lightingforpeople
CONNECTING OPPORTUNITIES FOR INNOVATION

REPORT ON GREEN BUSINESS DEVELOPMENT IN SUSTAINABLE CITIES

Accelerate SSL

Innovation for Europe

SSL-erate

www.ssl-erate.eu

FP7-ICT-2013-11-619249

ACCELERATE SSL INNOVATION FOR EUROPE

DELIVERABLE 2.9

AUTHOR: Reine Karlsson, Lund University

CO-AUTHORS:
Tove Karlsson, Lund University
Jos Kunen, TNO
Pranciškus Vitta, Vilnius University
Olle Strandberg, Malmö City
Ingjerd Bratterud, Stavanger Municipality
Marta Krakowiak, Bassano del Grappa
Mark Burton-Page, LUCI association
Jim Collin, Lund University

TABLE OF CONTENTS

SUMMARY

This report describes the progress in green business development related to SSL lighting take-up by sustainable cities, during the SSL-erate project, and provides recommendations and background for "how" the deployment of high quality SSL can be accelerated.

The report also illustrates the more basic aspect **"why"** it is so important for cities to build awareness and invest in more advanced lighting and intelligent lighting systems. The main advantage is that Human Centric Lighting enables installations that are more functional, effective, appreciated and better for health and wellbeing. The research on HCL clearly shows that the character and quality of the light influence human activation/relaxation and circadian wake/sleep cycles. HCL is described in dedicated reports which can be downloaded from www.lightingforpeople.eu. One other perspective on why it is important to invest in better lighting is that the quality of the light is very visible and that better-lit cities and facilities are more attractive, for example for tourists, potential employees and experienced staff. Investments in high quality SSL with long lifetime also enable significant reductions of energy cost and operational costs for maintenance, i.e. a lower Life Cycle Cost. A city that demonstrates the potential of SSL to their citizens and staff can then attain many kinds of indirect and sometimes direct support for SSL investments and related activities, from the persons that have seen the light.

The main aim of the suggested green business development for SSL is to contribute to sustainable development by social and economic progress. One important basis for more advanced deployment of SSL is the simultaneous appearance of new knowledge on health and wellbeing effects of light (human centric lighting concept) and new technical potential (digital control of the lighting output especially). This combination gives lighting policies in cities an extra dimension, that of being more part of their societal social responsibility. Here it should be noted that the World Health Organisation (WHO) defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity". This is an important aspect of the basis for a socially sustainable development. It has become a Societal Social Responsibility to invest in better lighting, because it is a possible way to improve human "health". Brochures and guidelines have been produced to promote a higher awareness of cities on why to invest in SSL use beyond energy saving and how to move ahead. SSL enables the use of human centric lighting concepts and the development of intelligent lighting systems that connect to the digital age.

To be able to make proper use of SSL it is important to take it seriously that SSL is significantly different from the earlier lighting technologies. In many respects lighting is becoming a kind of electronics and ICT. It is possible to vary the light in many different ways and there are significant differences between different products.

One suggested way to systemic development is to aim for open integrated system solutions. This is a challenge, because systems engineering and interoperationability are quite new subject areas for the lighting sector, and reversely, lighting is almost unknown to most actors within ICT and facility management systems. This report includes descriptions of some ICT system concepts as well as guidelines for development of systemic solutions. Open systems solutions that are upgradable can be used for demonstrations to build awareness, support explicit dialogue and gain concrete experience. This report describes an extended environmental LCA-quotient and how this perspective can be used to clarify the relations between different development priorities.

One vital circular economy aspect is developing a synergy between more value and less load. The primary key to meaningful recycling is making value enhancing front-end investments, which in turn will improve the societal stock of recyclable material.

The SSL-erate studies and dialogues verify that, it is now possible to achieve much more advanced lighting functionalities than before. However, the character and quality of LED products on the market varies considerably and there is a risk to make unsuitable choices. It is important to recognize the basic differences between SSL and the earlier lighting. Technical nuisances such as flickering, blue light and glare are some SSL particularities. These aspects can be contained, and avoided through proper understanding, light design and product choices.

The main conclusion is that there are great opportunities for green business development, but that these don't lead to value enhancing business growth, because the LED market is immature. There is a need for LED-adapted specifications that clarify new human centric lighting requirements. Very many functions are technically possible with SSL in combination with ICT, but there is a need for experimental installations and development of new specifications. This is important as a tool to clarify what it is that is most important and also feasible. This is crucial to move ahead from energy savings to the value enhancements that SSL and intelligent system solutions enable.

In order to make something significantly new together there is a need for trustful investments of time and engagement, e.g. in future oriented demonstrations of human centric lighting. This report uses the experiences from the Malmö City demonstration of Human Centric School lighting as an example. There is a need for business development drivers e.g. by introducing LED-adapted specifications for more advanced lighting. The start-up of markets for more advanced lighting can be enabled by green public procurement and, in particular, Public Procurement for Innovation (PPI) and Pre-Commercial Procurement (PCP).

The new EU Directive on public procurement can be used to support early deployment of intelligent lighting solutions. Energy analyses can be used to guide the design of solutions with better spatial and temporal light variations. This is crucial in making sure that the money that is invested in green SSL solutions is used in such a way that we promote intelligent human centric lighting, i.e. solutions that also promote the social and economic dimensions of sustainable development.

More people are starting to realize that light is vital for health and wellbeing. When more cities start to demonstrate more advanced lighting and takes it seriously that it is important to develop policies and specifications for more advanced lighting, this will result in a large market with higher willingness to pay for better lighting. One advantage of SSL is a reduction of the life-cycle cost, but it will also enable better living and working environments, i.e. higher value creation. This is a great opportunity for local innovation, green business development and city branding.

INTRODUCTION

1

1 | INTRODUCTION

This report aims to support Sustainable City Development and Green Business development by promoting Smart Lighting solutions that are more functional, effective, user appreciated and better for health and wellbeing. One main new concept this report is referring to is Human Centric Lighting (HCL). There has been a lot of HCL related research and those results have been summarised in other SSL-reports, some of which (such as lighting for health and well-being in education, work places, nursing homes, domestic applications, and smart cities) are available via the project web-portal www.lightingforeople.eu. Lighting for People. One main conclusion is that, **"light is much more important for health and wellbeing than most people realize".**

We now have scientific evidence that SSL can be used to improve the working and living environments and it is important to start to do this.

This report summarizes the SSL potential as a tool for sustainable city development. It is obvious that SSL in combination with intelligent light control enable significant energy savings, but we want to show that SSL can go beyond energy savings and leads to more advanced lighting that contribute to more appreciated living and working environments. The enhancement of the user value means that there is significant potential for business development that generate added value. Cities that invest in innovative deployment of SSL can take a lead in making their facilities more functional and attractive and at the same time support green local business development.

At workshops organised by the SSL-erate project, cities expressed that SSL and Human Centric Lighting have great potential for sustainable city development. But just like in other kinds of radical change, there are numerous questions about the new potential benefits, the new technology and how to handle the hurdles related to the change of technology. This resulted in a survey of the development hurdles that cities are struggling with. During 20 city workshops in 2014 and 2015 we collected numerous related questions. This material has been used to develop the guidelines in this report as well as to write a Frequently Asked Questions material presented on the website *Lighting for People.eu*.

The new SSL technologies in combination with ICT are enabling many kinds of new functionalities and much more intelligent lighting solutions in cities. But it is vital that European cities' can enhance their ability to overcome the hurdles encountered when converting to SSL.

To support this, this report explains the present development situation and provide guidance for what a city can do to make better use of SSL, in the cities facilities and to build awareness that motivate investments and enhance the citizens' ability to make user adapted choices of lighting products.

1.1 This report in a SSL-erate perspective

This report describes the progress in green business development related to SSL lighting take-up by sustainable cities. It should be noted that the background situation is that the SSL-erate WP2 focus and framing for the deployment of SSL is to move ahead from energy saving to acceleration of 'green' business development. The SSL-erate interpretation of the objectives for this "green" business development is to:

- Activate sustainability interests as motives and tools for accelerated deployment of SSL.
- Stimulate that sustainability-oriented interests, knowledge and control measures are used to enhance European investments in high quality SSL solutions.

This report mainly discusses **how** cities can move ahead. But the objectives above also relates to the more basic question **why** a city should engage in accelerated deployment of SSL. The interpretation of green business development here is that the goal is to promote sustainable development, in a broad meaning, not only energy saving. This means that the background setting is that we want to clarify the sustainable development reason for why cities should invest in high quality SSL solutions.

BACKGROUND

2 |

2 | BACKGROUND

This section presents the general framing and key concepts of sustainable development and advanced LED lighting. More background information can be found in the following reports that are available at LightingforPeople.eu:

- Lighting for health and wellbeing
- Green Business Development Opportunities
- Recommendations and opportunities for implementation of human centric lighting
- Sustainability issues for SSL

One background for the importance of lighting improvements is that the incandescent lamp's light character (spectral distribution) differs significantly from sun light and doesn't fit the human sensory system in many lighting applications but nevertheless became a standard to be imitated by fluorescent lighting and also by the (first) LED replacement bulbs.

The most important effects of lighting on health and wellbeing appear indoors. The SSL-erate project dialogues with stakeholders on HCL revealed that there are barriers related to: (1) Lack of information and practical advice; (2) Lack of awareness of effect on health and well being; (3) Lack of products available on the market meeting customer requirements; (4) Lack of successful examples in practice; (5) Lack of evidence on benefits; (6) Cost; (7) Lack of practical knowledge on how light can be used to improve health and well being; (8) Lack of a common supply side approach; (9) Lack of legislation favorable for HCL and existing legislation (to be followed in lighting procurement) unfavorable for HCL adoption; (10) Risk aversion.

