



SOLAR-POWERED LED-BASED LIGHTING FACILITIES: AN OVERVIEW ON RECENT TECHNOLOGIES AND EMBEDDED IoT DEVICES TO OBTAIN WIRELESS CONTROL, ENERGY SAVINGS AND QUICK MAINTENANCE

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ABSTRACT

Aim of this paper is to illustrate and describe the trend of last technological innovations and new IoT-based devices employed in solar-powered LED-based lighting systems, in order to obtain energy savings, low maintenance costs and to offer additional services to the users or community. Technological developments, in the last years, have allowed the use of LEDs technology in many general illumination applications, from houses to commercial or outdoor spaces. LED lighting is projected to reduce related energy consumption of 15% in 2020 up to 40% in 2030; in this contest, solar-powered LED lighting facilities offer a significant contribution to obtain energy savings, together with substantial environmental and health benefits. Last innovations in nanotechnology and quantum physics have the potential to strongly increase the electrical power obtained from solar panels for feeding any portable device. Furthermore, the spread of Internet of Things (IoT) and the huge use of smartphones and related apps allow wirelessly to control and drive the LED-based lighting systems, that also can be provided with integrated sensors thus realizing new functionalities, an improved management of energy and new services for smart cities. Finally, systems made up of connected lighting devices could become data collection platforms that, making use of renewable energies, enable even greater energy savings referred to lighting and in general electrical facilities present in smart buildings or cities.

Keywords: renewable energies, LED lighting, wireless control, data monitoring, IoT-based devices, energy savings, sensors.

INTRODUCTION

Light Emitting Diode (LED) plays a fundamental role for energy saving and environmental protection in lighting industry. LED-based lights are up to 80% more efficient than traditional lighting sources such as fluorescence and incandescent lamps. Unlike of these which create light with filaments and gases encased in a glass bulb, the LEDs or organic light-emitting diodes (OLEDs), commonly referred to as Solid-State Lighting (SSL) devices, consist of semiconductor or polymeric materials that convert electricity into light. LEDs have been around for 50 years but until the early 2000s were used only in electronic devices as indicator lamps (Vitta *et al.*, 2012). Technological developments in the last two decades have allowed LEDs to be used first in signal devices, like traffic lights and exit signs, then in some limited illumination applications, such as flashlights, and now for many general illumination applications, from houses to commercial spaces up to outdoor lighting (Visconti *et al.*, 2011, 2012), (Costantini *et al.*, 2011).

Solid-state lighting is used in a variety of lighting applications because it offers many benefits such as:

- **long life:** the LEDs can provide 50000 hours or more of life, which can reduce maintenance costs (in comparison, an incandescent light bulb lasts approximately 1000 hours).
- **Energy savings:** white LED-based lighting systems provide three or more times the luminous efficacy (lumens/watt) of incandescent lamps. Colored LEDs are especially advantageous for colored lighting applications because optical filters are not needed.

- **Emitted light with better quality:** LEDs have minimum ultraviolet and infrared radiation and its light can be tuned to any color appearance.
- **Intrinsically safe:** LED-based systems are fed at low voltage (few tens of Volt) and generally are cool to the touch (compared to traditional lamps).
- **Smaller, flexible light fixtures:** the small size of LEDs makes them useful for lighting tight spaces. OLEDs are flat and flexible, allowing for unique applications.
- **Durable:** LEDs have no filament to break and can withstand vibrations.

SSL technology is demonstrating improved efficacy over conventional lighting sources and low prices that enable a payback within reasonable time periods. In addition to improved source efficacy, SSL devices can be more effective in delivering light when and where it is needed, representing an additional factor of energy saving.

As shown in Figure-1 which shows the lighting energy consumption forecast, LED lighting is projected to reduce energy consumption by 15% in 2020 and 40% in 2030, which, in absolute terms, is 261 teraWattHours or 3.0 quads saved in 2030 (DOE SSL Program, 2014).

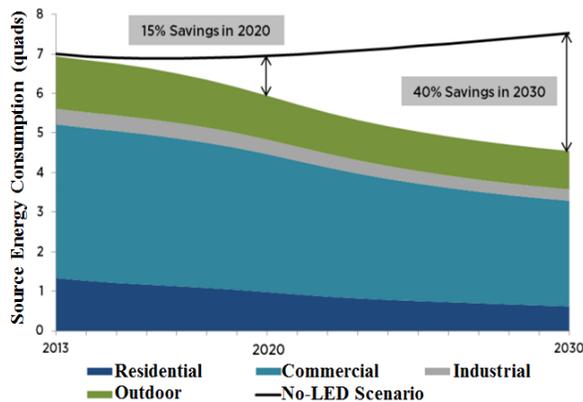


Figure-1. Lighting energy consumption forecast as predicted by the lighting market model.

As SSL technology has developed, it has become clear that the impacts of SSL will go far beyond energy savings alone. SSL-based facilities can bring to profound beneficial impacts on the environment, horticulture, livestock production, transportation safety, human health, and productivity. All of these benefits can be realized while saving significant amounts of energy compared to conventional lighting technologies. Furthermore, LED lighting manufacturers can choose to trade efficacy for cost, life-time, color quality, light distribution and other technical features. OLED technology is still in its infancy but it promises high efficacy and low cost, as well as new options for form factor and light distribution.

