LED's Light the Future

Showcasing Models of Innovative Lighting Solutions

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Foreword

The lighting sector has experienced substantial transformations in recent years. Light Emitting Diode (LED) technology is the primary reason for this revolution. Fast LED uptake has subsequently highlighted new possibilities and functions for lighting. Advances in LED technology allow for a shift in lighting function from purely brightening, to a human-centric approach. For the first time in history, lighting design does not just address the visual effect of illumination, but can increasingly add the emotional and biological wellbeing of a person, and even plants. Furthermore, the wider smart city approach is enabling the integration of lighting into the wider urban landscape.

Given the rapid expansion of new LED uses, numerous actors are being inspired to experiment with application strategies and business models. It is therefore critically important to share best practices and guidelines for the successful implementation of LED innovations.

This publication is a collective undertaking of Masters of Environmental Science, Policy and Management (MESPOM) Batch 10 students, studying at International Institute for Industrial Environmental Economics (IIIEE) at Lund University, in collaboration with the Lighting Metropolis Project.

The report follows a case-study approach to highlight best practises in LED implementation. The eight chapters are divided into two sections according to municipal and private sector themes. The first section addresses municipalities and demonstrates current practice and lessons learned for a variety of LED applications in urban spaces. **Chapter one** describes opportunities and risks of various business model solutions for municipal street lighting systems. **Chapter two** examines safety, aesthetic, cost and environmental benefits of LED use in pedestrian tunnels. **Chapter three** analyses these benefits for LED-based holiday lighting displays, and develops an implementation guideline for interested municipalities. **Chapter four** moves across the Atlantic to contrast and compare LED streetlight transitions in Copenhagen versus Rio de Janeiro. **Chapter five** and the end of this section closes with a case study identifying barriers impeding transitions to sustainable lighting systems in school buildings.

The second section is concerned with LED lighting solutions in the private sector. **Chapter six** presents the challenges and benefits of an early LED adapter experience, in the hotel industry. **Chapter seven** discusses drivers and barriers for implementing advanced LED solutions in sports facilities from a multi-stakeholder perspective. Finally, **Chapter eight** analyses the significance of LED technology for fresh food production in urban indoor spaces

“Lighting Metropolis is the first and most important step towards turning the whole Öresund region into the world’s leading living lab for human centric and smart urban lighting. The project aims to create better light for people in cities and buildings. Light that supports security, accessibility, identity, health, learning and intelligent solutions that create energy savings, efficient and user-friendly cities and new services.”

BUSINESS MODELS FOR SMART STREET LIGHTING SYSTEMS

Log-In Opportunities and Lock-In Risks

By Mile Misic & Laurin Wuennenberg

Light emitting diode (LED) technology represents a major technological breakthrough and offers new prospects in the field of public outdoor lighting. The benefits from this technology are multiple. Due to high energy efficiency of LEDs, the energy savings are significant. According to the European Commission (EC), the implementation of LEDs can save up to 70% of energy used for lighting as well as associated energy costs. Moreover, maintenance costs can be reduced significantly.[1] Targets of the European Union (EU) to reduce their energy consumption by 20% by the year 2020 are set. Taking into account that around 50% of energy consumed in cities is for public lighting, it is evident that LED outdoor lighting will play an important role to achieve EU targets, as well as national and local environmental objectives[1]

Figure 1 Market outlook for outdoor LED lighting and lighting control systems.[7] Created by authors

Considering these targets, it is plausible that the market outlook for outdoor LED lighting is promising as shown in Figure 1. The prospect for lighting control systems remains slightly weaker as their contributing potential for energy efficiency appears not yet fully recognized.[1,2]

At the same time, LED public lighting infrastructure, together with software for steerable management system, represents an additional step towards smarter cities. This can be done by providing an interlink with and for diverse city infrastructures such as information and communication technology (ICT), sensor networks, as well as energy, facility and mobility management systems.[1] On top of that, LED street lighting improves safety and aesthetic experience by providing better quality light, compared to traditional public lighting.[3]

Despite these promising local and global benefits of LED lighting, the diffusion of smart street lighting solutions and innovative business models for providing lighting services is limited.[3] Moreover, the scale of public procurement can accelerate market penetration of LED and contribute to a shift in the overall lighting sector to more energy efficient solutions. Therefore, the purpose of this chapter is to present insights on how municipalities and businesses approach the diffusion of smart street lighting solutions. On a case study basis, this chapter demonstrates private sector perspectives on accelerating and impeding factors for the uptake of LED street lighting. Likewise, the chapter sheds light on the benefits (log-in opportunities) and drawbacks (lock-in risks) of business models selected by municipalities for updating their street lighting infrastructure. Consequently, decision makers in municipalities and businesses may draw conclusions for future street lighting projects from these insight.

LED Street Lighting & New Business Opportunities

With the advancement of LED technology and the variety of integrative smart applications, the lighting industry is changing. By now, "LED is the new standard for lighting" says Mr. Gyllner, Sales Manager of Philips Sverige.[4] LED will make up 85% of the sales volume of Philip´s lighting business in 2015. Hence, the market potential appears to be high. At the same time, the market landscape is becoming more diverse, utility companies are entering and previous niche actors are scaling-up. Increasing competition is inevitable and market actors need to position themselves to secure market shares.[4,3]

Diffusion of LED Street Lighting

Cities and municipalities are a major customer segment for new solutions, as their outdoor lighting infrastructure is increasingly outdated, energy intensive and lacks controllability. In Europe, there are 90 million traditional streetlights,

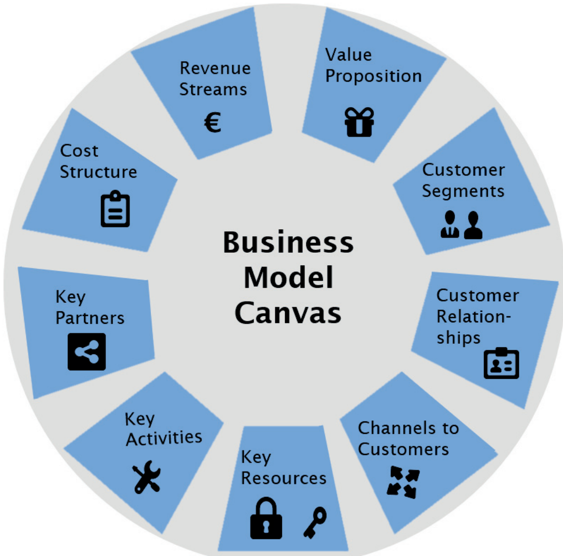


Figure 2 Business Model Canvas. Created by authors

with more than 75% of the installations being older than 25 years.[1]

The revenue potential for companies by updating cities´ outdoor lighting infrastructure is apparent. However, not all cities have identical needs or are administered in a similar manner. Quite the opposite is the case, as the Swedish cities of Malmö and Sala exemplify. As a consequence, companies or strategic alliances of companies need to have a diversity of business model components in their portfolio, allowing them to cater to differing needs and service-focused solutions. The *Business Model Canvas*, shown in Figure 2, gives an overview of what companies need to consider when designing new business models. Philips and E.ON, two companies engaged in developing new lighting solutions, are starting to redefine central components of their business models, such as value proposition, key partners and nature of revenue stream.

Even though investment costs for purchasing LED technology are decreasing, they remain higher than traditional street lighting solutions

New LED lights (foreground) and old high-pressure sodium vapour lamps (background) in the centre of Sala. Photo credit: Laurin Wuennenberg

"Customers are more frequently requesting the option to obtain lighting hardware that is not invoiced upfront but integrated into the running costs of the lighting product use phase."[3] Mr. Johnsson, Project Manager Business Innovation at E.ON.

such as high pressure sodium vapour lamps.[5] These upfront costs need to be financed, this can be a significant amount when considering the scale of city lighting infrastructure.

Depending on the city´s context, financial constraints, size of LED installation, risk perception, capabilities and resources of the procurer, national procurement obligations, timetable, local availability of funding, and business solutions, there are three observed financing strategies[5]:

1. Self-Funding

a. Direct payment of upfront investments: This can be done if cities have a sufficient budget in the respective year due to cash reserves, central government grants or self-raised finance through bonds or debts from banks;[5]

b. Gradual infrastructure updates**:** On a regular basis part of the old lighting infrastructure can be replaced by LEDs to allow direct payments of fragmented investment volumes, as implemented in Malmö;[6]

2. Third Party Finance

a. Public Private Partnerships: Payment of annual instalments by the municipality in order to share the upfront investments over (part of) the operating lifetime, and integrate these into the running costs (as implemented in Sala). The municipality pays for a defined and performance-based lighting service, as well as the installation and maintenance service. The provider (such as Philips) can raise finance from various private sector sources;[4]

b. Energy Services Company (ESCo): Based on performance contracting, the ESCo provides different energy efficiency services to a municipality and finances itself by revenues from the energy savings (E.ON is considering such a model in Sweden);[5,3]

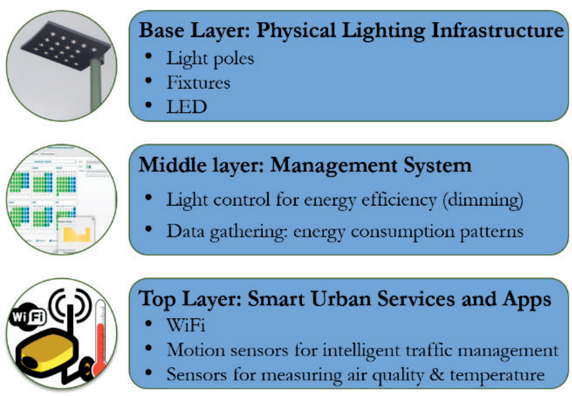
3. Leasing/ Debt Finance

The producer (lighting or utility company), owns the physical lighting infrastructure. The municipality, as the procurer, obtains the right to use the asset for a defined time through paying a lease. Upfront costs do not occur for the municipality, since acquiring ownership of the infrastructure is not the aim.[5]

All finance models have advantages and disadvantages in terms of investment risks and ownership rights, as described through the case study, findings and conclusion of the chapter.

Realising Multiple LED Benefits

The benefits of LED technology for cities go beyond the superior energy efficiency of the light source, longer lifetime, improved lighting quality and lower maintenance costs. LED technology enables the integration of specific steering and control functions, as well as new ICT. According to Mr. Brostrøm of the Danish Outdoor Lighting Lab (DOLL), three layers of integrative LED systems can be distinguished[7]:



Created by authors

According to Mr. Johnsson, the smart city movement is an opportunity for E.ON. Instead of the traditional utility company approach of selling kilowatt hours, new business areas (including energy saving services) and product diversification need to be pursued. Offering a basket of different product-services through cooperation with different companies is the way forward. For exploring respective prospects, E.ON, together with Philips, is in development of an outdoor lighting project in Lund for a private company.[3]

The integrative nature of LED provides the city management with new opportunities to adjust lighting to their citizen´s needs, offer smart services, gather data, as well as save further energy costs thanks to lamp-specific dimming control. According to Mr. Moritz from Malmö Municipality, LED in itself, has not yet progressed enough to reduce the total life costs given the high upfront investmen.[6]

Therefore, a management system is vital to reduce energy costs during the use phase to make LED a viable business case.

Lighting companies like Philips, as well as energy companies like E.ON, are seeking to create and offer integrative solutions by designing new product and service packages and incorporate these into new business models.[4,3] Both companies see potential to join forces for delivering added-value to customers and hence capture market potential. On the one hand, E.ON has a huge customer base being a major energy provider in Sweden, and is seeking business models that offer energy efficient LED lighting solutions as an energy saving service to its current customers. A pivotal way forward is simplifying the lighting value chain, reducing customer´s transaction costs and offering full solutions with transparent prices.[3]

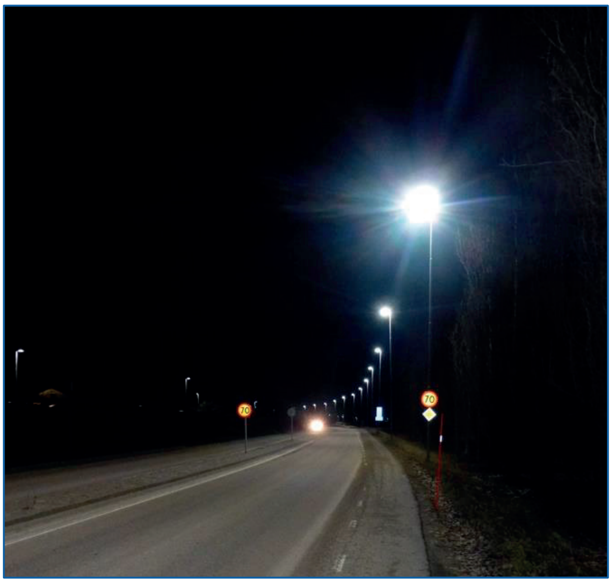
Philips, on the other hand, can provide the LED technology and offers lighting control services through its management system CityTouch.

Both Philips and E.ON emphasise the importance of cooperating with a diversity of actors in the lighting value chain. For E.ON, one desirable option is to cooperate with wholesalers in Sweden, since they provide a variety of lighting products and brands which subsequently enable E.ON to offer customer-specialised lighting solutions.[3] Philips is eager to cooperate with several utility companies in Sweden, as they allow access to new and a broad range of customers.[4]

The following case study demonstrates how the city of Sala implemented an integrative base and middle layer solution from Philips for their new street lighting infrastructure.

Sala Municipality Case study

Sala is a small municipality with a population of 20 000 people, located around 100 km northwest of Stockholm. It is the site of the largest LED public lighting project in Sweden, which from 2015 onward seeks to replace a total of



Newly installed LED street lighting in Sala Municipality. Photo credit: Laurin Wuennenberg

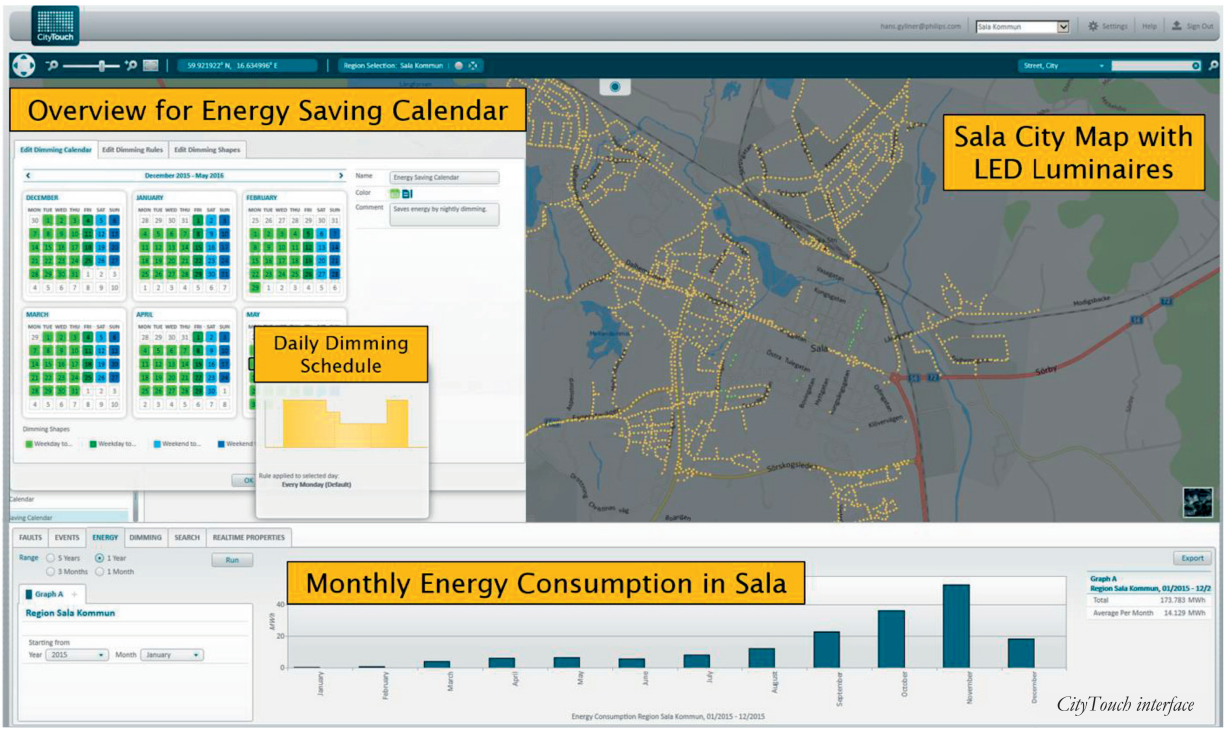
5 166 high pressure sodium lamps.[4] The ambition for improving the environmental profile was mentioned as the main driver for switching to LED street lighting. The municipality and its public utility company Sala Heby Energi (SHE) aim to reduce their carbon footprint through energy savings.[4]

SHE is the owner of the lighting poles and cables in Sala and acts as the contractee. The contractor, after winning the negotiated tender, is Philips Sverige. Major tender requirements by SHE were zero upfront costs, a maximum of SEK 1.9 M (EUR 203 000) annual operational costs, and implementation of the best available technology for energy efficient street lighting. For addressing these requirements, implementing a steerable lighting management system also became part of the tender negotiation. According to Mr. Gyllner, municipalities in general are so far not particularly interested in integrative lighting systems beyond the controllability feature, which restricts prospects for ICT add-on opportunities.[4]

Management Systems for LED Lighting

Philips Sverige provided LED lighting fixtures and a small device attached to the lighting fixture that is necessary for access to a web-based management platform called CityTouch. Through this installation, a steerable public lighting management system is provided that can communicate with every single LED light fixture through an individual control module. LED lights can be grouped in clusters for aligning settings in a specific part of the city. The communication between CityTouch and LED lights is established through the local mobile network. The CityTouch service is included in the annual instalments over the ten-year project period.

Patterns and schedules for dimming lights can be defined and adjusted by SHE. Two SHE employees were trained to use CityTouch. There is however a risk that, in an effort to save energy, local bodies might dim lighting below the level



Excerpts from Philip's CityTouch management platform for LED lighting control. Demonstration of dimming controllability with CityTouch can be seen by following the link: https://vimeo.com/148806156.

given in quality standards for safety and comfort. As a protective measure, Philips can set minimum brightness levels.[4]

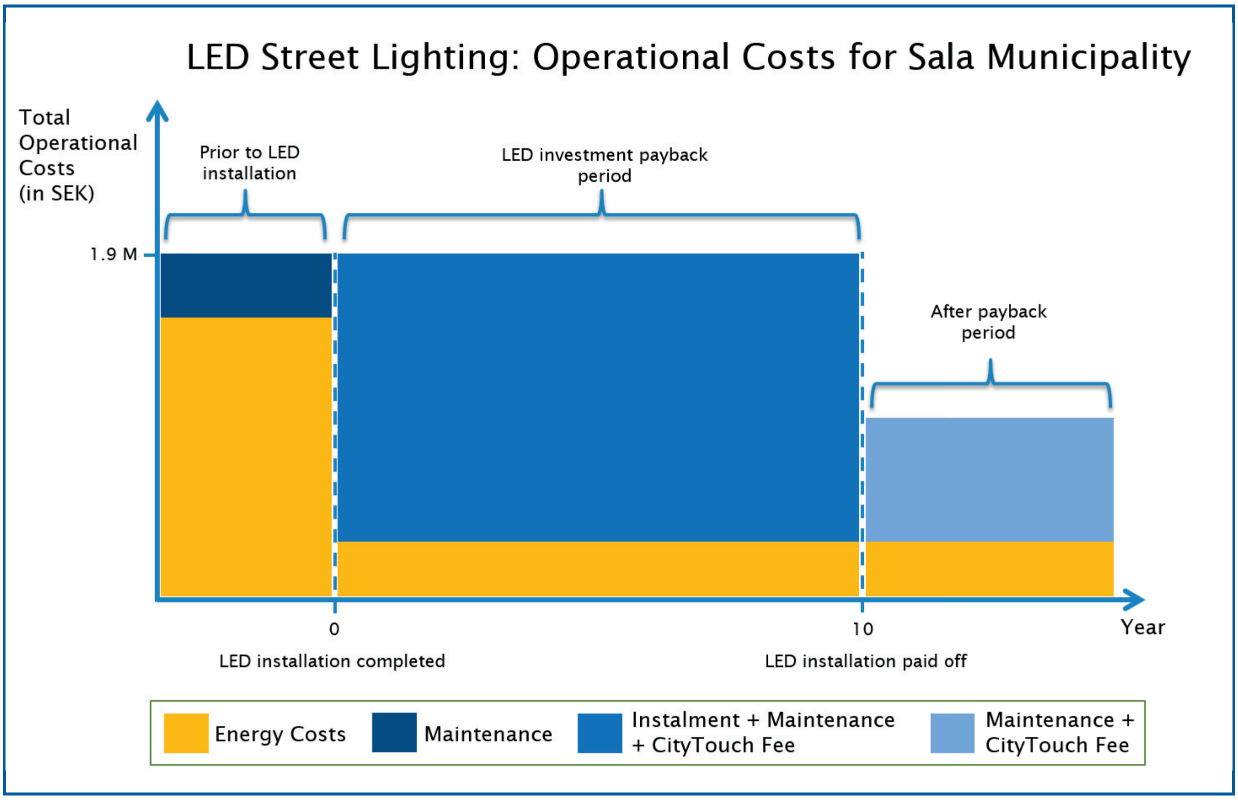
Beyond lighting control, the platform can collect large amounts of statistical data on energy consumption of each light fixture, groups of fixture and the system for Sala in general. It is possible to recognise trends in energy consumption, as shown in the figure below. According to the contract, SHE has full ownership over collected data and Philips is not permitted to use it.[4]

The Finance Model for Sala Municipality

SHE has defined a cap for annual operational costs of public lighting and did not want to pay any upfront costs either. The third-party finance model provided by Philips, in cooperation with DLL Finance Group, is meeting these requirements. After the LED equipment installation, SHE pays an annual instalment of SEK 1.9 M (EUR 203 000), equal to the amount of previous operational costs for energy consumption and maintenance.[4] The contract defines a 10 year payback length of the project, as well as a warranty for LED equipment for the same time period. As part of the warranty, Philips will also cover costs related to equipment malfunction. Likewise, the contract-based guarantee of annually 70% less maintenance costs shifts financial risks to the contractor. However, the defined project length provides attractive revenue streams for Philips, given the overall reduced energy and maintenance expenses of SHE.[4]

As shown in the figure below, the annual operational costs for SHE after the equipment installation comprise instalments for the investment costs, maintenance costs, CityTouch fees and remaining energy costs (80% less than prior to the LED installation as calculated in the project planning phase).[4]

According to Mr. Gyllner, the key value proposition for this project offered by Philips is energy savings. Out of the 80% reduction in energy costs, one-half is related to more energy efficient LED lights.[4] The second-half can be achieved thanks to control functions of CityTouch. While



LED Street Lighting project in Sala, Municipality: Operational costs approximations before, during, and after the investment. Created by authors from SHE´s point of view, operational costs do not decrease despite the energy savings, Malmö Municipality benefits from receiving completely new lighting equipment. Also, they significantly reduce their environmental impact due to less energy consumption.

