# Granular Lighting Control Enables Significant Energy Savings with Optimized User Comfort

While the last generation of LED lighting products is already very advanced with respect to energy savings, quality and end-user experience, these are still important topics and therefore also parameters on which the EnLight project needs to be evaluated. Eveliina Juntunen from VTT, Frank van Tuijl from Philips Lighting, Herbert Weiß from Osram, and Ambali Talen from Philips Research provide insight on the results of the demonstration installations in comparison to current state-of-the-art lighting systems.

In the course of the project, real-life demonstration pilots of intelligent lighting systems were developed in three locations in Europe. In this article these implementations of the EnLight intelligent lighting system are described. The performance was evaluated by comparing the installations with a baseline of state-of-the-art lighting systems. Validation concentrates on measuring the energy consumption and illumination at the pilot installation sites. In order to validate the light quality, end user acceptance was evaluated with user surveys. The goal of the project was to achieve 40% energy reduction compared to today's LED retrofit systems without compromising light quality and user comfort. The main results are discussed in this article with some considerations for future development.

## Description of Demos

The real-life demonstration pilots focused on office and hospitality applications with a broad range of functionalities in indoor lighting scenarios. The implementation relies on control system intelligence to provide the right light in the right amount at the right place and at the right time. The energy-saving strategies applied in the project are summarized in (Table 1).
The general energy-saving strategy was to adjust the lighting according to the presence of people and the available amount of daylight.
With wireless communication and multiple sensors integrated into the demo space, people's presence and the availability of daylight could be detected locally and with a granular 'light only when needed' strategy, significant energy savings was achieved. Experiments with circadian rhythm lighting were also done in both the office and the hospitality environment. Additionally, personal lighting control with push buttons and desk lights was implemented for energy-saving and user comfort reasons.

The largest demonstration pilot was built by Philips at the High Tech Campus in Eindhoven, the Netherlands, with more than 120 luminaires along with other dedicated infrastructure elements, such as external sensors, user controls, and energy meters. The demo area consisted of an open plan office, corridor and meeting room. The demo area was well populated with office employees and had good access to natural light with big windows, especially in the open plan office space (n=24).

The VTT Technical Research Centre of Finland also built an office pilot in its multifunctional meeting, working and lounge space in Oulu, Finland. Compared to the office pilot in Eindhoven, the implementation was smaller with 43 luminaires among other infrastructure needed for sensing and control. The occupancy in the VTT pilot space in Oulu was lower and there was less natural light available than in Eindhoven, which provided a diversified perspective for the office demonstrations.

| | Application | Task tuning | Personal control | Occupancy | Time schedule | Daylight harvest | Load shedding |
|---|---|---|---|---|---|---|---|
| OFFICE | Open office | Ambient / task tuning | Desk light | Local occupancy sensing with a light bubble | Sunrise rhythm | Local constant lux | √ |
| OFFICE | Meeting room | 5 scenes | Scene selection with a push button | Local occupancy sensing | - | - | - |
| OFFICE | Lounge | 4 scenes | Scene selection with a push button | Global occupancy sensing | - | - | - |
| BOTH | Corridor | - | - | Local occupancy sensing with a light bubble | Office hours | - | √ |
| HOSPITALITY | Guest room | 4 scenes and CCT tuning | Scene selection and CCT tuning with a push button | Local occupancy Sensing | - | - | - |
| HOSPITALITY | Rest room | 4 color temperatures | CCT selection with a push button | Local occupancy sensing | - | - | - |
| HOSPITALITY | Lobby | - | - | Local occupancy sensing | - | - | √ |

**Table 1:** Energy-saving strategies of the demos ("-": Feature not available)

The hospitality demonstration pilot was built by Osram in Garching, Germany. The demo comprised a guest room, a corridor, a restroom, and lobby areas. The lighting system was also of significant size with nearly 100 luminaires, controls and monitor components installed in total. The demo area had no access to natural light except for the guest room which had only a small window with limited daylight contribution. Test persons frequently used the installation, in particular the guest room for making a break, relaxing, chatting or working. However, no overnight stays like in a real hotel could be hosted.

