Results of EnLight Lighting Solutions applied to a Hospitality Environment

Abstract

The EnLight [1] consortium, made up of 27 key players in the lighting value chain, worked together to develop a next generation lighting solution based on efficient and intelligent, networked luminaire systems.

At LPS 2013 a concept preview of an EnLight hospitality pilot installation built by OSRAM was given [2]. This article provides an overview of technical details and results of the hospitality installation as it was finally realized at OSRAM.

As a "green field approach" EnLight revealed solutions to overcome restrictions of legacy technology and infrastructure. The project examined the integration of electronics and controls into luminaires, with a focus on optimal utilization of LEDs, optics, sensors and heat management systems. The goal was not just to improve efficiency but also to take a next step towards the shape and functional integration of the luminaire, breaking free from form factors associated with traditional lighting. Free configuration of luminaire components was greatly facilitated by a Plug-and-Play intra-luminaire bus.

The intelligence, traditionally located in a central controller unit of a network, was decomposed into a decentralized architecture. Luminaires, sensors and user controls could react on events raised by their embedded sensors and by other sensors and control units. The EnLight system thus enabled each individual light source to adjust to the conditions around it.

The main goal of EnLight was to enable energy savings of >40% compared to LED lamps retrofitted into traditional luminaires with basic control. Three pilot installations have been set up as "living labs" with full implementation of the EnLight solution. Depending on the application energy savings of up to 81% were realized which largely exceeded the project target.

User feedback surveys showed that user comfort was not impaired by intelligent lighting control and users were well in favor of the EnLight system.

Introduction

Breakthrough innovations in LED light source efficiency and lifetime have led to a radical transition of the lighting industry towards solid-state lighting (SSL). This transition is characterized by several phases. The 1st phase follows the traditional logic of incremental adaptation of new technology to conventional infrastructure. This is known as the retrofit approach and is now widely in use on the market. Retrofitting presents several disadvantages mainly related to thermal and optical constraints obliterating the potential of SSL technology. The 2nd transition phase aims to avoid these drawbacks by dedicated designs of luminaires and lighting components as well as by standardization of mechanical, thermal and electrical interfaces of these components [3]. In view of the fact that this approach does not only concern the light source manufacturer but implies the whole lighting value chain, it is obvious that it ultimately cannot develop its full potential in short time as required by actual business needs. The 3rd SSL transition will bring the most drastical changes and is yet to come. It is associated with the digitization of lighting and will involve a paradigm shift from a lighting component approach to an application centric approach [4].

In order to speed up these transition processes and to set free the full potential of all technology aspects, research projects which explore new possibilities of SSL technology in its entirety and in an open-innovation ecosystem setting have become necessary. The EnLight consortium performed most extensive research in these directions. EnLight stands for "Energy efficient & intelligent lighting systems" and was an EU funded project which ran from 2011 to 2014. The consortium consisted of 27 leading European companies and academic institutions from across the entire lighting value chain.

Within the project a next generation lighting solution was demonstrated which was based on intelligent, networked luminaires. Shifting from a centralized control system to a network of intelligent luminaires, the EnLight system enabled each individual light source to adjust to the conditions around it based on inputs of its own embedded sensors and of other peripheral sensor and control devices. The high level of granularity in lighting control allowed for new possibilities to save energy and adapt the light to the user's needs in ways conventional systems never could.

Three pilot installations targeting office and hospitality applications were built which implemented the EnLight solution. In the final phase of the project all three pilots have been validated with regards to energy savings, light quality and user comfort.

This article gives an overview of EnLight objectives, reviews the EnLight network and intelligent luminaire architecture and finally focuses on the setup of the hospitality pilot built by OSRAM and on findings which were made during validation of this demo.

EnLight Objectives

EnLight objective was to exploit the full potential of solid state lighting by considering all system levels of lighting. The ultimate goal was to achieve 40% energy reduction compared to today's LED retrofit systems.