At the end of the ten-year contract, SHE owns the LED street lighting equipment. They can decide on prolonging the CityTouch contract to keep lighting controllability and hence ensure continuing energy and cost savings. If they decide against that, they would save fees for CityTouch but at the same time would dismiss energy saving. The total energy consumption without a steerable control system is estimated at 60% of the consumption before project implementation. Furthermore, it is expected that the burden of maintenance costs for SHE, increases as the contract guarantee of 70% less maintenance runs out.[4]

Concerns of Municipalities: Log-In = Lock-In?

As indicated by the case study, the reduction of carbon footprint and energy costs are major drivers for municipalities to implement new LED street lighting systems. However, financing these systems and arising opportunities associated with ICT applications, have far reaching implications for municipalities in terms of ownership, flexibility for future investments, data control and financial risk management.

Knowledge of these implications is crucial for municipal decision-makers in order to set relevant criteria for the procurement process in alignment with the optimal business model.

Supplier Diversity

According to Mr. Moritz of Malmö Municipality it is critical to understand the technicalities of the lighting system, as well as the overall environmental footprint.[6] Malmö only purchased a small amount of LED street lights from Philips and is gradually updating their lighting infrastructure through self-funding over the years. The longstanding process, to replace old lighting in the old town of Malmö City with whiter and higher colour rendered LED lights, was initiated to improve the comfort of people. To ensure the satisfaction of citizen needs, experts of Malmö Municipality engaged with Philips to design appropriate light fixtures.[6] They also purchased Philip´s CityTouch to enable controllability of these lighting fixtures.

However, Mr. Moritz states that it would be unacceptable to purchase LED street lights and surrounding services for the whole city from a single supplier. On the one hand, ensuring competition between companies and procuring product diversity are procurement obligations for municipalities. On the other hand, he is not willing to approve the purchase of a lighting control system for the whole city if the system is owned and managed by the same single company.[6] He recognises a risk of (future) dependency on one company, and hence prefers diversification as an approach to mitigate lock-in risks.[6] As a response, Mr. Moritz encourages the development of open source software for lighting management systems and also suggests inclusion of open source software as a requirement in tender processes for LED lighting.[6]

LED lights in front of the train station in Sala. Photo credit: Laurin Wuennenberg

Mr. Brostrøm (CTO of DOLL) emphasises that intelligent (light) poles as access points for a diversity of smart applications are the key for smart city concepts. However, decision-makers in municipalities still lack knowledge about these opportunities. The related data gathering prospects are tremendous and having ownership of these data is the "oil" of the future.[7]

Ownership Considerations

Mr. Johnsson from E.ON argues that procurement requirements which undermine solutions for whole system and full service providers for large-scale and capital intensive projects, may become an obstacle for the diffusion of well-designed lighting products and services.[3] There seems to be a trade-off for municipalities between procuring optimised lighting solutions at an affordable price and the desire to stay in full control and ownership of the lighting infrastructure and related services and avoid increasing knowledge gaps.

The question of ownership raises another lock-in risk for municipalities. Although the leasing model can enable municipalities to update their lighting infrastructure, even if budgets do not allow high upfront investments, this finance model implies that the infrastructure provider maintains ownership of the complete lighting equipment. Hence, limited infrastructure ownership equals limited decision-making ability and flexibility. This is especially relevant when it comes to infrastructure updating and upgrading, as well as the utilisation of data gathering

The Burden of LED Supply Chains

Next to ownership challenges, Mr. Moritz is convinced that LED currently cannot be the panacea for public lighting solutions due to unresolved supply chain issues.[6] Severe environmental and social impacts in the upstream supply chain – especially in the mining and processing of rare earth metals – are intolerable as experienced by him during an industry visit in China.[6] Moreover, the carbon footprint of transporting all raw materials around the world cannot be ignored. At the other end of the supply chain, there is limited knowledge about the recyclability of LED products and the recovery of incorporated rare earth metals. Decision makers in municipalities need to take these limitations and uncertainties into consideration when they procure goods, as responsible decision-makers can contribute to the competitiveness of potentially precarious LED products.[8] Hence, product responsibility needs to go beyond reducing environmental impacts during the use-phase, and decision-makers need greater awareness of this when designing future concepts for their cities. It is inevitable, that socially responsible

Log-In Opportunities	Lock-In Risks
Increasing energy efficiency through integrative combination of base layer infrastructure and middle layer management system.	Leasing/ debt finance equals handover of infrastructure ownership to producers and hence **loss of data control and revenue opportunities** for municipalities.
Valuable data gathering capacities through top level smart applications.	**Future dependency** from single whole system provider.
Shift of investment and maintenance risk to producer through new finance models.	Unintended diffusion of LED products with **adverse social and environmental impacts** in downstream supply chains.
User focused street lighting solutions for enhanced life quality of citizens.	Diffusion of technology with **unresolved end-of-life management burden**.
Infrastructure for **smart city movement.**	Purchase **of immature system elements** characterised by **technology obsolescence**.

procurement increases transaction costs for municipalities, as it complicates the process of defining tenders and selecting the best alternative.[9]

Market Maturity Concerns

There is a discrepancy between the maturity of different elements of smart lighting solutions. Whereas LED lighting products have achieved market maturity, the complementing smart add-on functions (top layer) have not yet reached this maturity level. This impedes the provision of whole package solutions by companies and also creates resistance and a lack of interest within municipalities.[4,8,6]

Lastly, the rapid development within the lighting industry also poses a risk for municipalities as lighting products suffer from rapid technology obsolescence.[9] Hence, LED installations are likely to be outdated quickly if technology updates are not part of the contract.

Conclusion

This chapter outlined existing business model solutions for municipalities looking to update their lighting infrastructure to a smarter system that enables energy efficiency gains and additional safety and comfort benefits for citizens.

Based on interviews with stakeholders from the private and public sector, it was unveiled that not every business and finance option is an appropriate solution for every municipality. New technological solutions for public lighting are not only about reducing energy consumption or minimising financial risks associated with maintenance and product lifetime. Integrative and steerable street lighting systems also have relevant implications for citizen well-being and the control over data utilisation. Therefore, ownership and continuous control over the street lighting infrastructure is key for municipalities, suggesting self-funding or third party finance as the funding options of choice.

From a company point of view, it is not sufficient to only alter the value proposition to a stronger service and solution orientation, design a different revenue and cost structure based on new finance models, or establish new strategic partnerships. It is also necessary to improve communication channels and information transparency between lighting suppliers and municipalities.[9] Philips and E.ON have recognised this and are adjusting their organisational structures and internal learning capabilities for developing customer focused solutions.[4,3]

Beyond that, some municipalities recognise unresolved social and environmental issues in the upstream supply chain and end-of life stage of LED technology.[6] In order to engage the private sector to address those issues, it appears inevitable that respective social and environmental standards for LED products are being developed and set in public tenders.

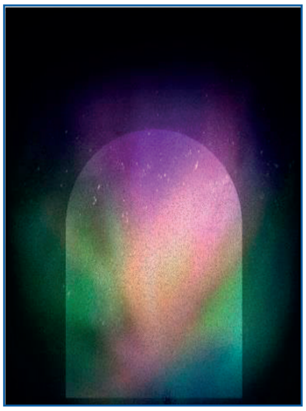
Lastly, limited maturity of smart applications restrict the full utilisation of integrative LED street lighting systems so far.

References

1. European Commission (EC). (2013). *Lighting the Cities - Accelerating the Deployment of Innovative Lighting in European Cities*. Luxembourg, EC, Directorate-General Communications Networks, Contents & Technology. Photonics: 36.
2. McKinsey&Company. (2012). Lighting the way. *Perspectives on the global lighting market – second edition.*
3. Johnsson, Thomas (Project Manager Retrofit at E.ON). Personal Communication. November 20 and December 1, 2015.
4. Gyllner, Hans (Sales Manager at Philips AB). Personal Communication. December 7, 2015.
5. Climate Change Group. (2013). *LED Street Lighting. Climate Group Document – Financial Section.*
6. Moritz, Johan (Lighting Designer at City of Malmö). Personal Communication. December 11, 2015.
7. Brostrøm, Kim (Chief Technical Officer at DOLL). Personal Communication during study visit. November 24, 201.
8. Mårtenson, Kenneth (Chief Executive Officer at Sala-Heby Energi AB). Personal Communication. December 10, 2015.
9. Plepys, A., Richter, J.L., Lindhqvist, T. and Dalhammar C. 2015. *Public procurement for sustainable lighting solutions.* IIIEE Lund University. Conference paper (unpublished).

BEYOND TUNNEL VISION

Revitalising Pedestrian Tunnels Through LEDs



By Sophie Peter, Imelda Phadtare & Pin Udomcharoenchaikit

Tunnels are often located in public places in most global cities, and function as an improvement to street and route connectivity.[1] Tunnels can also be conduits for journeys, exchanges and human interaction across the urban landscape, while delivering a functional, enjoyable and safe experience to "Users" (e.g. pedestrians, cyclists, etc.). Improved lighting through LEDs has the ability to enhance and even optimise this experience.

Project Rationale

Tunnels play a key role in the urban landscape and may play a more crucial role going forward, based on urban growth and transit options. LED lighting in pedestrian and cycling tunnels and bridges may provide a pathway towards greater urban security, attractiveness; and cost, energy and CO_2 reductions.

This research is significant because:

- City populations and amenities are under increasing demand, as more residents require more infrastructural upgrades, retrofits or new builds;
- A 'Liveable cities' approach is being adopted by progressive planners;[2]
- Smart cities and CO_2 reduction plans are including energy efficiency technology, as well as convenient and safe multi-modal transit options;[2]
- Urban pedestrian tunnels are often associated with fear, crime and grime, and consequently, are underappreciated and not maximized pieces of central infrastructure;
- Holistic city plans are now driven by multi-stakeholder engagement; and
- LEDs are on an upward trend, due to technological sophistication (e.g. colour temperature, sensors, dimming, etc.), cost savings delivery and energy savings delivery.[3,4]

Project Objective

The objective is to examine to what extent the uptake of LEDs in pedestrian tunnels delivers improved security and attractiveness, as well as reduced costs, energy use and CO_2 emissions.

Focusing on pedestrians and cyclists using tunnel underpasses, this explorative journey takes place in three European cities: Lund, Copenhagen and Hamburg. This chapter examines the theory to practice of these demonstrations, highlighting successes, barriers and novel learnings based on site observations, seven stakeholder interviews and desktop research.

Watch the three demonstrations on LED pedestrian tunnels by the following link: "**Beyond Tunnel Vision**", https://www.youtube.com/watch?v=9Uq4WFjy16A

Demonstration Sites

Tunavägen/E22, Lund

The mixed vehicle, cycle and pedestrian tunnel at Tunavägen and Lund's E22 highway, experiences frequent traffic due to proximity bordering Lund University Campus and its road connectivity with Ideon Industrial Park.

The tunnel was retrofitted with a LED design in August 2015. Drivers behind the project were two-fold. Firstly, Lunds Kommun (Lund Municipality) replaces existing high-pressure mercury lamps across the city through a prioritized list of locations.[5] Secondly, numerous security concerns and an interest in increasing attractiveness resulted in the tunnel being nominated for an upgrade. Initially, wall artwork was to be installed, however joint owners, the Swedish Road Administration, did not approve.[5] Lunds Kommun turned then to hiring light designer, Bertile Göransson from LUXERA. Göransson's brief was simple: improve tunnel lighting for pedestrian security, ensure people can see and be seen, and make it fun and attractive.

Göransson's design, consists of white and blue LEDs for pedestrian and cycle pathways installed at the top of eight columns. The white LEDs provide indirect backlighting, while the blue LEDs provide indirect downward lighting. Lunds Kommun both owns the lighting infrastructure and is responsible for operation and maintenance of the installation. The Municipality invested SEK 300 000 (EUR 32 175) in the infrastructure and a further SEK 150 000 (EUR 16 087) for the installation.[5]

Experiencing the demonstration as a pedestrian and cycler, day and night, validates a fit-for-purpose solution. The tunnel provides a safe, inviting and secure feeling when entering, passing through, and when exiting. Users can see each other throughout the 15 metre tunnel, with faces being visible at ten metres.

The Municpality is delighted with the Tunavägen tunnel result, as it substantially improved features of security and attractiveness. They are considering retrofitting other priority tunnels in the city.[6] Post-installation evaluation has not been undertaken, but ad-hoc inspections went well and no complaints have been received from the active citizen base. Challenges include technology lock-ins, cross-departmental misalignment in decision-making and information-sharing, across procurement, energy efficiency and hazardous waste management. LED energy efficiency gains are not key drivers for the retrofits.[5] However, the Municipality acknowledge these important features of tunnel design and lighting, especially given future possibilities of digitalised LED technology.[5]

> "When choosing options for retrofitting, attractiveness is the main thing we look for, along with cost." – Anna Karlsson[5]

Photo collage of Tunavägen/E22, Lund. Photo credit: S. Peter, I. Phadtare & P. Udomcharoenchaikit

Langebro, Copenhagen

Langebro (The Long Bridge) is in central Copenhagen, Denmarkm connecting the city to Amager Island. Owned and operated by Copenhagen Municipality, it services thousands of cars and bicycles daily. The bridge also opens up to allow large ships to pass. Given the bridge's central location, the frequency and volume of pedestrian and cycling traffic moving through the underpass is huge. A public open space, adjacent to the underpass, is set aside for social events, festivals, and concerts.[3] However, the underpass area is not well lit and reports revealed walkers felt generally unsafe, both during the day and night.[3]

The Municipality recognised the underpass area has significant urban mobility and wellbeing functions, leading to a decision to install a decorative lighting scheme to revitalise the area.[7] Jesper Kongshaug, an international award-winning Copenhagen-based light designer, was invited to present a design. *"Lighting Something"*, Kongshaug's vision, was adopted by the Municipality.[3] It focused on integrating LEDs with existing city structures and activities. For example, LED "pulsing", records the bridge's traffic frequency synced with lighting, to deliver Users an optimal lighting experience, while blending with the cityscape. Also, the Rådshuset's (City Hall) clock is synced with LEDs and colour temperature changes, creating a rhythm for the city.

> "Lighting something - there is no desire to spotlight the tunnel, it must blend in with surroundings." – Jesper Kongshaug[3]

For this project, the designer considered the decorative lighting separately from security and street lighting. The light needs to be Red, Green, Blue (RGB) instead of Red, Green, Blue, White (RGBW), based on regulations that require public light with high voltages to retain double layer insulate. Kongshaug installed more subtle and indirect LEDs deepening his vision for lights to blend further into the cityscape, while citizens enjoy and appreciate their city for functional and attractive reasons.[3]

No program evaluation has been conducted because implementation is ongoing, though initial results appear positive. The Municipality is responsible for full costs of the design plans, installation and operation.[3] Overall maintenance costs were lower due to reduced frequency for controlling and changing the diodes. The rebound effect is prevalent however, as lower energy consumption of LEDs has encouraged the designer to use more diodes than traditional options. The trend in LED from the designer's perspective is an increasing uptake of LEDs in public procurement, aiding a transformation. However, this is somewhat challenged by the higher cost of good quality LED products.

Photo collage of Langebro underpass, Copenhagen. Photo credit: S. Peter, I. Phadtare & P. Udomcharoenchaikit

Sternschanzenbrücke, Hamburg

The underpass lighting of Sternschanzenbrücke, Altona, Hamburg, was driven by the "Lebendige Stadt" (Liveable City) Foundation.[8] With the advent of a ten-year anniversary in 2010, the Foundation decided to invest in an innovative, attractive and nation-wide project, with 'light' being the key project focus.[9] Foundation Board Member, light designer and artist, Mr. Michael Batz, had the necessary skills, insights and networks to manage the project. This setting led to the illumination of underpasses supported through various partnerships. [10] Three critical issues were addressed: the removal of underappreciated space, increasing the aesthetics, and modernisation of public lighting through LED.[9]

> "Best practice in LED lighting seeks to stimulate other cities to do the same." – Fuchs, Gerhard[9]

Altona is a successful best-practice model designed to inspire other cities to adopt and replicate.[8] The project includes not only blue and white LED-installations (blue is the colour of Hamburg), but also wall art to create a more integrated solution.[9] Unfortunately the wall art in Altona was defaced with unapproved poster advertisements. Nevertheless, overall success was achieved through the combined efforts of the project consortium. Major partners included the local Chamber of Crafts, the Deutsche Bahn AG, and the Municipality of the District Altona, who define illumination as critical.[4,8,10]

Various levels of government and partners influenced the project. At a national level, Germany's "Wegegesetz" (pathway law) regulates lighting for security and ease of traffic flow. At a city level, Hamburg's laws specify requirements for street lighting (DIN standard).[10] At the district level, Altona provides manpower and equipment.[9] A significant partner is the private lighting-company Philips, who has been in partnership with the Foundation for almost ten years.

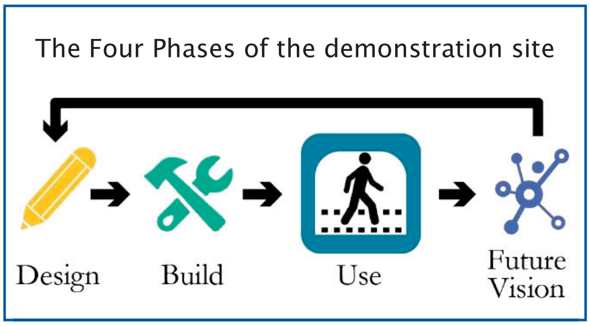
The "Guidance Through Light"[4] concept of the Foundation focuses on the interaction between outdoor lighting, urban design and light quality. Batz and Philips worked closely to technically translate their designs into reality. The total cost of this project was around EUR 25 000.[8] The "best-practice to best-practice model" has been transferred 31 times in 24 German cities. Of great assistance was the EUR 750 000 start-up financing by the Foundation and support by the Deutsche Bahn AG.[8]

Photo collages of LED Sternschanzenbrücke, Hamburg. Photo credit: S. Peter, I. Phadtare & P. Udomcharoenchaikit

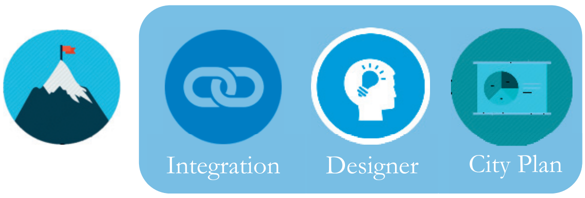
Findings

All three demonstrations presented were owned and operated by municipalities and have not yet had full use-phase evaluations undertaken. However, overall, LED installations in these pedestrian tunnels were found to play a vital role in improving urban security, attractiveness and mitigating costs, energy use and CO_2 emissions.

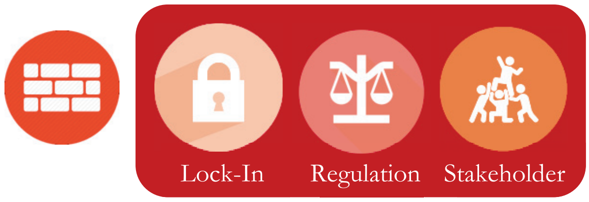
Project findings are summarised under each of the four Phases: Design, Build (implementation), Use (operation) and Future Vision.