## Saving Energy through Distributed Intelligence

The intelligence in the EnLight system was based on a granular, location-specific approach to sensing with high local accuracy. As an example, a 'light bubble' concept was developed for lighting the open plan office and the corridors. In the open plan office use case, the primary design objective was the reduction of energy consumption while providing good quality and comfortable lighting to office workers enabling them to do their daily tasks. In the corridors the same concept was used for reducing energy consumption while maintaining the impression that the corridor lighting is always on.

**The following control strategies were applied when implementing the light bubble concept:**

- A light bubble around the luminaires that detect the presence of people
- A low background lighting level is applied if there is someone present in the area
- Smooth brightness transitions with low fade rates are used to hide differences in the brightness of luminaires
- In the office use case, personal control is facilitated by a desk light, which can be activated manually when the user wants to increase the light on the work surface
- In the corridor use case, the ends of the corridor are lit to suggest that the lighting in the corridor is always on. Also, external presence sensors are applied to turn on the lights before the user arrives in the empty corridor and sees it completely dark


**Figure 1:** Demo areas: Open plan office at Philips, Eindhoven (top), multifunctional office space at VTT, Oulu (middle) and hospitality guest room at OSRAM, Garching (bottom)

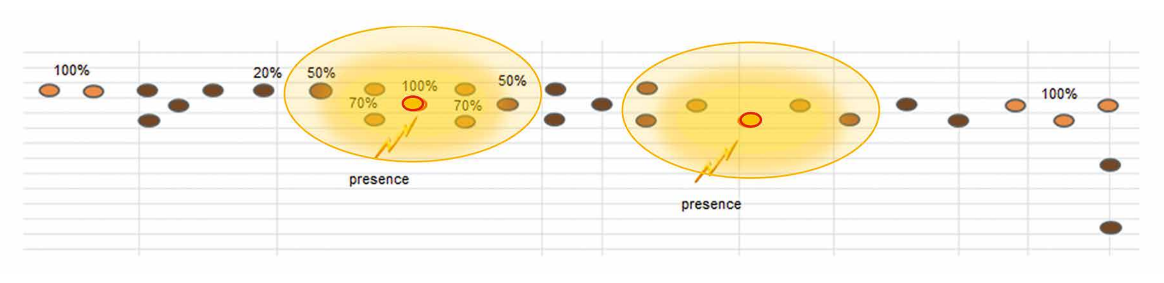



**Figure 2:** Simulation of the corridor with a light bubble control concept

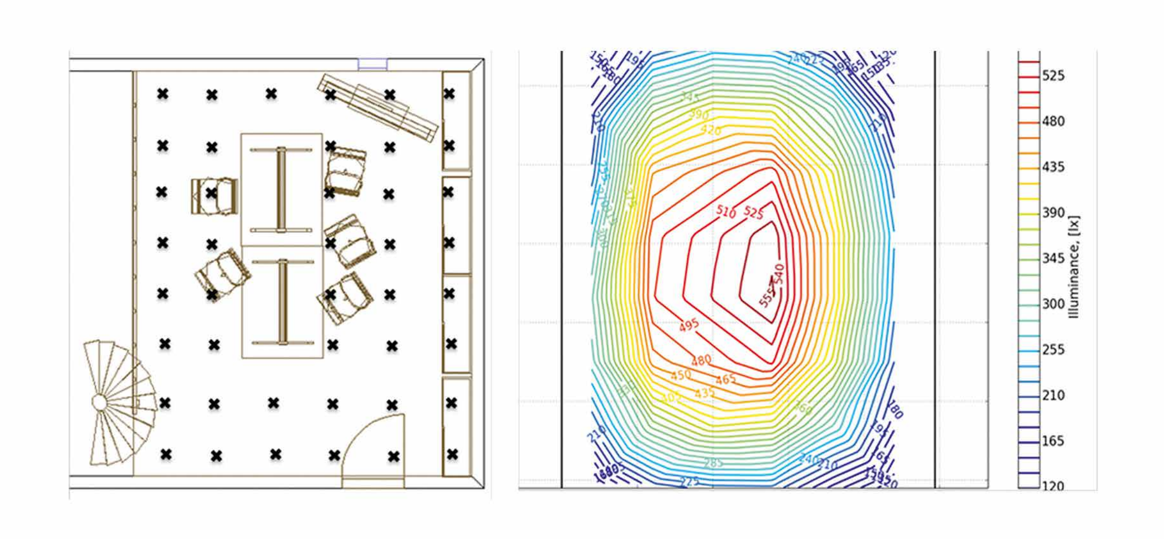



**Figure 3:** Measurement grid (left) and illuminance map (right) in the meeting room in the office demo

Figure 2 shows a snapshot of the simulation of the light bubble in the corridor. The bubble was used to create a smooth transition from 100% brightness towards background level (20%). The luminaire that detects the presence of people sets its brightness to 100% on a high priority level. The neighboring luminaires were set to 70% on a lower priority level and the far neighbors have an even lower priority level for setting their brightness to 50%. In case of overlap the highest level will win. In the real-life demos, in most cases the bubble was hardly visible because in practice several bubbles overlap.

The bubble turns to background brightness (20%) after 2 minutes of not detecting motion. The measurements in the demo installations showed significant energy savings with this kind of granular control strategy. For example, in the office application 30% energy savings was shown in the corridor compared to a traditional system with global presence detection.