The EnLight consortium set out to achieve this goal by working on three technical objectives, namely the optimization of LED lighting modules (improved optical design, thermal management, driver integration and realization of a communication interface), the design of future non-conventional luminaires (allowing for freedom of design, integration of novel features, architectural flexibility, unrestricted by retrofit solution constraints) and the use of new and intelligent lighting systems (providing means for smart sensors, sensor fusion, data mining and interfacing with building management systems).

These objectives cover the entire range from component level up to the building level and thus extend beyond Zhaga [3], which focuses on the standardization of mechanical, electrical and thermal interfaces on the components level only. The EnLight system architecture provided the central structure across all system levels for developments carried out in the project.

EnLight System Architecture

The EnLight system architecture is made up of four aggregation levels (Figure 1). The focus was especially on area and luminaire level. On the area level, a lighting control connects the intelligent luminaires, peripheral sensors and other components such as local user controls. A subsystem of the area level is the intelligent luminaire. In EnLight the luminaire architecture is designed in a way that enables a modular, plug-and-play composition of intra-luminaire building blocks.

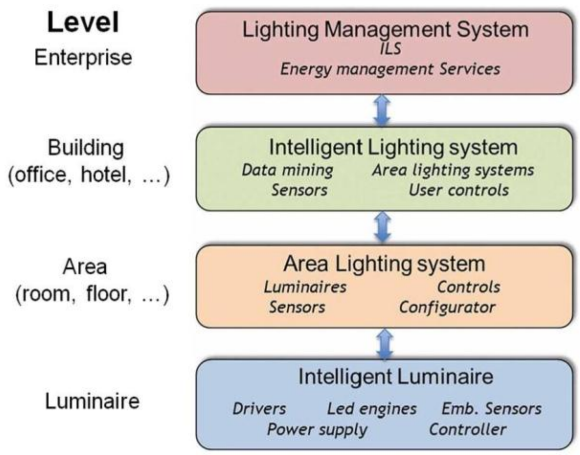

Figure 1: Levels of lighting control. EnLight focus is on "Area" and "Luminaire" level.

Distributed Intelligence

The decentralized EnLight architecture is based on distribution of information rather than on controlling individual luminaires via a centralized control unit. An "event" generated by a network device (such as a sensor, which, e.g., generates a "presence event" upon detection of motion in a certain area) is distributed across the whole network. Each luminaire which is "subscriber" to this event then decides autonomously, according to its own embedded rules, how to control its lighting function (i.e. brightness, color temperature, etc.) based on this event.

The inherent characteristic of the EnLight distributed intelligence is therefore decision making at the lowest aggregation level instead of in a centralized control unit. Principal advantage of this characteristic is the smooth scaling of the number of network nodes from a single luminaire to many hundreds of network devices.

Network devices can be added or removed just like that. Their behavior can be easily changed "by software". Failures will only affect subparts but will not lead to a catastrophic shutdown of the entire system.

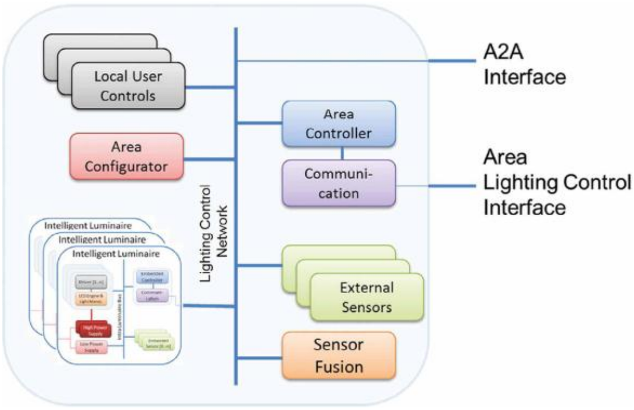

Figure 2: Distributed intelligence on Area level.