In addition, light control systems provide tangible benefits by improving lighting energy efficiency, saving energy costs, by respecting local rules relative to ignition timing and percentages (both mandatory requirements and best practices), so allowing to get numerous rebates and government incentives or financing.

ADVANCED LED/OLED-BASED LIGHTING SYSTEMS FOR OBTAINING ENERGY SAVINGS

The full efficiency of a lighting point is affected by light utilization, which represents how well the light generated from the luminaire reaches the target area and provides suitable illumination. For example, thanks to the small size of LEDs, an improved optical control and directionality can be obtained; conversely, the large size of OLEDs emitting surface in conjunction with low brightness and low glare can enable their use very close to the task area. For maximizing light utilization for both LED and OLED sources, it is required a move beyond the obsolete form factors such as those of the light bulb and recessed luminaire, toward form factors that maximize application efficiency as well as optical, electrical, and thermal efficiencies. New LED-based facilities for outdoor areas have demonstrated the ability to provide suitable illuminance levels using a significantly lower total emitted light respect to conventional lighting points that the new LED devices have replaced. This is accomplished through improved light distribution that reduces over-lighting in

the target area, improves illuminance uniformity and produces less wasted light falling outside the target area.

Figure-2 shows a specific example of improved light utilization of LED-based outdoor lighting facilities. A parking lot lighting is realized using Cree LEDs in each light point, getting 66% reduction of energy consumption compared with High Intensity Discharge (HID) lamps due to improved efficiency and reduced total light generation. In addition, a significantly larger area of the parking lot is illuminated much better, particularly advantageous for driver and pedestrian safety (Edmond, Cree Inc., 2015).



Figure-2. Improved light utilization of LED-based outdoor lighting facilities compared to HID light sources.

Furthermore, given the small size of LEDs, they can be combined with specially designed lenses to improve light utilization. Instead of a traditional spherical shape, specific lenses have complex, multi-curved surfaces without any prescribed symmetry. They precisely control light to achieve a desired energy distribution in the illuminated area. Each light ray emitted by LEDs mounted on a flat installation board is directed by corresponding lens to an appointed region as shown in Figure-3.

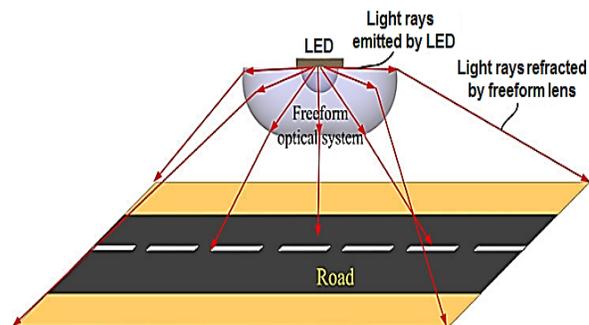


Figure-3. Properly designed lenses for improving light utilization of LED-based outdoor lighting systems.

Effective light utilization is very important also for indoor application, where OLEDs and low brightness



planar LED solutions can be employed; the low brightness and diffuse nature of these sources enables them to be used very close to the task area without generating excessive glare, enabling adequate illumination using less light, or conversely, more illumination without unacceptable glare.

Figure-4 shows two examples of SSL desk lamps sold by Workrite Ergonomics company, one LED (Figure 4a) and the other one OLED (Figure 4b). Both lamps deliver nearly identical brightness (106 and 108 footcandles respectively) at the center of the incident task area; the OLED desk lamp delivers its 442 lumens over a larger area, whereas the LED's 306 lumens are much more concentrated as shown in Figure-4a.

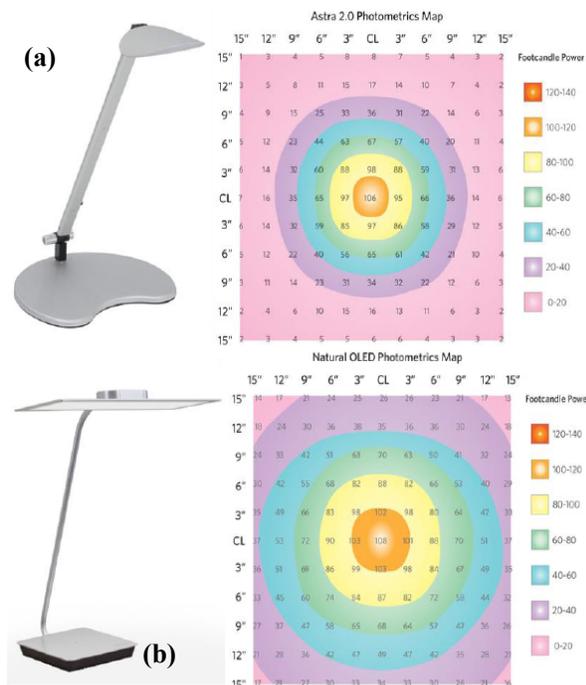


Figure-4. Two examples of LED (a) and OLED (b) desk lamps that deliver their lumens over different areas.