## User Comfort - a Matter of Quality

In this project, it was not an option to compromise the quality of light in order to increase energy efficiency. Therefore both photometric measurements and user surveys were carried out at all the pilot sites to guarantee user acceptance of the developed lighting system.

### Photometric measurements

To evaluate the lighting on flat surfaces, such as a table or floor, illuminance in the demo areas was measured with a lux meter. A grid defining the specific measurement points over the demo area was used as shown in an example in (Figure 3). The illuminance is indicated with colors (lx) shown in the color palette at the right. Other photometric quantities such as CCT, CRI and color coordinates could be recorded during the measurement as well. In addition, luminance in the open office pilot was measured using a luminance camera with a fish eye lens.

The photometric measurements showed that the developed lighting system gave functional and nicely distributed illumination in the pilot office and hospitality environments. The measurements also showed that the proposed new system can provide the same light level and light distribution as the baseline of state-of-the-art lighting systems used as the reference in the performance comparison.

### End user feedback

The overall user experience was evaluated with validated questionnaires made available to the users of the pilot areas. The questionnaires focused on visual comfort, room appearance and personal control in the demo space. In addition, face-to-face interviews were carried out to collect more detailed feedback of the installation. An example of the results is shown in (Figure 4) below.

In general, the quality of light was evaluated to be at a good level in all the demonstration pilots.

Although statistically significant improvements in comfort were only shown for some particular aspects, qualitative analysis showed an increase in user comfort compared to state-of-the-art lighting systems used as a reference. In particular, non-conventional LED luminaires ("New Form Factor Luminaires and New Light Effects" - article) scored especially high in user preference in the hospitality environment. Thus, based on photometric measurements and user tests carried out in the project, it was concluded that the energy savings were not attained at the expense of light quality.

The user studies revealed that good communication and awareness of the benefits are important when introducing new lighting control systems. In conclusion, the majority of end users preferred the new system over the state-of-the-art reference for saving energy and maintaining a good quality of light.

Furthermore, taking care of smooth fading times is essential, since noticeable changes in the lighting settings were experienced as disturbing. User control with modern push buttons and desk lights was discovered to be important for user acceptance in the office because, in general, people like to have control over changes. The desk light, for example, was well appreciated because it enables a user to adjust the amount of light according to personal preferences when needed.