Figure 2 shows key components of the EnLight system on area level. The area configurator enables the commissioning of the area components simply by setting up the rules-based logic of the intelligent luminaires. With the sensor fusion function, events generated by multiple external sensors can be processed which effectively reduces the network's overall communication load. The area controller and communication units serve as a bidirectional interface from the area network to the higher building level. This can be used for monitoring or logging functions. The area controller is also able to induce a certain lighting function at the entire area level such as an orchestrated color change or emergency mode for all area network devices.

In the final EnLight pilot installations, the lighting control network which connects all area level devices was based on wireless ZigBee technology [5]. ZigBee was used since it allowed implementing the scalability provided by the EnLight system and provided low power consumption and low cost implementation. Optionally, subsystems based on other technologies like DALI [6] or DLT [7] can be connected to the area network by means of technology bridges which will allow the subsystem to behave like an EnLight system.

The EnLight lighting system is effectively a collection of connected and cooperating intelligent luminaires which are able to adapt to changes in the environment. As it is shown later in this article EnLight is thus perfectly suited to serve energy saving and human comfort needs.

Digital modular luminaire architecture

The EnLight intelligent luminaire can act as both a subscriber to events and publisher of events. It contains LED light engines, which react upon events communicated from inside and outside the luminaire, as well as embedded sensors which publish events and distribute them within the luminaire but also into the external network via the communication interface to the area level.

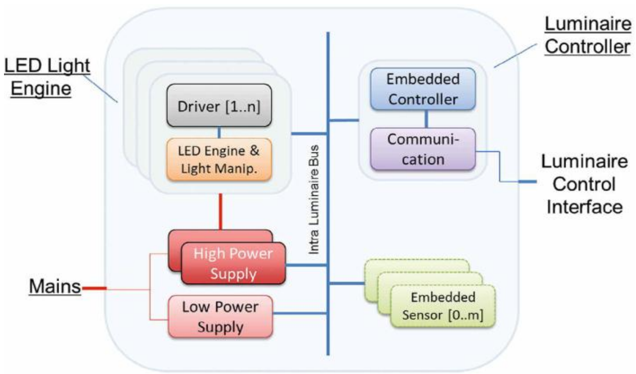

Figure 3: Modular intra-luminaire architecture.

The EnLight luminaire architecture is shown in Figure 3. It uses an I^2C-bus interface to interconnect components within the luminaire. This intra luminaire bus enables high luminaire diversity with only a limited amount of EnLight modules. The consortium realized 14 distinctively different luminaires, all based on the same building blocks. These luminaires have been used in large numbers for the three EnLight pilot installations. It could be demonstrated that modularity of EnLight intelligent luminaires greatly facilitates the contribution of components and technologies from different vendors, enables late stage configurations and future upgrades. It thus reduces potential cost-of-non-quality and decouples the lifecycles of independent technologies.

Hospitality demo installation

In parallel to two pilot installations targeting office application which have been built by Philips in Eindhoven, Netherlands, and by VTT in Oulu, Finland, a hospitality pilot was built by OSRAM in Garching, Germany. All pilots made use of the entire pool of EnLight components, modules and luminaires provided within the consortium. For the hospitality demo a part of an OSRAM building where kitchen, relax and meeting areas as well as restrooms were located was refurbished and modified in order to simulate a real hospitality environment. The final EnLight area "living-lab" comprised a guest room (Figure 4), a corridor, a rest room and a lobby area.

Figure 4: Guest room of the EnLight hospitality demo.

The lighting system included 49 luminaires along with another 50 infrastructure elements such as external sensors, user controls and energy meters. Test persons frequently used the installation, especially the guest room for making a break, relaxing, chatting or working. However, no overnight stays like in a real hotel could be hosted.

For the hospitality pilot much more than just conventional luminaires were realized. The EnLight network and intelligent luminaire architecture proved to perfectly leverage the design freedom enabled by LED technology. EnLight luminaires designed for hospitality application thus not only became creative elements but even merged into building structures and took over parts of those structures' functional properties. The notion of a luminaire was thus taken much farther than could be imagined with traditional light sources.

EnLight hospitality luminaires

Outstanding examples of this new design freedom are a luminous door and an extremely flat wedge-like luminaire which allows for a large variety of applications.