Another aspect of light utilization is the use of smart electronic controls to minimize power consumption of the light source without affecting the lighting application. LED and OLED sources are inherently controllable (i.e., brightness dimmable and on/off turning), which makes them compatible with the full range of lighting controls.

Acuity Brands, one of the world's leading providers of innovative lighting systems, has announced the development of Duet SSL™ Technology, blending the use of OLED and LED light sources in the same luminaire, optimizing both to produce refined photometric performances, improved lighting quality and cost effectiveness. As shown in Figure-5, downward-facing OLEDs are incident on the task surface, while LEDs face upward and provide general illumination that can reflect off from the ceiling to light the space. This combination

utilizes the soft diffuse glow of OLEDs where the light interacts with the user whereas the LEDs provide cost-effective supplementary lumens to fully light the space.

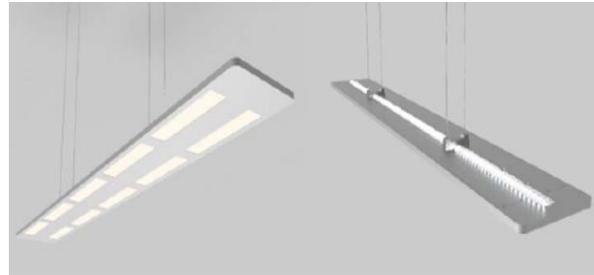


Figure-5. Duet SSL™ technology applied to new smart luminaire with OLEDs for producing downward illumination to light the task area and on the right, LED devices on top to produce light that fills the room.

These examples provide just a perspective of how SSL technology can improve lighting performances and the value of a lighting facility. As product developers, architects and lighting designers fully embrace the possibilities of SSL technologies, new form factors, lighting layouts and building integration approaches will emerge. In this way, SSL technology will ensure not only source efficiency but also optimized energy utilization, building efficiency and better lighting performances, finally ensuring energy savings and quick maintenance.

The electrical connection of light points can also be improved through the use of direct current (DC) grids in the building, removing the requirement for alternating current (AC) to DC conversion at each LED lamp. This can also facilitate direct connection to renewable energy sources, such as solar panels or wind turbines, and to their battery systems without requiring DC to AC conversion and then conversion back to DC for the LED operation.

SOLAR-POWERED LED LIGHTING SYSTEMS EMPLOYED IN MANY DIFFERENT AREAS

The reduction of the electrical consumption of lighting systems, through SSL technology adoption, allows to provide substantial relief from the pressure to obtain additional power quantities in almost all developed economies. In under-developed countries, the major impact of SSL devices might be to provide high-quality lighting in places where the illumination level has previously been inadequate. For off-grid communities or sites, the diffusion of SSL sources and photovoltaic technology offers an optimal solution for lighting facilities feeding instead of developing the grid to deliver electricity.



Figure-6. Photovoltaic technology offers an affordable solution for power supplying the light points, allowing to obtain electricity in many developing countries and places.

In addition to the money savings, solar-powered LED lighting offers substantial environmental and health benefits. The burning of kerosene lamps, still diffused in many countries, produces several emissions such as black carbon, strongly implicated in climate changes and a responsible for global warming, producing the equivalent of 240 million tons of CO₂ each year. The use of kerosene lamps is also dangerous due to the risk of fires and toxicity, containing high amount of heavy particulates (Mills, 2016). According to the 2016 report prepared by Bloomberg New Energy Finance and Lighting Global for the Global Off-Grid Lighting Association, the off-grid solar lighting market has experienced remarkable growth in the past 5 years, with more than 100 companies selling 20 million branded products. These solar powered LED lamps have provided light for about 100 million people, or less than 8% of the potential market. Kenya, Tanzania and Ethiopia are Africa's prime markets while India is leader in Asia (Off-Grid Solar Market Trends Report, 2016).

On the other hand, due to the increasing use of renewable energies, home storage systems for electricity produced by photovoltaic (PV) facilities are gaining attractiveness, as their cost is reducing. These systems store excess amounts of irregularly produced solar or wind power and makes it available when necessary to power supply the household appliances. More and more private houses use storage systems to temporarily store power generated by photovoltaics plants; instead of consuming power from grid, the households can increasingly feed home facilities and appliances by using renewable energy produced on their own (Visconti *et al.*, 2015).

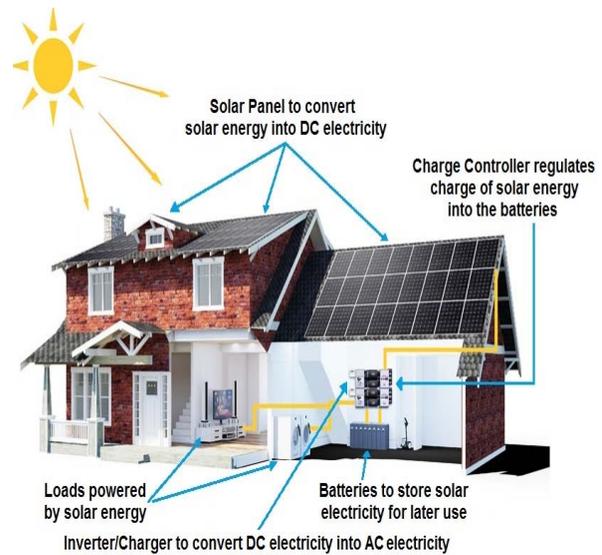


Figure-7. Photovoltaic off-grid plant employed to feed household facilities and appliances.