After becoming accustomed to the algorithm and understanding it as an effective way to save energy, almost none of the users complained about the smart control causing darker spots in the demo area when only a few people were present. The light bubble in the corridor was only noticed by those who arrived first early in the morning or left late in the afternoon. The feedback was positive as they were charmed by this energy-saving approach.

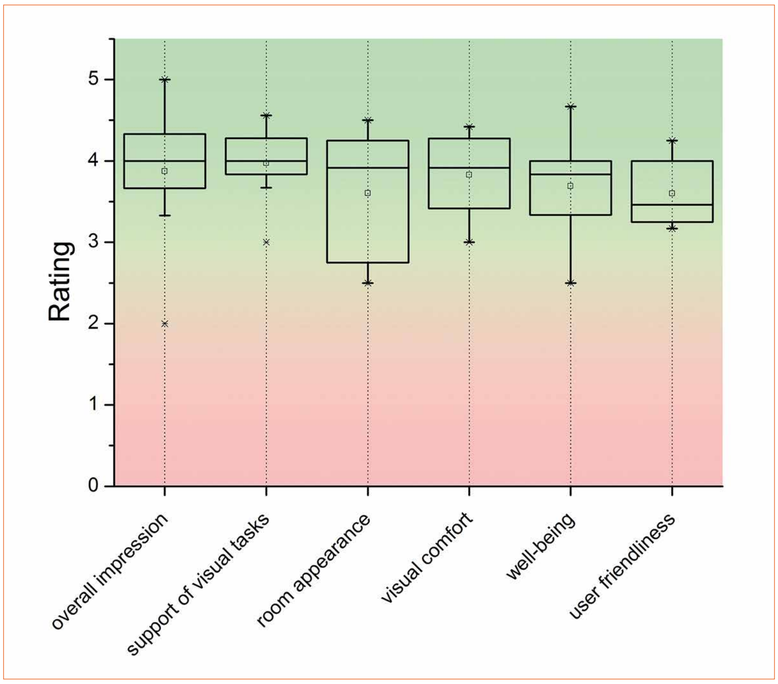



**Figure 4:**
**User rating of the hospitality installation. The rating scale ranges from 1 (very bad) to 5 (excellent)**

## Energy Savings: Metrics and Measurements

The Lighting Energy Numeric Indicator (LENI) described in the EN 15193: Energy performance of buildings - Energy requirements for lighting standard was used as the indicator of the energy performance. LENI describes the annual energy consumption of the lighting (kWh/m$^2$, per year) taking into account the power of the luminaires and the parasitic systems.

The energy savings were validated by comparing the developed system with the baseline installation of state-of-the-art lighting technology in an identical demo area.