Luminous door

The luminaire with the highest functional versatility and functional integration into building components realized in EnLight was a luminous door (Figure 5). Both back and front sides emitted light and could be controlled individually in color or color temperature. The door was virtually mimicking a window and is thus ideal for, e.g., windowless rooms deep inside a building. Also special scenes such as sunrise, favorite color patterns or optimized color compositions for light therapy could be realized.

In a hospitality environment an obvious option is to use the luminous door for showing a hotel guest the way to his room by raising light output, or tuning color.

Figure 5: Luminous door with two light emitting sides. Homogeneous daylight (left) as well as colored patterns (right) can be realized.

The luminous door was made of linear multicolor LED boards, which were hosted inside the doorframe. Light guide optics mixed colors and coupled the light of the LEDs into a special light guide sheet and out of its surface facing the room. Thermal management was especially efficient since LED boards as well as heat sensitive driver components were coupled to the metal door frame which had a large cooling surface.

Wedge luminaire

An EnLight luminaire which served as a platform for a wide range of room lighting and decorative designs was dubbed “wedge” for its wedge shaped design. Light was emitted at the wide edge of the wedge which is ideal for mounting the luminaire at vertical surfaces to light a desk or use it for a wall-wash effect. With a maximum height of only 25 mm the luminaire was exceptionally flat and required little mounting space. The unobtrusive appearance made the luminaire almost disappear, and directed the user’s attention to the light and the illuminated object.

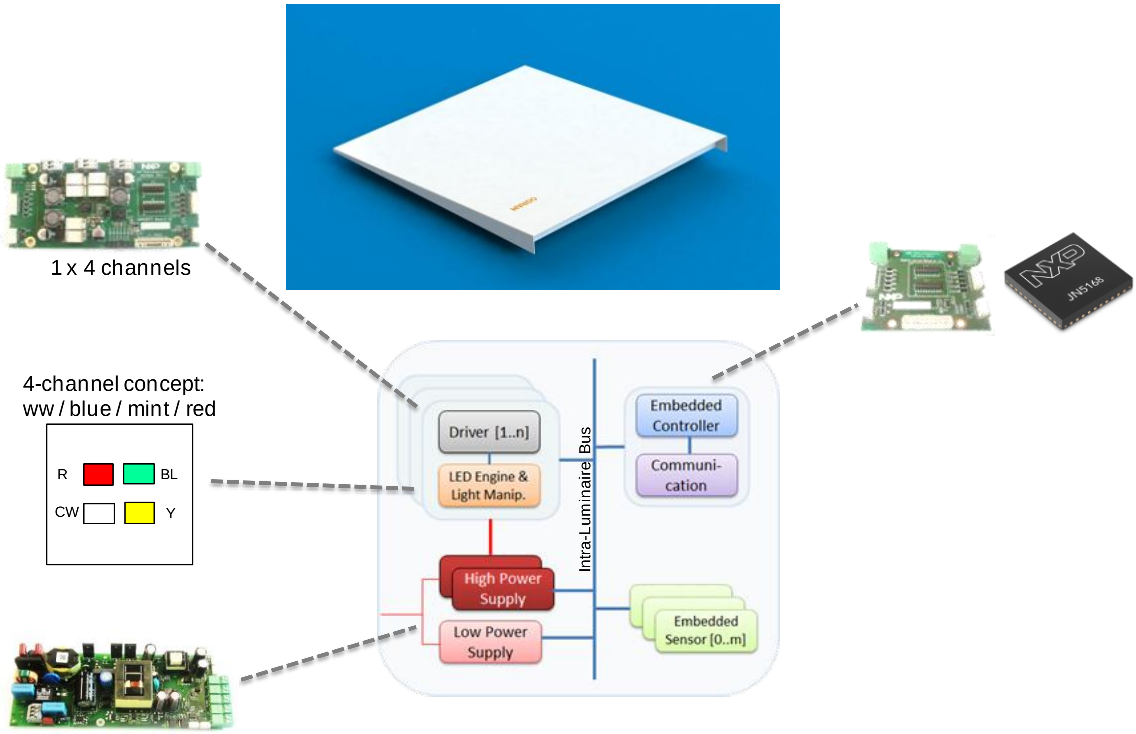

Figure 6: “Wedge” luminaire and luminaire architecture according to Figure 3.