Phase 1 Design



Success a) Integration of specific LEDs into local context, as opposed to a uniform model transfer. **b)** Skilled lighting designers influence selected tunnel designs, preferred technology and beyond tunnel LED decisions. This relates to broader urban wellbeing aspects and continued investments in holistic approaches of urban revitalisation. This is done by integrating tunnel lighting within other aspects of the city e.g. in art pieces and close to cafés, increasing the value of the space. **c)** Municipalities that own and operate the lighting infrastructure can make decisions more quickly because costs and timelines are internally managed – this means alignment with other city plans such as multimodal transit, CO_2 reductions and cost savings.



Barrier a) Municipalities feel compromised when investing one type of infrastructure because they want to avoid technological lock-ins and await a more stable market, especially with the LED digitalisation field moving so rapidly – often this delays decisions. **b)** Public lighting regulations must be fulfilled, restricting new LED tunnel design possibilities. **c)** Municipal cross-departmental alignment between procurement, traffic, energy efficiency and hazardous waste departments can be poor and in the wrong order, resulting in less effective decisions. **d)** Designers may hold too much influence in this phase of the process leading to expensive investments.

Phase 2 Build

Success a) New lighting products bring the design into reality, leading to further development of innovative lighting products and their applications. **b)** Sensors, pulses, indirect lighting and automatic systems enable a customized and high performing interactive light experience, resulting in improvements in tunnel security and aesthetics. **c)** A nuanced relationship between lighting and human behaviour, is being explored i.e. 'Guidance Through Light'.

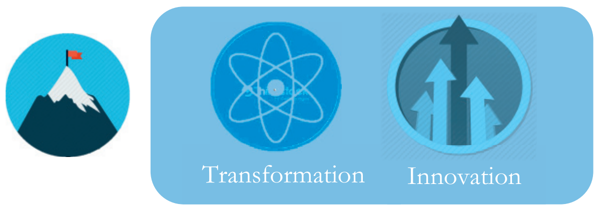
Barrier a) Decorative LEDs must remain separate from security LEDs, or have to fulfil the same standard as the latter. **b)** Outdoor use of LEDs, such as in the tunnel setting, is impacted by humidity, resulting in shorter diode lifespans. **c)** LEDs do generate high quality vision output, resulting in visibility of cityscape dirt. **d)** Budget is a critical factor and good quality LEDs, remain expensive purchases. **e)** Municipalities may find themselves dependent on one service provider for technology – leaving them vulnerable to price increases. **f)** Municipalities have bought in bulk following LED installations to avoid issues with technology obsolescence.

Phase 3 Use

Success a) Indirect blue and white LEDs are effective in allowing tunnel users to see and be seen, thereby increasing safety. **b)** Municipalities typically record success in the absence of citizens calls and complaints[5], however no evaluations were undertaken on the demonstrations. **c)** From observations, each of the demonstrations are actively used, day and night, by both pedestrian and cycling groups, suggesting a good project result.

Barrier a) Failure to evaluate the effectiveness of tunnel LEDs creates difficulty in matching project objectives with outcomes in an evidenced, or at least meaningful way. **b)** Rebound effects were detected where the low energy consumption of LEDs and its spotlight, led to a higher number of LEDs being installed. **c)** Lower maintenance, replacement and repair costs are still contentiously debated – there was no conclusion among the demonstrations if conventional lighting or LEDs actually cost less in the long run. **d)** Although municipalities discuss tunnel LEDs as adding to the bottom line energy savings and being more responsible for the environment, it is likely these politically correct statements are unable to be evidenced in the project plans or operational data. **e)** Business models such as buying LUX or leasing equipment is still in experimentation phase, generally Municipalities own, operate and buy technology from service providers, with private contractors sometimes replacing and maintaining the LED installations.

Phase 4 Future Vision



Success a) Transformation from conventional lighting in tunnels to LEDs is likely with the current best practice showing overall improvements. **b)** The concept of integrated and interactive lighting would result in an innovative new level of lighting experience enhancing the pedestrian and cycling experience in tunnels.

Barrier a) Technology lock-ins and obsolescence **b)** Mixed business models look likely to continue on a case by case basis, implying continued uncertainty for the market and long term plans for cities. **c)** Significant development is required to fully transition outdoor lighting to LEDs. **d)** The Internet of Things and digitalization of big data may result in intelligence control system gaps through security violations of private data and LED tunnel operations.

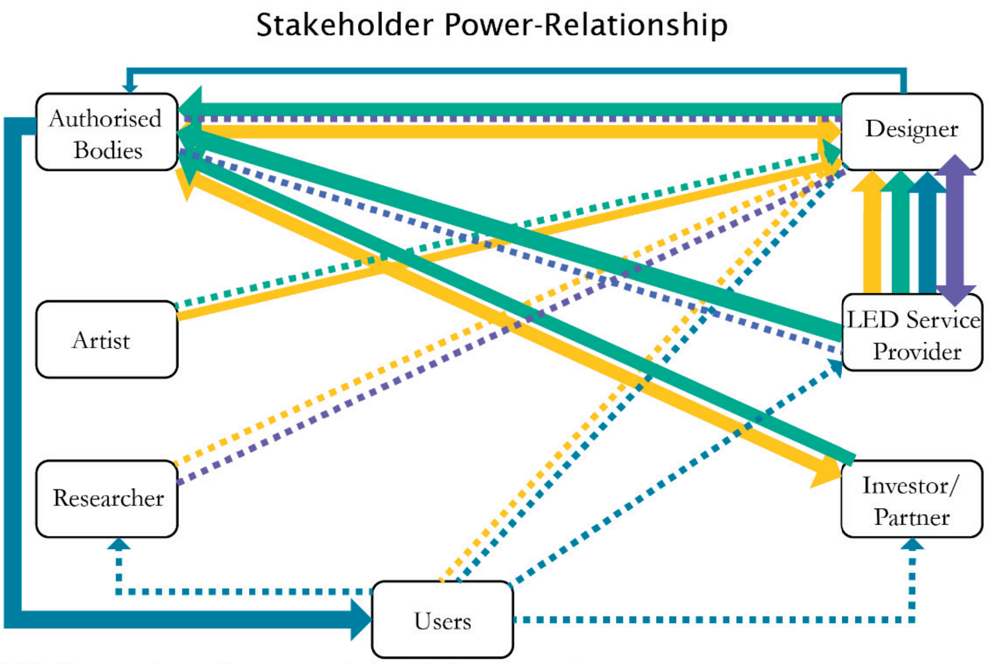
Novel Learnings

- Research and development into replication of artificial light to match realistic day light, adapting to the human eye is evolving rapidly.[12]
- Challenges can lead to innovative and successful LED application in pedestrian tunnels; such was the case for Lund Municipality, who originally planned wall art but were refused by joint owners the Swedish Road Administration. An alternative approach to increasing security and attractiveness led to the LED installation.
- Pedestrian and cycling underpass tunnels are less preferable in some smart city plans (e.g. Lund Kommun prioritise a level city without underpasses[5]). However, sustainable development builds on existing infrastructure leading to LED tunnel retrofits.[11]
- Blue light in the tunnel may lead to a rebound effect, where citizens are aware blue light is used to increase security and, psychologically, this may lead to an increase of feeling unsafe in the tunnel.[12]
- The nexus of integration between lighting engineering, design and human psychology can be expected in the future projects.

Conclusion

From theory to practice, the tunnel demonstrations show a fit-for-purpose installation of LEDs with improvements at all sites, based on the following elements in priority order: security, attractiveness, cost savings, energy and CO_2 savings.

There is a clear trend towards LED transformation in public outdoor lighting and in particular, pedestrian tunnels. This upward trend is exemplified through best practice models operating across northern Europe. Focal areas for this chapter included: Germany, Denmark and Sweden, which are contextually different but



This diagram shows the power relationship between stakeholders in each Phase of the studied LED project. The arrowheads show the direction of support in the relationship, while the line thickness shows the strength of the relationship. A shift in power between stakeholders and Phases is evident.

Created by authors

aligned in terms of key objectives. Common objectives of the LED tunnel projects through the modernisation of public light include: enhancing an underappreciated or poorly lit space within the city and transforming it to an attractive and safe open space, saving costs through reduced diodes replacement and saved energy, securing CO_2 reductions, and meeting any city visions aligned with smart city development.

The demonstration results have supported these initial objectives where replication of the LED tunnel enhancements have either occurred, or are being planned for the future. Challenges remain in terms of full cost effectiveness, management of the rebound effect, the optimal procurement model, availability of technology, avoidance of lock-ins, and aligned decision-making at the city level.

Looking ahead, the opportunities to light up "something" by applying the third dimension of a building, in combination with sensors and overall digitalisation, are enormous and exciting. We are just at the beginning of this journey, as echoed by the light designers, municipal traffic and procurement officers and environmental psychologists interviewed.

Continued experimentation with LEDs in pedestrian tunnels is needed, in addition to examining the bigger picture of the demonstrations and their combined results. This will allow for the identification of common successes and barriers, enabling optimal decision-making for LED pedestrian tunnel investments.

References

1. Safe Routes To School. (2015). *Pedestrian and Bicycle Bridges and Tunnels*. Retrieved 09 November 2015 from http://guide.saferoutesinfo.org/engineering/pedestrian_and_bicycle_bridges_and_tunnels.cfm
2. Philips. (2015). *Case Study: How Railway Underpasses Can Become Safe and Inviting*. Koninklijke Philips N.V.
3. Jesper, K. (2015, November 30). Light Designer in Copenhagen Denmark. Personal Interview. (S. Peter, I. Phadtare & P. Udomcharoenchaikit, Interviewers).
4. Representative of Philips Germany. (2015, November 25). Telephone Interview. (S. Peter, I. Phadtare & P. Udomcharoenchaikit, Interviewers).
5. Karlsson, A. (2015, November 25). Technical Management Street and Traffic Department Lunds Kommun. Personal Interview. (S. Peter, I. Phadtare & P. Udomcharoenchaikit, Interviewers).
6. LundaMaTs. (2009). *LundaMaTs II. Background and Results*. Municipality Lund.
7. City of Copenhagen. (2011). *Good, Better, Best: The City of Copenhagen's Bicycle Strategy 2011-2025*. Copenhagen: Traffic Department
8. Fuchs et al. (2014). *Die künstlerische Illumination von Bahnunterführungen*. Hamburg: Societäts Verlag in order of the foundation "Lebendige Stadt".
9. Fuchs, G. (2015, November 25). Board member of "Lebendige Stadt" Foundation. Personal Interview. (S. Peter, I. Phadtare & P. Udomcharoenchaikit, Interviewers).
10. Representative of Street Management City Hamburg. (2015, November 25). Telephone Interview. (S. Peter, I. Phadtare & P. Udomcharoenchaikit, Interviewers).
11. Riderberg, U. (2015, December 02). Lightdesigner in Linköping. Email Communication. (S. Peter, I. Phadtare & P. Udomcharoenchaikit, Interviewers).
12. Lund University Psychologist. (2015, November 27). Personal Interview. (S. Peter, I. Phadtare & P. Udomcharoenchaikit, Interviewers).

HAPPY HoLEDays

A Guideline to Greening Public Holiday Lighting Displays

By Beatrice Ch'ng Sin Yi, Jennifer Tollmann & Krithi Venkat

Holiday lighting displays are at the heart of many Northern European cities' holiday decorations. However, there is very little research on public LED displays or planning and procurement considerations necessary for ensuring a greener holiday display.

Municipal level public lighting has been on the increase in the past decade, as more and more municipalities seek to install elaborate Christmas displays to enhance their city's festive spirit.[1] However, this proliferation of increasingly extravagant lighting installations risks seriously increasing a municipality's environmental footprint. While municipalities are unlikely to forgo seasonal holiday lighting, it is possible to minimize the inherent environmental footprint of these installations by choosing to transition to LED-only lighting.

This chapter will outline the benefits of installing LED public holiday lighting displays and provide an implementation pathway for municipalities seeking to "green" their lighting displays. In doing so we draw mainly on our research and interaction with the City of Stockholm and their annual LED-lighting extravaganza #Stockholmsjul. Launched in 2011 and now in its second project phase, #Stockholmsjul is a festive LED-lighting success story.

The royal palace in Stockholm, Sweden. Lighting leads the way to this popular tourist attraction. Photo credit: Mikael Sjöberg

#Stockholmsjul: The Benefits of Holiday Lighting

Christmas is one of the most important festive seasons in Europe. The winter season is marked by shorter days and growing darkness, making Christmas lighting essential in bringing a sense of comfort and warmth to communities.

Stockholm, the capital of Sweden, was labelled "not a Christmas city" by the local newspaper Dagens Nyheter in 2007.[1] This along with other drivers prompted the municipality to set a goal to use new innovative LED technology to create a lighting display that would make the "the best Christmas in Scandinavia". To pursue this goal, City i Samverkan, a joint venture between the Stockholm municipality, the shop owner's association and real estate owners, launched #Stockholmsjul in 2011.[1,2]

#Stockholmsjul has been a hit among Stockholmers and visitors alike. To better assess the

perception of the project, an annual attitude survey was conducted by the City of Stockholm and City i Samverkan between 2012 and 2014.

The results revealed that by 2014 over 70% of interviewees found the lights highly attractive to attractive and 40% of them directly attributed the city's warm Christmas spirit to #Stockholmsjul.[3]

Christmas lighting can also play an important role in preserving tradition and highlighting cultural heritage sites. In addition to giving the city a festive spirit, Christmas lighting draws tourism to Stockholm City.[1]

Christmas time is also one of the most lucrative periods for shop owners, with some retailers generating up to half of their annual revenue in this period.[4] The placement of Christmas lighting can draw locals and tourists alike to the main shopping streets.[1] Alternatively, municipalities can choose to support smaller retailers and cultural sites by where they place lighting displays.

Over 60% of people surveyed were Christmas shopping; others were out with friends and family for meals or drinks.[3] Particularly during the short Scandinavian days, with sunset coming as early as 3 PM in Stockholm, Christmas lighting is crucial in creating a warm, safe and inviting atmosphere to encourage prolonged shopping hours. Christmas lighting in the city can thus bring business to shops, restaurants and entertainment venues.[3]

70% Would recommend visiting the city to see the Christmas lights

Why LED Holiday Lighting?

Environmental Benefits

In comparison to traditional incandescent lights, decorative LED lights consume between 25% to 80% less electricity, and have a 3 to 25 times longer lifespan.[5] According to a Swedish Energy Agency study, an 11-armed candlestick with incandescent light bulbs consumes 43 times more electricity than its LED equivalent.[6] Figure 1 shows that the energy savings potential is particularly high for Christmas lights.

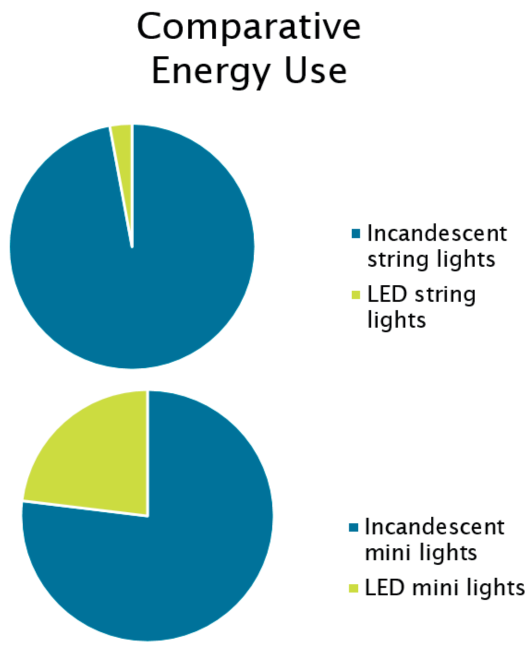


Figure 1 Comparing energy usage of incandescent and LED string lights and mini lights.[5]

On a wider scale, participating streets in #Stockholmsjul have experienced significant savings.[1]

Furthermore, resource efficiency can be improved alongside energy efficiency, due to the longer lifetime.[5]

70% Energy savings (2013) from LED in Drotinggatan street

#Stockholmsjul2014

Technological Benefits

Christmas lights need to fulfil a range of functions, therefore the type of lights selected play an important role in determining the quality and impact of the display. LED lights have a great number of benefits over traditional festive lighting.

LED lights can be produced in the smallest sizes, and allow for a controlled and adjustable emission of light, which prevents a jarring glare.[7]

The iconic moose structures, Stockholm, Sweden. Photo credit: Mikael Sjöberg

A single string of LED holiday lights has a lifetime of about 40 years,[5] due to the lower burnout rate and substitution need, thus reducing the cost of operation and maintenance. In Solothurn, Switzerland, prior to installation of LED lights, the city had to replace one-third of incandescent Christmas bulbs every year.[8] As the wider European Community recognises the technical benefits of LED, more and more municipalities are making the transition. For example, most municipalities in Cyprus have opted for LED Christmas lights.[9] Additionally, LED lights do not emit as much heat as the incandescent bulbs and thus reduce fire or overheating risk and allowing for safer clustering of the lights to create spectacular lighting structures.[7]

One of the greatest benefits of using LED lights for festive displays is their easy integration into technologically advanced control systems. These systems enable automatic turn on and off, easy monitoring to ensure all the lights are working, and facilitate quick identification and replacement of defect lights. Additionally, one of the best features of the control systems is that they are programmable and automatic, thus allowing for dynamic storytelling displays.[7]

Economic Benefits

Building on their reputational gains and the technological potential, a switch to LED lighting can contribute to a number of economic benefits, alongside the primary cost-savings from energy efficiency. LED lighting displays have been shown to contribute to boosting tourism and sales, with Stockholm experiencing a range of economic benefits from the #Stockholmsjul LED installation, which has become a significant attraction for visitors.[2] For example, Drottinggattan, the main shopping street, experienced a 3% increase in visitors after its inclusion in the #Stockholmsjul project in 2014.[1,2] While this and the wider economic gains experienced by the city since the expansion of #Stockholmsjul in 2014 [2] (see box below) cannot be attributed only to the lighting display, the results of the #Stockholmsjul perception survey indicate that lighting is nevertheless a significant draw-factor. Interviewees have stated that it increases a feeling of safety and desire to venture out in the winter, while visitors express that they have travelled to Stockholm with an intention to enjoy the #Stockholmsjul experience.

9% Increased number guests nights
Increased trade

Implementation Guideline

On the basis of our research and personal communications with the #Stockholmsjul stakeholders, we've developed the following guideline for a successful implementation of LED holiday lighting displays (See Figure 2). This guideline is meant to assist municipalities and their partner associations throughout the entire project cycle, by summarizing our insights on recommendations according to the Plan-Do-Check-Act cycle.

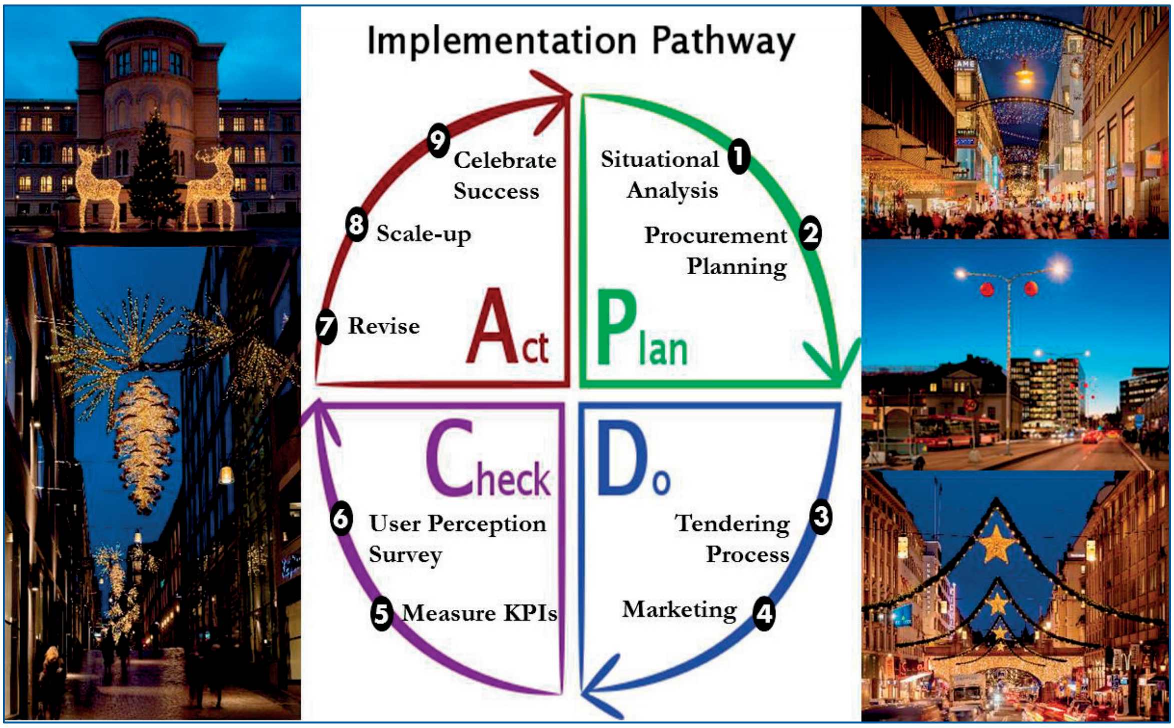


Figure 2 Centre: Implementation Pathway for Greening Public Procurement. Corners #Stockholmsjul displays. Photo credit: Mikael Sjöberg

Table 1 Barriers to the transition

Barriers	Considerations
Funding	Availability of funds; and Cost of LED technology and control system.
Suppliers	Availability of suppliers of LED technology; and Sourcing: high environmental footprint due to distance from manufacturers.
Administrative capacity	Availability capacity for design, procurement; Responsible stakeholders; and Technical know-how regarding selection given wide range of LED with varying performance.
Technological barriers	Weather conditions that could hinder lifetime of lights.