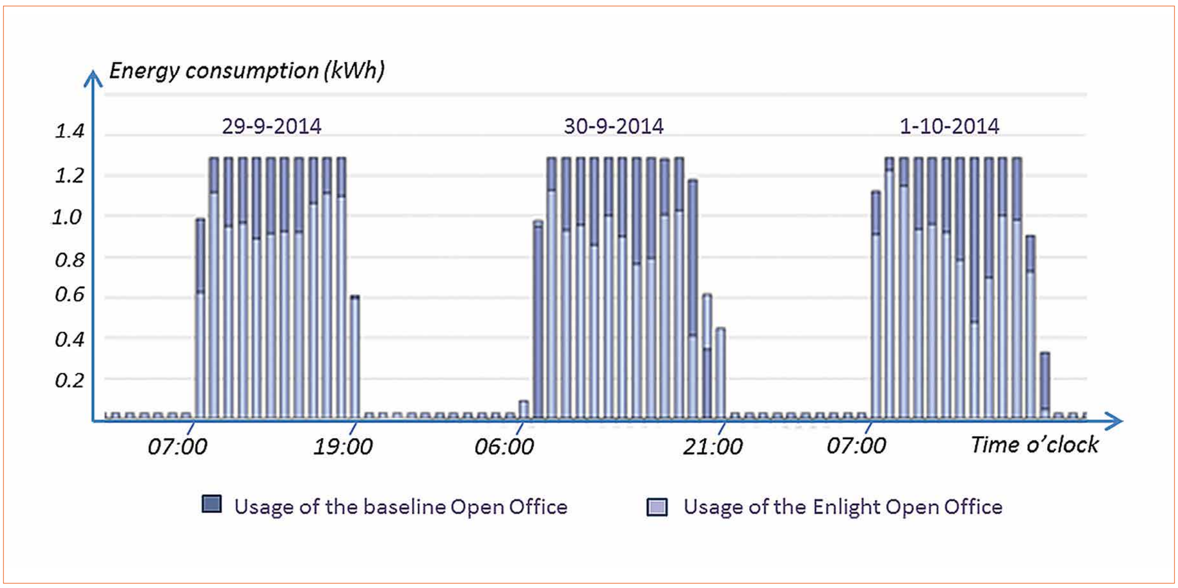
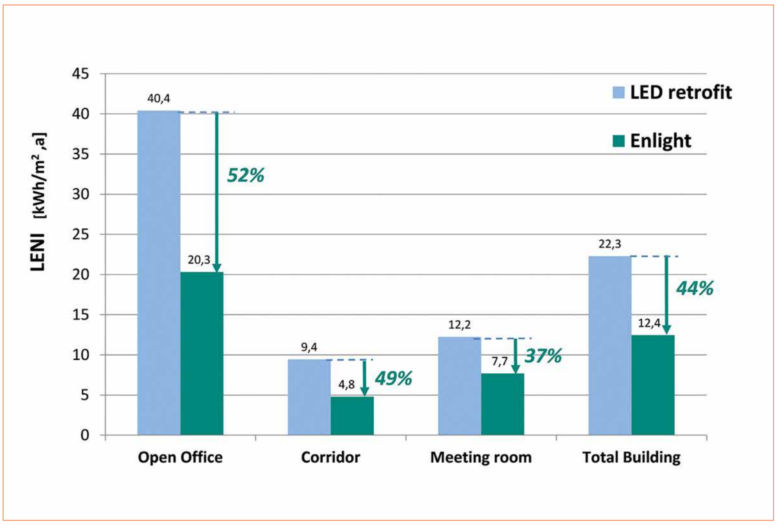



**Figure 5:**
**Energy consumption of lighting in the baseline system (dark) and the EnLight system (light) recorded on an hourly basis**

Figure 6:
LENI results measured for both test installations in the office application




The power consumption was measured and the LENI was calculated for both the baseline and the EnLight installation. Examples of measurement data in the office demo are shown in (Figure 5). The occupancy and daylight supply in different spaces with variable control strategy were also taken into account in the LENI calculations. Thus, it was possible to find out the differences in the energy performance in different situations.

## Overall Energy Saving Results

The main goal of the project was to achieve more than 40% energy saving compared to state-of-the-art lighting in real-life demonstrations. This target was accomplished in both the office and hospitality applications. Furthermore, the energy performance was compared against regional building energy performance benchmarks [1, 2, 3, 4] to bring the results in a wider perspective.

Table 2:
Energy benchmarks of the office installation

| Normative benchmarks LENI [kWh/m2, a] | EN15193 Office ** | ASHRAE 90.1 | LEED 18 pnt credit | Title 24 | EnLight Granular control |
|---|---|---|---|---|---|
| Open office | | 37.6 | 20.3 | 25.4 | 20.3 |
| Corridor | | 23.0 | 12.4 | 25.2 | 4.8 |
| Meeting room | | 25.7 | 13.9 | | 7.7 |
| Total building | 45.5 | | | 27.1 | 12.4 |

### Office

The baseline reference for an office application was a lighting installation which used retrofit LED lamps, such as TLED, LED Spot, and LED bulb, retrofitted into traditional office luminaires designed for incandescent and fluorescent lamps. No daylight regulation was exploited, but a commonly used automatic on/off control strategy based on global occupancy sensing per area with a switch-off delay of 15 minutes was used in the baseline.

