation to implementation Energy Management (EM) successfully. The complex sets of correct and objective facts in the required details are the point of data mining. The measuring of key quantities is necessary for the realization of all activities of EM which are doing after.

Monitoring is a set of activities checking the aim of Energy Management (in our case a public lighting). The result of Energy Management should be numerical details, verbal records, evaluations, and etc.

Monitoring included checking of:

- Energy consumption and coherent expenses,
- The other indexes of energy performance,
- Parameters of public lighting (a number of active users, temporal schedule etc.),
- Parameters of the measuring instruments (the identification of measure, current service and its changes etc.),
- realized actions (exchange of luminaires, actions which influenced the energy consumption, light intensity etc.),
- and the next selected indicators.

The monitoring without the analysis is functionless as well as the analysis without the monitoring. This is the answer either to a question if the monthly or annual data are sufficient for management, or if minute data from every single luminaire is needed. The level and scope of monitoring and management rise from the needs and the purposes. Dynamic public lighting without high level of monitoring and efficient management and control is slight and waste of municipal budget.

Monitoring includes:

- Basic review.
    - The key is practising basic energy consumption which is the fundament of long term process by monitoring of consumption; the energy consumption can evaluate the new trends.
- Parameters and indicators assessment.
- Continual measuring.

3.2.1 Measurement

Within the frame of energy consumption measurement and the further indicators it is necessary to have actual information about the number, type, statement and other significant characteristics of eletricity supply points (each luminaires) at every moment, information about the location including.

3.2.1.1 Electricity measurement

Two types of electrictity metering facilities are in use:

- Legally controlled metering facilities which are used to bill organization for individual measured utility usage.
- In other case there are utility submeter (mainly informative). These meterings are used for detailed specification and partition of consumption, control, checking etc.

Legally controlled metering facilities have to conform to prescribed legal metrological requirements. These requirements set the conditions which have to be respected either by supplier or final customer. Issued certificate confirms that the measuring data are always in toleration of allowed metering inaccuracy. **The final customer can refuse the billing without the valid verification.**

The types of the electricity metering are the most often set by law or local ordinance by individual countries. In most cases, there are two types of metering:

Metering A	Interval metering with daily remote data transmission, continuous evidence of median active and reactive power. Metering is provided by metering facility directly.
Metering B	Interval metering with other than daily remote data transmission (minute transmission or other appropriate), continuous evidence of median active and reactive power. Metering is provided by metering facility directly or by other utility submeter.

In most cases, the use of pulse outputs or providing data via other communication interfaces is probibited without the permission of the TSO or DSOs.

3.2.1.2 Other data measurement related to dynamic lighting

The special data could be measured by help of different methods, meters and detectors. Public lighting control/set up can be derived from various characteristics: Movement and User density, Lightlevel, Weather/climate data and etc.

Various sensor technologies are available to measurement. Each technology has its own advantages and applications in public space (Passive Infrared (PIR) Sensors, High Frequency sensors (HFS), Intelligent high frequency sensors (IhFS), Ultrasonic, Camerasensors). Sensor technologies are described detaily in the chapter „Sensor technologies“.

3.2.2 Data mining for dynamic light control

For most outcomes of energy management are data in the monthly or weekly period quite sufficient. In the case of public lighting the current data are needed at one-minute intervals usually. For the public lighting metering and control it is appropriate to provide remote control metering, or a higher degree of energy management, eg. the energy dispatching. These allow selected technical equipment operated remotely.

The corporate practice the automatic tracking is more frequent. In instance where it is installed, it is usually a sophisticated system fully integrated into the management system. This makes it possible to maximize the use of the data and gain control over the energy intensity of production and other processes. An example of such industrial system as SIMATIC or ENERGIS.

3.2.2.1 Remote monitoring technologies

Most remote monitoring and management technologies of energy data combine of the basic hardware, system software, data processing and data visualization.

However, there are also solutions for measuring of energy values here which transmit data via a application programming interfaces (API) from which data can be taken either to any software for energy management or variety of individual applications can be built on these basis. It is an advantageous solution particularly with regard to the emerging concept of Smart City which should be based on open data.

Automatic meter reading

Large number of automatic meter readings or similar technical equipments exist on the market. However, for effective management of specified meters or sub-meters a substantial choice of a specific technology is not crucial in the first step. Definition of clear concept must be foregoing.

A key task is the organization of the whole concept of monitoring and data evaluation. Either given to the level of cost associated with the installation of automatic meter readings or in especially to the operating costs of the system in the long term, is necessary to carefully consider the reasons why organization want to install the system what potential benefits can be expected, and consequently how this system is worthy to operate.

This concept should answer questions listed as follow:

- Why is the system installed?
- What is expected from the implementation of the system?
- Will the Automatic meter readings be implemented in all gauges?
- Who will be responsible for the overall system for managing, maintaining and data evaluation?
- How much cost the whole system (including investment and operating costs)?

Initial costs consist of the costs of the technology, installation and commissioning. The technology development will reduce these cost in the future and therefore automatic meter readings will be standard. The cost of installation and commissioning of the system may constitute more than 50% of total cost at the moment.

The cost of the automatic meter reading depends on the type of technology and ranges between € 200 to 500 per utility meter or sub-meter. Annual operating cost range between € 40 to100 per utility meter or sub-meter.

The key parameter of the sustainability of the monitoring system will always be operating costs. If a long-term operation of the system is considered, the close attention must be applied. Various technological solutions entail different operating costs and in each situation it is necessary to consider the most appropriate solution, based on the number, type and placement of metering facilities, the total number and distribution of objects, and also based on environmental conditions, as the surrounding area, the presence of buildings, terrain or overall coverage.