Multicolor LED modules allowed for full color tunability. LEDs were placed in a highly reflective mixing chamber which was optimized for high light output, homogeneous color mixing and prevention of glare from direct view into the LED light source. Since the housing was made of metal, it was effectively used for heat spreading and cooling of LEDs and electronic components.

Wedge Wall

The side emitting design of the wedge luminaire unfolded its full potential when combined in luminaire arrays where one luminaire sheds its light onto its neighbor. Arbitrary panel configurations can be chosen. Together with the variability of color temperature and color combinations an infinite number of scene settings can be achieved. Two examples of scene settings which were chosen for the EnLight guest room are shown in Figure 7.

Figure 7: Two examples of wedge wall scene settings.

The wedge wall and the luminous door substantially contributed to vertical lighting which is a vital prerequisite for spatial experience. With a high component of vertical lighting, faces were well illuminated and were not obscured by shadows which proved to be especially pleasant in the guest room where people came to meet and talk together.

Wedge wall architecture

The wedge wall provided a good example of how the EnLight modular architecture can be employed for most flexible configuration of multiple components and luminaires (Figure 8). The entire wedge panel was regarded as a single luminaire which is composed of modular building blocks. For the hospitality demo shown in Figure 7 a total of 12 wedges was used in one panel. The entire panel was supplied by three 75 W power supply units. Communication from outside the panel was done wireless by ZigBee to the luminaire controller. The intra luminaire communication bus enabled communication from the luminaire controller to the LED driver controllers and allowed for adding or removing luminaires, sensors and user interfaces without further need of recommissioning.

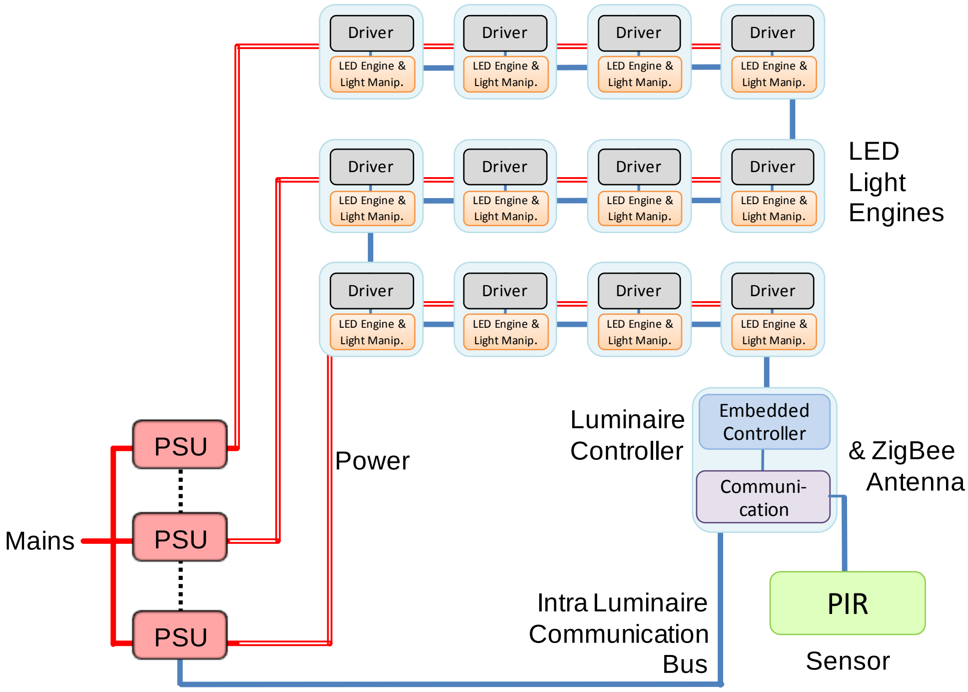

Figure 8: EnLight architecture of the “wedge wall” which can be regarded as one single luminaire. A panel with 12 “wedge” units is shown in this example.