Table 2 Drivers of the transition

Drivers	Considerations
Policies	City level Sustainability strategy and emissions targets;[10] National level, county level or city level Sustainability strategy[10]; and National level, county level or city level public lighting requirements.
Grant/Funding	Regional, national or city level sustainability fund; and Opportunities to collaborate with other interested local bodies.
Public Perception	Culture of festival celebration in the city or region; Grand/competing festival celebrations in other cities in the region/country using LED; High environmental awareness of citizens in the city; Willingness among city dwellers to celebrate outdoors; and Willingness to spread the word to tourists and visitors.
Energy cost and savings	Low cost of energy/electricity?; and Priority of the energy sector- energy efficiency or diversification or both?

Plan

The first step in any project should always be to perform a *situational analysis* to identify the potential barriers and drivers.

Tables 1 and 2 outline barriers and drivers identified by our own research, as well as by the #Stockholmsjul team, which should be considered in conducting the situational analysis.

Once the situation has been assessed, it is possible to start the procurement process. Based on the experiences and documentation of the #Stockholmsjul process,[10,13] we recommend taking once the situation has been assessed, it is possible to start the *procurement process*. Taking the following factors into account when deciding your procurement process, if you're aiming to reduce the environmental footprint of your lighting installations, while still reaping the benefits of impactful Christmas lighting:

- **Vision and mission** – It is extremely important to formulate a clear vision and mission for a sustainable lighting project to ensure that success is clearly defined and the project helps set the path for improvement and growth in your city's brand and practices.
- **Strategy** – Based on the vision and mission, develop an implementation strategy. This step should include the involvement of other local bodies, such as shopkeepers and real estate owners.
- **Concept development** – Exploit the flexibility of LED lighting function in developing the display theme. LED displays work well to enhance story telling capacity and highlight the region's culture and traditions.
- **Administrative structure** – Organising larger lighting displays can be a complex administrative project, involving numerous stakeholders at various points. For example, in planning the installation it is necessary to cooperate with local real estate owners and shop owners, if the lights will use or be installed on their premises; this will clarify responsibility from the start. In allocating responsibility, account for existing administrative capacity and technical know-how. For larger projects consider setting up a joint working group or committee that coordinates between different stakeholders, such as City i Samverkan.[11] However, if you choose to pursue a joint venture or partnership system,

  for administrative or financial purposes, include a clear contractual agreement outlining responsibilities and capacities of each party and the ownership of specific project components.
- **Funding** – Funding these lighting displays can be the greatest challenge for municipalities. However, this can be overcome by exploring the opportunities for joint ventures with stakeholder groups from retail and real estate, or by gaining sponsorship from local businesses. For example, #Stockholmsjul benefited from a SEK 1 million (EUR 107 000) sponsorship by Finnish energy provider Fortum to purchase a new control system.[2]

  For smaller cities, consider purchasing used lighting display or display elements and structures at reduced rates from lighting providers. MK Illuminations, the lighting provider of #Stockholmsjul, is currently pursuing the option of diversifying its business model by offering used elements of larger installations for re-sale to smaller municipalities, in an effort to extend product lifetime and make high-quality LED installations available at lower costs.[7] While Mr Johannson, head of MK Illuminations in Sweden emphasizes that this is still in the development phase, they hope to begin piloting it in the near future.[7]

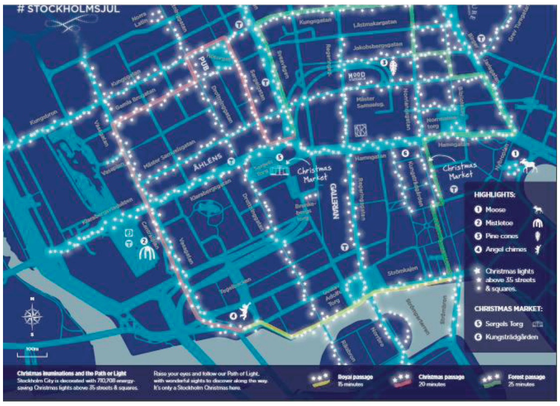
An example of a reindeer lighting sculptures that could be resold by the retailer or municipality to a smaller municipality after the end of the installation, Stockholm, Sweden. Photo credit: Mikael Sjöberg

- **Business models** – Festive lighting can involve numerous and expensive lighting displays, only used during the holiday period. Therefore, consider the different options available for procuring the lights. You can either:
  - o **Purchase the lights** and sell the lights and installations back to the lighting provider at the end of the project cycle (three to five years). The maintenance, monitoring, installation and storage of the lights can either be handled by the city, or by the provider, if these services are included in the purchase.[12] This is currently the dominant model for Swedish municipalities, according to Mr Johannson.[7]
  - o **Lease the lights** for the duration of the project cycle**.** While this business model has been growing in recent years, it still accounts for only an insignificant portion of the Swedish market.[7] Conversely, the model has seen much larger uptake by UK municipalities, according to MK Illuminations.[7]
- **Goals and Targets (Key Performance Indicators, KPIs)** – Finally, to ensure success and continuous improvement, identify main goals and measurable targets. These should be based on the stated mission and vision.

Do

One of the main tasks in the Do phase is the *tendering process* which aims to select the "best fit" supplier for the desired goods (lighting, decoration etc.) and/ or services (concept design, installation and maintenance, etc.). In general, augment standard tendering processes to include the following specifications and considerations tailored for festive lighting procurement:

- **Concept ownership** – i.e. will you, the municipality, or the supplier/designer own the concept; this should be clearly stated from the start, as it determines relationship dynamics and responsibilities. For example, the #Stockholmsjul 2014-2016 concept is owned by City i Samverkan,[1,13] although the main supplier jointly developed the concept, and delivered the materials. The decision could vary based on in-house capability and human resources.
- **Selection of priority streets, squares, and places** – Areas could be selected based on involved stakeholder and cultural significance. Selected areas could then be prioritised accordingly: (1) high workmanship with a high impact factor; (2) expressive and/or mass impact; (3) simple and/or lesser impact.



Path of Lights of #Stockholmsjul 2015.

- **Installation, maintenance, transportation, and storage** – The supplier or the municipality could be responsible. However, a poor installation can significantly damage the display and impact on its product lifetime.[11] Develop a work plan and timeline for installation and dismantling; this should also include contractor management, traffic management, ground works plan, and tree management (suitable weight, size, and installation methods). Provisions for ad-hoc installation, should there be additional funding should also be covered in the contract. A penalty model could be incorporated for damage compensation, in case of tree damage or damage to existing infrastructure.

- **Environmental requirements** – Require documentation of quality and environmental product performance to meet relevant regional and national standards and/or certifications, as there are LED products with varying performance on the market. Environmental performance could be measured based on: (1) work performance of suppliers at work; and (2) energy efficiency, carbon footprint, environmental footprint, and end-of-life management of the products. Also consider requesting the following information from the supplier: life cycle assessment; total energy usage and estimated energy cost of all installations; total number of light points in every areas.

- **Technical requirements** – For ease of control, the tender should require control systems equipped with: possibilities for dynamic interface, default on/off switch; separate section level lighting control; lit section display; dimming function; and other desired functionalities. Information on product dimensions and estimated lifespan under relevant conditions should be known. Possibility to integrate mobile data transfer and network connectivity could be included.

- **Contract and project period** – For certain municipalities, early expression of interest could be considered to enable early feedback on feasibility of the concept.

- **Supplier's references** – Depending on the project's complexity, the supplier should prove a track record to be technically competent; and sound financially and commercially. Communication and collaboration culture should be known to guarantee positive experience and outcome. Throughout the project period, the lighting should be integrated into the city's wider *marketing strategy*. Marketing strategy should be adapted for two types of audience:

- **Functional attributes** – target business, shop owners, and investors, highlight collaboration opportunities, storytelling potential and expected benefits.

- **Emotional attributes** – target general public and business owners in order to raise awareness of visitors and users. Use interactive marketing through social media to simultaneously market and gather real time data on user experience and satisfaction. Consider including an official hashtag (#Stockholmsjul) in this social media strategy, to ensure uniform branding and optimal traceability.

Strategic marketing has the considerable potential to attract more investment and visitors to the event.

Interactive social media lighting display, Stockholm, Sweden. Photo credit: Mikael Sjöberg

Check

Not all lighting decisions will be optimal from the start. Therefore it is important to check the performance of your chosen lighting display, in order to improve and refine the lighting benefits in future versions. To do this consider two complementary methods:

1. Measure *key performance indicators (KPIs)*; and
2. Conduct a user perception survey.

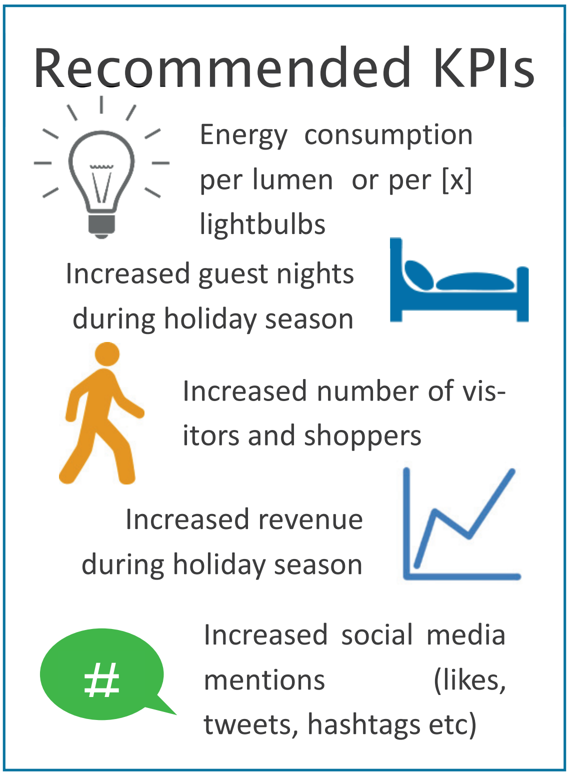


Figure 3 Recommended Key Performance Indicators. Created by authors

Act

One of the most important parts of greening public festive displays is to continuously reassess and improve both the environmental footprint and the user experience of the display. *Revise* and improvise the underlying concept on the asis of the user perception survey and KPI performance;

Consider *scaling-up* as knowledge, stakeholder interest and funding increase, it is possible to consider more varied, extensive and elaborate displays. Do not be afraid to start small and build your way up to a world class display. In 2007 Stockholm had no Christmas lighting to speak of, and is now Scandinavia's most popular Christmas destination.[1]

And importantly, *celebrate success*. Advertise successes and milestones reached in order to improve awareness of the value of the project among stakeholders.

Conclusion

Lighting is a key feature of the European Christmas experience, and switching to LED lights can counteract the environmental footprint of increasingly extensive displays. This chapter outlines the numerous benefits of this transition. Furthermore, it offers municipalities a guideline to facilitate the successful integration of social, economic and environmental concerns throughout their project cycle, from planning, through procurement to final assessment. It highlights best practices from the successful #Stockholmsjul project and crucially, reminds municipalities to strive for continuous improvement while celebrating success.

References

1. Sunnros, G. (2015, December 8). Project Manager City i Samverkan. Personal Communication (J. Tollmann, B. Ch'ng, & K. Venkat, Interviewers)
2. City i Samverkan & Stockholm Stad. (2015). #Stockholmsjul- Projektpresentation 2014-2015 [#Stockholmsjul- Project presentation]. Stockholm, Sweden: City i Samverkan.
3. City i Samverkan. (2015). #Stockholmsjul Intervjuundersökning 2014-2015. [#Stockholmsjul perception survey 2014-2015] Stockholm, Sweden: City i Samverkan.
4. Thompson, D. (2011, December 7). Is Christmas Bad for the Economy? The Atlantic.
5. US Department of Energy. (2015, December 14). LED Lighting. Retrieved from http://energy.gov/energysaver/led-lighting
6. Swedish Energy Agency. (2011). Goodnight light bulb. Swedish Energy Agency.
7. Johansson, N. (2015, November 25). M K Illumination. Personal Communication (J. Tollmann, B. Ch'ng, & K. Venkat, Interviewers).
8. European Commission Joint Research Centre. (2012a). LED projects and economic test cases in Europe. Ispra, Italy: European Commission Joint Research Centre Institute for Energy and Transport.

9. European Commission Joint Research Centre. (2012b). Public procurement of LED lighting in European Union member states. Ispra, Italy: European Commission Joint Research Centre Institute for Energy and Transport.
10. Stockholms Stad. (2014). Strategi för julbelysning i Stockholm City 2014 [Strategy for the Christmas lights in Stockholm City 2014-2016]. Unpublished raw data.
11. Hedlund, A. (2015, November 23). Trafikkontoret Stockholm Stad. Personal Communication (J. Tollmann, B. Ch'ng, & K. Venkat, Interviewers)
12. M K Illumination. (2014). Enlightening your Vision-Buy Smart. Malmo, Sweden: M K Illumination.
13. City i Samverkan. (2014). Upp handling gällande designatävling för Julbelysning Stockholm City [The tender for Christmas lighting in Stockholm City]. Unpublished raw data.

SPREADING THE LIGHT

Copenhagen Case Study with Recommendations for Rio de Janeiro, Brazil

By Yi-Chieh Chan & Laura Fostinone

LED light for urban areas has many benefits: CO_2 emissions reduction, security improvements, and energy savings, to name a few. Since 20% of the world's global electricity use is for lighting, most cities in the world have been realizing the potential for savings and better lighting for society.[1] For example, 29% of cities in the United States' are prioritizing LED lighting solutions on the political agenda and initiating plans to make a transition to Smart City technology.[1] As these political agendas change more rapidly than implementation, global and local studies have focused on finding out how to best transition, considering the choice of policies, public procurement and technologies.

Aiming to be a CO_2 neutral city by 2025, Copenhagen started the transition in 2012 and is close to finalisation,[2] making it an excellent role model for cities running similar projects. Thus, building on a combination of meetings, interviews and research, this paper details Copenhagen's processes, success factors, and possible pitfalls. It also outlines Rio de Janeiro's large-scale LED transition plan. The aim is to test the transferability of lessons learned and recommendations from Copenhagen to cases such as Rio de Janeiro, as well as other interesting cities.

Copenhagen Case Study

Københavns Kommune (Copenhagen Municipality) prioritized energy savings as the main political agenda item in the past few years.[3] Under the Lighting project, Copenhagen is aiming for 50% energy savings from street lighting compared to 2010, by replacing 20 000 fixtures by May 2016.[3] The predicted payback period is within 10 years, if solely considering fixtures; while calculations including the change of poles, network cables and the management company contract show a payback period of 25 years.[3]

Public Procurement

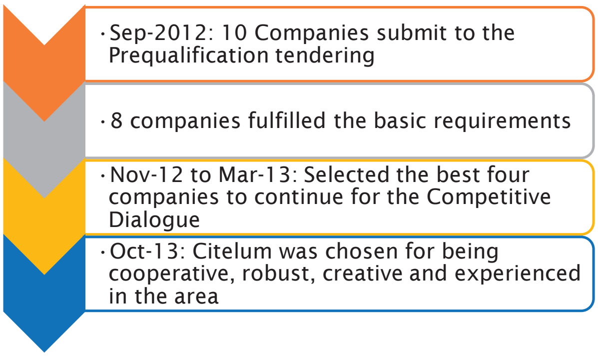
Up to DKK 500 million (EUR 66 million) is invested in the LED project, which is completely financed by the municipality.[4] The public procurement procedures in Copenhagen followed EU Directives under Public-Private Partnership (PPP) which contributed to a successful and efficient project implementation.

Tendering Process

Following Directive 2014/24/EU on public procurement, Copenhagen Municipality spent over one year communicating with potential suppliers.[5] The whole procurement process was divided into pre-qualification, dialogue, bidding, and finally, the contracting stage.[4]

Initially, a dialogue was held to announce the key concepts of the project and the criteria for suppliers' qualification. All companies were requested to deliver a dossier and detailed information about their past experiences with providing innovative solutions to Smarter Cities.

The dialogue between Copenhagen and the four best companies lasted four months. They were conducted through bilateral communication, which enabled both sides to interact and understand respective expectations and capacities. From this phase, Copenhagen Municipality staff learned about technologies capabilities from the companies, while companies gained insight into rules, processes and tender documents necessary to carry out a proposal. The final winner was based on solution creativity and the tender price.[4] In the end, only Citelum's bid was accepted.



Copenhagen has now had a contract with Citelum since October 2013 until 2025, with an optional extension clause till 2028.[4] It explicitly includes bonuses and penalties tied to the project implementation progress. The former is to incentivize the company to go beyond the basic requests from the municipality and the latter establishes consequences for non-compliance.[4]

The Copenhagen experience shows that the inclusion of bonuses could play a role in driving contractor ambition, as Citelum is targeting 57% energy savings, rather than the 50% outlined in the initial plan.[4]

Public-Private Partnership & Competitive Dialogue

The Copenhagen tendering process can be characterised by a number of factors. First, the project is awarded to the best single contractor, and the contract relationship between the municipality and Citelum is long-term. This contract period runs from the initiation to finalization of the project, which indicates that both actors collaboratively share the risk in the whole project implementation. Secondly, the cooperation between the two sides does indeed work as a partnership, with Citelum and Copenhagen Municipality continuously discussing issues and working together after contracting finalisation.[3]

Public-private partnership generally uses one of four different methodologies for procurement procedures (see table below). Copenhagen adopted the one called "competitive dialogue," while time-intensive, helps both bidders and the municipality to become more familiar with the project goals through several rounds of dialogue. This approach promotes trust, building towards long-term partnership, and contributes

EU PROCUREMENT PROCEDURES COMPARISON (ADAPTED[7])

	Open Procedure	Restricted Procedure	Negotiated Procedure	**Competitive Dialogue**
Number of bidders	Any company may submit a bid.	Prequalification exists. No less than five bidders.	Prequalification exists. No less than three bidders.	
Discussions during process with bidders	No negotiations or dialogue with bidders.		Negotiations permitted. Used to reduce the number of bidders.	Dialogue permitted on all aspects. Solution presented based on dialogues.
Discussions after final bid is submitted	No scope for negotiations.		Negotiations can continue until the contract is agreed.	Only permitted to clarify fine tune or specify a bid.
Basis for award	Lowest price or most economically advantageous			Most economically advantageous

to a successful and efficient project implementation.[6]

The Solution

The Smart City solution being implemented in Copenhagen involves two completely new designs for fixtures and poles, replacement of 50% of old fixtures and approximately 80 km of new underground cables networks. All new fixtures are connected to Citelum's management centre and can be controlled in real-time.[4]

As higher light temperatures are more energy efficient, the solution planned each area in consideration of its needs, while ensuring that light was not too dark or too bright:[4]

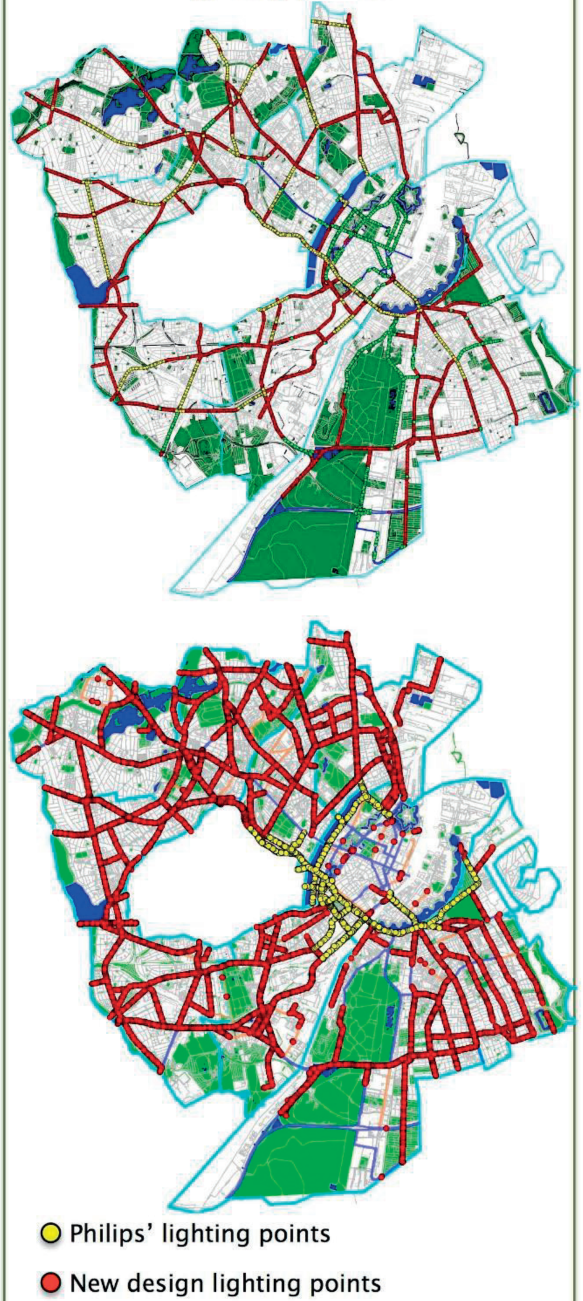
LED Temperature planning[4]	
Light temperature	**Places**
4000 K	Main streets, avenues
3500 K	Secondary streets
3000 K	Residential streets

The new poles are textured against graffiti and stickers and the new fixtures were designed from scratch in partnership with Thorn.[4] The interviewees sound proud of their unique fixture style.