3.2.2.2 Data transmission

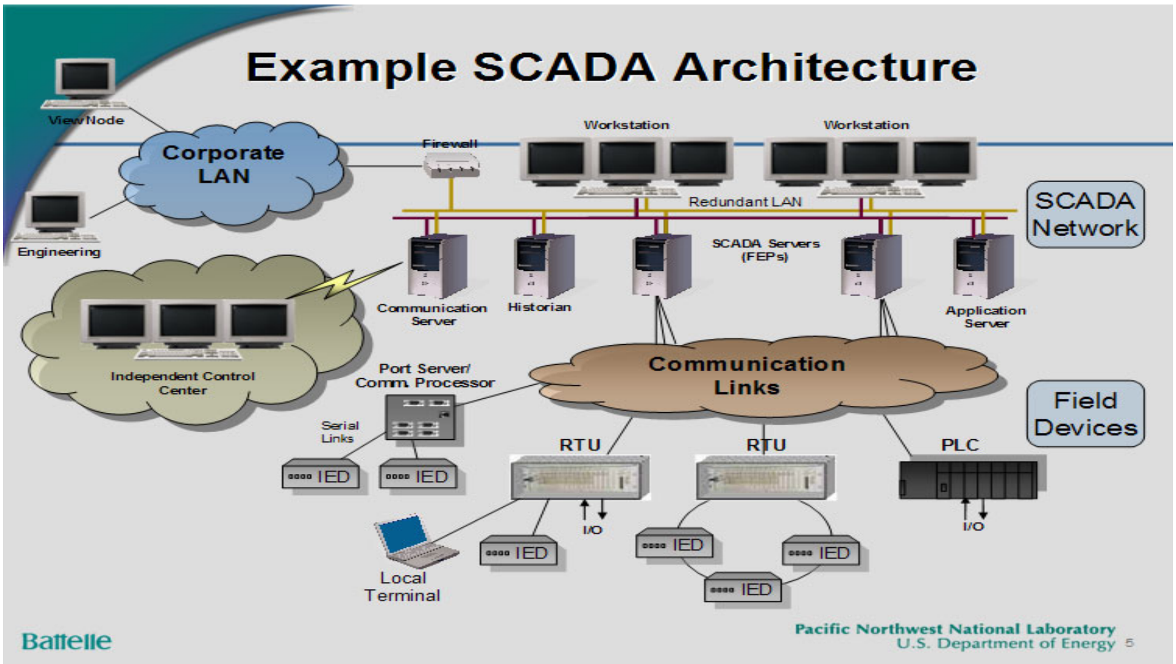
Data from the meters and sub-meters can be obtained by direct metering, passing through the TSOs or DSOs, by installing its own meter readings or installing parallel sub-meter, respectivelly.

In the case of electricity metering, the two electronic systems with a common ground is not allowed by TSOs or DSOs (must be galvanically isolated) and therefore the opto-isolator is in used (e.g. Optocoupler).

For remote data transmission itself is almost always use the internet with some exceptions HDO type or otherwise protected data transmission. Before the internet transmission usage, the wire, radio transmission using GSM or wi-fi can be used for primary data transfer.

System based on M-bus technology

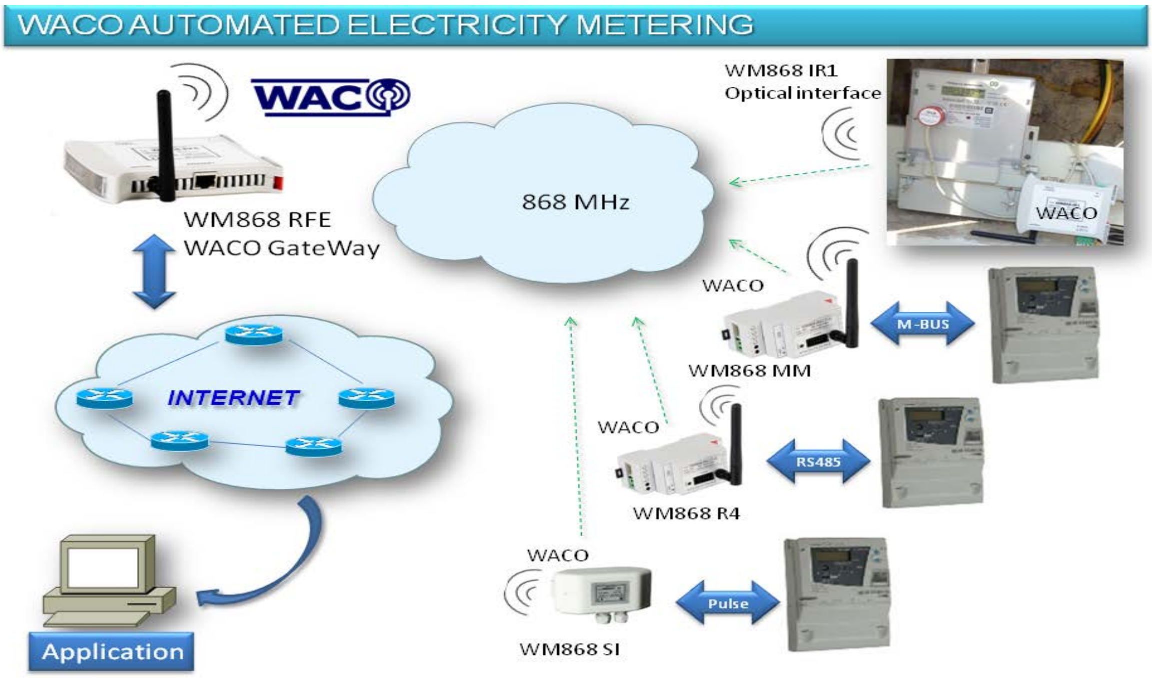
One of the fundamental technologies using m-bus is a SCADA (Supervisory Control and Data Acquisition), ie. supervisory control and data gathering. SCADA is not full-featured controling system but focuses rather on the level of the supervisor, eg. Dispatcher. Generally, this is a software functioning above the real control system, eg. PLC (programmable logic controller) or other hardware devices.



Source: What are differences Between SCADA and HMI, Retrieved from http://www.ooshutup.com/what-are-differences-between-scada-and-hmi/

Radio-controlled systems

One of the successful systems for the transmission of data (and controling potentionally) ist he the system WACO (Wireless Automatic Collector). This radio-controlled technology for remote metering operates in free 868 MHz frequency band. Using WACO modules all meters can be controlled with M-BUS interface, RS-485 or pulses.