The wedge wall concept demonstrates how an apparently complex intelligent luminaire can be configured by just “stock-picking” ingredients from the building block inventory provided by all EnLight partners without a special need for customized development.

Energy saving strategy

Energy saving strategies implemented in the EnLight hospitality demo are listed in Table 1. Personal control by push buttons was made available in the guest room and the rest room. It allowed the user to choose and adjust the right lighting for his actual needs. All rooms except for the lobby area, where lighting remained switched on all day, were equipped with EnLight system intelligence based on granular sensing. In addition to external sensors in the area network also sensors integrated in the luminaire were used, which facilitates installation and thus reduces installation costs. This allowed sensing with high local accuracy and providing light in the right amount, at the right place and at the right time.

	Task tuning	**Personal control**	**Occupancy**	**Time schedule**	**Daylight harvest**	**Load shedding**
Corridor	-	-	Local occupancy sensing with a light bubble	Office hours	-	√
Guest room	4 scenes & CCT tuning	Scene selection & CCT tuning with a push button	Local occupancy sensing	-	-	-
Rest room	4 color temperatures	CCT selection with a push button	Local occupancy sensing	-	-	-
Lobby	-	-	-	Office hours	-	√

Table 1: Energy saving strategies of the EnLight hospitality demo. The rooms had no access to natural light except for the guest room which had a small window with, however, very little daylight contribution. Daylight harvesting was therefore not implemented. " – ": Feature not available. √ : Load shedding is possible with EnLight, but no interface to a building management system was implemented in the demo installation.

Apart from gradually dimming and finally switching off luminaires where no presence was detected an especially efficient strategy was chosen for the corridor. A "light bubble" concept was developed which turned luminaire light levels to 100% in the direct vicinity of a person whereas neighboring luminaires were set to 50% light level. Transition times were chosen in a way that users did not notice any unpleasant switching when they passed through the corridor.

Energy measurement results

Energy measurements were carried out over several weeks. An example of a measurement for the corridor during a full day is shown in Figure 9.

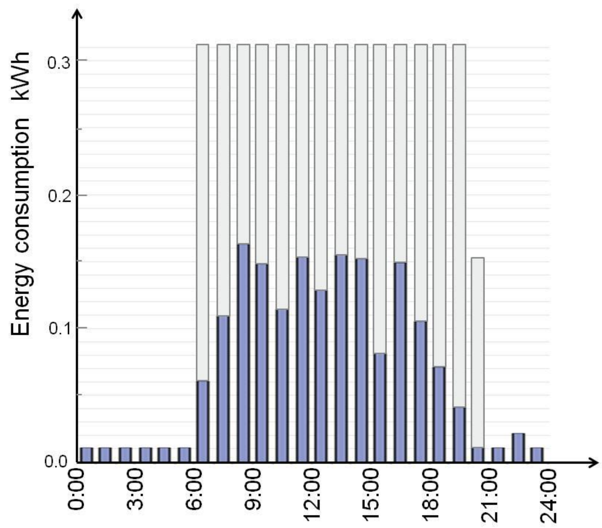

Figure 9: Energy consumption of the lighting installation in the corridor during the course of one day recorded on an hourly basis. Dark bars show the consumption of the EnLight system. Light bars indicate energy

savings by intelligent control (savings by efficient component and luminaire design are not shown in this figure).