> "The largest change in the city is that on the main streets there is a change in light colour, from the Orange High Pressure Sodium to LED with 3500-4000 K. Most of the fixtures used, are also new fixture designs."[3]
> – Stine Ellermann, municipality employee

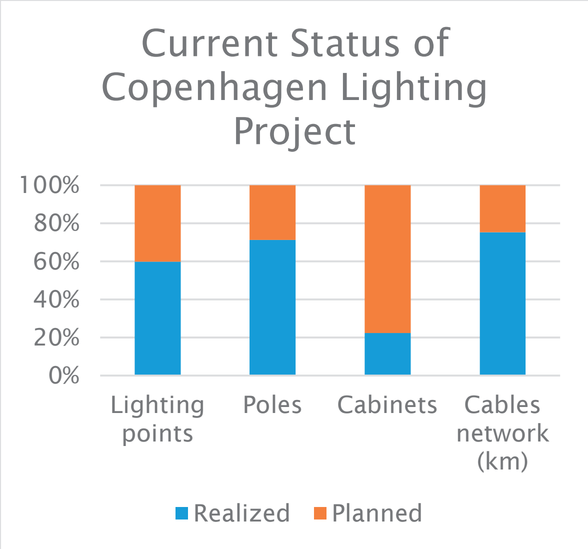
Before this process, Copenhagen had already installed 9 000 Philips LED lights, but the older technology only allowed for dimming. This meant that the lighting was the same for winter and summer time, because there was no remote control for each lighting point. The actors involved decided to maintain those lighting points and cluster them together (they were installed in several less trafficked areas) and installed the new ones following the prioritization approach. The maps on the right show the changes.[4]

Replacement and relocation of lighting points[4]



Current Completion

The project's current implementation has a strict schedule and aims to reach 57% of energy savings compared to 2010 by May 2016. The graph below shows installation progress for each infrastructure item[4] (current status in the following chart).



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Citizens' Perception

Regarding bigger streets, citizens are satisfied with light quality, even if it is a lot "whiter".[4] In residential areas the opinion is more varied: people that did not like the new lighting solution feel that there is now less light, because the LED lights are more focused, compared to older lighting points which had more diffuse beams.[4] Therefore, while the municipality was previously spending energy to illuminate private areas (such as gardens and garages), now offers light only where it should.[5]

Rio de Janeiro

Brazil's second biggest city aims to renovate public street lighting and has given the LED implementation process a kick-off.[8] Due to hosting the 2014 World Cup and the 2016 Olympics Games, Rio de Janeiro has been in the spotlight. This has driven the municipal project "Low Carbon City"[9] and their collaboration with the organisation "Regions of Climate Action,"[10] in order to plan ahead and evaluate energy savings and emissions reduction. In this case study, these two design projects were analysed.

Inventory

The inventory has shown that Rio de Janeiro has 425 000 lighting points, of which 67% are high-pressure sodium (HPS) lamps and 23% are mercury vapour.[8] That is 10 times more than Copenhagen, meaning a complete replacement would require substantial initial investment.[4]

Stakeholders – Main Actors

Meetings and negotiations have been happening since 2012.[8] The Municipality and its Secretaries for Public Services and Conservation (SECONSERVA) and the Municipal Company for Energy and Lighting (here called, "RioLuz") are the key decision makers. RioLuz provides the street

Rio de Janeiro lights from the Sugar Loaf. Photo credit: Thiago Dias do Couto. Brazil, 2013.

lighting infrastructure and maintenance while "Light S.A", provides the energy supply.[8]

Project Design

The main motivation is energy savings, however, the actors analysed three design possibilities for LED adaptation.[8]

Option	Replace the…	Evaluation
1	Lighting fixtures	Attractive return rate
2	Lighting fixtures and control system	Potential social and economic benefits with Smart City solutions
3	Lighting fixtures, control system and distribution cables	"Prohibitively costly"

Option two was chosen to be studied more deeply because Smart City technology provides other benefits such as easiness to adjust street lighting and the possibility to support other structural organisms, like the police, that could end in safety improvements.[8]

Finances and Public Procurement

To replace 75% of the lighting in the next five years, the investment would be BRL 420 million (EUR 100 million) with a provisioned 57% energy savings and a payback period of 8.5 years.[8] While this seems like a good investment with high carbon offset (300 000 tCO_2 reduction), the challenge is how to finance the implementation.

> With a provisioned 57% energy savings and a payback period of 8.5 years[8]

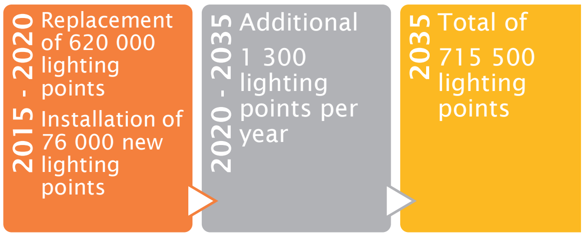
A specific law for public procurement and LED Lighting (Law 8.666/93)[11] would allow the city to utilize faster tender procedures to make the transition. However, this law requires the city to forecast budget up-front or go into debt. The other possibility studied, the PPP, is legally allowed but with no precedents for street lighting. The cities that seek to apply for the PPP solution would have to update their regulatory framework.[8]

São Paulo also aims for energy savings

A PPP procurement is being negotiated to enable investments of BRL 7.3 billion (EUR 1.7 billion) and upgrade 620 000 lighting points and create another 76 000 new ones. The expected outcome, in a 15-year period, is to save 50% in energy costs, double the lamps' lifetime and reduce time for lighting point replacements from 72h to 24h.[14]

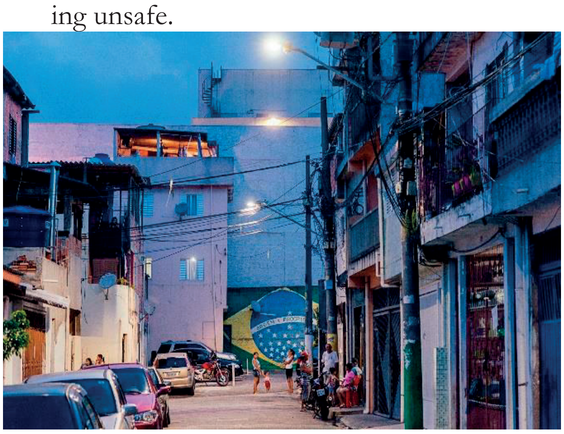
The contract will be based on performance: number of lighting points working and quality of light provided.[14]

Timeframe of implementation.[14] Created by author



Heliópolis: quick facts and figures[15]

- A whole neighbourhood in LED: 1 300 lighting points on 224 streets
- Municipality invested BRL 3 million (EUR 704 million) in the neighbourhood and other main avenues of São Paulo
- Local leaders and women's groups had been protesting to improve the neighbourhood lighting quality, due to fear and feeling unsafe.



Heliópolis neighbourhood, São Paulo, Brazil. Photo credit: São Paulo Municipality

Progress of the Project

Employees of RioLuz and Light S.A were interviewed and both affirmed that much of the project has yet to be implemented.[12,13] Mainly because of financial reasons, PPP for a large-scale transition has not yet been established.

It is estimated that up to 3% of all street lighting contains LED, particularly in tunnels, touristic places and the new cycleway, which are already being planned and built with new lights.[13] These places counted on private investments from companies like General Electric, Osram, Odebrecht.[13]

Lighting is perceived to be better in these places when compared with the older solutions, but no specific studies have been performed yet to assess improvements in safety and traffic accidents, for example, maintenance costs can be as low as zero.[13]

Conclusion and Recommendations

Key Success Factors

- **Competitive Dialogue**: the tendering process was key in finding the best solution. The Municipality did not know all the possibilities and technologies upfront, which also changed as the process went on; therefore, a continuous dialogue was key to provide a creative solution for Copenhagen.[5] Evaluation studies believe that the effort involved pays off and allows municipalities to share the project performance risk with partners.[8]

> "We did not have the knowledge ourselves, so we went to the market." – Thomas Maare (lighting specialist of DCL and former municipality employee)

- **Municipality's 100%-financed project**: promotes fast changes and complete control of the project. Contractual bonuses and penalties are also a good factor for supplier's engagement.[4]
- **Design**: Investments in new fixtures maintains the city identity and studies to choose the best temperature for each area are recommended.[4,5]

Key Barriers

- **Energy for longer term**: Since LED projects can reach 50% savings or more, energy companies' revenues (i.e. Light S.A and Dong Energy) will be cut in half. Interestingly, when asked if payment per lux or other new formats of contract were being negotiated, both cities affirmed to still use KWh as a payment measure and there are no other plans so far.[4,5,12]
- **Number of lighting points**: Both Copenhagen and Rio are not planning to expand their number of lighting points.[3,8]
  Copenhagen's lighting specialist says that LED put "the light exactly where it is supposed to be", therefore, in places like Rio de Janeiro, just provisioning the change from HPS and mercury bulbs to LED can actually be worse for light quality than leaving it as it is.[5] However, LED fixtures have the capability to deliver very evenly dispersed light, across and along the street, when the design is well thought and planned[5]. The preoccupation and opportunity to reduce energy consumption and maintenance should come hand-in-hand with good design and lighting quality.
  Rio de Janeiro's evaluation plans also do not mention colour temperature or potential design for LED fixtures.[8]
- **Responsibility to a single organization**: Handing the whole project to a single company (Citelum) enhances the consistency and efficiency of implementation, and the costs incurred from communication between several companies can be prevented as well. However, it could be risky to have

such short-time-frame project in the hands of one, potentially inexperienced, organisation in the area. While the Copenhagen case shows otherwise, this might not be transferable to a large-scale project like Rio de Janeiro.

- **Inventory check**: To start with a perfect baseline of what the city already has will save time and revenue. Sometimes it can be hard, but the extra effort should be put in upfront.
- **Fast new technologies**: Technologies for LED advance faster than public procurement procedures. It is important to find a balance to avoid an obsolete solution.

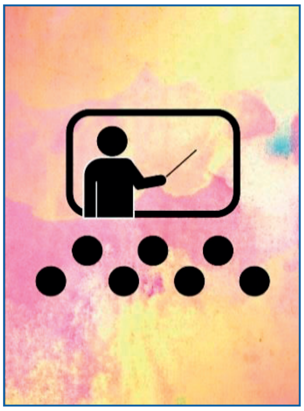
To conclude, the cases of Copenhagen and Rio de Janeiro are set in very different contexts, from culture, governmental and financial status, to climate conditions, etc. Despite that it is challenging to draw a direct comparison between both cities; there are several lessons learned by analysing both cases together.

References

1. Ferrari, B. (2014). *LEDs in public lighting: energy efficiency in municipalities*. Retrieved December 13, 2015, from: http://www.theclimategroup.org/_assets/files/Brazil-10-Sep-SLIDES-part-1---English.pdf
2. Kommune, K. (2011). *Copenhagen climate adaption plan*. Denmark: City of Copenhagen.
3. Ellermann, S. (2015, December 9). Lighting Engineer at Københavns Kommune. Email Communication (L. Fostinone & Y. Chan, Interviewers).
4. Eraldo, M. (2015, December 8). Project Manager at Citelum. Personal Communication (L. Fostinone & Y. Chan, Interviewers).
5. Thomas, M. (2015, December 8). Specialist Lighting Project Manager at Danish Lighting Center. Personal Communication (L. Fostinone & Y. Chan, Interviewers).
6. Seibert, T. (2006). *PPP-The EIB Experience*. Presentation at First International Conference Perspectives for Ukraine on Implementation of Public Private Partnerships.
7. The epec PPP Guide. (2015, December 13). Before launching the tender: select the procurement method. Retrieved from: http://www.eib.org/epec/g2g/ii-detailed-preparation/22/223/index.htm
8. World Bank Group. (2014). Prefeasibility study – Municipal Energy Efficient Public Street Lighting Project in the City of Rio de Janeiro.
9. World Bank and City Government of Rio de Janeiro. (2012). The Rio de Janeiro Low Carbon City Development Program.
10. R20 Regional of Climate Action. (2014). The Next Generation of Street Lighting: A Feasibility Study & Action Plan for Rio de Janeiro. Municipal Secretary of Conservation and Public Services and RioLuz.
11. Republic/Civil Cabinet (1993). *Law 8.666/93 and Modifications*. Ministry of Planning, Budget and Management, Brazil. Retrieved December 13, 2015, from: http://www.planalto.gov.br/ccivil_03/Leis/L8666cons.htm
12. André, C. (2015, November 30). Commercial manager at Light S.A. Telephone Communication (L. Fostinone, Interviewer).
13. Heitor, D. (2015, November 30). Project Director at Rio Luz. Telephone Communication (L. Fostinone, Interviewer).
14. G1 São Paulo. (2015). Municipal Court authorizes PPP procurement for public street lighting to continue [TCM autoriza retomada de licitação da PPP da iluminação pública em SP]. Retrieved December 13, 2015, from: http://g1.globo.com/sao-paulo/noticia/2015/10/tcm-autoriza-retomada-de-licitacao-da-ppp-da-iluminacao-publica-em-sp.html.
15. São Paulo Municipality Press. Heliópolis is the first neighbourhood with LED Lighting in Latin America [Heliópolis é o primeiro bairro da América Latina com iluminação LED]. Retrieved December 13, 2015, from: http://www.capital.sp.gov.br/portal/noticia/7347#ad-image-0.

ILLUMINATING LEARNING

Barriers for Energy-Efficient Lighting Systems for Academia in Sweden



By Simona Getova, Chao-Mei Pai & Soraya Soemadiredja

The United Nations has designated 2015 as the International Year of Light and Lighting Technologies. This year also marks an important milestone for the United Nations Framework Convention for Climate Change (UNFCCC). While the former focuses on a broader role of lighting, the fight to mitigate climate change impacts and the search for innovative lighting technologies are interlinked.

For Scandinavian countries like Sweden, energy efficiency is an important component of their climate change mitigation portfolio. One of the suggestions that the Swedish Energy Agency puts forward for action on mitigation is emphasizing the linkage between lighting and climate.

A study by the Swedish Energy Agency in 2011 revealed that 26% of the electricity use goes to lighting.[1] While this is for households, it is clear that lighting plays a significant role in people's daily lives, and the attention to energy-efficient lighting should not be isolated to the domestic realm.

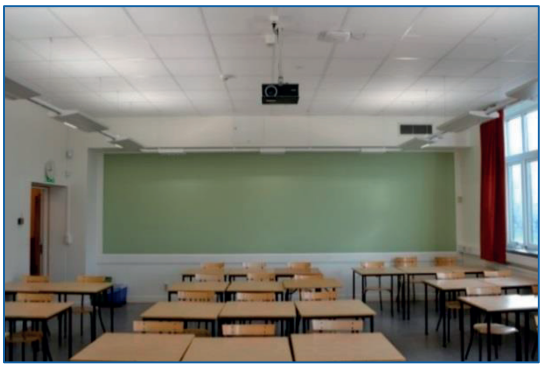
An important area for addressing lighting is in the academic sphere. An increasing number of studies have emerged on the impact of lighting on the academic performance of students. Based on this, it is particularly interesting to consider what the energy-efficiency role of lighting is or can be in schools and academic institutions.

Unfortunately, in Sweden there is no framework for sustainable lighting design for schools and academic institutions. In an interview Mr. Laike, a professor of environmental psychology at the Department of Architecture and Built Environment at Lund University, described the issue by saying, "in order to get a change, we cannot only use the concept related to efficiency because energy is quite cheap…while changing lighting systems could be quite expensive, so they still keep a bad solution that is not energy efficient."[2]

The emphasis on lighting is based on potential health effects. Mr. Laike has been involved in many lighting research projects, most of them focused on the effects of light on well-being, including lighting in public work environments.

Health, Safety & LED lights

In Sweden, there have been several initiatives on lighting in schools that focus on health, safety and well-being.



LED installed lighting in one of the four classrooms in Tycho Braheskolan participating in the experiment. Photo credit: Simona Getova

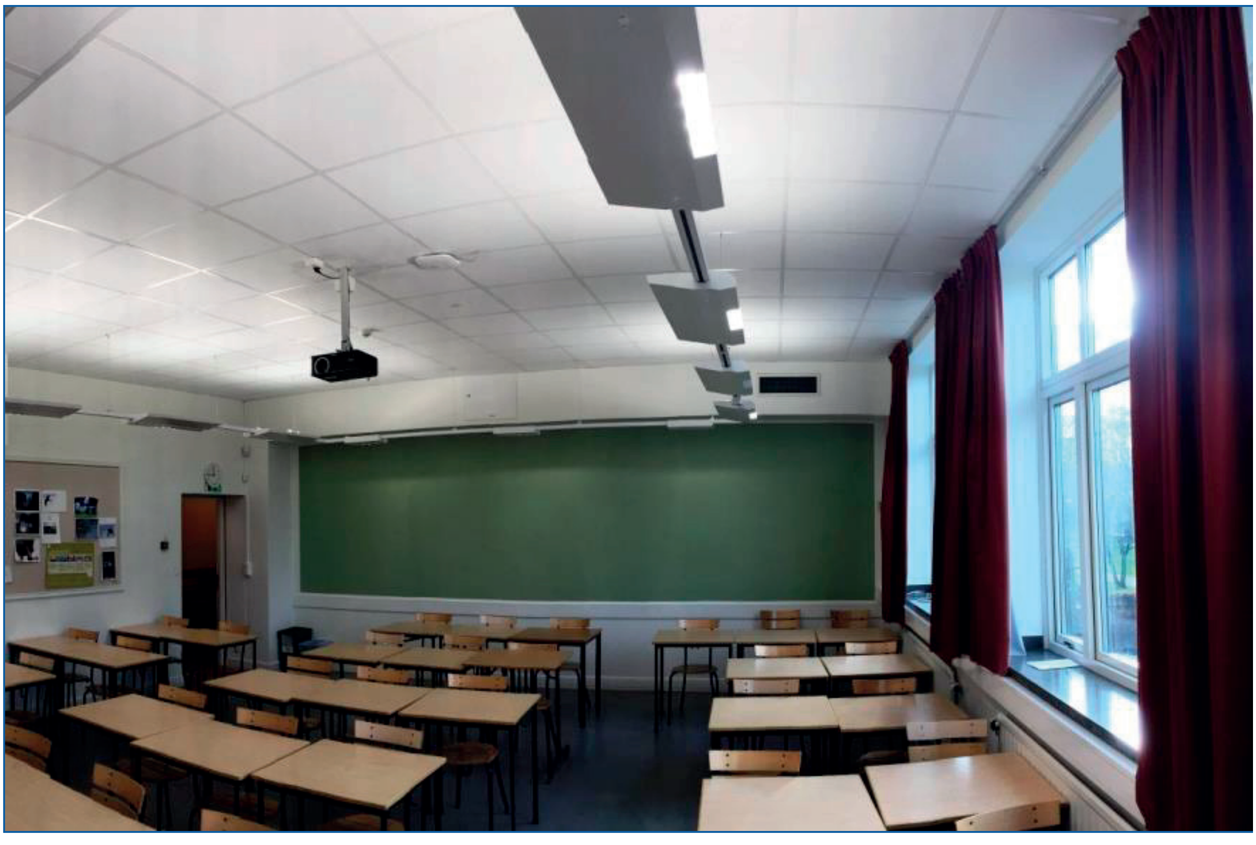
Tycho Braheskolan in Helsingborg

Tycho Braheskolan high school located in Helsingborg, Sweden, became involved in a lighting study that explored the links between energy-efficient lighting and student performance. This study was sponsored by the Swedish Energy Agency and involved multi-disciplinary scientists from academic institutions, including Lund University. Lighting systems in four classrooms were studied. Two were used as controls for the study, while two others received specially designed LED lighting systems. Each month, researchers came to collect data that would reflect the emotional and biological reactions of the students and teachers who used the four classrooms.[3]

According to a paper based on this study, students did not perceive a difference between the two different light sources, but there was higher appreciation for the LED-lit rooms. It was difficult to determine the biological effects in the different rooms, but there was a slight difference in the winter months.[3]

Regarding energy, there was an interesting outcome to this study. Movement sensors for lighting are generally touted as beneficial for energy-savings reasons, because they help to ensure all lights are off when no one is using the room. However, while the LED system for classrooms might achieve energy savings, this could be negatively offset by these "parasitic losses." Mr. Laike and his colleagues discovered that for irregularly occupied spaces, it may be more energy-efficient to have simpler lighting control systems with an easy "off" button.[2] From this experiment in the school, human behaviour and lighting control systems are equally important as the installation of the lighting itself.