The introduction of SSL opens up new opportunities on user and supply side, but their exploration results in new challenges, due to:

- A multitude of LED-based products with different characteristics
- New knowledge about the user value of adapted light variations
- Need to facilitate systems engineering, to make use of the controllability

This report aims to provide guidance for green business development to make use of these opportunities and to handle the challenges.

2.1 User driven innovation by cities

As in most other business sectors, it is the suppliers that mainly drive and control the development of new lighting products. In a growing number of cities' opinion this is a serious shortcoming of being restricted to buying the products that vendors want to sell with insufficient regards to their needs. These cities want to enhance the possibility to take a stronger role in the development of new lighting products and applications.

Another important innovation concern is that, it is a vital success factor to involve knowledgeable critical users in the product development process. In radical innovation it is not sufficient to ask users or user representatives what kind of new product they would appreciate. It is very unusual that users ask for development of something they have not seen. To some extent users may ask for new product properties, but in radical product development it is more effective to involve some selected uses in early phases of the development process.

This is crucial in the present phase of rapid SSL development. The LED controllability and the potential to develop and deploy intelligent lighting systems have resulted in a new level of freedom of action. In the replacement market LED is used to make light sources that give the same light as the outdated lighting products. But SSL + ICT enable very many new kinds of user adaptions and new lighting and system functionalities. To make optimum use of this potential it is important that the users get/take a significant role in the innovation process.

From sustainable development point of view it is crucial to minimize the deployment of useless or dysfunctional products. From environmental point of view, we should not waste resources, including energy, on glary, ugly and useless lighting. From social and economic sustainability point of view it is vital to develop lighting that is more functional and attractive. In a city perspective SSL can be used as a tool to make the city more attractive, e.g. by means of more stimulating and harmonious light variations in schools. City investments in early demonstration of new more intelligent lighting solutions will also attract interest from media, entrepreneurial persons and innovative companies. City engagement in innovative deployment of intelligent SSL systems is also important as a concrete and widespread way to build infrastructure and competence that open up for smart city development.

2.2 Sustainable attractive cities

There is no completely agreed upon definition of what a sustainable city is. The term generally refer to a city that is designed with consideration of environmental impact and inhabited by people that are dedicated to minimize the use of energy, water, food, and the output of heat, air pollution, carbon dioxide, methane and water pollution. A sustainable city should meet the needs of the present without sacrificing the ability of future generations to meet their own needs (Joss 2015). This formulation leads to a large variation regarding how cities carry out their attempts to become sustainable (Beryl 2011).

It is vital to build a conceptual link between "attractive" and "sustainable". It is not sufficient to polish the surface by trying to make the attractive solutions sustainable, or trying to make the sustainable solutions attractive. It is vital to develop and invest in solutions where the core functionality is both attractive and sustainable.

SSL and intelligent lighting systems can be used to create living and working environments that are much more attractive for the users, compared to the traditional lighting. The adaption of the lighting to what's needed and wanted is vital as a tool for social improvements, e.g. in schools and for elderly, and this adaption is also crucial to avoid energy wastage. It is also attractive that the green investments that are needed for those social improvements and business development generate green jobs.

In economic terms an investment to make a place or facility more attractive is a method to increase the market value and brand value. For example a city with attractive schools may attract teachers, students and well-informed parents.

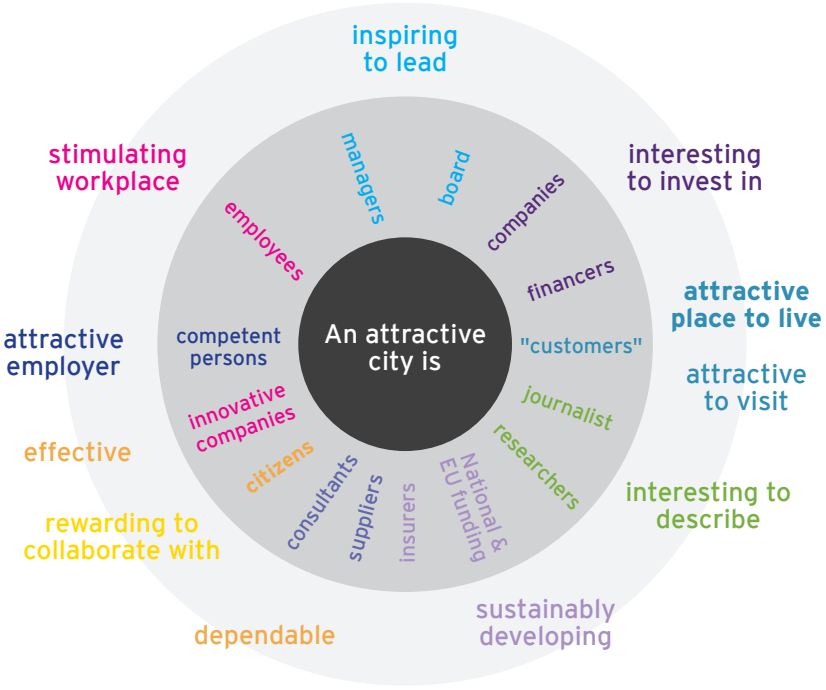

Figure 1 – An attractive city is vibrant in several different ways, as an attractive place to be and as an attractive place to make things happen through innovative business development. This is interesting in relation to SSL because Human Centric Lighting promotes human health and wellbeing. Development and deployment of SSL and intelligent lighting systems attracts innovative companies and entrepreneurial companies.

2.3 Societal Social Responsibility

It is a Societal Social Responsibility (SSR) to make use of the new SSL advantages to create better living and working environments, in an effective way, to reduce risks and stress and to avoid misuse of societal resources.

According to the precautionary principle it is a corporate and societal social responsibility (CSR and SSR respectively) to start to take action when something indicates that there is a serious risk with how the societal actors are handling what they are responsible for. If a company is doing something that is indicated to be risky for their employees or others they should take action as soon as possible. It is not acceptable to wait to take action until there is full scientific proof that it is a risk. The same applies for societal actors. If something that a public actor is doing has negative effects for their employees or others they should take action as soon as possible. This is particularly important for pupils in school and for the care sector.

The Lighting For People (http://lightingforpeople.eu) research compilation shows that blue light has an awakening effect, which is most positive in the morning. It is vital that the character and variation of light sets our body clock, thus regulating our sleep-wake cycle, immune responses, appetite and many more of our functions and behaviours. Next to this, light has acute effects on mood, alertness and attention. Bad lighting is a stress and exhaustion factor, which is crucial not least in schools, considering the growing number of diagnoses and also for the quality of life, not least for elderly people. Consequently, it is a social responsibility, e.g. for cities, to take action to make use of the new lighting opportunities, to achieve a better environment around us in many aspects.

Figure 2 – SSL and intelligent lighting systems can be used to create living and working environments that are much more attractive for the users.

2.4 Human Centric Lighting Design

This report is aiming to provide guidance for SSL demonstrations and business development and to describe the global business development potential for a selection of potentially interesting concrete market segments. The green business development potential is related to both the added values that Human Centric Lighting can provide and to Intelligent Lighting control and supervision.

2.4.1 Definition of Human Centric Lighting

Human Centric Lighting (HCL) supports well-being, performance and health of humans throughout a holistic design of the visual, biological and emotional effects of light. Human centric lighting:

- Balances visual, emotional and biological benefits of lighting for humans,
- Promotes good vision and simultaneously satisfies the emotional and biological needs of humans,
- Takes into account that light also stimulates non-visual effects on human psychology and physiology.

It has a basis in traditional lighting design that dynamically adapt the light to various human needs. The main novelty is to take also into account the nonvisual circadian effects of the daily variation of the blue (460-500 nm wavelength) part of the light spectrum. This is also related to the activating effect of intense light with high color temperature.

It should be noted that HCL design and its main basis in traditional light design is a major concern. In a broad sense HCL includes all kinds of light that in some way is better for and more appreciated by humans.

The blue part in the Figure 3 bars illustrate the distribution of the traditional interest. The red parts show the now possible user value enhancements with HCL. The ambition includes improvement of all the three factors, including visual and emotional aspects via user adapted light design. The relative improvement is very much larger for the biological effects.

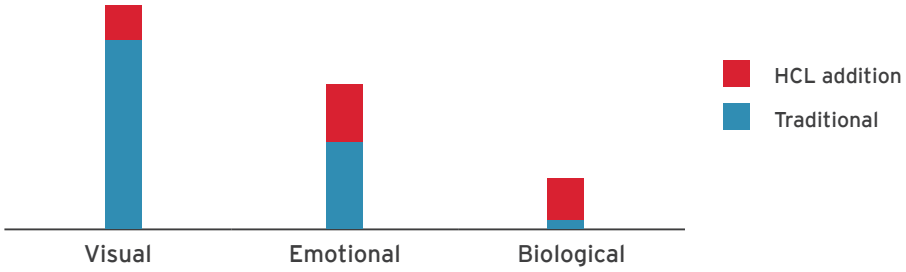

Figure 3 – The change of perspective from traditional lighting (blue) to Human Centric Lighting that also includes nonvisual activating and circadian effects (red).

To exemplify the importance of human centric lighting we will use the case of class room lighting. in schools. Introduction of HCL in schools not only improves the often-neglected environments in schools. It will build awareness among pupils about the importance of good lighting for health and wellbeing. When this happens, they also tend to stimulate their parents and grandparents to become better informed about SSL products. In particular the cities of Malmö and Bassano del Grappa are making school demonstrations and are active building awareness and exchanging information on development opportunities and hurdles.