Quantitative analysis of energy savings have been based on the Lighting Energy Numeric Indicator (LENI) [8]. This indicator describes the annual energy consumption of lighting including luminaires and parasitic systems in kWh/m², per year. Energy savings have been compared to a baseline reference with LED lamps retrofitted into traditional luminaires designed for incandescent and fluorescent lamps and having only basic on/off control. All EnLight luminaires but especially the non-conventional luminaires described above made full use of design possibilities which arise with LED technology and can thus hardly be realized in a retrofit approach in the usual sense. Nevertheless, state-of-the-art lighting technology retrofitted with LED lamps with only on/off control was assumed as a basis for the estimation of baseline performance. Energy measurements were carried out over several weeks. Even though usage of the demo area by test persons was not planned beforehand but just happened on a random and anonymous basis by company staff which worked in the building, usage hours which are relevant for deriving LENI numbers were nearly the same as given in the EN 15193 standard [8]. Energy monitoring measurements of the EnLight installation revealed an overall energy consumption of 20.2 kWh/m², per year (Figure 10). Compared to the LED retrofit baseline, this corresponds to savings of 81%. Even if savings compared to the LED retrofit baseline with only on/off control (savings of 42% in Figure 10) would have been overestimated, 67% savings were still gained exclusively due to intelligent control. Broken down into the different areas of the hospitality demo, the savings by control amounted to about 50% in the corridor and restroom. In the lobby, no savings could be realized, since luminaires have to run all day long in this application. Most significant savings, namely 80%, were realized in the guest room. In order to provide a large range of scene and light level setting options, the installed lighting power density was especially high in this area. This would entail large energy consumption for installations with basic control. However, using the interactive and granular control, the light was adjusted according to presence in the room areas and energy was drawn only as much as required by the user's needs.

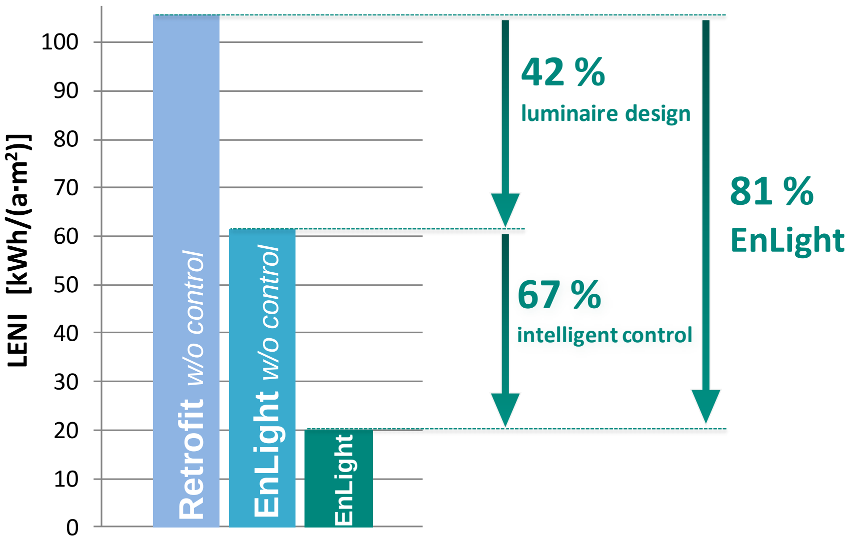

Figure 10: LENI results of the EnLight hospitality pilot installation. For the data without intelligent control, occupancy factors given in [8] are assumed.

The results show that savings are largely above the EnLight target. In fact, the EnLight system allows realizing especially high savings for hospitality application. Lighting products targeting this application have never been designed for highest efficacy levels but with focus on decorative elements that usually counteract good efficacy. Dedicated designs as they were applied in the EnLight project provided large efficacy gains. Also, the lighting power density installed in hospitality environment is usually higher than in, e.g., office applications. Consequently, there is good potential for energy savings with intelligent control as demonstrated with these results.

Table 2 shows how the system energy performance of the EnLight hospitality demo compares to commonly used building energy standards.