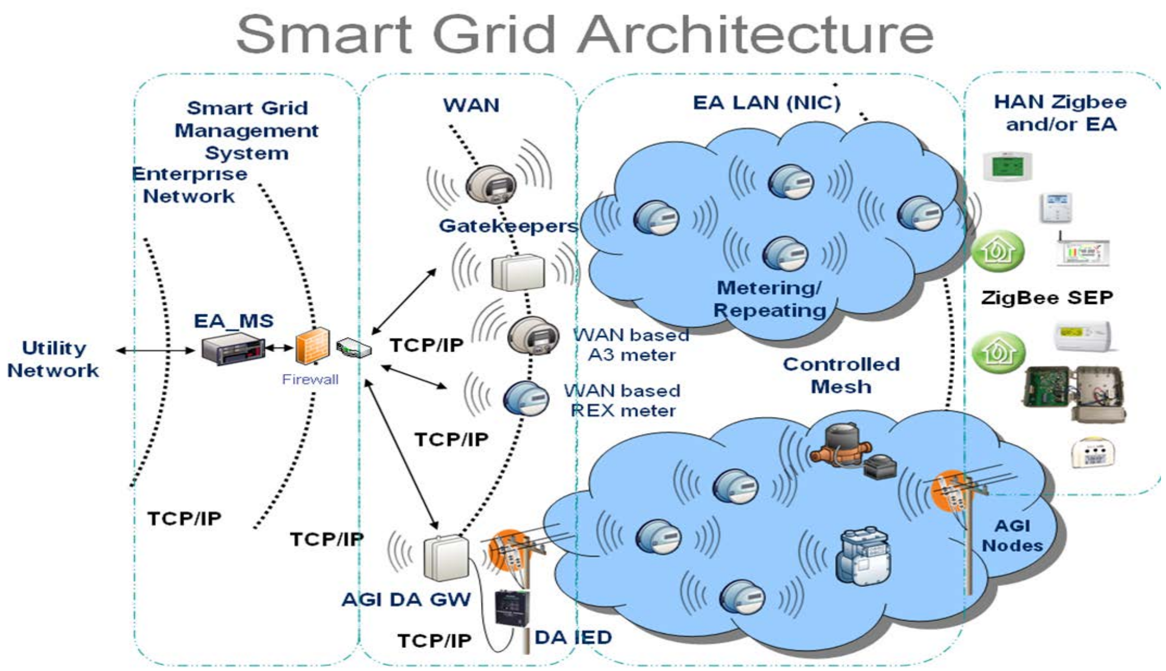
Source: Wacosystem, Scheme of Wacosystem, Retrieved from http://www.wacosystem.com/cs/waco-system/description.html

Example for Radio control systems related to dynamic lighting	
CZE	Monitoring and operation of street lights is ensured by wireless system StarSense Wireless system. This complex system consists of two fundamental sections: Segment Controller Kit (SC) and Outdoor Luminaire Controllers (OLC). Its ensure: Remote control of each luminaire unit online (CityTouch), Setting power for different levels of luminaire, Available current information about luminaire condition. OLC system – the device is placed on top of each luminaire UrbanStar (each lamp has an unique code). The device controls combination luminaire – ballast and the communication is ensured on radio frequency. The system monitors current

	measurement such as the power supply, voltage, energy consumption and the amount of lighting hours. In case of deviations from established parameters, the system sends an error message to the central unit. SC Kit – the device consists of several components (central control unit CPU, battery for CPU, radio module, antenna, power cable and SB and UTP cables) which monitor and control all the OLC units. Information are sent to CityTouch Software. Central administration CityTouch System – the system is used for failure detection as well as effective maintenance planning. It uses individual settings for each luminaire unit. The system works as online web service, the app is based on GIS.

"SMART grids"

The so-called smart grids are currently based on radio data transmission. The basic parameter and overall concept of the "smart city" is an open data access. Compliance with this principle a great development of applications can be assumed, especially for data visualization which are within the smart grid publicly shared (in certain cases with security restrictions).



Source: Joey McDonald, Smart Grid Network, Retrieved from http://jmacism3004.blogspot.cz/2011/04/smart-grid-network.html

To ensure sub-meters' communication such as a sub-meter pulse counter is as an appropriate solution ofte choose APIs or any "thin clients" standardized interface, respectively. This principle is common to the main concept of the creed SC, i.e. sharing open data.

Bus system EIB established association of leading companies in the field of electrical installations in Europe, European instalation Bus Association (EIBA). It is a decentralized installation control system for building equipment, enabling the measurement, control, switching on and off, monitoring and control of machines, devices and equipment in buildings. EIBA associations and major world manufacturers association founded KNXA (Konnex-Association) and began to introduce a new standard KNX. This standard is backward compatible with earlier products labeled EIB. The solution can also be wireless (KNX RF).

Within the Europe there are a number of concepts, inter alia:

- LoRa Alliance™ Technology.
- SigFOx.

3.3 DISPATCHING FOR DYNAMIC LIGHTING CONTROL

Dispatching enables the active management of dynamic public lighting through control of steering controls. But even here there is a need to distinguish between the supervisory dispatching and managing dispatching. Supervisory dispatching monitors only individual "queries" to remote gauges and evaluate the parameters needed for evaluation, core role of such monitoring is watching emergency situations, especially break downs.

For the purposes of managing dynamic public lighting is essential managing dispatching which ensures collection of data, evaluation, regulation and optimald day-to-day control.

Source: Esonic, Řídící systémy a vizualizace, Retrieved from http://www.esonic.cz/cz/ridici-systemy-a-vizualizace

Its appropriate for the organization to define standards that will be requested and implemented gradually. The purpose is to ensure long-term systems compatibility. Each of the individual dispatching should (at some level) be either able to communicate with a superior system of management or with others dispatching on other devices, and in particular the acquired systems should always be connectable with current MaR systems (metering and regulating devices).

Examples	
CZE	**CityTouch System** Central administration CityTouch System – the system is used for failure detection as well as effective maintenance planning. It uses individual settings for each luminaire unit. The system works as online web service, the app is based on GIS.

Chapter – 4: Control Regimes

4.1 STATUS QUO OF USED CONTROL SYSTEMS FOR DELAYED DIMMING AND SWITCHING

Conventional control systems for street lighting are mainly used for the purpose of switching on and off the lighting systems and simple adaptations of the lighting level to the traffic volume. The decisive factor when choosing of the control technology is whether the lighting system has an independent power supply. In this case, the control elements are usually installed in switchgear or control cabinets and can control various switching mechanisms. If not, stand alone solutions are necessary.

The simplest control technology by existence of a separate lighting network is realized by time switches. These usually have an astronomical year calendar and switch on and off the connected lighting points at fixed times. However, no further influencing parameters like weather or traffic density has an effect on the switching times.

Stand alone systems

If the street lighting systems are directly connected with the public power supply, then switching can carried out with stand alone solutions. In this case the outdoor illuminance will be detected by photoelectric sensors and generate switching signals by given levels. The main disadvantage of this strategy is the possible different switching time of neighbouring lighting points.

Ripple control systems

By control technique which is used in the most conventional street lighting systems the control commands are initiated by voltage harmonic waves, which are superimposed on the supply voltages. On the receiver side after the detection of these harmonics, commands will be generated to actuate of relays. In this way, either by switching on or off of individual lamps or luminaires or by targeted tapping of ballasts (impedance transformers) the power reduction takes place.