The time spent at school and being exposed to the classroom lighting is a significant part of the day of pupils. The lighting has different effects. It is not acceptable to continue to use flickering fluorescent tubes in primitive lighting designs if better and also economical solutions have become available. With the new knowledge about circadian effects of various kinds of light in various parts of the day, it is questionable to continue to use static light levels. Considering the rapidly growing use of PC's, iPod's and Smart boards in the classrooms, it is a powerful tool to dynamically adapt the lighting to the changing needs, e.g. to be able to see both the smart-board information, the own work material and each other at the same time. It is also important to educate pupils and teachers, e.g. about the negative circadian effect of strong bluish light late in the evenings. This leads to an urgent need of demonstrations of the potential of SSL and advanced light variation.

The perspective that is illustrated in Figure 3 is a conceptual model. The effect of a lighting solution may be split in visual, emotional (psychological) and biological (physiological) parts. The latter concerns light affecting hormone levels through non-vision related sensors in the eye. (and emotional values of the light. There is no explicit method for summation of these effects, but a basic idea is that these are interrelated. Good visibility is also an emotional concern and the adaption to biological needs also influence the emotional aspects. The other way around the emotional interpretation of the light environment is probably one way to decode the visual and maybe also biological effects. Light designers tend to focus on the esthetical dimension and this is related to the visual and emotional considerations. The main change with HCL appears in the biological dimension, but it is important to note that the entire three effects of light should be considered.

An attempt to work with the visual, biological and emotional aspects in a coherent way when designing a lighting system is made by the VBE-model (see e.g. Influence of ambient light on the performance, mood, endocrine systems and other factors of school children, T. Govén, T. Laike (Lund University), P. Raynham, E. Sansal (UCL); http://www.livingdaylights.nl/wp-content/uploads/2014/11/The-influence-of-ambient-light-on-school-children.pdf).

The aim of the VBE model is to describe the subjective lighting experience within a room; visually, biologically and emotionally. The parameters are individually evaluated (on a scale of 1-5) and can be weighted differently depending on the type of room and the activity (resulting in a final index). The visual aspects are related to the possibility to perform the visual tasks within the environment over time and include the task area lighting, the visual performance, the luminance ratio, contrast and glare.

The biological aspects are primarily related to how the light within the environment influences the daily and seasonal biological rhythms and include ocular light, circadian effects, mental health and alertness. The level of ambient light and its spectral composition primarily affects the biological aspects.

The emotional aspects are related to how we generally perceive the light in a room, the first impression as well as the reaction over time and include comfort, safety, dynamics, colors and color of the light.

2.4.2 Intelligent Lighting Systems

The technology of today is enabling virtually unlimited development potential for Intelligent Lighting Systems, including interconnection with other devices and appliances, systems and services (internet of things). One dimension is to enable supervision and user adapted lighting control functionalities that surpass the fixed dimming schedules. One other dimension is to enable utilization of lighting related data and infrastructure as a resource for other systems and functions, e.g. property surveillance and facility management. It is also possible to make use of data from other systems to improve the lighting control.

The SSL controllability in combination with the rapid development of ICT means that there is a lot of potential for innovation. One aspect is technical developments of open system solutions for intelligent lighting, see chapter 4.

2.4.3 Synergies between SSL, ICT and HCL

The most important new property with LED and SSL in a broader respect is the controllability. Combination of SSL and information and communication technology enable significant enhancement of the total business potential. SSL and in particular HCL has a strong connection to knowledge-intensive development of the user value. ICT enable many kinds of systemic system developments and the ICT sector and digital age is characterized by rapid innovations that enable very many kinds of added values. One explicit example of combined potential is the combination of tunable white luminaires and advanced control functions. Figure 4 shows a lighting variation scheme and some targeted effects of an experimental installation that is being tested in in a classroom in Malmö. Some experiences from this installation are presented in this report as well as on LightingforPeople.eu (including a case study of transfer of HCL knowledge from Malmö to Bassano city).

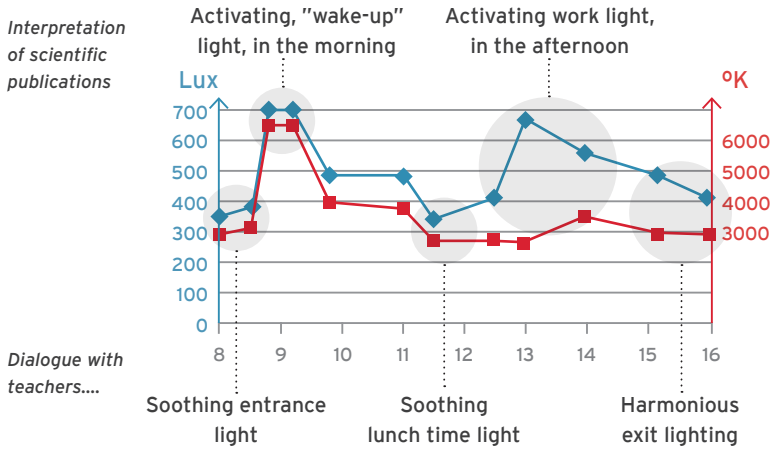

Figure 4 – Automatic human centric light variation in a classroom in Malmö (blue: illuminance, red: colour temperature).

It should also be noted that the combination of SSL and ICT enable very many more kinds of temporal and spatial light variations. The broad variety of SSL products and control options means that the lighting design expertise has become even more important than before.

2.5 User values of SSL compared to earlier technologies

It is generally accepted that LED can save energy, but it is questioned if the LED light can be trusted to provide a light that is as good as the earlier forms of light sources. In addition, installation of LED has been considered to be expensive and there were a lot of reports about LED lamps with inferior technical quality, i.e. not reaching stated life times, with glary light, high content of 450 nm blue light, flicker, etc. Because of the market becoming mature, these are decreasing, but the rapid product development is considered to be problematic from a product replace-ability point of view. When one light source (in an installation with many light sources) fails it may be difficult to find a replacement lamp with the same light character and functionality.

At the start of the SSL-erate project numerous experts where already confident that there are significant business development opportunities for SSL. However the character and quality of the LED products may differ substantially from the replaced lamps. This light quality dimension of this variation is illustrated in Figure 5, which compares quality and function distribution range of traditional and LED lighting (see also Section 5.5 of this report).

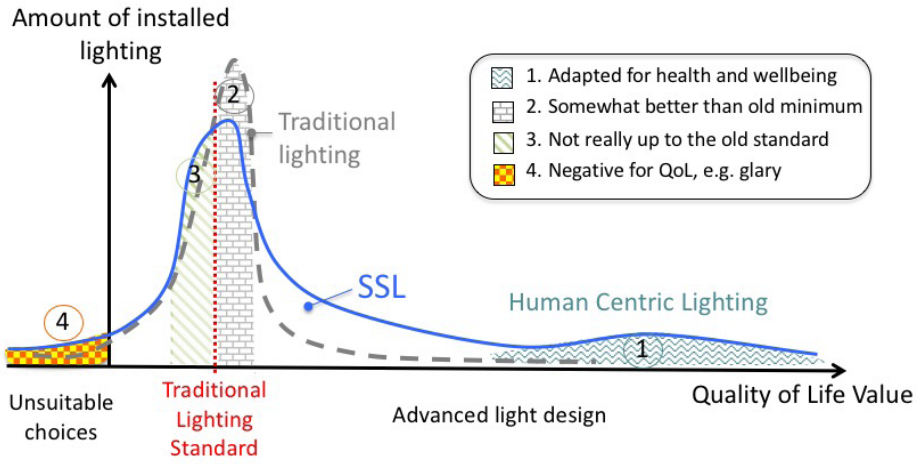

Figure 5 – Distribution of quality of life value of the light from various kinds of SSL installations, compared to the traditional lighting technologies. The blue line illustrates the distribution for SSL based lighting and the grey dashed line the distribution for traditional lighting, primarily incandescent and fluorescent.

A main added value potential for SSL is Human Centric Lighting, (1) in Figure 5. It should be noted it is now with LED possible to achieve much more advanced lighting functionalities than before. But because of the large range of qualities and options at the other end of the user values scale there is also a risk to make unsuitable choices, resulting in a negative user value, e.g. because of glare or flickering. The quality of traditional lighting was normally somewhat better than the minimum requirements, illustrated by the grey field (2). For LED lighting it has been a main priority to save energy, and it has often been considered to be sufficient to aim for the traditional lighting standards, which mean that the specifications for LED are made in terms of the parameters that were most relevant for the old technologies. Some of the characteristics that where almost self-evident and quite constant for the old technologies, e.g. the continuous spectrum of the incandescent light, vary significantly between different SSL products. It has been fairly common that some aspects of the SSL light are worse than they were with traditional lighting, e.g. a high content of blue light, illustrated by the green field (3).

SUSTAINABLE SOCIETAL DEVELOPMENT

3 |

3 | SUSTAINABLE SOCIETAL DEVELOPMENT

SSL has potential to provide many kinds of values. So far the main political priority for LED has been to save energy and for sure smart LED based system solutions can save a lot of energy. But of course the main reason for investments in any type of lighting is that we want to have good light environments. The following sections explains the relations between the energy saving priority and other sustainable considerations.

3.1 Sustainable Development

Sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technical development and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations.

On one hand side, the sustainability aspect that appears to have attracted most interest the latest decades is the risk of environmental pollution, climate change and degradation of the systems in nature. But it is also crucial to promote social and economic development that enables many people to live a better life.