The major barrier to more rapid adoption of renewable energies has been the shortage of financing and loans to potential customers in order to realize the necessary distribution infrastructure. The cost of solar panels and storage batteries has not decreased over time as rapidly as that of the LED-based lighting sources. Thus, the major further contribution that the SSL technology can make would be to increase the efficacy of the LED packages in order to reduce the necessary capacity of solar panels and batteries that feed the lighting systems.

However, with the introduction of flexible thin-film solar cells shown in Figure-8a, the solar power generator can be integrated into the building envelope replacing conventional materials in roof, skylights or facades (named *building integrated photovoltaics*). Sharp, a solar panel manufacturer with headquarter in Japan, recently introduced transparent solar power windows, as shown in Figure-8b. There are no moving parts involved in photovoltaic embedded systems and no related electrical or acoustic noise; these features favours domestic solar plants respect to other green-techs such as wind turbines.



Figure-8. Technological advancements in PV production: flexible thin-film solar cells (a) and transparent solar power windows (b).



The majority of today's photovoltaic systems does not require a lot of maintenance. Residential solar panels usually only require cleaning a couple of times a year. Major solar manufacturers guarantee a properly operation for 20 or 25 years of their photovoltaic panels. Technological advancements are continuously made in the solar power industry; the innovations in nanotechnology and quantum physics have the potential to strongly increase produced electrical power from the solar panels.

ARCHITECTURE AND OPERATION MODE OF SOLAR POWERED LED-LIGHTING SYSTEMS

The reduction of maintenance costs by improving lamp life and luminaire's reliability is a key factor of outdoor lighting. In fact, for some outdoor applications such as roadways, the obtainable maintenance savings can far exceed energy savings. Solar-powered LED-based street lamps require very little maintenance and are easier to install than their wired counterparts connected to mains. Underground wiring, on-site transformers and electrical enclosures are typically more costly than installing new photovoltaic lights. LED lamps require fewer replacements, are dimmable and ensure significant energy savings respect to traditional lamps (Visconti *et al.*, 2013). Sun light is converted into DC electricity when it falls on the top surface of the solar cells inside the PV module by means of photovoltaic conversion process. The generated electricity can either be directly used during the sunshine hours or may be stored in storage batteries to be used later. Solar street lighting systems essentially include a properly sized PV module, a battery whose charge is managed by an electronic controller and in some cases an automatic dusk-down switching system for turning on at the dusk and off at the dawn the street lights.

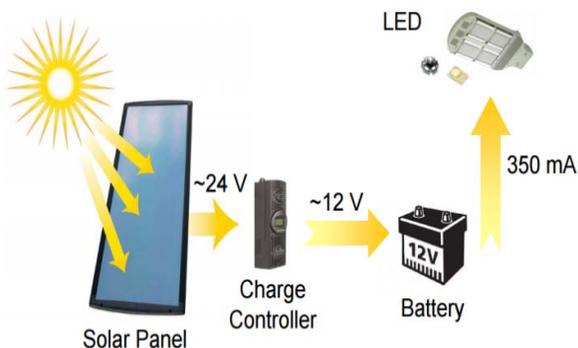


Figure-9. Main components of solar powered LED-based street lighting systems.

Therefore, solar panels harness solar energy converting it into electric energy that, during the day, is stored into the battery and, during the night, used to power supply the street lamps.

Figure-10 shows the principal functional blocks of a solar powered LED-based street lamp: a photovoltaic module, a LED lamp, a charge controller and a lithium battery are employed. Also a motion sensor is used in

order to switch on/off the LED street lamp depending on the presence or absence of some pedestrian or vehicle.

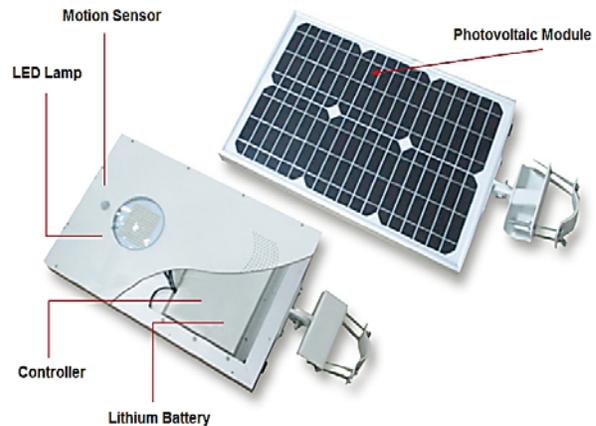


Figure-10. Typical solar powered LED-based street lamp with embedded a motion sensor.