Long wave systems

In recent years long wave control systems have also been used as a control technology for street lighting systems in Central Europe (Fig. 1) . In this technique, the control commands are generated in the form of long waves and are forwarded to receive-sited decoders for switching commands.
Lightsensors spread over the control area detect the switching time. These data are then forwarded via secure connections to the central computer of the operator (long wave antenna). After receiving the switching signal requests, the operator generates the long wave signals with specific frequencies for each city. At the receiver site a receiver antenna is required on a control cabinet or several lighting points. The received long wave signals are used by decoders to move contacts to activate the target switching operation (on/off, dimming). This one way control systems allows also dimming scenarios in steps and is particularly suitable for larger lighting systems without a separate lighting network.

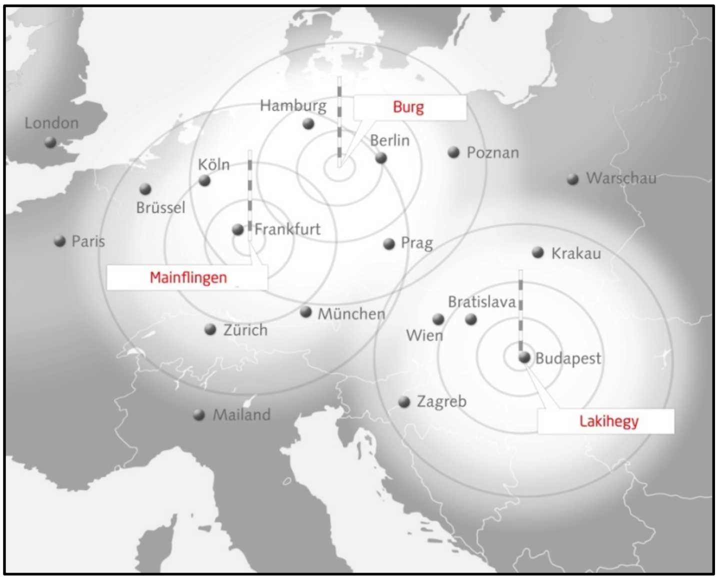


Figure 1: Applications area for long wave control systems [27]

Wireless control systems

In the case of the wireless control systems of street lighting, the control signals are transmitted via Internet connections to an on-site segment controller. This component then controls the surrounding luminaires wirelessly via luminaire controllers. The so-called mesh network, is installed automatically between the luminaires and the segment element, ensures a functioning communication network. Even if single luminaires fail. In addition his function as a control system, this system makes it possible to reduce the power of the system as well as further possibilities. A big advantage is that the line-bound disadvantages of Powerline technology are excluded.

Thus, wireless control systems, with the abovementioned characteristics of the LED lamps, form the technical basis for the realising of dynamic control systems.

Figure 2: Princips of function of a wireless controle system [28]

Widely applied algorithm scenarios and innovative algorithms
Algorithms used by conventional street lighting systems

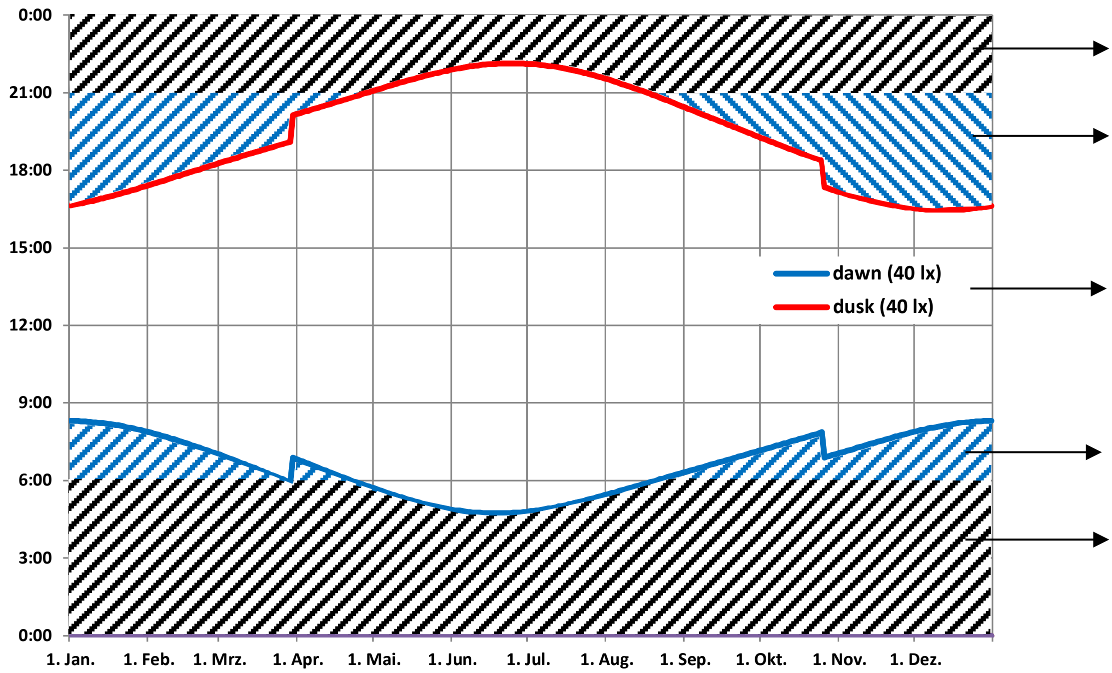


Figure 3: Yearly regimes of dawn and dusk in Berlin

In Central Europe, the average operating time of lighting systems is between 4.000 h - 4,200 h per year. The course of morning and evening dusk is illustrated in Figure 2. In the night hours, however, significantly less traffic is expected (vehicles, pedestrians and cyclists). According to valid standards, such as DIN EN 13201, the lighting level can be reduced in these low-traffic hours.

Figure 3 shows for Berlin the course of the morning and evening twilight times as well as the resulting lighting times in the during a year. For a threshold value of 40 lx, the lighting time is approx. 4.100 hours per year. In the predominant illumination period marginally traffic is expected. This applies particularly to over 18.00 hours the time between midnight and 5:00 h. In addition, the time between 21:00 h and midnight as well as 5:00 - 7:00 h periods in which significantly less traffic is to be expected. Usually, the time from dusk to about 21:00 h is the period in which the most frequent traffic arises and thus the highest lighting level is to be generated. On weekdays and weekends, there is a daily shift in the frequency of the traffic.