On other hand side, the main societal development priority is "growth" and in this perspective there is a fair bit of similarity between a "sustainable development" and the societal goal to promote growth. However the growth of GDP also includes very many products and activities that are almost contradictory to sustainable development.

3.2 Green Business Development

Investments in green technologies are essential to enable sustainable development. They are the economic enablers of the green jobs that are vital for the deeply needed social and environmental improvements. To make appropriate use of the potential of SSL there is a need for renewal oriented investments to enable a change from the traditional lighting to an adapted light variation that is significantly better for human health and wellbeing, productivity and sustainability. This requires to develop and deploy the SSL solutions in such a way that the resulting installations become truly appreciated by the users. The following describes a value enhancing perspective on green business development.

Good lighting has a significant social value. Investments in better lighting and intelligent system solutions can contribute to health, wellbeing and productivity. It is important to promote a human centric orientation of investments, technical development and institutional change. It is a core issue to promote effectiveness, i.e. to the ability to provide the wanted light, where and when it is wanted. Sustainable solutions should not use more material and energy than what is needed to provide the specified functionality. The products should not be heavier than needed; we do not want to carry useless weight. An excessive use of energy means that there are undesirable side effects, e.g. hot light sources, glare, stressing or sleep disturbing light or light pollution.

But we do want the possibility to get stimulating light and at other times harmonious light when that is needed and wanted, e.g. in schools and for elderly people..

When specifying a lighting system It is crucial to clarify the needs and wants of the users as well as how these can be met. It is often obvious that a higher light intensity improves (or appears to improve) visibility. But it is more complex to design an optimum human centric lighting solution. One side is to find the needs for additional light (intensity, colour). The other side is to clarify which parts of the lighting it is that are useless and which also tend to degrade the user's experience value of the lighting. One way to gain better overview is to make energy analyses that clarify which different light sources there are, which parts of the day and night they are on and which lighting effects they provide.

The principle of focussing on wanted effects and to minimize all others is vital in product development and especially in EcoDesign. One should realise that the experience of light is relative. When coming in from bright sun light most indoor lighting appears to be dark. When entering the same room from a dark corridor one and the same light may appear to be very bright.

The best basis for design of a light environment is to combine expertise of lighting systems and effects of light with thorough understanding of the context dependent needs and wants of the specific users. When these are combined in evidence-based design that optimise positive lighting effects and at the same time minimise glary, disturbing and useless lighting this will also result in low electricity consumption. This is reasonably straightforward when a lighting designer is managing the design of new installation. This happens often when developing demonstration SSL installations. But for most of the SSL installations this may not be the case.

The absolute majority of the SSL applications are retrofits in existing buildings. In most of these cases it is difficult to take a starting point in evidence based lighting design. It is also quite difficult to map and describe the characteristics of an existing lighting installation. The most manageable and concrete approach often is to make a map of the light sources and their electricity consumptions, i.e. which parts of day and night they are on. A map of the combined effect the various light-flows is a good basis for dialogue and communication with experts. Furthermore there are PC tools for this type of mapping, e.g. Dialux and Integrated Environmental Solutions (IES), which need however electronic (CAD) drawings of the assessed facilities. Keep in mind that software for light distribution calculations and photorealistic visualisation are often difficult to interpret with regard to what will be reached in practice with the final installations.

Also rather simple "lighting energy maps" are useful to help understand the user value of a specific lighting installation.

3.2.1 Energy analyses as a guide to more effective lighting

It is difficult to measure the user characteristics of a lighting system. It is common to make a theoretical calculation of the need for lighting, e.g. with DIAlux, as a basis for the lighting planning and then control the result with very simplistic measurements after installation. Light design considers numerous user aspects that rarely are measured. This means that thorough evaluation and feedback is missing.. In engineering there is an old saying:

What is measured gets done

The lack of follow-up measurements means that the quality and character of the lighting tend to be neglected and ability to improve the user value of the lighting is hampered. Hence use of more advanced methods for evidence-based assessments of the basic light characteristic, e.g. the light distribution, should be promoted. A suggestions is to start with energy mapping of lighting installations.

The only analyses that regularly are made for lighting systems are energy (kWh) analyses,which sometimes already include basic logging of how the electric power (kW) varies with the time of day. The resulting power variation logs can serve as a basis for approximate assessments of the light variation and then used to make "lighting maps" that provide an overview of the light sources in the premises, when these are switched on and their respective power level (dimming) at different times. Electric power (kW) maps can be used to assess how the amount of light varies between different areas and between different points in time.

The power variation maps can be extended with light distribution and colour distribution information for the different light sources to make informative mappings (renderings) of the intensity of the light flow in different areas, at different points of time and in different directions, e.g. vertical and horizontal light. The horizontal light is one important concern for the biological, e.g. circadian, effect of the light. This may serve as input for dialogue about the user characteristics of a light environment.

There is even more to learn when electric power variation logs are combined light measurements. Figure 3 shows concurrent measurements of lux, W and CCT for an experimental installation of automatic light variation by means of tuneable white luminaires. The curves show that the lux level variation is larger than the power variation. This is interesting considering that the V( )-curve has a very low value (5-10%) for blue light and that this means that a the light with higher color temperature ought to show lower lux values. with W measurement can be used to clarify the spatial and temporal distribution and variation of the light intensity. The Figure 6 combination of curves is only an example for a single installation. The ambition here is to show that this kind of measurements are enlightening and can be attention-grabbing.

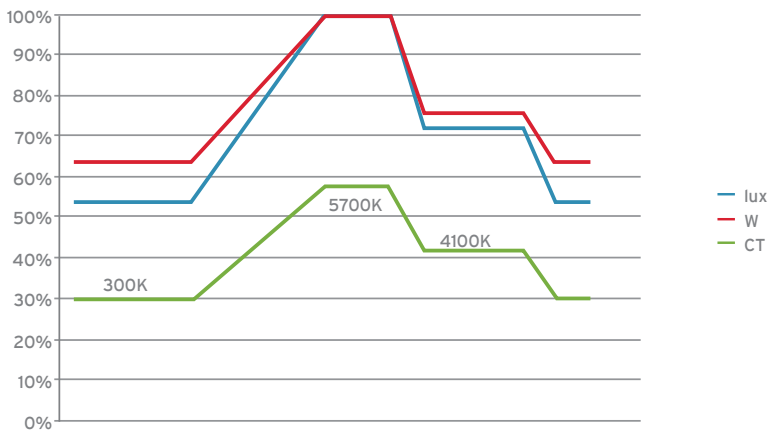

Figure 6 – Variation curves for Illumination (lux), electric power (W), and color temperature (CCT), measured in a test installation with automatic light variation by tuneable white luminaires, at LU Open, Lund University.

It shows that it that the period with the highest electric power correlates with the period that is intended to have the strongest circadian wake up effect, from light intensity and color temperature point of view.

Such curves can be a good starting point for evidence based dialogue about the light characteristics, e.g. among users, facility management people and light designers

It should be noted that the electric power curve only clarifies one aspect, light intensity. The spatial distribution of light, between different parts of the room and e.g. between vertical and horizontal light flows, is also important. However, the dialogues that can be triggered by studies of the power curve are likely to stimulate interest also in other aspects of the light environment. When nothing relevant is measured there is no trigger for awareness. In this respect it is a significant advantage to be able to study the power variation as a trigger for dialogue and mutual learning.

In future, advanced lighting systems' sensors will provide measured data for automatic control of and reporting on their output (e.g. to facility management systems) and possibly also for improving the user value by machine learning algorithms.

3.3 More value and less load: LCA quotient

The first environmental assessment methodology that has been standardised is Life Cycle Assessment (LCA). Environmental LCA focuses on the life cycle of physical products, not the lifetime on the market for a product model. Another standardised methodology is Environmental Impact Assessment (EIA) that focuses on the environmental load from production facilities. EIA is not included in the below overview. The LCA way of thinking is also important as a basis for assessments of the effect of a certain energy saving, and Ecological Footprint and scarcity considerations for comparison of diverse alternatives.

The use of LCA is always relative, for comparing alternative solutions and products. At a basic level LCA is assessing a quotient between the total functional value and the total environmental load:

$$\frac{\text{Value of light + Maintainability + Interoperationability + Capability}}{\text{Primary material + Production + Transport + Energy + Handling + Secondary material}}$$

Primary refers to the first use (in this product cycle) of material after mining and refining, secondary to re-used material (from disused products). This distinction is important to promote a circular economy that makes repeated use of the same quantity of material.

Value of light includes the user value of the light intensity, light character, light quality, spatial distribution and temporal variation that is enabled by the installation. The actual value of the light supply potential is also dependent on the user interface functionality, i.e. the users' possibility to control the lighting in a smooth way.

Maintainability is important for the maintenance cost and also influences dependability and upgradeability, e.g. by support functions for supervision, maintenance and recycling.

Inter-operationability describes the openness for integration with other systems and also the value of the lighting system infrastructure and sensors for other smart city and smart building functions, e.g. for communication, energy management, presence control and traffic supervision.

Capability describes the prospective build-up of innovation potential, e.g. by investment in early demonstrations and experimental installations, which promote development of renewal oriented competence and networks.

The denominator terms show the life cycle phases that cause environmental load.

Primary and secondary material refer to respectively the resource value of the materials (including the loads from mining, initial upgrading and waste) that are extracted from nature and the resource value of the output material (including upgrading that is needed to enable recycling based production).

Production includes the environmental load from all production processes for the production and assembly of all the included components.