A solar powered LED lighting system can include other different components, as reported in Figure-11, such as a device for anti-theft protection, an anti-corrosion treatment and a solar tracking device for following the solar movement to keep the PV panel facing the sun. In fact, by rotating solar panels to track the sun's path during the day, more solar energy up to 30% can be captured (Visconti *et al.*, 2016).

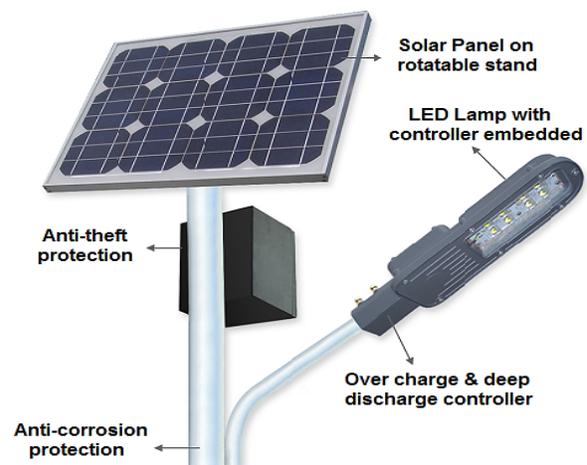


Figure-11. Typical solar powered LED-based system with anti-theft protection and a solar tracking device to follow the sun's path.

The key component of the LED-based street lamp is the LED source itself which allows to properly illuminate the desired area using less energy and with improved uniformity compared to a HID source, beside other advantages such as reliability, long life-time, improved color quality and reduced costs. A street lamp usually consists of many LED-lens combinations; in



Figure-12, a typical LED lamp for outdoor applications with indication of its different sections is shown.

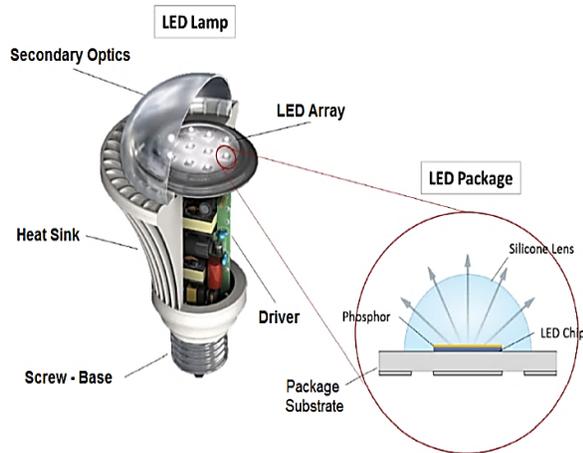


Figure-12. Typical LED-lamp with indication of the different sections that allow its proper functioning.

More recent lighting systems use wireless technology and fuzzy control theory for battery management. The street lights using this technology can operate as a network with each light point, having the capability of performing on or off the network.



Figure-13. Image of street light wirelessly controlled by remote terminal (a) and presence sensor embedded in the LED-based lighting system (b).

WIRELESS MONITORING AND CONTROL OF OUTDOOR LIGHTING SYSTEMS WITH DIFFERENT SENSORS EMBEDDED

Connected lighting, smart lighting and adaptive lighting are some of the terms that describe recent innovations in the lighting industry enabled by the development and diffusion of SSL technology. SSL is fundamentally controllable, can be designed to be spectrally tunable and can easily provide, with minimum cost, additional functionalities by integration of sensors, processors and network interfaces, as shown in Figure-14.

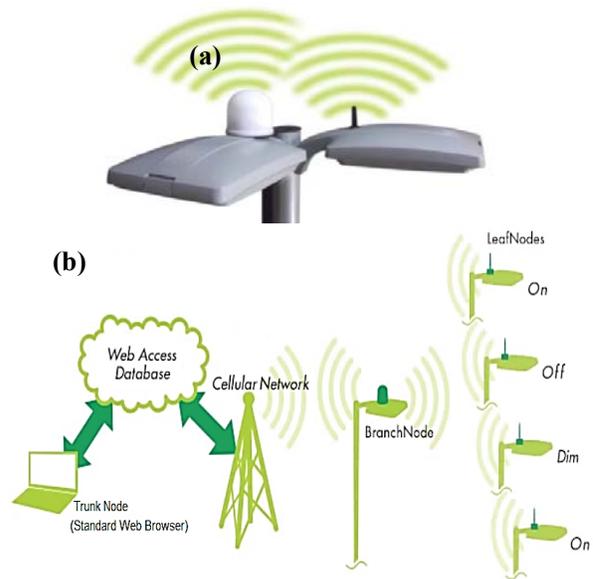


Figure-14. Wirelessly controlled lighting system: network node can accommodate additional functionalities through the integration of sensors (a). Lighting system wirelessly driven and controlled through a cellular network (b).

The integration between SSL technology, low-cost sensors, smartphones and IoT-based devices is expected to facilitate new lighting functionalities and a great exchange of data among lighting systems, installed everywhere both inside or outside of buildings, and a data collection/processing device (e.g. PC, tablet, smartphones) through cellular or Internet network. The ubiquity of lighting facilities, in fact, provides a unique and valuable opportunity to create a dense grid of network nodes for environmental/security data collection and sharing, as shown in Figure-15. This causes not only improved lighting control and energy management but also ensures traffic and sites monitoring getting more safety or early flood prediction or other useful services for community.