The meeting room and open office measurements of the baseline and the EnLight installation were running in parallel in twin areas with identical room characteristics and occupancy. The corridor measurements were alternated in time between the EnLight and the baseline system in the same installation area. The task light illuminance levels for both test systems were designed to be the same - in case of a small measured difference in the illumination and occupancy between the systems, the energy data were corrected. The measurements were conducted in the period from calendar week 24 (June) to week 44 (October) in 2014 and were extrapolated to yearly energy use without seasonal corrections.

The office pilot demonstrated total energy savings ranging from 37% for the meeting room to ~50% for the corridor and open office, compared to the state-of-the-art retrofit LED lighting systems as a reference. Thereby, the contribution of the granular control strategy ranges from 26% (meeting room) to maximum 37% (open office) improvement. The overall lumen efficacy on luminaire level has improved with more than 20% from 76 lm/W to 96 lm/W.

As the resulting energy saving for the total installation was 44%, the goal of the project was accomplished. Figure 6 shows the absolute LENI numbers measured for both systems for the open office, corridor and meeting room areas. With EnLight, the LENI number for the total office area was reduced to 12.4 kWh/m² per year from 22.3 kWh/m² per year shown for the LED retrofit baseline.

The EnLight system energy performance was compared to the regional energy building performance standards EN15193:2007 [1], LEED [2], ASRAE 90.1 [3], Title24 [4]). The results are summarized in table 2. All energy values were calculated from the measured occupancy data and the applicable Lighting Power Densities given by the standards. In conclusion, the LENI results (i.e., 20.3 kWh/m² per year) were approximately 20% better than the Title 24 Lighting Power Density (25.4 kWh/m² per year) in case of large office areas. Compared to the ASHRAE requirements, the results were more than 46% lower which results in a maximum LEED score of 18 points. The current European EN15193:2007 standard provides the least stringent performance benchmark figures with values almost 400% higher than the demonstrated LENI performance.

### Hospitality

Like in the office demonstration pilot, the baseline reference to which the EnLight luminaires and their energy consumption in the hospitality application was compared consisted of LED lamps retrofitted into traditional luminaires designed for incandescent and fluorescent lamps. Non-conventional luminaires described in the “New Form Factor Luminaires and New Light Effects“ article were exploited in the demo. Such luminaires make full use of design possibilities which arise with LED technology and can thus hardly be realized in a retrofit approach. 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 in a similar way as for the office installations. Test persons used, interacted, and judged the whole installation. Usage hours which are relevant for deriving LENI numbers were nearly the same as given in the EN 15193 standard [1]. Energy monitoring measurements of the EnLight installation revealed an overall energy consumption of 20.2 kWh/m² per year (Figure 7). Compared to the LED retrofit baseline, this corresponds to savings of 81% which is largely above the target. Even if savings compared to the LED retrofit baseline with only on/off control (savings of 42% in Figure 7) 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 had to run all day long in this area. 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 be highly detrimental for installations with basic control. However, using the interactive and granular control, the light was adjusted to the right level at the right time and energy was drawn only as much as required by the users’ needs.

Compared to energy savings demonstrated with the EnLight office installation, the savings shown with the hospitality demo were especially high. This is due to the fact that for decades a strong focus in office luminaire development has been on highest efficacy levels. This is not true for hospitality applications in which a large focus is still on decorative elements that often counteract good efficacy. Dedicated designs as they were applied in this project provided large efficacy gains.

Also, the lighting power density installed in hospitality environment is usually much higher than in office areas. Consequently, there is good potential for energy savings with intelligent control as demonstrated with these results.