4.2 ONE STEP, MORE STEP AND DYNAMIC ALGORITHMS

In conventional lighting technology, the most common algorithm is the reduction of the lighting level by a fixed stage prescribed by the luminaire and/ ore lamp technology in a defined period of time during the night hours.

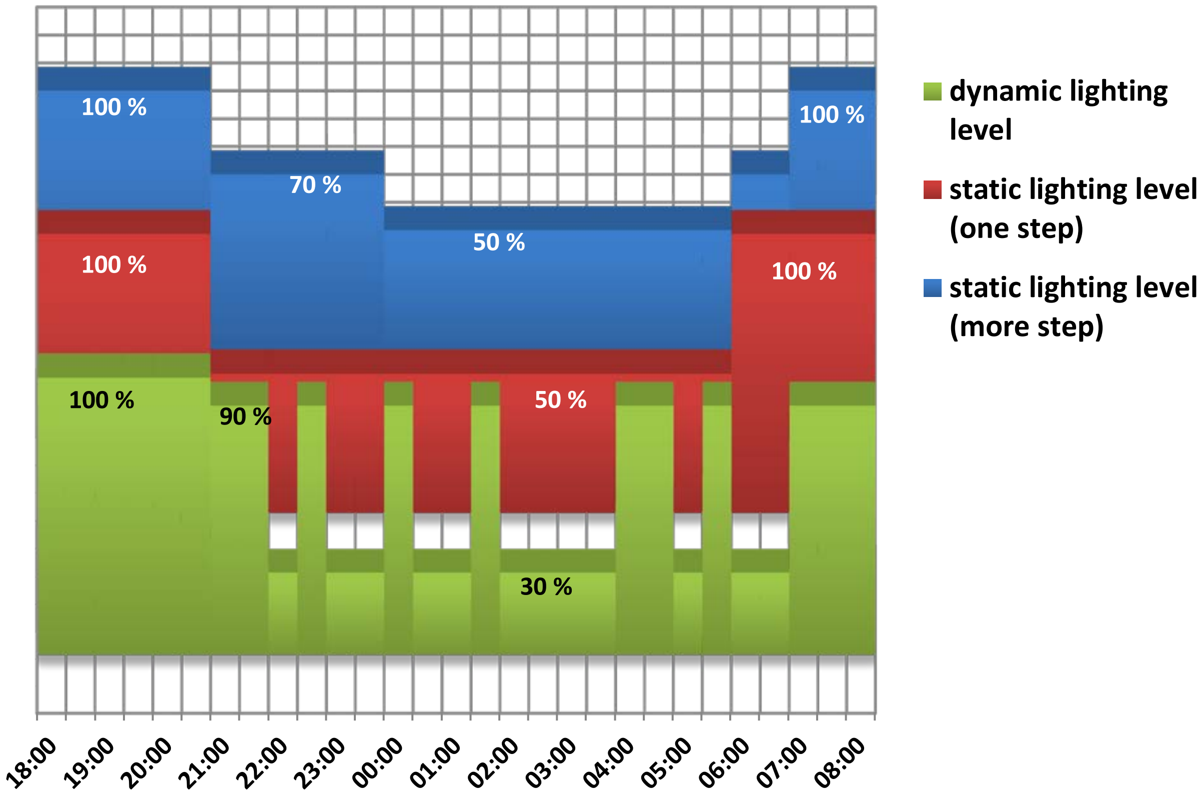


Figure 4: Control algorithms for public lighting

With the increased use of LED luminaires in street lighting as well as EU-wide efforts to save energy, more-step-algorithms have become attractive. The implementation is carried out either by means of the external switching commands (eg radio control or wireless systems) or by internal astronomical clocks in the luminaires. Above all, the overtime hours are used to minimize the lighting level. In these algorithms, no external influencing factors, such as the presence of a traffic users or other sensor signals, are taken into account.

With the technical realization of dynamic control systems in street lighting, which are based on two-way communication, the chronological sequence, as well as the consideration of further influencing factors for the adaptation of the illumination level, can now be freely selected. The following variables are relevant when defining the dynamic algorithms to be selected:

Dimming level in sleep mode: Minimum lighting level in the absence of traffic or other switch-on factors. When this level is determined, the identifiability (visibility) of the lighted section (safety aspects) plays an essential role and serves the remote orientation for the preferred use. In most cases a value of approx. 30% is used.

Dimming level according to detection: This defines the lighting level in case of detection or active influencing variables. The street lighting is usually operated at 100 %. However, it can be sufficient, for example, in low-traffic night hours, to use here only 80% - 90% of the full level.

Detection area: Is given by the lighting section to be switched on in the case of detection. This area can affect both the rear and the preceding light points. The rear lighting areas are designed for orientation and sense of safety, while the front lighting is used to ensure traffic safety.

Hold: This parameter is used to determine the duration of light level in case of detection. This time is mostly dependent on the type and speed of the detected user.

Ramp Up: Describes the temporal approach to achieve the dimming level by detectetion. In most cases the defined dimming level is realized without delay.

Ramp down: Describes the procedure when the hold time is out. Usually, the lighting level is reduced to the minimum value in a time interval of up to 10 seconds.

For the above parameters of dynamic control systems no normative or overlapping standards exist. Experiences are being collected in the first projects. These have as their main object acceptance aspects in combination with the possible maximization of energy savings. In order to achieve the maximal possible energy savings and thus the local and temporally optimized lighting of public areas, the user requirements must be taken into account. The following aspects are to be surveyed:

Controle options: Users prefer systems that they can control themselves. The control by presence must be designed intuitively and comprehensible for users.

Time sequences: Irritations due to rapid changes in the lighting level must be avoided for both users in the detection zone and for users who are outside of this zone, but can track the changes at a distance. It must in principle be assumed that the user expects a static lighting control system. Ddynamic controle systems could lead to increased failure messages.

Dimming levels: Here, the maximum levels must be adapted to the user requirements and traffic volumes. When defining the minimum level, the user must be motivated outside of the detection zone to use the dynamically controlled lighting path.

4.3 CONTROL STRATEGIES

Apart from the technical aspects of lighting control and its regimes, it is equally important to develop strategies for light control. These strategies should be ultimately based not only on the visual needs and demands but also on the non-visual, psychological aspects of light. This will ensure a dynamic lighting solution which meets the visual and non-visual needs of the users, is also widely accepted and at the same time energy efficient. Below is a short summary of the important topics and issues that could influence the development of control strategies in the coming years.

In addition examples of lighting control strategies and light management have been cited to provide an overview of the prevalent control strategies and means to control light.