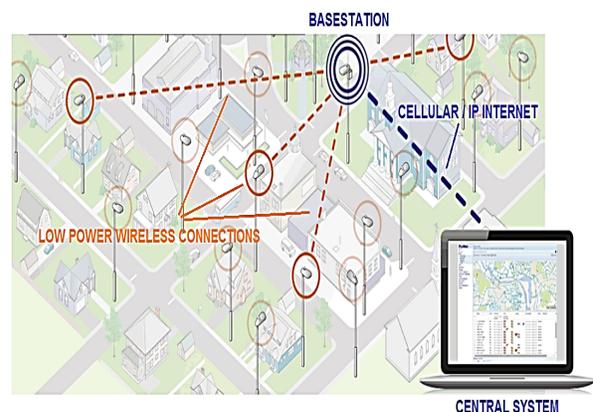


Figure-15. Connected lighting facilities: a base-station wirelessly communicates with other close nodes and with a central system through a cellular / IP internet network.



In addition to presence, motion and daylight sensors, other types of sensors could be installed on a street light pole, including those to measure CO₂ concentration, vibration, sound level, barometric pressure or to capture environment videos or photos. This allows for data collection and exchange in ways not previously possible so that the building owners/operators can manage and better understand their physical environment ensuring greater productivity, efficiency and security (Kathiresan *et al.*, 2014), (Sharath Patil *et al.*, 2015).



Figure-16. Extra services provided to a smart city when utilizing LED lighting street poles integrated with sensors.

To create a smart city, a dense sensor network must be deployed to provide data on different parameters such as air quality, weather warnings, video surveillance, parking space availability and traffic patterns. The installation of new LED street lights guarantees to cities considerable savings through increased energy efficiency, decreased maintenance needs, longer life-times; it can be the platform used to integrate a sensor network providing additional features to the city, as illustrated in Figure-16.

By adding wireless controls to monitor and drive lighting system integrated with sensors, LED street lights act as a wireless mesh communication network that would have a prohibitive cost if realized separately. Detected data are sent to a centralized control unit which can be used to provide to city staff useful information and to ensure appropriate site control for police officers activity, as shown in Figure-17. Thus, the street light poles could become the ideal platform for adding environmental sensors and security infrastructures, such as a cameras or acoustic sensors to detect, for example, gun shots cackles or cries of alarm in real time, and thus alerting the police staff (Priyanka *et al.*, 2015), (Saleem *et al.*, 2015).

Furthermore, due to the low cost of devices, sensors and electronic equipments available today thanks to technological advances, the value of additional provided services, made possible by means of SSL technology, fully offsets the incremental costs of the sensors, network interfaces and other additional components.

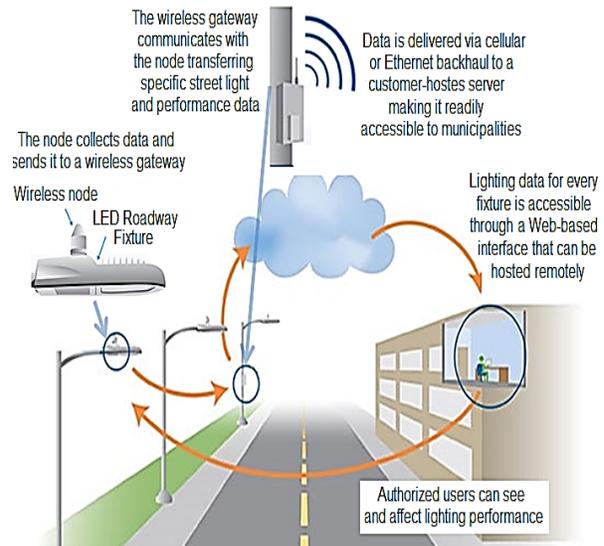


Figure-17. Collected data are sent to a centralized control unit to monitor and control the road environment.

The smart cities provided with LED-based lighting systems will save money because LED lights are more energy efficient than the outdated High Pressure Sodium (HPS) lamps and also because each LED street light can be easier switched on on-demand or by presence/motion sensors, thus paying only for used energy. In addition, city officials will be able to program when turning on/off street lights or dimming their brightness to obtain further energy savings (e.g. providing a 100% brightness when it turns dark and gradually to reduce to 50% in the middle of the night, returning to full brightness in the early morning for commuters). Connected street lights, beside the countless services that can offer, also communicate to the maintainers location and possible failure of each light pole for efficient and quick maintenance (Santhosh *et al.*, 2015).



Figure-18. Smart city platform employs a dense grid of network nodes for providing new different services and also ensuring energy savings and quick maintenance.



In conclusion, new LED-based facilities made up of connected light points will become data collection platforms enabling even greater lighting and non-lighting energy savings in smart buildings and cities. This ability to collect and exchange useful data, making use of the IoT capabilities, will offer the potential to enable a wide variety of services, benefits and new revenue streams that will enhance the money value of lighting plants itself.