Normative benchmarks LENI [kWh/m², a]	EN15193 [8] Hotel Quality Class ***	ASHRAE [9] 90.1	LEED [10] 18 pnt credit	Title 24 [11]	EnLight Hospitality Pilot
Corridor		37.9	20.5	26.0	15.4
Restroom		22.6	12.2	30.5	10.9
Guest room		38.7	20.9	52.2	29.4
Lobby		58.1	31.4	60.1	50.6
Total hospitality area	108.1			36.7	20.2

Table 2: Energy benchmarks of the EnLight hospitality demo.

The EnLight hospitality pilot performed far better than required by the European EN15193:2007 which provides the least stringent performance benchmark. However, the EnLight demo showed also excellent performance when compared to highest standards issued to date:

- by an average of 46% better than ASHRAE 90.1 requirements
- by 45% better than Title 24 for hospitality applications
- LEED score of 18 points in energy performance

Validation of lighting quality and user comfort

Even if energy saving was most important for project target achievement it was not an option to compromise light quality and user comfort. In order to validate the light quality and overall experience, end user acceptance was evaluated with standardized user surveys covering various quality aspects.

Users voted in favor of the EnLight installation (Figure 11) with the mean rating being by 20% above the average scaling range.

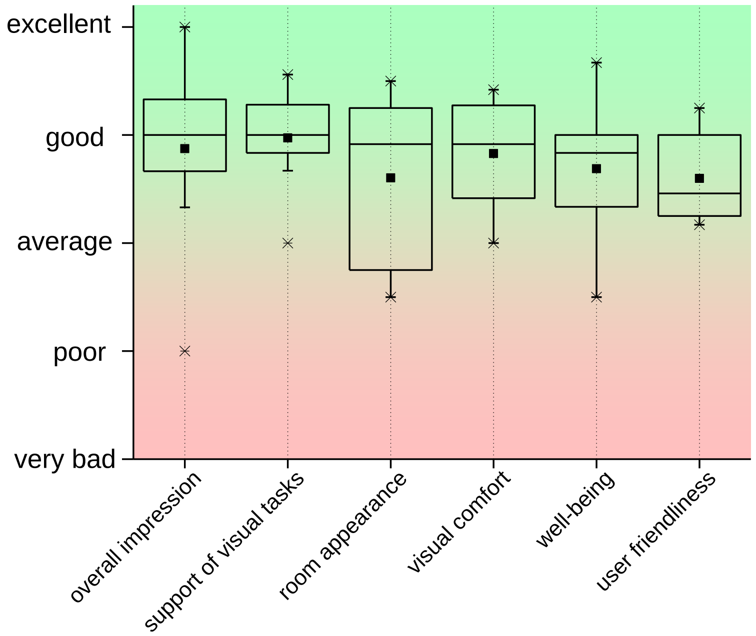

Figure 11: User rating of the EnLight hospitality pilot averaged over all room areas.

There is only little variation over all rating categories and within each category except for the room appearance. The broad voting range for the room appearance is most likely due to the various luminaire types which are completely new to users. They create unprecedented atmospheres by both luminaire appearance and room illumination scenes which tend to be subject to individual tastes to a higher extent than conventional luminaire and lighting designs.

Conclusion

The EnLight project had three technical objectives comprising the optimization of LED lighting modules, the design of future non-conventional luminaries and the development of intelligent lighting systems. Consortium partners represented the entire value chain and worked hand-in-hand on all lighting system levels. Groundbreaking innovations were demonstrated based on a new lighting network system having distributed intelligence instead of a centralized control unit. A modular intra-luminaire bus architecture enabled Plug-and-Play configuration as well as product diversity without much effort. The EnLight architecture proved to perfectly leverage the design freedom enabled by LED technology. It allowed for novel form factor luminaires and lighting solutions that can inspire and enable designers in ways traditional lighting technology never could. A hospitality application pilot was built by OSRAM using the entire pool of components provided within the project consortium. It could demonstrate energy savings of 81% which exceeded project targets by a factor of 2. Systematic user feedback surveys demonstrated that user comfort was not impaired by intelligent lighting control and users were well in favor of the EnLight system.

A comprehensive summary over project outcomes and all activities carried out in the EnLight project can be found in [12].

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