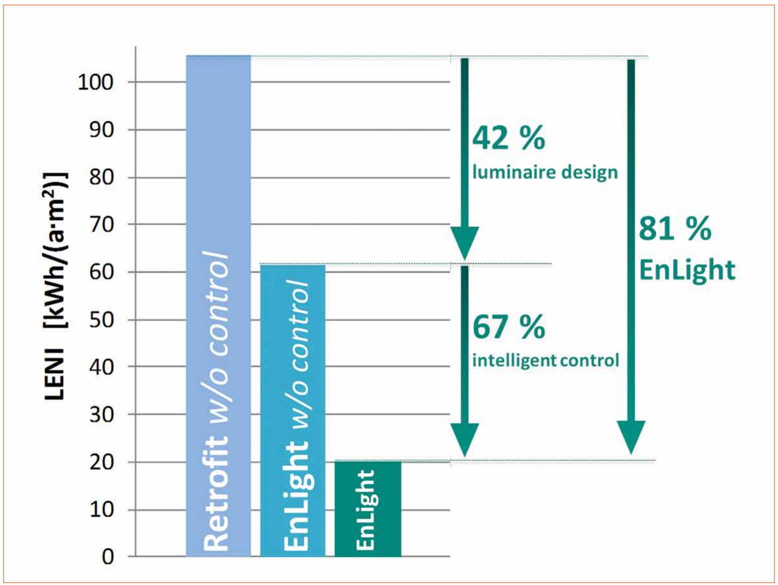



Figure 7:
LENI results of the EnLight hospitality installation. For the data without intelligent control, occupancy factors given in EN 15193 are assumed

Table 3:
Energy benchmarks of hospitality installation

| Normative benchmarks LENI [kWh/m², a] | EN15193 Hotel Quality Class *** | ASHRAE 90.1 | LEED 18 pnt credit | Title 24 | EnLight |
|---|---|---|---|---|---|
| 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 |

Similar to the office demo, the hospitality installation compared well with the most stringent international standards. The installation performed 45% better than the Title 24 standard for hospitality applications and exceeded ASHRAE 90.1 requirements by an average of 46%. A LEED score of 18 points was therefore achieved. Table 3 gives an overview of the LENI benchmark in detail.

## Recommendations and Future Work

It was shown by the validation results that the right metric for energy consumption of lighting systems should be based on actual energy usage per area and per year (i.e., kWh/m² per year). Therefore, the Lighting Energy Numerical Indicator (LENI) is a more suitable energy performance metric than commonly used installed lighting power (W/m²). The validated energy savings are an important stepping stone to realize the EU directive

2010/31/EU of the European Parliament and of the Counsel for a near zero energy performance of buildings in 2020. More stringent LENI benchmark numbers than in the current EN15193:2007 standard would be instrumental to achieve that goal.

At the moment, dynamic lighting systems are relatively new to the lighting industry. Development of dynamic lighting systems requires a combination of automated and personal control. Introduction of novel granular lighting control and sensors embedded in luminaires facilitate significant energy savings and user comfort enhancements.

However, end-user acceptance of high-end 'activity' sensors will require corresponding algorithms to enable unobtrusive implementation.

In the future, companies should further strive to limit energy consumption of stand-by power, ahead of future legislation. Joint activities in standardization bodies may guide to a stable market acceptance and therefore growth. Also, further research and validation of effects of human-centric lighting on health impacts of dynamic lighting - e.g. impacts on productivity in office lighting and also on psychological stability - should be addressed.

## Summary

In the EnLight project, intelligent lighting systems for office and hospitality applications have been developed that demonstrate significant energy savings of 44% - 81% compared with state-of-the-art LED retrofit systems while maintaining, or even increasing, user comfort. These results have been achieved by using sophisticated energy-saving strategies, such as task tuning, personal control, and granular occupancy sensing.