Transport includes the environmental load from all transports of raw materials, upgraded materials, components, complete products, and to enable maintenance, reuse and recycling. In total, the main part of this load tend to be caused by transports of small quantities of products, in the worst-case car transport of single products, e.g. due to inefficient organisation of procurement and maintenance.

Energy includes the resource consumption for and all environmentally relevant emissions from electricity production. The main present focus is the CO2 emission from combustion of non-renewable fuels. It should be noted that electricity is a valuable resource and that there are different kinds of environmental concerns for all forms of electricity generation.

Handling includes other loads from storage of new products, maintenance, sorting and storage of products, components and material for reuse and recycling. Handling can also include loads from installation.

It is very difficult to obtain and agree (with all actors in the value chain) on all input needed to calculate a reasonably accurate number for this quotient. It is difficult to calculate a single number to describe the "total environmental impact" that is caused by the sum of the denominator terms, but at least people have understood that this is one principal goal of LCA.

The situation is much more confusing regarding the "total functional value" in the numerator. Too many LCA-reports neglect that the total functional value may differ quite considerably between the different alternatives to be compared.

The interoperationability is important for development of smart cities and smart buildings and the build-up of renewal-oriented capability is important for ability to make proper use of new technologies.

The functional value can be increased by optimisation of firms' activities to better fulfil the needs and objectives of its customers. A maximisation of the value creating abilities of the functions, activities and processes gives the customer the highest possible value at the lowest total cost and also avoiding waste of energy on activities that do not serve any purpose. The functional unit is an important basis that enables relevant comparison of alternative systems, installations or services.

The basic reason for why it is so important to use a sufficiently broad methodology for assessment of the functional value is that the total functional value may be considerably higher for an advanced innovative solution, than it is for a more traditional, primitive low quality alternative. If the difference in user value and functional value is neglected or assessed in a narrow-minded way there is a serious risk that environmental comparisons counteract innovation and renewal oriented development opportunities. It is important to promote green investments in deployment of more sustainable Intelligent Lighting alternatives.

The interest in enhancement of the user value is not new. For example it is a main focus in the report *Factor Four: Doubling Wealth, Halving Resource Use,* to the Club of Rome, that 1997 presented 50 case studies with significantly higher functional value and/or lower resource use and environmental load.

3.4 Circular economy

Circular economy is a generic term for an industrial economy that produce no waste and pollution through product-life extension, long-life goods, reconditioning activities and waste prevention and it also insists on the importance of selling services, e.g. functional sales, rather than products.

The most widely known goal for the circular economy is to recycle reusable materials to reduce diffusion of environmentally problematic materials. The superior goal includes maintenance, reuse, refurbishment and remanufacture. The overarching goal is to continue to make value-creating use of the refined resources that have been extracted from nature and produced in earlier industrial production. One starting point for the circular economy is to invest in production of components and materials that are really valuable as resources for reuse and recycling.

A circular economy aims to reflect the natural systems in which waste from one process becomes nourishment to another. The products, components and materials circulate in distinct streams where the renewable organic materials often can be returned to the biosphere, and technical, in which the materials are designed to circulate while maintaining quality in order to become "nourishment" for industrial processes. The cleaner these flows and the higher the qualities of the materials are when they circulate, the more value can be retained in the economic system.

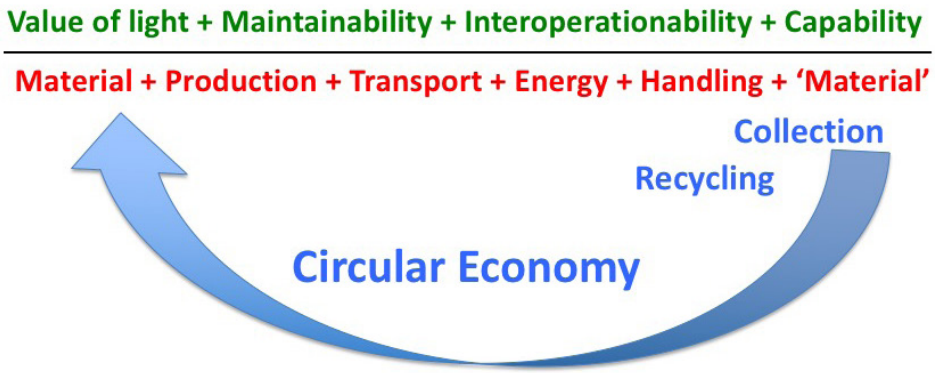

Figure 7 – The main aspect in a circular economy is that the materials should be used in a continuous process. The denominator in the quotient has "material" both as input and output. The reason is that it is important to promote a circular economy that makes repeated use of the same quantity of material.

The denominator of the above quotient has "material" both as input and output. The reason is that it is important to promote a circular economy that makes repeated use of the same quantity of material.

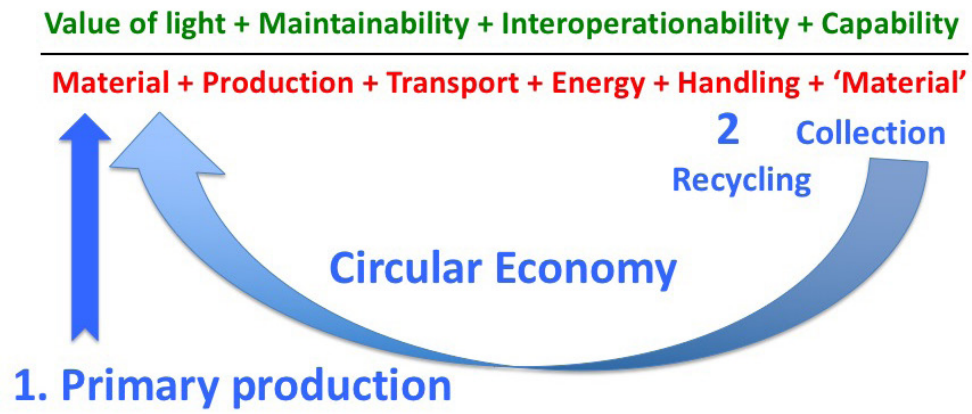

Figure 8 – The most obvious recycling goal is that that the materials in the scraped products should be collected and brought back to new products. But it should also be noted that the content of materials, in the used and scrapped products, is dependent on the primary production and initial choices of materials.

The process aims to reflect the natural systems by bringing the materials in the used products back as input to new materials. The primary goal is to aim for high quality materials in the primary production to enable more value to be retained in the economic system.

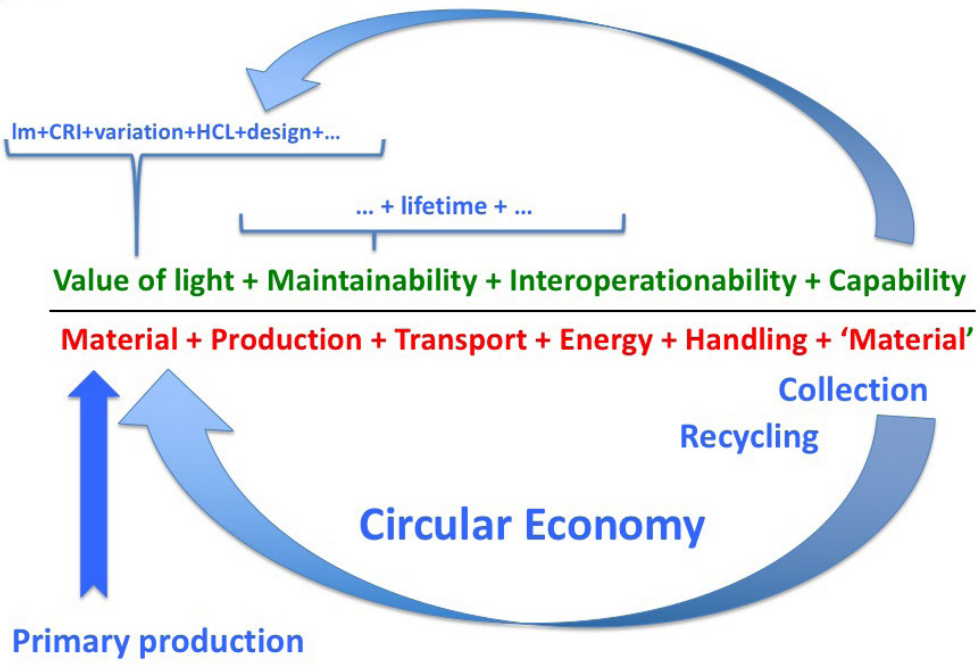

Figure 9 – It is essential to create and make continuous use of a valuable material stock as well as knowledge and well-functioning processes.

The numerator aims to provide a similar reflection of the natural systems as in the denominator. The value of light, Maintainability, Interoperationability and Capability aims to summarize the total functional value of the installation and the increased knowledge and ability to provide work are valuable as resources in the improvement of the Value of light, Maintainability and Interoperationability. The circular economy is about reducing waste and protecting the environment, but it is also about a profound transformation of how our economy works. By changing the way we produce, work and buy, we can create new opportunities and new jobs. If we can become more resource efficient and reduce our dependence on scarce raw materials, we can develop competitive advantages.

The cities do not manufacture the products, but in a call for a procurement tender they have the opportunity to influence what products are going to be used in the cities' installations. One option for them is to make it a priority "that the products have a high sustainability value". What is considered a valuable material is of course dependent upon the demand on the material market. It is important to distinguish the product collection opportunity from the product materials' real benefit in a continued production.

A serious environmental and recyclability concern is that numerous LED luminaries have non-replaceable LEDs. This means that the whole luminaire is tending to be scrapped when some of the LEDs or some component in the driver circuitry breaks.