While the addition of sensors does not add any significant cost to final street light facility, the 7-pin American National Standards Institute (ANSI) receptacle allows manufacturers an easy way to add on a sensors location (see Figure-19). A wireless node can be added to the street light receptacle providing the following features:

- Accurate, utility-grade energy metering for each street pole, thus paying only for used energy.
- GPS chip embedded into sensor node, so knowing its exact location.
- The node automatically connects to network and acquires or transmits information in a short time so reducing related costs.
- Control and sensing units integrated in a single piece (in blue color in Figure-19). Node simply is connected to external socket so it can be added easily at any time without additional electronics in the LED street light.
- Operates with programmed schedules in case of network outage.

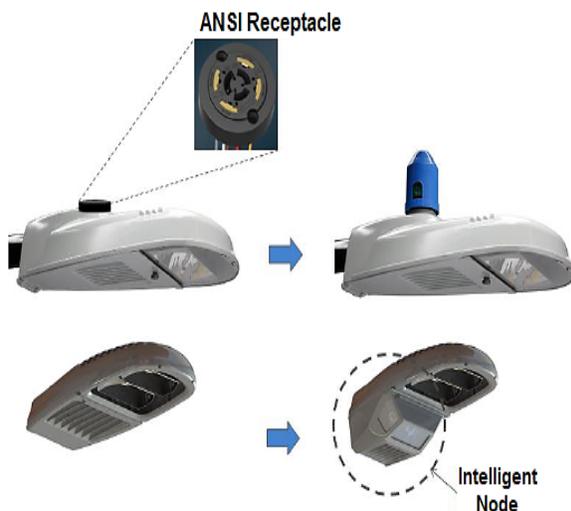


Figure-19. LED street lamps with added the sensor node.

NEW LED-BASED LIGHTING TECHNOLOGIES FOR ENERGY SAVINGS AND LOW COST MAINTENANCE

Besides improved form factors and building integration as reported in the introduction, SSL offers a new range of features and design flexibility. For indoor applications, an example of the design flexibility of LED lighting technology and of efficient light utilization is the OSRAM OmniPoint™, a remotely manageable lighting system that enables users to instantly shape the emitted light (i.e., beam angle, direction, distribution, shape and intensity) with a touch screen wireless interface (Figure-20b). As shown in Figure-20a, the luminaire consists of an array of individually controlled LED devices with a small aperture, allowing wirelessly to properly illuminate an ambient and/or a dark hidden place on user demand.

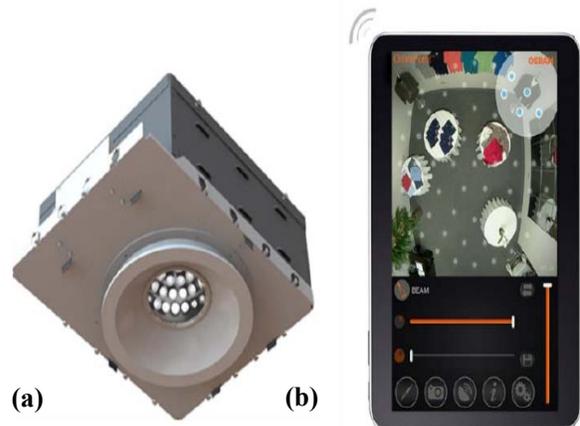


Figure-20. The OSRAM OmniPoint™ luminaire (a) and the relative wireless user interface (b).

The user interface, shown in Figure-20b, allows to select portions of space of the ambient in which adjust lighting, as well as to control light intensity in the whole room, so obtaining energy savings. Thus, this lighting device offers significant improvement over traditional lighting systems which would require a manual adjustment of multiple fixtures on the ceiling (Mathews *et al.*, 2016).

For outdoor applications such as street lighting facilities, the use of integrated sensors allows to obtain different services as discussed before, besides energy savings. The street light system, reported in Figure-21, is an example in which its turning on with full brightness is provided only in case of presence/motion of vehicles. In fact, lighting system decides if there is need of light or not, detecting the movement of a vehicle and thus turning on lights when the vehicle is coming and then reducing up to 50% light brightness when vehicle passes away.

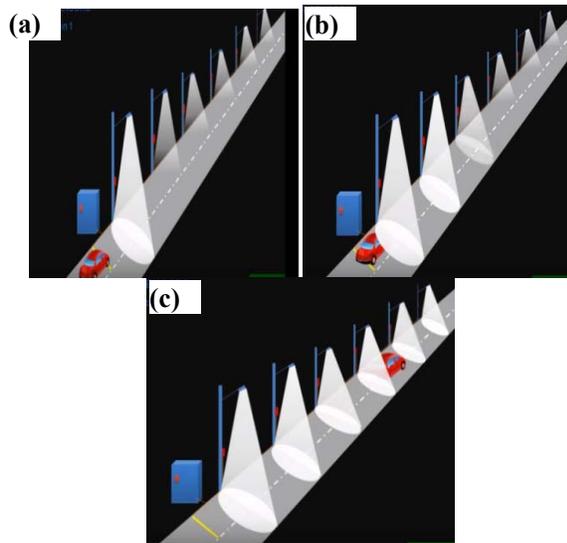


Figure-21. Detecting system of vehicles movement on highways or roads to properly adjust light brightness; oncoming car (a) and sequence of lighting switching during car transition (b and c).