Biological effects of light

- **Summary:** The effect of light on biological rhythm depends, among other things, on the intensity, duration, time of day, and the spatial distribution of light. Thereby, light can have both a fatiguing as well as stimulating effect, and can cause other physical symptoms. Studies have been investigating the effects of different sources of light on human biology through 24h cycle and findings are presented in this study. Also, it is noted that exposure to light at night may cause cancer.

[29] Christian Cajochen, Sarah L. Chellappa, Christina Schmidt

Circadian and Light Effect on Human Sleepiness – Alertness

☐**Summary:** It addresses the importance of the circadian regulation of sleepiness-alertness and sleep and highlight the impact of the light on sleep, neuroendocrine, alerting and neurocognitive responses. The emphasis is to increase our awareness of the importance of circadian and acute effects of both natural and artificial light for human alertness-sleepiness regulation.

[30] Till Roenneberg, Russell G. Foster (1997)

Light and the Circadian System

☐**Summary:**

Basic information about circadian clock are listed and explained in this article. It describes the areas that are affected by changes in the circadian clock and define factors by which organisms „reveal the phase of twilight“ and problems that occur if the phase of twilight is disturbed. An analysis of different light patterns is made for individual living organisms.

[31] USAI Lighting (March 16, 2015)

Retrieved from http://www.usailighting.com/circadian-rhythm-lighting ;

Circadian Rhythm Lighting

☐**Summary:** Advantages of creating an artificial light for human needs in closed and open spaces are listed. Health problems that can occur if circadian system is disrupted are mentioned as well. Also, LED technology is mentioned as a leading technology that can change the intensity and color of light. Picture of 24h circadian system is interesting to see as well.

[32] Scott Roos (2014)

Circadian Correct Lighting: The Time is Now

Retrieved from http://www.junolightinggroup.com/ ;

http://www.junolightinggroup.com/Whats_New/New_Products/Circadian_Correct_Lighting_The_Time_is_Now?alttemplate=newsArticle1

☐ **Summary**: The importance of including circadian lighting into lighting design using LED technology, luminaries and control technologies is stressed in this article. The emphasis is put on several facts that lighting designers and organizations should consider when implementing circadian system.

[33] Sei Ping Lau, Geoff V.Merrett, Alex S. Weddell, Neil M. White – Electronics and Computer Science, University of Southmapton, UK.

A Traffic-Aware Street Lighting Scheme for Smart Cities using Autonomous Network Sensors

☐**Summary:** This study proposes a real-time adaptive lighting scheme, which detects the presence of vehicles and pedestrians and dynamically adjusts their brightness to the optimal level. The proposed scheme is simulated using an environment modelling of road network, users, and a networked communication system – and considers a real streetlight topology of a residential area.

[34] Gabriel Villarrubia, Sara Rodriguez, Juan F. De Paz, Javier Bajo, Fernando De la Prieta, Juan M. Corchado – Universidad de Salamanca and Polytechnic University of Madrid

Smartlighting: System for management and monitoring street lights

☐ **Summary:** City lighting represents an important part of the maintenance and energy budget for many towns. For this reason, it is important to monitor and manage the energy consumption in order to reduce the consumption with a low impact to the users. The proposed system allows monitoring and managing of the lighting in order to reduce consumption and the costs of the maintenance and management. The system has been tested in a real environment and incorporates the software and hardware to carry out the needed functionality.

[35] Disano Illuminazione Cataloge

Retrieved from http://www.disano.it/

Street lighting managemnet systems

☐ **Summary**: In this catalogue, methods of management of public lighting that will contribute to reducing energy consumption and reducing management costs are described. The described methods are BIPOWER SYSTEM and REMOTE CONTROL SYSTEM MANAGEMNET.

[36] Rodrigo Pantoni, Cleber Fonseca and Dennis Brandao – Federal Institute of Sao Paulo and University of Sao Paulo

Street Ligting System Based on Wireless Sensor Networks

☐ **Summary:** This paper presents an application for urban networks using the IEEE 802.15.4 standard, which is used for monitoring and control of electric variables in a public lighting scenario. This application consists of an urban network, where sensors are coupled to the lamp posts or lighting points in order to control the lighting for these points and capture important information from diagnostics, operation and failures. Section 3 describes the system requirements, understanding which is fundamental to develop the control and to monitor application and routing protocols. In section 4 the solutions regarding the control and monitoring application are detailed. Section 5 presented the routing protocols strategies.

[37] OSRAM

Retrieved from https://www.osram.com/osram_com/news-and-knowledge/light-management-systems/product-knowledge/street-light-control/index.jsp

Street Light Control: Innovative Light Control

☐ **Summary:** These days there is a need for innovative solutions that can handle the technical and economic requirements of the 21st century. In this brochure, OSRAM is describing innovative light management systems: Street Light Control, an intelligent light control for outdoor areas.

[38] Schreder brochure

Smart control for efficient lighting

☐**Summary:** Major concern that require a quick answer is the reduction of public expenditure. In this brochure, Schreder is describing how smart control technology when implemented can reduce energy bills by up to 85%, improve maintenance and asset management and provide increased safety with enhanced well-being for citizens.

[39] Marta Kolasa (2016), UTP University of Science and Technology

The concept of intelligent system for street lighting control using artificial neural networks

☐**Summary:** Street lighting systems which are commonly used today are inefficient in terms of energy consumption, as they don't take into account actual current demand for lighting intensity. This paper presents a concept of an intelligent street lighting control system, which aims to improve energy efficiency by matching lighting intensity to weather conditions. In this study, an overview of state-of-the-art solutions of this type is presented, which is a background for the concept of the proposed intelligent system. In the paper selected preliminary experimental results are also shown.

Chapter – 5: Multi-Functional Luminaires and Future technologies

In Europe alone, around ten million street lamps will be replaced or repaired over the next few years. This modernisation now gives local authorities the chance to go beyond saving energy and costs and to develop innovative, digital urban infrastructure. Street lamps are becoming multi-functional masts: equipped with everything from public WLAN, emergency call functions, sensors for measuring pollutants and CO2, traffic flow measurement and control instruments right through to charging stations for electric vehicles, they are accelerating the digitisation of the urban environment. [9]

Today the luminaires can be fitted not only with multiple photometric engines for different light distributions but many control solutions; photocell and presence detection sensors can also be fitted in the same fixture. The next stage of design involves the integration of beyond light features like CCTV camera, loudspeaker, WLAN, EV charger, advertisement, emergency services etc.