There are two basic methods to minimize this problem, on design and acquisition (regulation) level:

- To procure high quality products, where all the components and the whole product are guaranteed to have a sufficiently long lifetime.

- To aim for modularization that enables meaningful recycling of different parts, i.e. different materials and different kinds of component blocks.

With regard to the latter, it should be noted that the SSL technology's flexibility is very suitable for luminaries and system solutions that are modular.

In the short term, cities' short-term sustainable development priority for SSL could be to build up competence in Human Centric Lighting by engaging in demonstrations of advanced lighting environments. In the long-term, cities can become drivers for eco-cyclic innovation by demanding modular solutions that enable smooth recycling when they start buying larger volumes of new more advanced lighting.

3.5 Public procurement

Ever more people are talking about the potential to get better lighting and also making plans for more intelligent system installations. But when it comes to procurement the normal reality so far is that the city has a more or less standardized budget for the procurement of lighting – besides of often having to follow regulations that don't take into account potential of advanced lighting. In most cases it is so far difficult to increase the budget to enable better and more intelligent lighting.

The large indirect value potential of better lighting is not considered in the normal procurement processes. It would be good to formulate specific economic answers to questions such as: what is the added societal value of the more productive and restful school environments Human Centric Lighting enable?

The product prices for LED-based replacement lamps have been very much higher than the prices for incandescent lamps and CFL. But the LED prices have fallen a lot and are continuing to go down very rapidly. Combined with the much lower electricity consumption and longer lifetime, the life-cycle cost is lower than for incandescent bulbs.

However, it is important to put the product price and also the life-cycle cost in a relevant perspective. The basic question is which light and functionalities it is that are needed and wanted. An advanced high quality Intelligent Human Centric Lighting solution can offer a much higher value of light than the traditional static lighting. A primitive LED solution may result in a lighting environment and functionality that is much worse than the traditional lighting. The product qualities also vary quite a lot.

With new light solutions new customer benefits will emerge. Until today the most noted aspect has been the energy saving. With new aspects/benefits, like better results and less stress in schools, fewer accidents among patients in elderly care, more alertness, etc. the willingness to pay for more advanced lighting ought to increase.

There is an interest in Human Centric Lighting and more intelligent functionalities, but there is hardly any willingness to pay for the added functionalities. There is a need for a conceptual clarification of the significance of the difference between the old lighting and the new diversity of user adapted light variations that now are achievable.

3.6 Landlord tenant problem

One reason why it is important to make serious green investments is the principle agent problem, also known as the landlord tenant problem. The landlord tenant problem occurs when a person or entity (the "agent") make decisions that impact another person or entity (the "principal"). It is a dilemma because the agent tends to act in his own best interests rather than those of the principal. One example of the principal agent problem in relation to lighting is the landlord – tenant problem where the landlord is responsible for the procurement of new lighting and the tenant is paying the electricity bill. If the landlord chooses a cheap alternative it can affect the tenants' electricity cost and/or health and wellbeing.

Another example is the CEO - employee where the CEO's choice of lighting affects the employees' health, wellbeing and performance. This problem is more likely to occur in times of recession, limited budget and high unemployment. If the transport department (or other responsible department) has a limited budget for the investment and maintenance of the street lighting in one area it might result in accidents or an assault.

In municipalities, the procurement and maintenance are often divided into different budgets, which can cause problems in relation to street lighting or lighting in public buildings. If the procurement team has not thought through the upgrading and maintenance possibilities it might cause extra (unnecessary) money, time and frustration. For SSL the investment (procurement and installation) is normally higher than for traditional lighting while the maintenance (traditionally shift to new products when the old ones are broken) rate is lower. If the installation is advanced there might be a need to hire a specialist in order to be able to handle the upgrading of the system. SSL provides ability to save large amounts of energy in comparison to traditional lighting.

In a study by the International Energy Agency (IEA) (2007) it was found that that for lighting 5 % of the households are affected by Principal Agent problems. According to the study, the traditional lighting (incandescent and fluorescent tubes), are such small and inexpensive devices that the end users almost always control the device selection. Fixtures that are hard-wired for only one type of bulb, such as fluorescent tube lighting or downlights were not included in the study. In recent years, downlights has become more common in public buildings and common areas in residential buildings. For most standard screw-in fixtures and lamps, the Principal Agent problem only arises when the end users do not pay the cost of the light sources.

An ESCO (energy service company or energy savings company) is a commercial or non-profit business that provides several different energy solutions, e.g. design and implementation of retrofitting, energy conservation, and energy infrastructure outsourcing and risk management. The landlord tenant problem can be avoided if an ESCO is responsible for the procurement as well as the maintenance and energy. Making use of an ESCO can be a way for a real estate company to market themselves as taking their Societal Social Responsibility (SSR).

3.7 Total Cost of Ownership

The Total Cost of Ownership (TCO) and the Life Cycle Cost (LCC) are important as a framing for procurement and investments. The background is that the cost minimising ambition tend be limited to the cost categories for energy and replacement of light source and tend to neglect the cost categories for investments and labour. The calculation of the Total Cost of Ownership should include the total cost of acquisition (capex) and operating costs (opex), including both direct and indirect costs. Otherwise it is not correct to use the term TCO.

The total cost for upgrading of lighting infrastructure, including the investment and work, tend to be significant and this ought to be considered in the calculation of the life-cycle cost. It also should be noted that upgrading's of the lighting infrastructure may enable significant saving in maintenance cost. Even more importantly, the investments in upgrading of the infrastructure are necessary to enable a change to todays' lighting technology and even more to enable more effective ways of working. In addition to the potential to reduce the long-term costs this is valuable to ensure that the lighting is working, as it should, all the time, i.e. to improve the availability. Furthermore, renewal of the lighting infrastructure is one way to open up for the digital age by stimulation of the networking and competence development that is needed to get ready for the digital age.

It tends to build a resistance to change if the cost evaluation is extended to include all kinds of investment costs, also those that are needed for renewal, because the improvements for the future tend to be neglected. To be considered in procurement analyses the future benefits have to be included as explicit values in the economic evaluation. It is important to ensure that the total methodology promotes sustainability-oriented innovation.

The quality of the LED products on the retail market, including web-shops, varies quite a lot and it is difficult to assess the quality. One aspect is that some products are technically immature and that there are compatibility problems, e.g. between old dimmers and LED light sources. This results in uncertainty about the electric stability of the electronics, flicker risks and the reliability of the stated lifetimes. As a customer it is difficult to assess the quality of the various products on the market. One advantage and challenge also is that there is a diversity of LED products that have quite various properties. There are products with different colour temperatures and the spectral distributions also differ in other respects. The blue light is hardly included in the lux values and consequently it is difficult to assess how the intensity will be experienced, for various light sources.

The safest way to buy replacement light sources probably is to buy from a reliable knowledgeable supplier and to aim for high-quality brands. This is relevant also when you aim for more advanced products and system applications. But in this case it is also more important to have a dialogue with a broader network of knowledgeable persons.

Publicly funded agencies and projects are not allowed to make recommendations for certain brands. The public testing and market supervision is important for electric safety testing and for energy efficiency. But it is a time consuming process to test the lifetime and new product versions tend to appear on the market before the tests on earlier generations are ready. But at least a lifetime number is shown on the packages of most LED light sources.

It is even more difficult to assess and define the reliability in a broader sense, in particular for lighting as a part of a system and concerning long-term maintainability and upgradability. There is no commonly accepted explicit measure for total "reliability" of SSL. There is quite a bit of information on the web, but it is difficult to know what to trust and also how to make relevant interpretations. This means that there is a need for competence development and networking among peers with explicit practical experiences of LED products and lighting system functionalities.

So far almost the same labelling parameters are used for LED as for the traditional light sources. This is reasonable for replacement products to achieve the same kind of light as before. In a broader perspective this is a crucial question and weak spot in the present systems.

The aspects that are evaluated and labelled are electric safety and efficiency in terms of lumen/W. But there is no consensus about integrated quality measures for the new lighting from user point of view. Furthermore, the interest in higher colour temperatures and circadian entrainment effects by blue light means that there is a need for new lumen measures, e.g. melanoptic irradiance (melanoptic lumen) and color saturation.

From electric safety point of view, LED's and their driver and control circuitry is a kind of electronics that are tested according to the normal rules for electronics.
Considering the risk of causing electric shock and fire, the LED power level is much lower than it is for incandescent bulbs and consequently the risk of overheating is lower. The more advanced current supervision and driver circuitry is also enabling a new level of risk reduction. But as long as we keep the 240 V AC supply power we tend to distribute this electrical net to ever more points. And all kinds of electronics have some power loss, which means that they generate heat and consequently there is some risk of overheating if they are covered with heat-isolating material.

OPEN INTEGRATED SYSTEM SOLUTIONS

4 |

4 | OPEN INTEGRATED SYSTEM SOLUTIONS

4.1 Lighting as part of integrated systems

This section is about connecting lamps to motion sensors and control systems, or on a higher level, for example to security services or building maintenanceIt introduces concepts and issues that are relevant when making SSL lighting interoperable with other systems.

Interconnecting of systems can be done for different purposes:

- **Operational (around the lamp):** for example between lamps, light or motion sensors and control systems.
- **Tactical:** for information exchange with systems outside the lighting domain, for example between a lighting system and a security or a maintenance system.
- **Strategic:** exchange of information from the lighting system (e.g. operational settings) for further analysis in order to improve the functionality, costs and performance for a given task (lighting a class room for example).

As an example, the City of Malmö has implemented human centric SSL lighting in a school. The installed system can change the color and intensity of the lighting during the day in a programmed manner. It is possible to switch between programs manually or to switch off the lighting.