This study focused mainly on perceptions of light: "if [students] think the light is good, [and] if it is positive for their health and well-being," as Mr. Laike explained. However, he is hopeful that such research will be useful. "Not only that



LED installed lighting in Tycho Braheskolan. Photo credit: Simona Getova it is energy efficient but it could be healthful and it's a better light," Mr. Laike continued.[2] A health-based argument may assist in having sustainable lighting options reach decision makers to convince them to change to a lighting system.

Dragonskolan in Umeå

Dragonskolan, a high school in Umeå, Sweden, was the recipient of a light therapy-focused lighting initiative, a project initiated by Umeå Energi. Based on the minimal documentation which is publically available, it is clear that the focus of the initiative is explicitly on the health and well-being of the students at the school and is intended to help them cope during the long winters in Northern Sweden.

The only mention of sustainability is on the energy sources used by the company in its work. For example, the lights in the Dragonskolan project are powered by renewable solar energy.[4]

Lighting Up Playtime

That same concern for the effects of lengthy and dark winters in Sweden on children led to a cooperation between Uppsala and the light manufacturer Philips. Through this partnership, the Philips "Light Up the Dark" campaign focused on outdoor playground areas for children.[5] It directly focuses on the safety and well-being of children and extending their outdoor playtime throughout the winter.

Barriers to Energy Efficient Lighting

For lighting designers, including Mr. Laike, using the argument to improve the environment is not sufficient when convincing building owners to switch to sustainable LED lighting in academic settings. In addition, there are a few opportunities that could be developed in Sweden.

Standards and Regulations Setting by Governments

Unlike ventilation, which is an intrinsic part of the building and part of the property owner's responsibility, lighting is usually the tenants' responsibility. According to Mr. Laike, this is why schools would not prioritise, or at times overlook, lighting.

One thing that would help attention shift toward lighting is a set of regulated standards. This lack of standards is problematic for Mr. Nothnagl, who is the Lund University Area Manager for Akademiska Hus.[6] Akademiska Hus is the state-owned company which owns or manages many university buildings throughout Sweden. Because there are so many buildings, the initiative to improve buildings in any aspect, including lighting upgrades, may come either at the behest of the owner or at the request of the university.[6]

E-Huset is a propery managed by Akademiska Hus at Lund University. It was chosen by university management for an experimental and innovative sustainable LED-lighting project. The lighting system was focused on public co-working areas for students and reading rooms; however, the original design could not be fully implemented. Mr. Nothnagl believes the reason why the sustainable LED lighting designs were not fully implemented was due to a non-conformance of the accessibility regulation in the design.[6]

Overall at Lund University sustainable lighting does not seem to be a priority. For example, the small-scale policy-making of procurement within Lund University has no suggestions for addressing sustainable lighting. This is missing both from the procurement guidelines and the *Krav & råd - Byggnadsenhetens råd och anvisningar*, or the requirements and advice for building units.[7]

This lack of standard setting for lighting is also bemoaned by practitioners and students at Aalborg University Copenhagen,[8] across the

Öresund, which demonstrates that the problem is not just confined to Sweden.

While energy-wasting production design has been eliminated using eco-design standards, there is not yet a regulatory incentive to switch to LEDs. Energy agencies and ministries provide suggestions in some areas of lighting,[8] and there are some guidelines set by individual institutions, such as Lund University,[7] however, it is important that standards are presented in the form of administrative tools. This would incentivise the more conservative potential beneficiaries of these newer lighting technologies.

Simplifying Complicated Designs

For those in the building industry, such as Mr. Nothnagl and his colleagues, a standardised design for LEDs could be beneficial to introduce those outside of the lighting industry to the benefits of more environmentally friendly LEDs. One such design is the Zhaga design.

The Zhaga consortium is a collaboration between companies that are related to lighting industry. This includes manufacturers of light, LED modules and suppliers. The purpose of their consortium is to enable interchangeability between the various LEDs, their interfaces and amongst the different manufacturers. Their contribution could be one of many that simplify energy-efficient LEDs for use by the general public.

Pushing LED through Capacity Building

While industry wide cooperation may be beneficial to encourage the use of LEDs and assure newcomers that the technology is scaleable and easy to use, for Mr. Laike there is

LED installed lighting in co-working space at E-Huset at Lund University. Photo credit: Simona Getova a conservatism in the building industry to move toward changes in lighting.[2]

Training architects, building contractors and electricians, among others, is important. Programmes such as Denmark's Aalborg University's Masters programme on lighting design is one such formal education where there is an interdisciplinary cooperation and mingling of lighting experts with architects, designers, and researchers.

However, there is also an opportunity for informal training for practicioners and those in the building and construction industry to introduce sustainable LEDs and sustainable lighting systems. These types of training should cover lighting as both part of the design process and as part of the construction process. It should also address the practical aspects of installing or scaling up lighting to newer, more environmentally and energy-efficient models. Currently, there is already training schemes for energy efficient buildings in EU that are implemented in Sweden.

Conclusion

Schools are significant places where energy-efficiency gains can be made, especially through the conversion of lighting sources into sustainable forms such as LED. However, this is not widely implemented in Sweden. The main challenge is that there is a lack of supporting incentives to switch to sustainable lighting systems in academic buildings. There are no standards for these on the macro- and micro-scale for academic buildings, such as during the procurement documents or as regulations by agencies, ministries or local governments.

As LEDs are a relatively new lighting technology, there are many different design manufacturers. Due to this technical complexity, it would be beneficial to train the stakeholders in lighting who are involved in design and installation of lights such as architects, building management, etc.

The rhetoric of health, well-being and safety is more commonly accessible and a greater priority for schools when it comes to lighting considerations. This may be viewed as an opportunity for encouraging a shift to LEDs while providing energy efficiency and sustainable lighting co-benefits.

With these starting points, there may be a shift toward sustainable lighting for infrastructure dedicated to academia and may allow the light to shine through.

Acknowledgement

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References

1. Swedish Energy Agency (2011). *Goodnight Light bulb. The Swedish Energy Agency's guide to the new light.* Eskiltsuna: Energimyndigheten.
2. Laike, T. (2015). Environmental psychology professor at Lund University. Personal interview. 17 November 2015. Lund, Sweden.
3. Govén, T, Gentile, N., Laike, T., and Sjöberg, K. (2014). *Energy efficient and study promoting lighting at high school: preliminary results.* Proceedings of CIE 2014, Kuala Lumpur; 772-779.
4. Umeå Energy. (2015 December 9). N.D. "Light therapy – saved sun benefits winter tired children". Retrieved from http://www.umeaenergi.se/om-oss/light-therapy
5. Philips (2014). *Light Up the Dark*. Koninklijke Philips N.V.
6. Nothnagl, C. (2015, November 29). Area manager of Akademiska Hus. Personal communications (S. Getova, C. Pai & S. Soemadiredja, Interviewers)
7. Lund University (2015 November 29). "Krav & råd - Byggnadsenhetens råd och anvisningar." Retrieved from http://www.medarbetarwebben.lu.se/sites/medarbetarwebben.lu.se/files/krav-rad-2012.pdf

8. Hansen, E. (2015, November 24). Lighting design professor at Aalborg University. Personal communications (S. Getova, C. Pai & S. Soemadiredja, Interviewers)

9. Zhaga Standard (2015, December 10). *Zhaga*. "About Zhaga". Retrieved from http://www.zhagastandard.org/about-us/

10. Tullstedt, L. and Douhan, Å (2013). *Build Up Skills – Sweden.* Roadmap: Building Skills for Energy-Buildings. Intelligent Energy Europe.

11. Swedish Institute (2013). *Facts about Sweden – Energy*. Stockholm: Swedish Institute.

12. Adler, K. (2015, November 20). English and Swedish language teacher at Tycho Braheskolan. Personal communications (S. Getova, C. Pai & S. Soemadiredja, Interviewers)

LED THE SPORT

Implementation of Leading LED Solutions in Sport Facilities

By Yuanlong Li, Xi Liu & Juan Andres Garcia Padron

Millions of people practice sports every day, mainly in facilities that require artificial lighting when daylight is not sufficient. These sports facilities include a variety of fields, stadiums, swimming pools, courts and gymnasiums utilised not only for sports but also to enjoy various outdoor and indoor activities.

Consequently, artificial light is necessary to watch and play sports. For example, in professional leagues, certain stadiums demand specific light intensity to light the playing field and facilities around it.

Nowadays most stadiums make use of traditional technologies such as High Intensity Discharge (HID) lamps to light their playing fields. Yet, HID lamps can bring high costs in energy bills, and lead to environmental degradation depending on the energy source. According to estimations from the US Department of Energy in 2012, in the United States alone 83% of outdoor lighting consumption came from HID lamps.[1] Global estimations suggest that indoor sporting facilities comprised about 540 million square meters in 2013, and out of those approximately 88% required HID lamps.[2] Considering this, there is great potential in reducing the energy consumption from sports complex.

However, over time, the lighting market has expanded to offer new available technologies such as LEDs and on the way to new ones such as Organic Light Emitting Diodes (OLEDs) with different applications. These technologies can offer new and exciting possibilities to improve light quality, efficiency and flexibility.[3]

This chapter focuses on significant drivers and barriers for implementing current LEDs solutions in sports facilities.

Benefits of LEDs in Sport Facilities

Compared with traditional lighting, in the field of arenas and sports facilities, the application of LED lighting has diverse advantages, such as higher energy efficiency, lower operating costs, greater illumination quality, and adaptability and flexibility for various purposes.[4]

Energy Efficiency - Cost Savings

LED lighting is more energy efficient than HID. With LED lighting, energy consumption decreases while saving on energy expenses. At the stadium and sports complex of Guadassuar in Valencia, Spain, updating to LED lighting led to a 50% decrease in energy consumption. Another exciting fact is the long-life LEDs have at the rated life of 60 000 to 100 000 hours delivering consistent and reliable lighting. That is four times longer than HID lamps.[5]

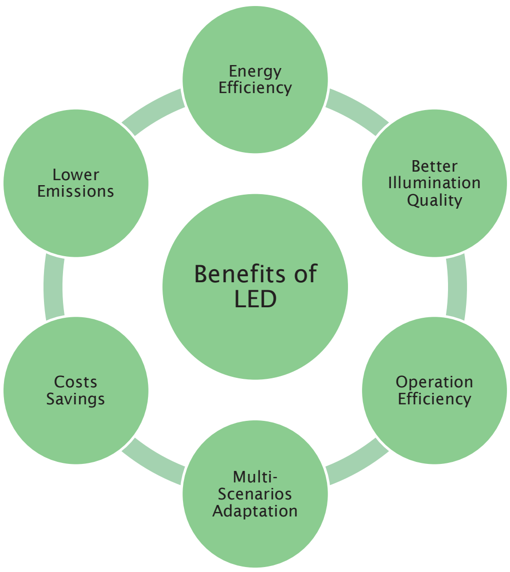
User Experience - Greater Illumination

The benefits extend beyond energy efficiency. Lighting systems at sports facilities must be responsive to the needs of athletes, on-site fans, and especially to the lighting needs for television (TV) broadcasters.[2]

LEDs can deliver a high level of light uniformity and distribution for optimal live and TV broadcasting viewers. LED light also enable ultra-slow motion frame captures for highly detailed broadcasting, and has the advantage that it minimises wasted angles compared to conventional light. Another significant advantage is that the LEDs' low-glare light improves vision for players on the field.[6] Furthermore, LED light shows in professional stadiums have become an extra attraction for fans.[7]

Operation Efficiency

LEDs as a solid-state lighting solution do not need mechanical shade options as conventional lights do for an instant blackout effect, LED light is able to deliver immediate on/off capabilities with no warm-up time required. Design of LED lamps allows for dust-free and moisture resistant electrical installations. At the same time, better heat dissipation and remote controls make maintenance more convenient.



Multi-Scenarios Adaptation – Extra Bonus

Light can serve many purposes. For example, light can influence emotional atmosphere on the field. One must consider that sports facilities might host a variety of events, not only sports-related. Therefore, arena operators prefer different lighting settings to better reflect the variety of events by creating diverse atmospheres.

Nowadays, light is not only about illuminating fields, it goes beyond that. With the use of new technologies, it enables immense possibilities in terms of playing with light itself to offer enhance lighting experiences. As an additional benefit, the unique fixtures of LEDs, multicolour options, advanced dimming capabilities, and colour temperature-tuning adjustments with no decrease in light on the surface, can address the needs of facilities properly.

Challenges of LEDs Implementation in Sports Fields

Despite the aforementioned benefits, there are some challenges for the implementation of LED light. For example, the lack of retrofits incentives, energy-efficiency awareness from management, instability of LED standards and performances, and the time needed for installation. In particular, manager may focus on short-term or mid-term cost-efficiency when estimating potential savings and maintenance costs for LED applications in replacement of existing conventional light sources. Therefore, although energy efficiency and savings are acknowledged as important, there is currently no immediate desire to achieve this today through retrofitting lamps with LEDs.[8]

Benefits of LED lighting in Sports Complex. Created by authors

Without reference to standards, it is difficult to identify the costs and benefits and satisfy the standards for TV broadcasting and transmission. Performance varies from one manufacturer to another. Managers would only opt for LEDs to replace existing light lamps if the advantages are clear and if the high costs are justifiable.[9]

Regarding the time needed for installation, Managers must find the right time since these sports complex are constantly being used.

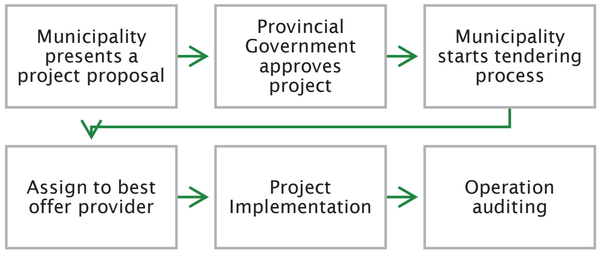
Case Studies

In this report, we discussed two cases where leading LED solutions are being implemented. The first one is the case of a municipal sports complex in Valencia, Spain and the second is Gerdahallen, a University owned Sport Complex in Lund, Sweden. Both offer different implementation models with distinct drivers and expectations.

Valencia's Energy Efficiency Program

As many sports facilities are owned and operated by municipalities, we looked at how Valencian Municipalities are implementing LED light technologies into their local sport complexes.

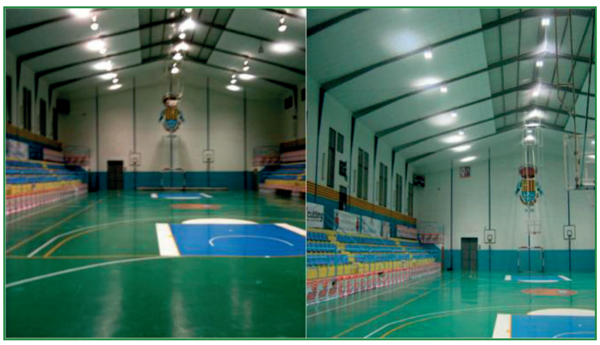
In the Province of Valencia, there is a plan that aims to substitute conventional lights with LEDs for municipal buildings and public spaces. The aim of this plan, besides reducing energy consumption, is to reduce environmental pollution and light pollution. With this plan, in 2014 alone, the Province of Valencia spent more than EUR 7.5 million, and in 2015 is spending about EUR 8.5 million on lighting related energy efficiency projects.[10]



LED light implementation process in Valencian Municipalities. Created by authors

These types of projects are possible due to the participation of different government agencies. In this case, the Province of Valencia provides a grant of 80% and the municipalities complement the remaining 20% of funds. At the same time, municipalities are responsible for presenting a proposal to the Province, and if approved, a public tender process is initiated and consequently assigned to the best offer and subsequently implemented. To gain further insights and understanding behind this program, we interviewed Mr. Madramany, an energy expert and collaborator of the local Ribera Energy Agency. He indicated that the main driver for municipalities to upgrade their lighting systems is related to costs savings, and that other drivers include the need for upgrading the facilities and also to meet with energy efficiency targets.

Following this energy efficiency program, one of the cases is the Football Stadium and Sports Complex in the Municipality of Guadassuar, where there has been a successful installation of LED lighting technologies. Mr. Madramany indicated that in Guadassuar, there have been reductions of up to 50% in energy savings while maintaining or improving the lighting quality according to current users' feedback.[12]



Comparison Old lighting at Guadassuar Sports Complex and new LED lighting. Photo credit: Salvador Madramany

Ribera Energy Agency
• Consortium of municipalities to collaborate on energy efficiency matters • Provides technical support for project implementation • Helps municipalities to implement EU level initiatives

Along with this case, an illustrative case is the Ribera Energy Agency, this autonomous public agency is the result of a consortium of municipalities, that have joined efforts to collaborate on energy efficiency matters. Consequently, Mr. Madramany added that at the Agency they encourage municipalities to implement energy efficiency projects, and at the same time, they work to provide technical support to all members.[12] Along with this, Mr. Madramany indicated that European Level initiatives serve as additional drivers for municipalities to implement energy efficiency projects. [12]

Mr. Madramany stated that the implementation of such projects is highly dependent on the political will of local authorities.[12] However, there are some good practices to ease the administrative burden for implementation. One is to reduce paper consumption by using electronics and IT to speed up communication. Mr. Madramany also suggests that municipalities should align project readiness with availability of funding. Finally, he suggests designing energy efficiency policies according to the local context, so municipalities can participate and benefit from such projects.

The learning outcome from this model of LED light implementation can serve as a basis for similar cases such as sports facilities owned by local governments.

Gerdahallen – On the Way to Energy Efficiency

When you first step into Gerdahallen, the main Gym of Lund University, you would be surprised by the various training sessions it operates from early morning to night. You may also be inspired by the passion Swedes have for fitness and sauna temperatures. However, one very important thing that you not pay attention to is the lighting system.

Drivers
• Financial advantages • Energy efficiency • Better users' experience • Good previous experience with LEDs • Recommendations by lighting providers

In Sweden, daylight during the winter can be very short, consequently "it is very necessary to have good lighting systems in place", said the IT manager at Gerdahallen, Mr. Lorentz. He added that since many gym sessions are running during darker afternoon and night hours, good and reliable lighting can provide a feeling of safety for their users.

Their first encounter with LEDs was several years ago when Gerdahallen installed multicoloured spot lamps for the dancing rooms. Currently, Instructors have up to ten choices of different programs, with a control unit in each room allowing for manual operation. Lights can be linked with audio systems and manipulated in accordance with the rhythm of the music, such as in discotheques.

In order to save energy, Gerdahallen takes a simple approach, very user-friendly, and Instructors are trained to operate the systems.

This year Gerdahallen started to introduce LEDs and so far, they are satisfied with their performance. In summer 2015 the lighting initiative started with plans to renovate one of the exercise rooms. As a consequence Mr. Lorentz decided to explore lighting options further. Both lighting solution partners of Gerdahallen recommended new LED light technologies and provided financial advantages and sustainable aspects of the suggested installation. A decision was made to progress based on this.

Mr. Lorentz said, "As a self-financed and operated university-owned property, one of the main drivers for any renovation project is the total cost and possible savings from the improvement. Old lighting technology offers less durability, it turns yellowish after some time, and the installation takes up more space. The LED light is only a bit more expensive than traditional lights such as EUR 40 each, yet the lifespan is much longer. We can get our investment back soon based on the avoided energy costs of electricity in the future".[11]

Suggestions from Gerdahallen

- Consider consumers experience.
- Segmentation for better management of costs.
- Ensure good technicians for maintenance or renovations.
- Build good relationship with suppliers.

Lights used in sports facilities can play a major role in context sports instructors especially for various activities as indicated by sports instructors. For example, instructors have suggested that for a calming session such as Yoga, calming tones with low light intensity are applied. Instructors should consider different preferences and needs according to user's ages, preferences and also medical conditions by members, staff and visitors, such as epilepsy. Gerdahallen has received complaints about colour lighting especially from static activities such as spinning. We interviewed several users and instructors and they were very satisfied with the current lighting system and indicated that they mainly enjoyed the animated multi-colour lighting in different activities.

LEDs are in line with other sustainability-related efforts at Gerdahallen. The Gym is working to improve ventilation, better temperature control, reduce water usage and ensure regular cleaning and maintenance. A suggestion from Mr. Lorentz to other Facilities' Managers is to divide areas for better management of costs and ability to identify savings and wastage.[11] So far Gerdahallen has been very satisfied with the application of LED light technologies. Mr. Lorentz recommends that other gyms interested in LEDs should have good technicians or experts from well-established partners to assist in case of maintenance or renovation needs.[11] Although the cost of LED light technology has decreased quickly in recent years, financial accessibility and availability is still a crucial aspect for its implementation. An additional trend is that Gerdahallen is integrating LED TVs and projectors for videos and pictures for exercise classes/trainings, and they are planning to explore more sophisticated LED products for these.