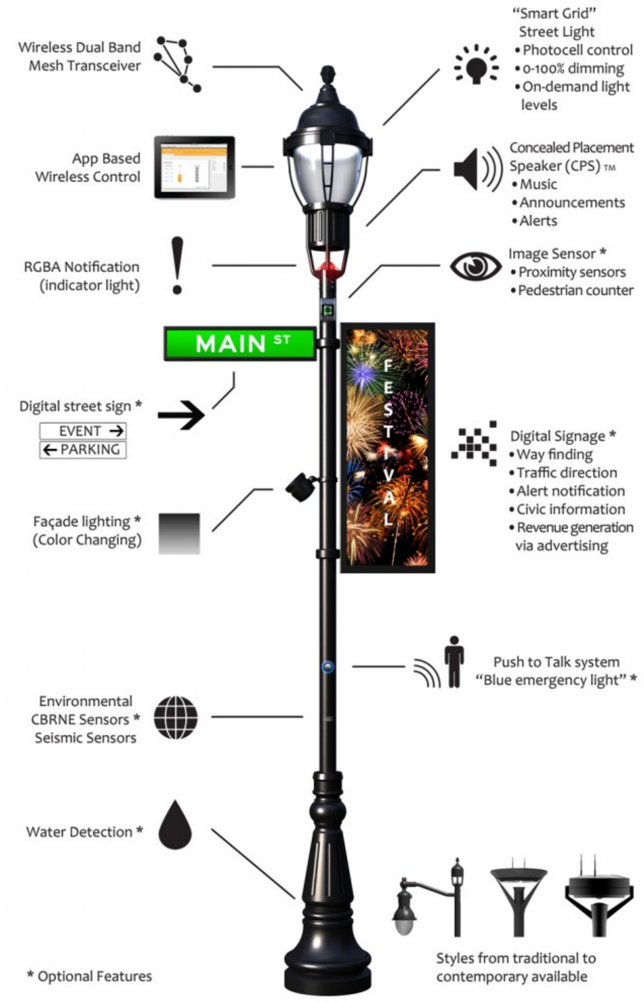


Fig.13: Example of multi-functional luminaires; Intellistreets. [18]

Fig.14: Modular multi-functional luminaires; Schréder. [19]

With the omnipresence of CCTV cameras, myriad of sensors ranging from weather, illuminance, luminance, traffic and so on, there is all of a sudden a deluge of information and data. In addition, the emergence of the 'Internet of Things' (IoT) has quickly transformed the way we live our day to day lives.

5.1 LUMINAIRE INTEGRATED SENSORS

These days fully standalone sensors can be installed in every fixture that operate in a wireless network. Connected movement sensor adapt public lighting it in real time to user needs The sensors analyse moving objects in the street and communicate amongst themselves to optimize public lighting.

The sensors can discriminate a car from a pedestrian or simply a branch movement. The motion detection relies on size and speed estimation. The sensors in turn then manage the power of LED's and regulate the light levels and light distribution.

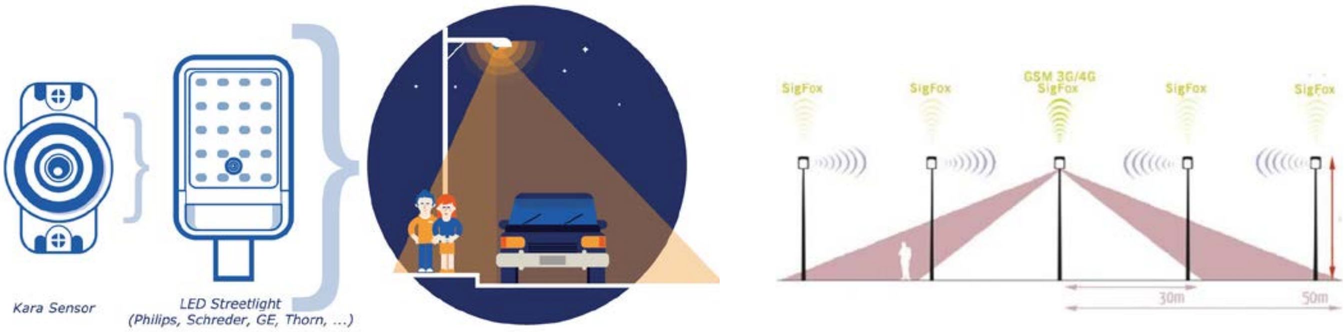


Fig.15: Standalone sensors; Kawantech. [20]

5.2 INTERNET OF THINGS (IoT)

The concept of IoT is simple, everyday objects will have network connectivity, allowing them to send and receive data across a network, whether that's wired or wireless. Some of the key features of the IoT are:

- Sensing — e.g., the ability to record environmental or physical inputs
- Efficiency — connecting devices can improve an otherwise manual process
- Networked — devices, or "things" are connected to a network facilitating them to send and receive data
- Specialised — the ability to customise technology and processes at a more granular level
- Everywhere — these connected devices surrounding us makes the IoT pervasive [21]

Sensors can detect motion, direction, footfall, ambient light levels, temperature, light output, colour temperature, quality and operating temperatures. On-board processors can locally analyse the data they receive or upload it to the central management system.

The cloud platform is the brain of the networks (ecosystem). The cloud platform can be designed to manage the high-velocity/high-volume transaction data from the on-premise environment and provide an extensible platform to develop applications and data visualizations. Some of the possibilities are:

- Energy management
- Lighting analytics
- Enterprise control

- Predictive maintenance

The heart of the smart lighting systems is scalable IT architecture. Below are examples of two successive principles of software architectures.

1. Development of a message-controlled architecture (message bus or event bus) according to the publish-subscribe principle with flexible expansion possibilities, e.g. with regard to the adaptation of further components and / or sensors.
2. Development of a consistently event-driven architecture (event-driven), with the possibility of an extremely energy-efficient implementation, since all communication is controlled exclusively by freely definable rules and events. The lighting systems are implemented as completely cyberphysical systems. [22]

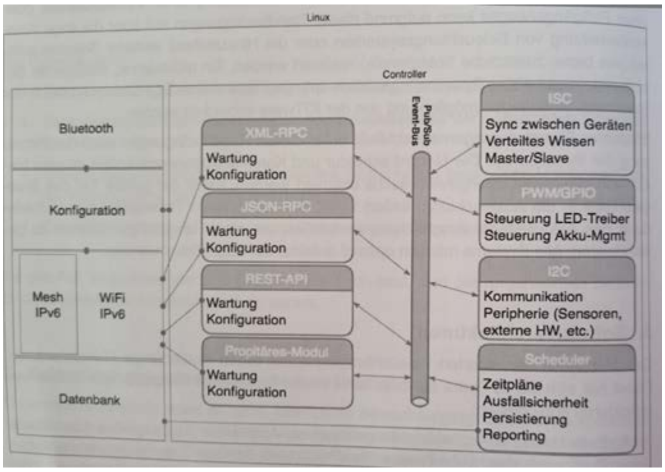


Fig.16: Example of software components of message-controlled intelligent lighting system; IOTware. [22]

A. DOLL (Danish Outdoor Lighting Lab):

   A smart lighting management platform changes the lighting scenarios, with dimming and controls.