Now imagine this lighting system to be connected to a network and interoperable (exchange information) with other devices. This capability adds various opportunities:

Operational:

- The classroom lighting control is integrated in a mobile device as an app. The mobile device contains all apps that are relevant to control systems and devices within the classroom. E.g. computers, beamer, sunscreens and lighting.
- The concierge or guard controls the lighting of the building via an app on his mobile phone, next to an app that controls the security system. In case off security issues the key holder is able to switch on the lighting before he even arrives at the location. Via the security app a clear view of the situation of the location can be presented.

Tactical:

- The security company that guards the school at night has a central system to connect to all lighting systems of the buildings in their portfolio. Security employees have an app installed on their mobile phone to connect to the security company system. Via that system they are able to control lighting of the buildings they have to survey. This solution prevents installing an app per building per employee.

Strategic:

- Local authorities are able to collect data from the school lighting system to analyze energy consumption and lighting schemes. These data are combined with data from the school (teaching and facility) monitoring systems to get insight in the effect of the lighting system's use and recommendations for improvement...

4.2 Challenges for lighting systems in a changing world

The current state of lighting solutions, the speed of evolvement and interconnection provides a massive load of new opportunities to connect systems. Today each city domain (e.g. energy, safety, education and lighting) has its own infrastructure, ICT-systems and services for citizens. In the near future we will see optimized services across domains for more efficiency, cleaner environment, lower costs, etc.

Until now, lighting is switched on and off based on the availability or lack of daylight. Connecting it to other domains provides a platform for solutions to get the right light, at the right place, at the right time. Such cross domain platforms represent a new model for connecting people, municipalities, lighting, and business in order to make the best – and most informed – lighting decisions in sectors from elderly care and healthcare to education and beyond. What happens is that:

- Luminaires and light sources are becoming parts of the ICT world.
- Society is making new connections between light and other priorities, eg. , energy, security and light pollution.
- The controllability of LED enables much more natural light variations.

Together with trends as sustainability, connected society, artificial intelligence, Internet of things, coming innovations will have to meet an increasing complexity of various issues.

Handling these complexities requires, apart from technical issues, administrative and governance understanding and agreement.

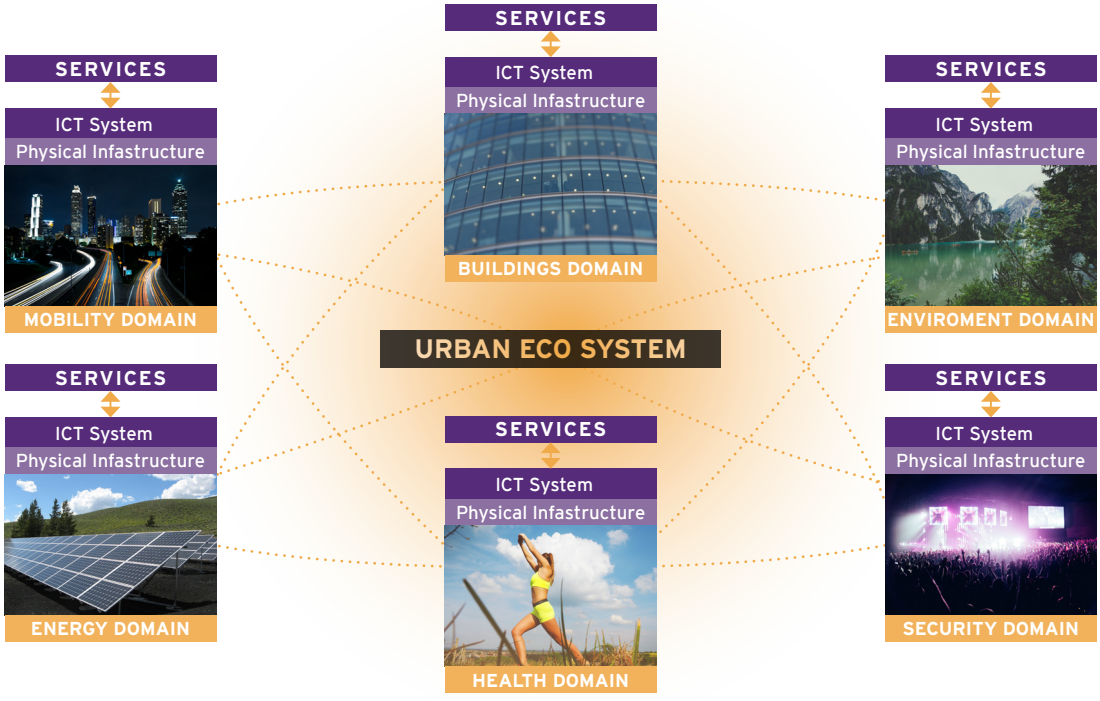

Figure 10 – Smart City needs: optimized services across domains for more efficient, cleaner, lower costs services for their citizens.

4.3 Issues and requirements in lighting application domains

In cities each domains (e.g. a department) has its own specific characteristics. Each domain has specific requirements regarding to lighting. In each domain there may be systems in which lighting functionality is important and could be integrated.

Mobility & Logistics.

Public Lighting is closely connected to mobility and traffic. Lighting provides circumstances to increase safety and creates a more convenient environment while using public space. Meanwhile the mobility domain is rapidly implementing improvements and innovations in vehicles. Combining information of vehicles and lighting could lead to more efficient use of energy.

Energy.

Reducing use of energy is a hot topic in relation to public lighting. An upcoming aspect (not limited to lighting) is the energy supply to lighting systems with varying power demands from sources whose output may also vary unpredictable.

Buildings & Infrastructure.

Lighting is a component of all buildings and cityscapes and is at large scale used in public infrastructure. Interactions exist both with users and maintenance systems, for example.

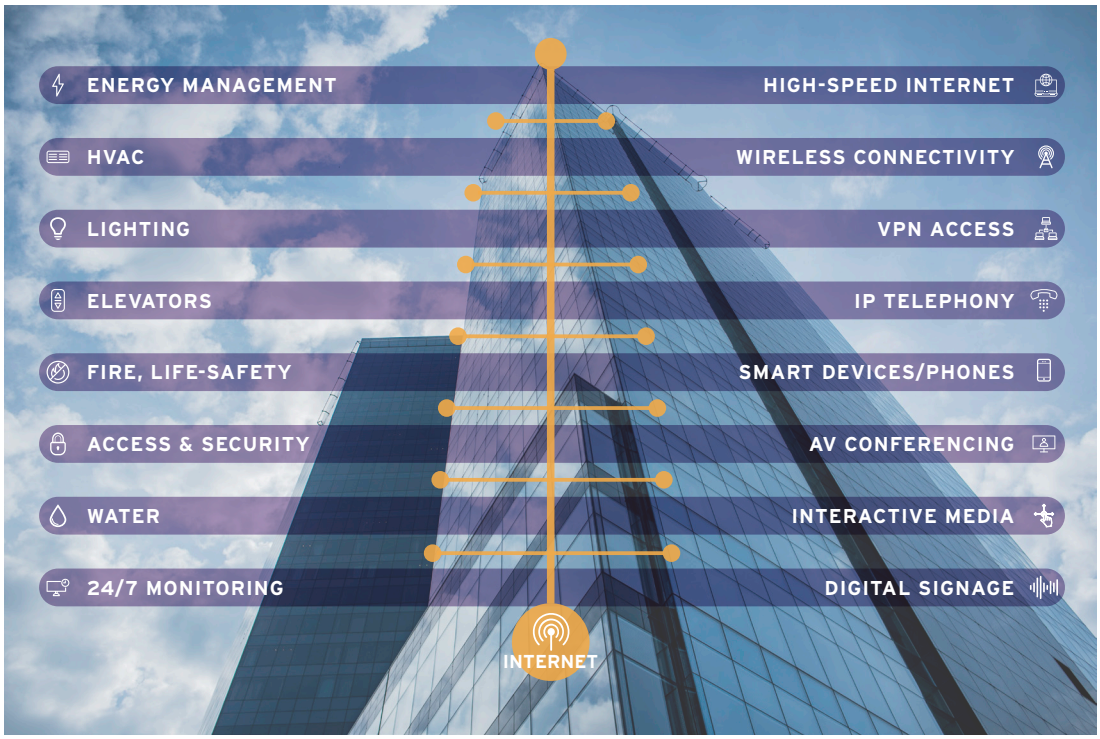

Figure 11 – Interactions between lighting and other facility systems in a smart building (Source: http://askebiz.com/blog/smart-buildings-intelligent-solutions; download: 03.03.2016)

Smart Cities.

The overall Smart City domain is the combination of many different domains. Cities are changing rapidly and service providers consequently have to keep up with the changing demands from citizens and government.

As a result of this pressure IT (control, sensor... systems) can be designed suboptimal and work only well in one specific domain only. Services may have to be modified to support other domains as well without the ability of connection or integration to other systems tin those domains (resulting in digital 'shanty towns').

4.4 System decisions

The aim of collecting and analysing data (e.g. lighting level, lamp settings, energy use) is to support decisions by control systems. These decisions will lead to actions, outside or within automated systems, which may vary from switching on and off of lamps.to even investments in infrastructure.

Decisions at various levels / layers of a control system can be distinguished, starting from the top:

City level decisions:

At this level local authorities decide on high-level instructions for services on lower level, e.g. based on information about power consumption, lighting type and road utilization. One conclusion could be to replace the lighting in specific parts of the city or to initiate a policy for the programming of street lighting control for when to switch on and off.