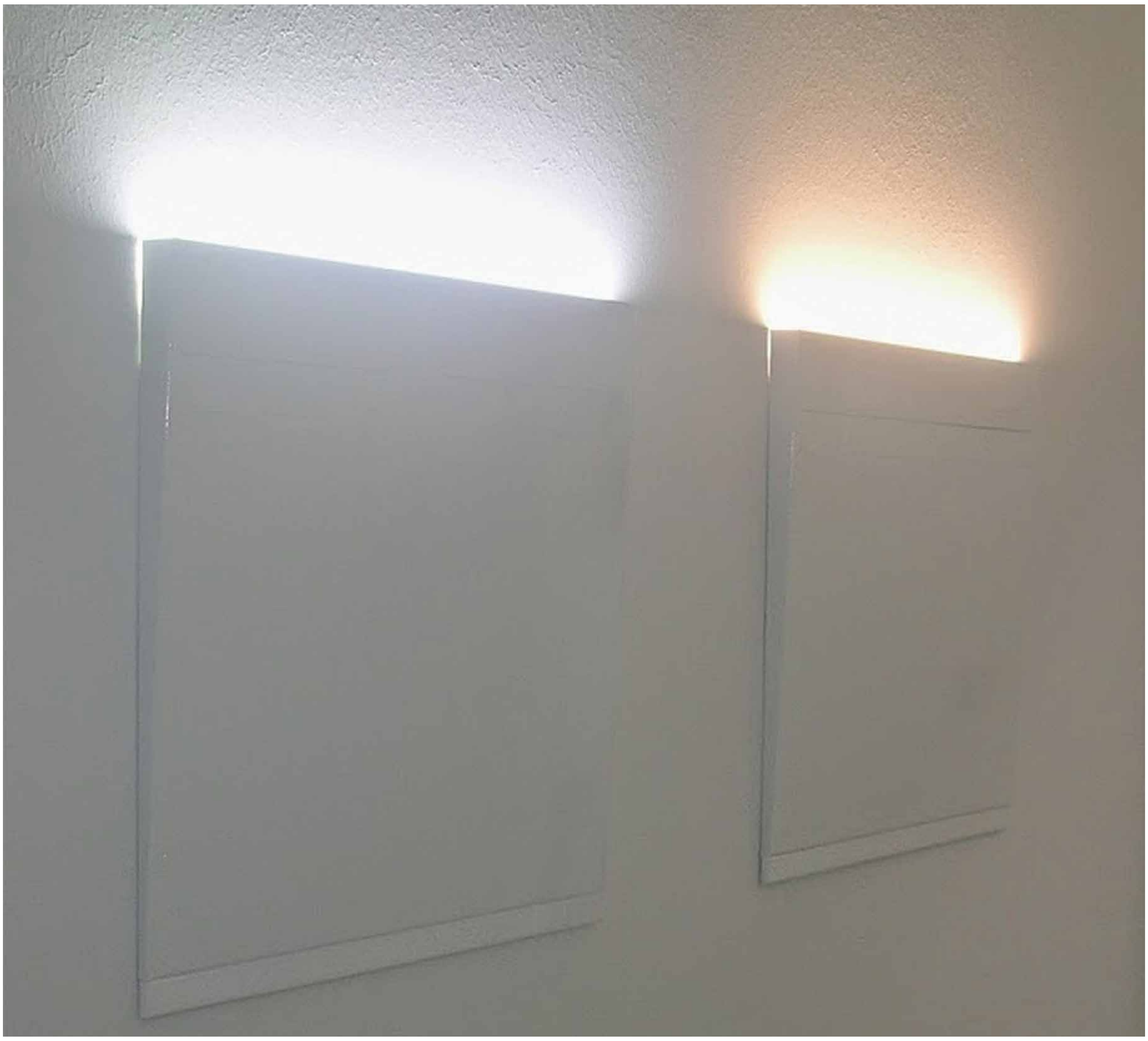


**Figure 8:**
**"Wedge Wall" luminaire, CCT tuned to neutral white and warm white**

**References:**

[1] EN 15193:2007 Energy performance of buildings — Energy requirements for lighting
[2] Leadership in Energy and Environmental Design (LEED)
[3] ANSI/ASHRAE/IES Standard 90.1-2007
[4] http://www.energy.ca.gov/2012publications/CEC-400-2012-004/CEC-400-2012-004-CMF-REV2.pdf