   The IPv6/6LoWPAN management system allows each luminaire to become part of a network. Each can be monitored and controlled, and used for data transmission, for example, monitoring temperature. It anticipates the Internet of Things (IoT), where devices are connected over the Internet, and smart cities where data can be used not only for smart lighting but also for smart parking, metering, or traffic flows. [23]

B. Intelligent lighting, Pilot Project, Seoul, South Korea

   Two pilot projects have been installed in the city centre. The aim is to provide on-demand lighting with light levels varying based on the local traffic and weather conditions. [24]

C. Intelligent Lighting in Berlin

The intelligent wireless lighting network rolled out at Bundesplatz, in Berlin's district of Wilmersdorf, incorporates new LED streetlights and state-of-the-art sensor street lighting controllers.

The innovative street lighting solution delivers adaptive "light on demand", making the streetlights adjust their brightness based on real-time human presence. [25]

5.3. DYNAMIC POTENTIAL

The true potential of energy saving through LED technology actually lies in the use of control systems to control the light. "Significantly more energy can be saved in a Lighting installation, when it is operated by an intelligent lighting control system" [26]

Technology today offers new ways of communicating and interacting with light. Lighting control systems can roughly be defined into two categories: Time-schedule-based and real-time lighting control.

Time-schedule based dimming is still commonly used strategy in public lighting control systems [10]. The time-schedule based system work well when the pattern of traffic volume and its variation with time can be established and are based on experience and previous analysis of data. The light can be controlled centrally and can be adjusted to different dimming levels according to pre-set time schedule. The solution is easy to implement and inexpensive.

However, the most significant drawback of this system is its inability to adapt to real-time needs for light.

A real-time lighting control system on the other hand has the ability to react quickly to changing needs and demands. Nowadays, with increasing use of cameras, sensors, weather reports, police and emergency service reports it is quite easy to gather real-time information and to be used as parameters to control lighting.

5. REFERENCES

[1] LED in Public Spaces; LED- Lenses and Reflectors, Uwe Rabenstein; 2012

[2] LED Optics Explained; Buying Guides, LED Optics & Lenses (http://www.ledsupply.com/blog); 22.01.2016; Taylor Scully.

[3] Design of primary optics for LED chip array in road lighting application; Shang Wang, Kai Wang, Fei Chen and Sheng Liu; Vol. 19, No. S4 / OPTICS EXPRESS A716; Optical Society of America, 2011

[4] Iluminación con LEDs, CREE, Ing. Rafael Charro, 2014

[5] marinelifetech Blog; Beam Me Up Scotty!! – Beam Angle and LED optics Explained (Part 2); 2012

[6] http://www.preci-light.com/optics.php

[7] Sustainable Street Lighting, Master Thesis, Julian Diaz, Hochschule Wismar, 2010

[8] Bielawny, Andreas. Direct or Indirect: That is the question for optical configurations, LEDMagazine. 2009

[9] More than just light, The Quintessence of Smart Cities I Issue 19 - 2016

[10] Complex surface optics for the realization of dynamic-white illumination concepts; G. Spielberger, C. Knoflach, C. Reisecker; Licht 2016, KIT Publication

[11] Cities Alive, Rethinking the Shades of Night, Arup Publication, 2015

[12] Light for Oublic Spaces; Susanne Seitinger, Antonia Weiss, Philips Publication, 2015

[13] Lichtgestaltung mit LED, Prof. Dr. Thomas Römhild , Peter Schmidt, Architektenkammer Niedersachsen, 2012

[14] Multifunktionsleuchte für Hamburg Mönckebergstraße, T. Schlothfeld, Iguzzini

[15] CITYLED, SILL Leuchten.

[16] Street lighting in Wellington City, Making a case for adopting LED Lighting.

[17] Article, How LEDs could make Wellington Streets safer, LUX Review Magazine, 2015

[18] Intellistreets, http://www.illuminatingconcepts.com/intellistreets/

[19] Schuffle Product Information, Schréder Lighting, 2016

[20] Kara Smart Lighting Sensors, Kawantech 2016

[21] Gooee, 2017

[22] Smart, networked exterior lighting systems for future applications; M. Przewloka, B-A Mokroß, A. Lenhardt, H. Wörmer; IOTware GmbH; Licht 2016, KIT Publication

[23] Denmark heads for the bright lights, smart city (MAGAZINE), Caroline Hayes, Contributing Editor, LEDs Magazine, 2015

[24] Intelligent lighting for a smart city pioneer, Lighting Heritage Sites, Cities & Lighting (LUCI), No.2 2015

[25] Berlin unveils 'on demand' street lighting, LUX Review, 2016

[26] Intelligent road lighting control systems- Experiences, measurements, and lighting control strategies. Thesis, Liping Guo, Helsinki University of Technology, Dept. of Electronics, Lighting Unit, Espoo, Finland 2008

[27] Informations of the Operator EFR: http://www.efr.de/

[28] Productinformations OWLET Company: http://owlet-streetlight.de/en/

[29] Christian Cajochen, Sarah L. Chellappa, Christina Schmidt

[30] Till Roenneberg, Russell G. Foster (1997)

[31] USAI Lighting (March 16, 2015)

[32] Scott Roos (2014)

[33] Sei Ping Lau, Geoff V.Merrett, Alex S. Weddell, Neil M. White – Electronics and Computer Science, University of Southmapton, UK.

[34] Gabriel Villarrubia, Sara Rodriguez, Juan F. De Paz, Javier Bajo, Fernando De la Prieta, Juan M. Corchado – Universidad de Salamanca and Polytechnic University of Madrid

[35] Disano Illuminazione Cataloge

[36] Rodrigo Pantoni, Cleber Fonseca and Dennis Brandao – Federal Institute of Sao Paulo and University of Sao Paulo

[37] OSRAM; https://www.osram.com/osram_com/news-and-knowledge/light-management-systems/product-knowledge/street-light-control/index.jsp

[38] Schreder brochure

[39] Marta Kolasa (2016), UTP University of Science and Technology

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