Major Findings from Gerdahallen

- Current gyms have recognised the benefits of LED lighting and started to implement such systems.
- The implementation of LED light should be a step-by-step approach and be aligned with the schedule of renovations for the buildings.

Perspectives from Commercial Suppliers

One-stop service and trouble-free solution providers to guarantee successful lighting projects with energy-efficient guidance

There are increasing demands and ambitious targets for better energy and lighting performance, particularly for sports facilities that have not upgraded their original lighting system since initial installations. However, most of these

Multi-purpose court,Gerdahallen. Photo credit: Yuanlong Li small and medium organisations that have ownership of sports facilities, lack expertise and capacity. Therefore they are challenged to fully make the switch to more energy efficient LED lighting, and accordingly avoid a significant amount of unnecessary energy costs. Therefore, business-oriented suppliers and customer service providers, are important actors that have arisen from the sport lighting market. These key stakeholders aim to provide comprehensive one-stop services from consultation to the operation and maintenance of lighting technologies.

A synthesis of the results of the research and interviews undertaken with some leading market-oriented suppliers (MUSCO Lighting) is shown below. This step-by-step process table shows how suppliers can help potential customers realise and maintain their lighting upgrades. Specifically the table shares common questions that concern customers, and supplier's involvement in each stage, specified in the light green boxes.

Steps	Expected Outcomes	Customers	Suppliers & Service Supporters
Consultation	Incorporate clients' requests into best solution	Concerns	Prioritise the requirements Pre-evaluation Feasibility analysis
		Is LED right for my project? How much light is enough? How can a lighted sports facility be a good neighbor?	
Financial Analysis	Energy saving, tailor payment schedules and financing terms to meet the needs of customers for facility improvements	Request a quote	Payment schedules
		How much will the LEDs cost to operate? How much will be saved by switching from X to Y? How long is the payback time? How can installation, operation, and maintenance costs be minimised?	Add revenue from expanded use of facility to next year's payment; Avoid inflationary pressures by completing the project at current prices; Lower energy and operating costs with cost/energy-efficient system; Take advantage of attractive, fixed interest rates
Design & Implementation	A complete sports-lighting system designed and manufactured for retrofits and new recreational facility lighting	Adaptation to the solutions	Trouble-free installation and operations
		Follow the system approach and integrate the new project with most existing electrical systems and supporting equipment	Provide guaranteed light levels, fast and trouble-free installation; Design as a modular system – with electrical components remote from luminaire assemblies; Factory assembled, aimed and tested for proven performance
Management & Monitor	Upgrading management and supporting system for quick adjustment and continuous improvement	Upgrading management: on-site and remote control	Extended services
		Operational and management data inputs and editing via the phone-based APP that connected to the overall monitoring system	User-friendly cyber platform to control the field lighting; 24/7 technical support for emergencies and reporting problems

A step by step process on realizing and maintaining LED sport lighting projects.[13] *Created by Xi Liu*

Conclusion

Considering the benefits of LEDs especially from a sustainability perspective, it is significant to look into the drivers and barriers for implementing LED lighting in sports facilities. In this chapter we also explored different stakeholder perspectives. Our findings indicate that currently sports facilities are at an early stage of implementing LED light technologies, it is voluntary, and it usually follows a broader renovation process, aiming as well to reduce operation costs.

The LED implementation process can follow energy efficiency governmental programs, such as in the case of Valencia. Here, the political will created a decisive step for LED implementation, with the possibility of influence from EU directives.

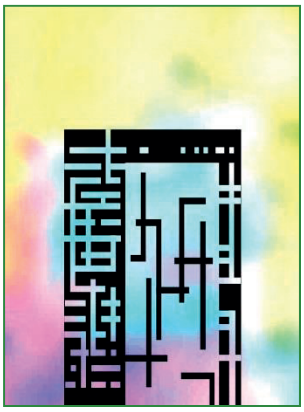
From the service provider's perspective, they might step in with financial help to supplement government models. Commercial suppliers can provide small and medium potential customers with a customised package of services, expertise and incentives. Overall, it is apparent that LEDs are not necessarily being implemented in the immediate short-term in sporting facilities, however, they are likely to gain more traction in the mid to longer-term future.

References

1. U.S. Energy Information Administration (EIA). (2015). *Stadiums and arenas use efficient, high wattage lamps - Today in Energy*. Retrieved December 12, 2015, from https://www.eia.gov/todayinenergy/detail.cfm?id=9871.
2. General Electricity. (2014). *Slam-Dunk Illumination: Knowing Your Facility's Unique Design Considerations Will Help You Score with Your Lighting Project*. GE.
3. Philips Lighting. (2015). *Arena Vision LED Arena Vision High-end sports floodlighting*. Retrieved December 12, 2015, from http://dev.ilte-luce.com/main/prof/outdoor-luminaires/sports-and-area-floodlighting/high-end-sports-floodlighting/arenavision/arenavision-led.
4. Philips Lighting. (2015). *How does LED work? Benefits of LED*. Retrieved December 12, 2015, from http://www.lighting.philips.com/main/education/lighting-academy/lighting-academy-browser/video/LEDs.html.
5. Design Recycle Incorporation. (2015). *Compare: LED Lights vs. CFL vs. Incandescent Lighting Chart*. Retrieved December 12, 2015 from http://www.designrecycleinc.com/led%20comp%20chart.html.
6. Arena LED. (2013). *Sports Solution*. Arena LED.
7. Philips Lighting. (2015). *Chelsea F.C. Lighting*. Retrieved December 12, 2015, from: http://www.lighting.philips.com/main/cases/cases/arena-sports/arenavision-led-sport-lighting.html.
8. Premier-light. (2015). *Replacing Fluorescent Ice Arena Lighting with LED Lighting*. Premier-light.
9. Ephesus lighting. (2015). *Bridgestone Arena, NHL Hockey Arena, TN, the USA*. Ephesus lighting.
10. Diputación de Valencia. (2015). *Plan de eficiencia energética en iluminación de tecnología led (PEEITL) | Diputación de Valencia*. Retrieved December 12, 2015, from http://www.dival.es/cooperacion-municipal/content/plan-de-eficiencia-energetica-en-iluminacion-de-tecnologia-led-peeitl.
11. Lorentz, M. (2015, December 03). IT Manager Gerdahallen Gym at Lund University. Personal Communication. (Y. Li, Interviewer)
12. Madramany, S. (2015, November 25). Energy Engineer Ribera Energy Agency. Personal Communication. (J. Padron, Interviewer)
13. Media Relations. (2015, December 03). MUSCO Lighting at United States. Personal Communication. (Xi. L, Interviewer)

LUND, WHERE ANYTHING IS POSSIBLE

Learnings from an Early Adopter of LED Technology



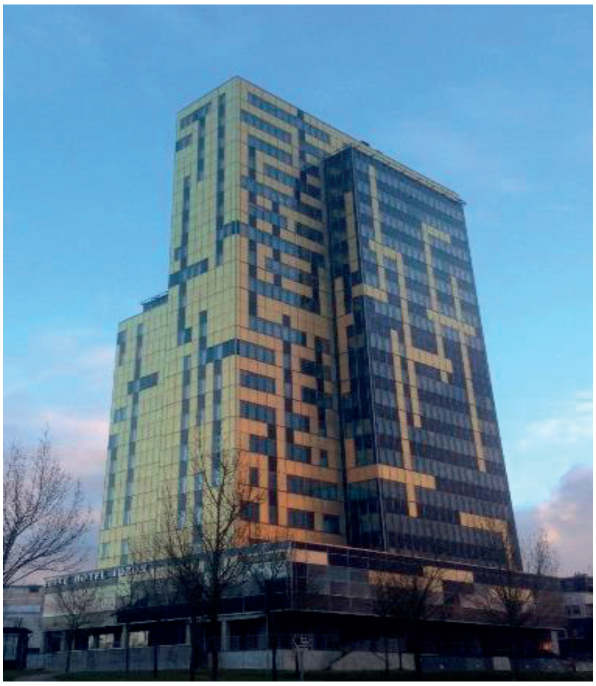
By Isaac Guzman, Thorge Ketelhodt & Shamim Zakaria

If you ask people how they feel after being nominated for an award they will tell you they feel proud. In Lund there is an award winning building that was designed to make people proud. This is the story of how a real estate developer decided to use new, promising energy efficient light technology even though it was still immature. This chapter describes the process as well as the challenges and benefits of LED technology in the hospitality industry in the mid-2000s.

Greening the Hospitality Industry

Buildings in general have a high energy consumption: according to the European Commission buildings account for about 40% of energy use in the EU.[1] The global environmental impact of the hotel industry that was measured in the year 2000[2] states that tourism was responsible for about five percent of global fossil energy consumption in the beginning of this century.

The core business of the hospitality industry is to accommodate and entertain guests. Since both activities are mainly indoors, functional and attractive facilities are of high importance. With this background, it is crucial to include the hospitality industry in the efforts to make buildings more energy efficient. Green label initiatives and certificates such as the Leadership in Energy and Environmental Design (LEED) are becoming more attractive for hotel owners year after year. Investors' willingness to spend money on green buildings increased from 28% to 48% between 2011 and 2013.[4] These efforts pay off for the environment and for the hotel's balance sheet. In a typical hotel the energy costs are between three to six percent of the overall operational cost[5], depending on hotel size, number of rooms, location (rural-city), climate zone, etc. Energy saving light technology is just one way to contribute towards energy reduction in hotels. Lights have a share of 12-20% of total energy consumption, in some cases of up to



Elite Hotel Ideon, Lund, Sweden.
Photo credit: Thorge Ketelhodt

40%.[5] In addition to the energy savings and monetary savings, LEDs have several co-benefits. Some are of particular interest for the hospitality industry such as the improvement of guests' and employees' well-being and comfort.

Ideon Gateway in Lund

The Ideon Gateway is located in the north of Lund. It is the entrance of the Ideon Science Park, the first science center in Sweden. The Elite Hotel Ideon with 178 modern hotel rooms is a 19 storey structure within the park's grounds. Additionally, there are about 700 offices. The 75 m building, the tallest in Lund, is owned by Wihlborgs Fastigheter AB. In 2006 the planning of the building began; in 2010 construction commenced. After about three years, in January 2013, the doors to the public opened. In 2014, it was among the top three ranked LEED certified buildings in Sweden.[3] Environmental concerns were thoroughly integrated in the planning and construction of the building. It included many energy saving technologies, even those that were new on the market.

The rationale sustainable approach of the Ideon Gateway building was to be a source of pride for those who work there and Lund citizens. It was planned as a platform for Lund University to showcase innovative ideas and to play the role of connecting the academic world to the industrial world.

As a result of the efforts, the building qualified for several sustainability labels, the LEED certificate, among others. With an overall score of 84/110 for the different criteria under the certificate, it was awarded with the LEED Platinum category, the highest certificate category.

LEDs as One Aspect in a Sustainable Approach

The Hotel has many features that contribute towards a minimal environmental impact. For example, their solar panels have an annual generation capacity of 65 MWh per year installed as part of the facade. That accounts for about ten percent of yearly electricity use of the building. In the early planning stage, considerations were made for installing more solar panels on the roof top. At the right angle the electricity generation would have been even higher. However, according to Ms. Hammargren, who was in charge of the planning of the building for the real estate developer Ikano, they dismissed the idea due to safety reasons. Strong winds at the rooftop would have made the project dangerous. Other features of the hotel such as the placement of heat generators on each floor of the building as opposed to circulation heat from a central heating system also saves overall energy consumption. Detectors and temperature sensors control the ventilation. According to the European Commission[5], the supply system for the ventilation of the building is highly efficient

View from the Lobby at the Elite Hotel Ideon.
Photo credit: Isaac Guzman

at recovering heat, with up to 80% recovery. Adding to this holistic sustainability approach, a geothermal system is used for cooling and heating of the building. The Ideon Gateway has a primary energy demand of 25,70 kWh/m^2 per year which is 41.5% less than a comparable (type, size, shape and orientation) conventional building.[6] This was achieved without reduction in comfort.

Finally the use of LEDs is an aspect that furthers energy savings. The next sections of this chapter will discuss the installation of this technology in the hotel.

Challenges

When the Swedish real estate developer Ikano made the decision to use LED lights for the Ideon Gateway in the mid-2000s, LED technology was still new. As a result, that decision resulted in a few challenges, Ms. Hammargren admitted. Working with a technology that was not mature was challenging in itself. The high demand did not make it any easier: for the building they were looking for 1100 LEDs, an amount that was above normal purchases. First of all, it was difficult to find a supplier who could deliver the needed quantity and quality. Secondly, it was difficult to foresee which of the many new suppliers would still be on the market in one to ten years. The developer wanted to be sure that the supplier would be able to provide warranty and maintenance services for the lights in the future.

The real estate developer was asked by suppliers to wait until the LEDs were developed due to a lack of fitting options on the market. For the project leaders this was not an option. They did not want to be involved in the development of a new technology but wanted to buy a ready-to-use one. Moreover the hotel developers wanted to find a company that could deliver the full package from technology provision to installations, which was also a challenge at the time. In the end, the light provider Thorn Lighting in collaboration with the installer Goodtech Projects & Services AB installed the lighting solutions for nine conference suites, gym, kitchen and banking area.

Benefits

Energy savings from the use of LED lights is one key component for Ideon Gateway. Financial benefits also exist due to the lower heat build-up, saving additional money that would otherwise be directed towards cooling demands. While this may be more noticeable in countries with hotter average temperatures, the effect is noticeable even in Scandinavia, Ms. Hammargren says, laughing.

The flexibility of LEDs is another co-benefit. In offices and hotels where people come and go frequently, the dimming option is valuable. If there are no guests present in hallways, the lights may be dimmed to as low as ten percent. If someone enters the corridor, the light intensity can be quickly increased to double that of a conventional light. This is achieved in combination with sensors. The movement detectors at Hotel Ideon make the system a smart system which additionally helps to reduce electricity consumption.

Another benefit is the new possibilities for light use. There are special LEDs installed in Hotel

Façade Elite Hotel Ideon. Photo credit: Isaac Guzman

Ideon's windowless rooms. These lights, covered behind a curtain, provide the impression of an actual window. Hotel guest Ms. Ravn was pleased by the room and added, "In most hotels you are not allowed to open the windows anyways. Having this installation is a good compromise especially if you mainly use the room for sleeping."

Windowless room with LED light wall at Elite Hotel Ideon. Photo credit: Isaac Guzman

Furthermore the maintenance of the lights is user friendly. The person in charge for the Swedish property developer and owner, affirms this.

Findings

The Ideon Gateway case draws on the fact that what may be a standard lighting purchase decision for a building today was more difficult to implement when the technology was still new. The technology was hardly ready to be placed on the market. There were many uncertainties concerning LED lights. Suppliers were still developing and experimenting with the technology and were not always able to deliver the needed quantities. At the same time, the upfront costs were higher than the expected energy savings, as interviews and desk research showed. In the case of Ideon Gateway a life cycle costing (LCC) showed that the long -term savings would hardly be large enough for a monetary justification of the additional investment, Ms. Hammargren stated. The developer therefore decided to go for a mixed approach with 1100 LEDs and some conventional lights.

Only after the installation in the Hotel did LEDs become more affordable on the market. Figure 1 shows the efficacy improvement of different light sources over time (light output per unit of energy). LED technology made large improvements since the initial development of the technology. While LEDs were a luxury 10 years ago, they are almost standard in the markets now. The lighting sector as a whole has seen drastic

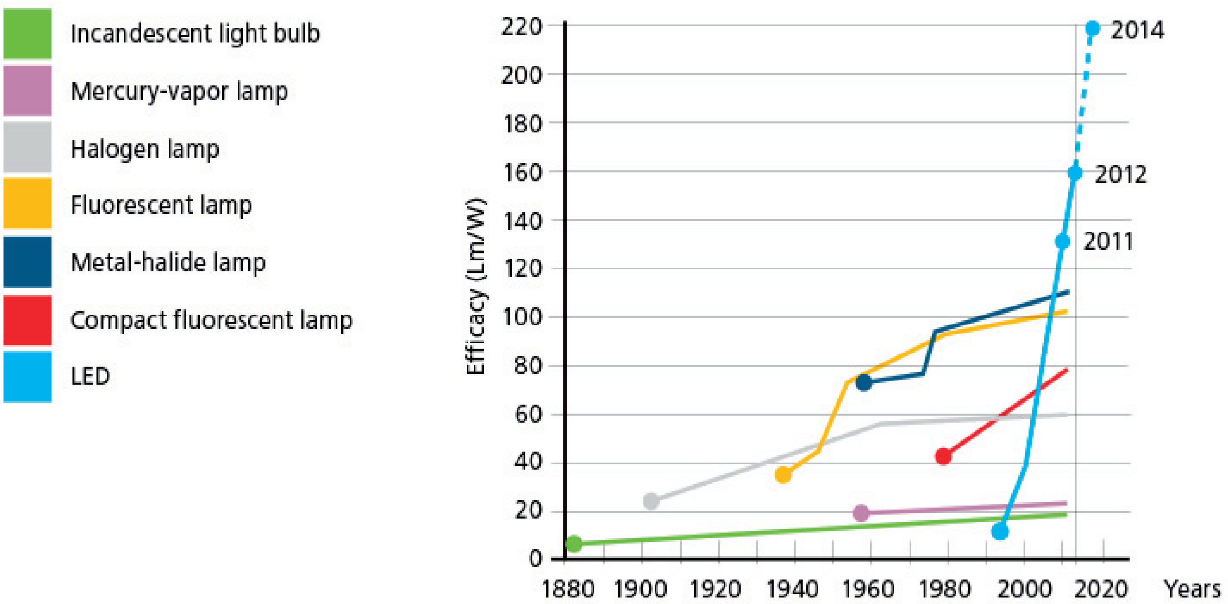


Figure 1 Efficacy increase over the time for various light sources.[7]

changes in terms of market penetration since then as indicated in Figure 1.

Conclusion

The Hotel Ideon case shows how the purchase of 1100 LED lights was not a simple task seven years ago. The main reasons for the installation of LEDs did not involve the need for a sustainability certification, as some certificates did not require LEDs. Nor was it because of the expectation to save electricity and money in the future. Yet the decision to install LEDs paid off. The developers followed a sustainability concept. Also the LEDs are visible, of which people could be proud. That is a feature that other energy efficient technologies such as efficient ventilation system do not possess. The installed lights showed the futuristic design and the green building concept. It could be a marketing tool as on the hotel's website the lights are mentioned several times.

Furthermore, the purchase of LEDs for Ideon Gateway contributed in the early market development of the technology. The benefits may be enjoyed by many today. The energy savings and flexibility of these lights has enabled broader market uptake thanks to early adopters.

For the developers the LED lighting served more as a luxury than a cost saving purchase. Hence conservative investors might say that the investment was not cost-effective. However, the holistic, sustainable concept that includes LEDs could be used as a selling point. Based on this, the developer Ikano was able to sell the building with a profit to the property management company Wihlborgs Fastigheter AB two years ago.

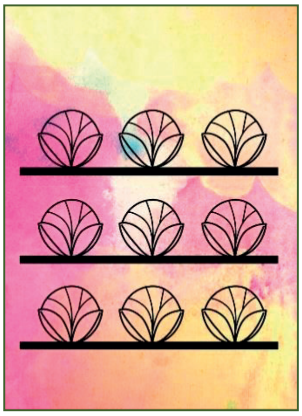
It is difficult to imagine that this took place less than 10 years ago as LEDs are considered normal now. This chapter shows that being an early adopter certainly pays off. In Lund, people can be proud because anything is possible.

References

1. European Commission. (2015). *Buildings*. Retrieved December 14, 2015, from: https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings
2. Gössling, S. (2002). Global environmental consequences of tourism. *Global Environmental Change*, 12(4), 283-302.
3. USGBC., & Kriss, J. (2014). *Three Billion Square Feet of Green Building Space LEED®-Certified.1*. Retrieved Accessed December 13, 2015 from: http://www.usgbc.org/articles/three-billion-square-feet-green-building-space-leed%C2%AE-certified
4. Korosec, K. (2013). *Retail, hospitality sectors up green building investment. Environmental Leader*. Retrieved December 13, 2015 from: http://www.environmentalleader.com/2013/06/26/retail-hospitality-sectors-up-green-building-investment/
5. Bohdanowicz, P., Churine-Kallhauge, A., & Martinac, I. (2001). *Energy efficiency and conservation in hotels - Towards sustainable tourism*. The 4th International symposium on Asia Pacific architecture, Hawai.
6. European Comission. (2015). Ideon Gateway. Retrieved December 14, 2015, from: http://iet.jrc.ec.europa.eu/energyefficiency/ideon-gateway.
7. LED-Academy. (2015). *High Efficacy*. Retrieved December 14, 2015, from: http://www.ledacademy.net/5-1-high-efficacy/

LED THERE BE LIGHT!