The latest innovations in street lighting systems provided by *EnGo company*, a famous manufacturer of lighting facilities, regard modern and multifunctional solutions powered by solar and kinetic energy. By exploiting only renewable energy sources, it is possible to illuminate streets, parks, parking lots, corporate and university campuses and to create appealing and modern visual environments that will promote more and more renewable energy diffusion due to lower installation, energy and maintenance costs. In Figure-22, the possibility to use kinetic energy tiles, through piezoelectric devices, is shown; in this application, energy is recovered from pedestrians' footsteps for feeding LED-based street lamp.

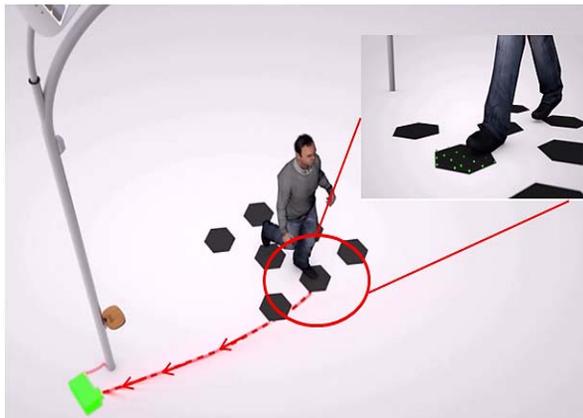


Figure-22. Piezoelectric tiles allow to obtain energy from pedestrians' footsteps for street lamp power supply.

With a remote management platform and many incorporated sensors, the LED-based street lighting system transforms traditional street light to a multifunctional unit

that will save money and collect many valuable data. These last, collected from different integrated sensors, are sent on cloud for monitoring and control environmental parameters and not only, as reported in Figure-23. The additional innovative features such as set of intelligent sensors, LED color change, charge spot as shown in Figure-24, represent a revolutionary step forward in modernizing of public lighting facilities.



Figure-23. Environmental information are collected by integrated sensors (a) and sent on cloud (b).



Figure-24. Charge spot provided by the street light pole in order to give to the user a further service making use of renewable energy.

In conclusion, the light street pole may provide many services thanks to the numerous sensors embedded and to the available renewable energies for feeding LED lamp, sensors and charging spot. As reported in Figure-25, thanks to intelligent sensors and using PV panel or tiles to exploit solar or kinetic energy respectively, it is possible to realize a multi-function light point, maintaining low power consumption and low maintenance costs.



Figure-25. Many services can be provided by new LED-based street light pole, thanks to the integrated sensors, exploiting the available renewable energies.

CONCLUSIONS

In this paper, we reported on new technologies and devices employed in advanced solar powered LED-based lighting systems, used for both outdoor and indoor applications, in order to obtain energy savings, new additional services for smart cities and quick low-cost maintainance. LED lights are up to 80% more efficient than traditional lamps, ensuring huge energy savings but also suitable illuminance levels, improved light distribution by using proper focusing lenses, illuminance uniformity and producing less wasted light falling outside the target area.

An efficient light utilization is very important; in indoor applications, where OLEDs and low brightness planar LED solutions can be employed, the low brightness and diffuse nature of these sources enable them to be used very close to the task area without generating excessive glare and with the possibility to adjust brightness in specific areas so creating desired lighting scenarios.

For off-grid communities or places, solar-powered LED-based lighting systems offer an excellent solution to efficiently illuminate large areas rather than bringing the electric grid to deliver needed electricity. Solar LED lighting gives substantial environmental and health benefits beside energy savings, such as the non-use of kerosene, still diffused in under-developed countries, that produces heavy particulates. Furthermore, new LED-based lighting facilities require very little maintenance and are easier to install than the wired counterparts, due to not need to carry the mains voltage being supplied by solar or kinetic energy, as described previously.

With the huge diffusion of IoT-based devices and apps, it is possible wirelessly to control and drive the LED-based lighting facilities, that can be provided of integrated sensors, thus realizing new lighting functionalities, improved management of the energy in order to obtain energy savings and new services for the community. By adding wireless modules, LED street

lights act as a mesh communication network, collecting and sending data on cloud to a centralized control unit, used to provide to city staff useful information and to ensure appropriate site control for police officers. Street light poles could become ideal platform for adding environmental sensors and security infrastructures but also to communicate to the maintainers location and failures of each light pole for efficient and quick maintenance.

The additional innovative features such as smart sensors, LED color change, availability of charge spots and other services represent a revolutionary step forward in modernizing public lighting facilities. Therefore, by exploiting only renewable energy sources (solar, kinetic or provided by wind), it is possible to illuminate streets, parks, parking lots and university campuses but also to provide other services to the community, ensuring, first of all, energy savings, lower installation and maintenance costs.

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