Using LED to Improve Urban Food Systems



By Margarita Roxas & Lindsey Zemler

Food security is defined as "the state where all members of a community have access to culturally acceptable, nutritionally adequate food through local, non-emergency sources at all times".[1] Food security is linked to global environmental issues, such as land degradation and overuse of resources, use of pesticides and chemical fertilizers, climate change and others.[2] From fertilizer and pesticide production, to transport, to waste disposal, food systems account for 19 to 29% of global anthropogenic greenhouse gas emissions in 2008. In absolute terms, this means 9 800 to 16 900 megatonnes of carbon dioxide equivalent ($MtCO_2e$) are released into the environment by food-related activities. Emissions from agriculture during the production stage alone, including land conversion, contribute the largest impact (7 318 to 12 683 $MtCO_2e$); storage, packaging and transport are also considered a major contributor (396 $MtCO_2e$) to food system emissions.[3] While absolute values are unknown, it is clear that food systems will play a significant role in combating climate change. Furthermore, food security is affected by ineffective legislation, social inequity, and compounds issues such as obesity, malnutrition and other human health problems.

Today food production takes place mainly in rural areas and is then transported into cities, where the majority of consumers are located. However, in recent years municipalities, companies and businesses, local communities and households have introduced various methods for urban food production. Set in the global context of increasing urbanization and rapid population growth, the ability to improve food security is reliant on robust and resilient food systems, particularly in urban areas.[1]

Many methods for growing food inside cities have been implemented on various scales and purposes, including: vertical farming, rooftop greenhouses, balcony gardens, community gardens, and others, all of which utilize limited space and scarce resources efficiently.[1] Most rely on specialized technology to enhance plant growth, and many of these systems apply LED technology. LED light, for instance, is used to extend the growing season during the winter, or small-scale to encourage plant growth which supplements a household's grocery shopping.

Artificial light has long been used to augment plant growth,[2] but the increasing interest in LED for various food production methods has great potential to address acute problems within the current food system. Increasing food production within cities, in addition to conventional rural agriculture, will contribute to a more equal distribution of fresh and healthy food with less harmful environmental impact.

Our research has identified recent trends in upscaling indoor agriculture using LED lighting systems; this chapter explores the potential of certain innovative food production practices to significantly address food security issues in cities. In particular, this research describes common characteristics identified amongst stakeholders using LED to supplement growth of edible plant, and attempts to define a form of "controlled environment agriculture" or CEA *(see Figure 1)*. Finally, it also seeks to assess the feasibility of CEA in addressing food security.

LED in Food Production

Although a wide variety of companies, businesses, research centers, organizations, entrepreneurs and others are involved in driving the use of LED in food production, there are several key demonstrative examples of innovative companies, which have unique potential to positively impact the food system. These companies exemplify recent trends wherein urban agricultural solutions does not only include LED for enhancement; rather they transfer from being a supporting technology to being a sole-source lighting technology. One such innovative use, initially implemented in Japan, the U.S., and Europe, is of LED for commercial food production in facilities which are completely controlled, free from external environmental conditions, and usually located in urban or semi-urban areas. In an attempt to streamline current practices, this chapter presents a set of characteristics to define this type of commercial food production, as CEA.

Controlled Environment Agriculture (CEA)

These sites or facilities generally meet the majority of the following criteria (see figure below); a) uses LED as sole-source lighting technology; b) grows edible plants, not animals; c) operates on a large and commercial scale; d) attends to/cooperates with local surroundings; and e) is located in urban or semi-urban area. Other (additional) attributes may be that the facility is f) a converted unused urban space, and/or is g) integrated with research and development initiatives. Henceforth, a company or entity with the

	Mirai Inc.	AeroFarms	Growing Underground	Upperhouse Restaurant	Wageningen UR Greenhouse Horticulture	Alfred Pederson & Sons	SLU Arnap - Dept. of Biosystems and Technology	Heliospectra
LED as the sole-source lighting	✓	✓	✓	✓			✓	✓
Edible plants	✓	✓	✓	✓	✓	✓		✓
Large and commercial scale	✓	✓	✓			✓		
Urban or semi-urban location	✓	✓	✓	✓	✓		✓	✓
Interaction with local stakeholders	✓	✓	✓	✓				✓
Converted spaces	✓		✓	✓				✓
Integrated with R&D initiatives	✓	✓	✓		✓	✓	✓	✓

Overview of cases which exemplify key characteristics of controlled environment agriculture (CEA). Created by authors majority of these characteristics will be referred to as practicing controlled environment agriculture (CEA).

Some CEA pioneers which have moved towards a particular trend that will be elaborated on further include Mirai Inc. in Japan, AeroFarms in New Jersey, U.S.A, and Growing Underground in London, U.K.

Mirai Inc. cultivates food in a controlled 2 323 m^2 facility converted from an old factory in Japan, and two small factories in Mongolia. The company promotes the use of LEDs not only to utilize indoor space but to appropriately control plant growth for better overall output. Lack of access to fresh and healthy vegetables in these localities are the main driver for the development of these facilities, especially due to food safety concerns and climate limitations. The system combines LED with other cultivation technologies for controlling water and nutrients. The facility in Japan is claimed to be the first to combine such technologies for large-scale indoor production and cultivation.[4]

AeroFarms in New Jersey is building the 'world's largest indoor vertical farm'[5] and aims to transform agriculture through enabling local production at scale. This is made possible by LED and other technologies. The company has expansion plans for similar facilities on three continents. The food produced in this specially-built facility will serve the New York Metro area, the biggest market in the United States. The facility is completely controlled, which allows production on a commercial scale regardless of the season, uses no pesticides, very little water, and recycles nutrients in a closed-loop system.[5,6]

Growing Underground is a company producing mainly micro greens and salad, located in a unique converted space in London. As of late 2015, the company cultivates and sells micro greens and salad leaves produced in underground tunnels, which once served as air-raid shelters in World War II. Independent of weather or seasonal change, production is controlled and lasts throughout the year, and is reliant on LED technology in vertically stacked growing beds. Currently there is 557 m^2 of growing area which equals around 700 boxes of produce daily. The operation is anticipated to triple within two years, and is expected to serve as an example for tunnel conversions in Germany and Scandinavia.[7]

Each of these examples are designed for quantity, quality and a production system which can be up-scaled easily. Nonetheless, these are also dependent on parallel technologies to provide water and nutrients; and on computer systems, which manage the lights, the temperature and other inputs. They also intend to affect urban food systems and provide local solutions, but are limited by what produce can be feasibly grown in short periods (e.g. lettuces, greens, tomatoes).

Lessons Learned from Various Applications of LED

In order to explore the feasibility of CEA as defined above, it is helpful to observe what else is influencing the market for LED lighting in food production. Five interviews provided a basis for this research to further explore the prospects of LED technology as understood from the perspective of several involved manufacturers, producers, researchers and businesses. Though the perspectives are not representative or comprehensive of an entire sector or of CEA companies, they provide insight into current practices, and possible future trends. These examples, although not direct examples of CEA, are important sources of information to identify transferability and feasibility of how LED for plant growth is used most commonly and whether it can progress towards CEA.

Feasibility of CEA for Improving Food Security

The examples demonstrate that there is great potential for CEA to advance further, expand to different ventures, and penetrate different markets and geographical regions. In order to assess its merit and value, a multi-criteria evaluation is used to assess its feasibility as a solution to food security issues. These criteria include relevance, effectiveness and impact, and cost-effectiveness.

Relevance

Food security is greatly dependent on stable and predictable climatic conditions. However, with the changing and variable climate, food growing must be able to adapt. With CEA, there is complete control over the micro-environment, which is independent of external conditions; users are able to regulate temperature, humidity, water and lighting more precisely.[8] Most of the operating CEA facilities are built in temperate regions and production lasts all year, regardless of the season or outdoor conditions.[2] However, it would be highly relevant for tropical countries, especially developing nations, to also consider this type of solution in light of climate change and the higher expected impact in tropical areas.

Not only is CEA ensuring an adequate quantity of food but it also reduces the impacts from production processes, such as environmental impact of food delivery/transportation, because food miles are significantly reduced. Production is on a local level and uniquely redefines the concept of being "grown locally". It is decentralized and independent of the global market, and is significantly closer to consumers' tables.[1] For example, Growing Underground has partnered with local restaurants to deliver produce within four hours of harvest.[7] Consequently, food is directly accessible to retailers and consumers, rather than going through a long or inefficient supply chain. Ideally, this model of production would also provide competitive or lower prices to consumers, due to reducing transportation-related costs, land/property ownership costs, and labor costs.[1]

Institution	Heliospectra	Upper House Restaurant	Alfred Pedersen & Søn	SLU Arnap - Dept. of Biosystems and Technology	Wageningen UR Greenhouse Horticulture
Interviewee	Christopher Steele, COO	Mathias Bjurmalm, Chef	Jan Ravensbergen, Production Manager / Senior Growmanager	Karl-Johan Bergstrand, Researcher	Anja Dieleman, Senior Scientist plant physiology
Description	A global company which develops and manufactures LED lighting systems, including automation	A restaurant in Gothenburg, Sweden that maintains a small-scale production of herbs using LED in a closed storage room	A leading company in Scandinavia for growing vegetables in greenhouses	An academic research centre that investigates on the effects of LED lighting on plant growth	A university-based research station which investigates the effect of light, especially LED, on plant growth
Main insight for CEA	Oriented towards a positive future for LED on a commercial level, especially in controlled environments	Exemplifies producer/client relationship, and pilot for upscaling	LED use is feasible in certain applications but many barriers, especially financial, exist	Stresses that there is still room to improve LED technology	Ongoing research has potential to understand the effect of light on plant growth and supports all uses of LED on food production, including greenhouses

Summary of personal interviews: Description and main insights. Created by authors

Effectiveness & Impact

LED lights are highly flexible and easy to control.[2] Hence, this allows the user to select a narrow-band region from the spectral composition to produce desired results. LED lights have been proven to increase biomass production, enhance food quality and nutritional content.[9] Using the same facility, LED lights can be applied beyond food production to post-harvest applications. For example, an LED lighting system can be used to preserve food quality and quantity, slow the aging process, and delay fruit and vegetable ripening.[9] It is also possible to prevent fungal spoilage, decrease viral resistance, increase suppression of pathogens, as LED acts as non-thermal decontamination technology that kills microorganism at the surface level.[9] In these circumstances it is conducive to growing organic products. However, the range of food is still limited to certain types, such as lettuces, salad greens, tomatoes and cucumbers. Regardless of this limitation, interest is high and wide research is currently being conducted to expand the scope and application of LED in food production.[8,10,11]

Using LED lights for food production is considered a better alternative to its predecessor technologies, such as high-intensity discharge lamps because it has lower human health risks; it does not contain hazardous chemical compounds. As a solid-state technology, it can also be easily wired for automation and remote control, thereby requiring minimal human interaction.[6] However, as a greenhouse manager, Mr. Ravensbergen of Alfred & Sons explained that continued exposure to LED lights on eye level can cause unanticipated eye strain, and currently no external health and safety regulations are in place to address it.[12]

The success of LED lights in enclosed facilities are of course dependent on the whole food production system. As seen in the examples, LED lights are used in combination with other technologies, such as hydroponics, aquaponics and aeroponics. LED lights are a constant in all these cases, while various parallel technologies are integrated to work in tandem.

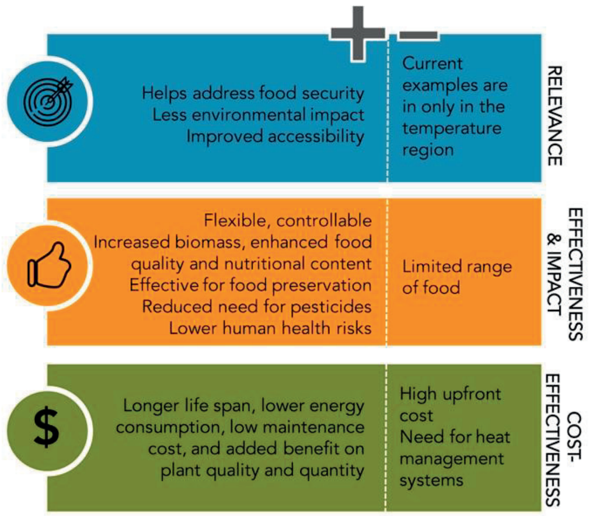
Cost-effectiveness

There are divergent viewpoints on whether LED is more cost-effective than other artificial light sources. Mr. Ravensbergen has expressed that the initial investment cost is high and payback time is too long, but this is dependent on the whole setup. Mr. Steele of Heliospectra acknowledges that the upfront cost is a major concern for many, yet argues that LEDs have a longer life expectancy (between 50 000 to 100 000 hours), lower energy consumption, added benefit on plant quantity and quality, and lower maintenance cost; therefore, the initial capital investment is justified and should not be a barrier.[12] Manufacturers and developers are exploring options on how to make it more economically feasible. Heliospectra has developed a number of superior quality and advanced products. Some of these address a specific niche, while others are "intelligent, but scaled back" products, which are accessible for many clients but retains their good performance.[10] For example, their most advanced product RX30 is the leading product in plant research with "nothing in the market as advanced like it".[10] The E60, on the other hand, is particularly developed for green leafy plants, while the LightBar is tailored for vertical farming of salad and herbs.

Some stakeholders, such as Mr. Johan Bergstrand, have expressed concerns that in addition to cost, the efficiency of LED grow lights is still not mature.[13] Others claim the efficiency is competitive with high-intensive energy discharge fixtures with an efficiency rate between 1.66 to 1.70 micromoles per joule.[14]

Despite being able to use high intensity light at low radiant heat output and no long-wave radiation, heat sinks or heat management systems are still necessary.[11] This is another area where there is great opportunity for improvement, especially in terms of cost.

Nevertheless, the market for LED grow lights is expected to grow from USD 395 million (EUR 359 million) in 2014 to USD 1.8 billion (EUR 1.6 billion) by 2021.[15] Also, with the general trend of technologies, it can be assumed that further investment will be put into research and development for technological improvement.



Criteria for analyzing feasibility of CEA using LEDs to addressed food security issues. Created by authors.

Key Findings & Discussion

Insights into the innovative production methods using CEA, as well as other methods of use for LED in food production, provide several key findings expressed further as opportunities and limitations.

Opportunities

- Shift from research stage to full implementation;
- Possibility to scale up or down;
- Investment in more advanced research, potential for investors;
- Enhanced cooperation between companies, research centers, and communities;
- Knowledge and technology transfer to other countries;
- Addresses some supply chain issues; and
- Utilizes abandoned or unused spaces

Limitations

- Efficiency of technology needs improvement;
- Financial capital and initial investment is high, needs to be more cost-effective;
- Only viable for certain types of produce (i.e. salad greens);
- Preference for conventional methods of some growers; and
- Lack of legislative or municipal support

Moving Forward

Referring to the problem of food security stated at the beginning - locally grown, fresh produce, should be continually accessible to all members of urban society and new solutions are needed to ensure this. Undoubtedly addressing food security is a larger issue than can be addressed by a single technology, and requires systemic change. However, this potential shift towards CEA is not expected to be the sole solution, but rather takes a both reactive and proactive approach to efficiently supplement urban food supply needs. While other light technologies exist for sole-source or multi-source lighting, LED is arguably more effective, cost-effective and relevant and therefore is presented as the best technology for controlled environment agriculture (CEA). On the grounds presented above, food producers are recommended to prioritize LED use for CEA and in general for food production, such as in greenhouses.

To realize the potential and growth, partnerships between various stakeholders (LED companies, food growers/farmers, research institutions) are acknowledged. Yet the cooperation and active participation of local government is essential. Currently, while no policy restricts the implementation of initiatives like this, a more proactive stance would further accelerate the uptake of these initiatives. This may involve assistance in urban planning, providing funding grants for research, tax incentives for converting unused spaces, and the like.

All of this being said, it's important to mention that CEA is a work in progress and requires ongoing research to improve its applicability to a wider range of food products and food quality. With regard to cost-effectiveness, LED lights follow a typical trajectory of innovation advancement. Hence, we can expect effective yet more affordable grow lights in the market in the near future.

A lingering question remains regarding the impact of CEA: will this trend cause a significant shift in conventional food production systems? Based on our analysis of *relevance, effectiveness and impact*, and *cost-effectiveness*, CEA has potential to be a component of an improved food system that can make significant local impact and therefore affect a global problem.

References

1. Opitz, I., Berges, R., Piorr, A., & Krikser, T. (2015). Contributing to food security in urban areas: Differences between urban agriculture and peri-urban agriculture in the Global North. *Agriculture and Human Values*. Retrieved December 14, 2015.
2. Yeh, N., & Chung, J. (2009). High-brightness LEDs: Energy efficient lighting sources and their potential in indoor plant cultivation. *Renewable and Sustainable Energy Reviews*, 13, 2175-2180. Retrieved December 14, 2015.
3. Vermeulen, S. J., Campbell, B. M., & Ingram, J. S. (2012). Climate change and food systems. *Annual Review of Environment and Resources*, *37*(1), 195.
4. Kellner, Tomas. (2014, Jul 14). Lettuce See the Future: LED Lighting Helps Farming Go High-Tech in Japan. GE Reports: retrieved from http://www.gereports.com/post/91250246340/lettuce-see-the-future-led-lighting-helps-farming/.
5. AeroFarms. (2015). The AeroFarms System. Retrieved from http://aerofarms.com/why/technology/.
6. Hughes, C. (2015, Apr 7). In Newark, a Vertical Indoor Farm Helps Anchor Area's Revival. New York Times: retrieved from http://www.nytimes.com/2015/04/08/realestate/commercial/in-newark-a-vertical-indoor-farm-helps-anchor-an-areas-revival.html.
7. Growing Underground. Home page. Retrieved from: http://growing-underground.com
8. Heliospectra AB. (2014). Private placement memorandum. Gothenberg: G&W Foundkommission. Retrieved December 1, 2015 from www.heliospectra.com
9. D'Souze, C., Yuk, H.G., Khoo, G.H., & Zhou, W. (2015). Application of Light-Emitting Diode in Food Production, Postharvest Preservation, and Microbiological Food Safety. Comprehensive Reviews in Food Science and Food Safety, 14(6), 719-740.
10. Steel, Christopher. Interviewed by Margarita Roxas and Lindsey Zemler. Personal interview. Skype, November 25, 2015.
11. Dieleman, Dr. Anna. Interviewed by Lindsey Zemler. Personal interview. Phone (n.l.), November 26, 2015.
12. Ravensbergen, Jan. Interviewed by Margarita Roxas and Lindsey Zemler. Personal interview. Phone, November 30, 2015.
13. Bergstrand, Karl-Johan. Interviewed by Margarita Roxas and Lindsey Zemler. Personal interview. Skype, December 2, 2015.
14. Nelson, J.A. & Bugbee, B. (2014). Economic analysis of greenhouse lighting: light emitting diodes vs. high intensity discharge fixtures.
15. PR Newswire. (2015). Global LED Agricultural Grow Lights Market Worth $1.8 billion by 20121. Retrieved November 20, 2015 from http://www.prnews-wire.com/news-release/global-led-agricultural-grow-lights-market-worth-18-billion-by-2021-29604511.html

The Authors

This report was compiled by the students of the masters course in Environmental Sciences, Policy and Management (MESPOM). MESPOM is a two-year Erasmus Mundus programme supported by the European Commission and operated by four European and two North American Universities.

Students study in at least three out of the six consortium universities: Central European University (Hungary); University of the Aegean (Greece); Lund University (Sweden); Manchester University (United Kingdom); Middleburry Institute of International Studies at Monterey (United States); and University of Saskatchewan (Canada).

MESPOM batch 10 consists of 29 students from 16 different countries. The authors are 21 (of the 29) students studying at the International Institute for Industrial Environmental Economics(IIIEE) at Lund University during the autumn 2015 semester. These 21 students represent Australia, Brazil, China, Germany, Indonesia, India, Macedonia, Malaysia, Mexico, Philippines, Taiwan, Tanzania, Thailand, United Kingdom and United States.

The report is part of a course in Strategic Environmental Development led by Professor Mikael Backman; Professor Thomas Lindhqvist; Charlotte Leire, Lecturer; and Bernadette Kiss, Research Associate; who steered the writing and publication process.

Established in 1994 by the Swedish Parliament, the International Institute for Industrial Environmental Economics (IIIEE) has grown to become a leading international research and teaching centre, pursuing strategic preventative solutions in sustainable development. As part of Lund University, the IIIEE offers undergraduate and postgraduate programmes in a multidisciplinary environment, focusing on pragmatic approaches to foster the transition towards an environmentally conscious society.

The IIIEE seeks to facilitate this transition by engaging in education and research activities, with a focus on connecting academia and practice. The Institute, with its international students, faculty and staff, is proud of its multidisciplinary and multicultural approaches to sustainability.

By collaborating with other departments at Lund University and various universities worldwide, the Institute explores and advances knowledge in design, application and evaluation of strategies, policies and tools for addressing global environmental challenges.

Working at the nexus of economy, industry and the environment, the IIIEE emphasises the need for sustainability in industry.

The Institute currently operates two international Master's programmes, as well as independent courses, a broad range of pioneering research projects, and numerous outreach activities.

Alumni are found within consulting, industry, research, NGOs, international, and national governments, and other fields. The IIIEE has a strong alumni network consisting of more than 700 members representing over 90 countries.

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