Cross-domain level decisions:

What happens in one domain may influence others. The programming of a system in one domain influences on processes in other domains or a decision can only be made with additional information from other domains. E.g. in domain Safety the city provides an app to guide cyclists at night, based on real time position data from their smart phone. In the evening, streetlights along a bicycle path can be controlled automatically using this position data, allowing switching on the lights before near-proximity sensors in the lampposts detect bikers. To do so, the Safety domain system needs an information exchange from the Lighting domain system: are streetlights ahead of the cyclist already switched on? If not it will request the Lighting to switch on these lights.

Domain level decisions:

This concerns (system) decisions, which have only impact within the domain (but may be influenced by information from other domains). This concerns functional instructions for a system, which follow from a (system supplier independent) procedural rule set, and translate these into technical instructions. E.g. based on the lighting rule set, instructions are sent to a (supplier specific or vendor) system, which can switch on lighting when it gets dark. This can be a one-time instruction or a daily instruction, depending on the capability of the vendor solution.

Next to this, the Safety domain can request lighting for a specific part of the town. Depending on daytime and lighting status, a request is sent to the vendor solution. Meanwhile a request from Energy-domain for power-balancing is handled only based on lighting status.

Object collection level decisions:

This concerns IT or control systems, to which different objects (e.g. lamp posts) are connected. These systems integrate he capabilities of / decisions made by all connected objects. Request and rules are executed instantly.

The objects may fall under different domains, but then care should be taken that the objects don't interfere directly with each other.

Object decisions:

These decisions are based on information that is available within the object, for example a lamppost, itself or on a request from the object collection module. E.g. a lamppost switches on as result of a request from an object collection module. Or an integrated motion sensor switches on the lighting object in case of traffic detection. As said in the object collection paragraph, integrated equipment that refers to other domains should not interfere directly with the lighting object.

4.5 Functional requirements of IT solutions for interconnected lighting

Technical solutions often pretend to solve all issues at once. However, the difference between (high level) strategic cross-domain and (ground level) operational decisions should be very clear and the solutions should anticipate future developments.

For each of the described decision layers, functional requirements apply to enable these to collaborate. These requirements are essential to keep activities in line with the scope of the level and to keep an overview of responsibility and authority. Starting at the ground level:

Object (e.g. a lamp) decision layer:

- Execute local actions
- Execute a command received from object collection layer
- Make Object information available for Object collection layer

Object collection layer:

- Supervise objects
- Initiate object commands based on rules or request from Domain layer
- Make Object collection information available for Domain layer

Domain layer:

- Integrate information from (various, multi-vendor) object collection layers
- Initiate object-collection commands based on rules or request from Cross Domain layer
- Make Domain information available for Cross Domain layer

Cross-domain layer:

- Integrate information from various domain layers
- Initiate Domain commands based on rules or request from City layer
- Make Cross domain information available for City layer

4.6 Application programming interfaces (API) management

In order to have information exchange between different software codes (e.g. for the electronic control of a LED lamp and for the individual control of lamps in a group) a common communication protocol is needed. An application programming interface (API) is a set of routines, protocols, and tools for the communication between software codes. It serves as an interface between codes, allowing automatic access to information or functionalities without having to know how the other code works. APIs are one of the most common ways technology companies integrate their products (e.g. laptop and printer) with each other.

To have good access to the APIs is essential for software developers. Software tools, which allow this, are called API-managers. These should be secure and remain applicable if the number of layers changes (so called endlessly scalable).

The challenges in defining and design of API management are to secure:

- Domain enhanced "business model"
- Domain independent open connectivity with regard to:
    - Data access (including social media)
    - Data semantic and meaning
    - Governance
    - Security (i.e. sensors for driving actuators)
    - Accounting and Billing
    - Actuators (i.e. software components which drive hardware)

4.7 Smart City Operation System (OS)

Please notice that an operating system for Smart Cities is not available as a ready-made solution which can be bought and used immediately. Aim of a Smart City OS is enable and orchestrate access to city related information and interaction.

E.g. citizens are using WhatsApp to create groups to inform users when they spot suspicious actions. To prevent overlapping initiatives, cities may inform their inhabitants to which group they should connect in order to share the group that is connected to the police department.

By means of this kind of orchestration a Smart City OS is able to lead citizens and companies to the most appropriate domain platform to interact with.

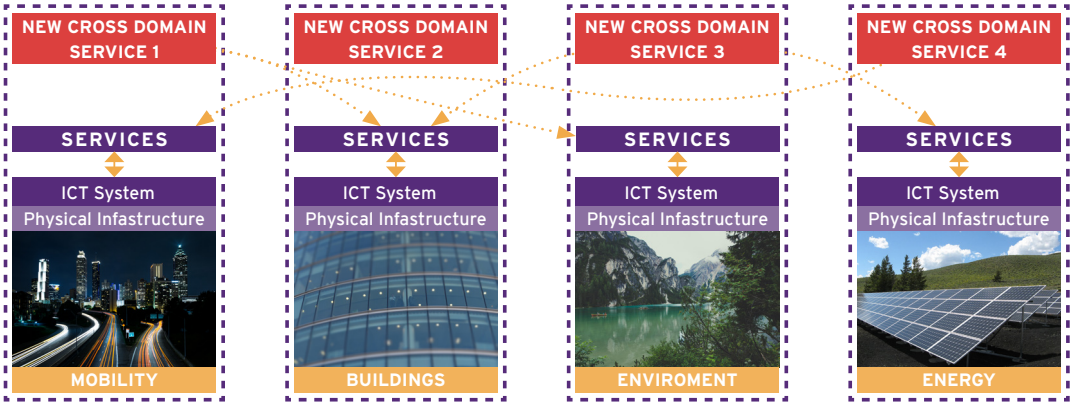

Figure 12 – Schematic representation of cross domain interconnections.

Figure 12. shows how the physical world/infrastructure in a city is connected to the virtual world. Distributing functionality over layers enables common solutions to share information and enables decision making on the right level accordingly to the responsibility and authority concerning that level. Knowing this, it shows how important it is to have a clear view of responsibilities and authority when it comes to interaction between domains. In the future Smart City OS will add functionality to overview governance issues that are relevant and/or essential to the city.

For now domain-managers should integrate functionality to meet domain-restrictions and regulations.

4.7.1 Do's and Don'ts when specifying open integrated system solutions

Do's:

- Setup a governance board for each part of the decision tree
- Describe an ECO-system for each part of the decision tree, in which advantage and contribution are balanced
- Provide a platform with services containing free open data source
- Use rather API's than connections directly to a data source
- In favour of response time: execute evaluation/decision as centralized as possible, but as local as needed

Don't:

- Include direct access to data stores without API in domain platforms
- Execute heavy cross data source functionality in domain platforms
- Implement "nice to have" cross-domain functionality, without a comprehensive business agreement.
- Purchase closed lighting systems

CITY EXPERIENCES AND GUIDELINES

5 |

5 | CITY EXPERIENCES AND GUIDELINES

This chapter summarizes the city related learning's from the SSL-erate project and provides guidance on what to consider and what cities ought to do to accelerate the deployment of value enhancing SSL.

5.1 City achievements

This section describes what the cities have done and learnt. The final part describes how the city lighting association LUCI has participated and the ongoing work to get start with a city taskforce.

5.1.1 Stavanger experiences

In the SSL-erate project, Stavanger has focused on outdoor lighting. The goal has been to create demand for and increase the use of LED and smart solutions for outdoor lighting. Our participation in the project has been important for accelerating the use of LED. Lyse Elnett, the municipality owned Energy Company who develops and operates all public lighting in Stavanger and its neighboring 11 municipalities, has been together with Stavanger in the project.

The lesson learned is that LED together with significant energy saving, also gives a better quality of light compared with conventional light sources. This improved quality means increased security for people and gives them a better sense of well-being. God lighting is also important for the attractiveness of the city.

Stavanger is installing new lighting in the recreational Lundsneset, along a hiking path along the ocean. In this pilot there will be options for:

- Dimming
- Better light management
- Improved operational control
- Connecting various sensors that can provide added value

The next stage is to introduce a cloud based central management system. This communicates with field-installed units through the Internet, the mobile phone network and license-free ISM radio. The solution enables central management of individual and clusters of luminaires.

Dimming when there is no need for full effect of the light can make further energy savings.
Beyond that, it will be possible for the smart system to interact with the end users and public authorities. The lights can be dimmed when there is little pedestrian or vehicle traffic or similarly, it can be boosted to 100% output when there is an emergency.

The smart system will also allow the artificial light to work together with the natural light in a way that will improve the citizens' health and wellbeing. This will also give better solutions for the impact of light on the natural environment.

Smart lighting systems can also bring us further on our way towards a Smart City concept for Stavanger. The system has to be future-proof. This means that various sensors, cameras can be added and by this offer new services and added value for the citizens.

Stavanger has not succeeded in making demonstrations of more advanced indoor installations so far in the project. Based on Malmö's experiences with Human Centric Lighting in schools, new initiatives will be taken for testing this in new school project.

5.1.2 Bassano del Grappa experiences

The City of Bassano, thanks to the SSL-erate project, has further explored the potential of Solid State Lighting and Smart Lighting, through green business development activities carried out in collaboration with the regional lighting cluster – Luce in Veneto (LiV) and its member lighting companies. Within the project, Bassano and Luce in Veneto cluster organised several awareness raising and demand-offer matchmaking workshops for regional stakeholders - lighting companies, lighting professionals, architects and municipal administrators, to deepen understanding and application of SSL solutions in different ambits, to share key project findings and to create open and co-learning networking space to meet market demand and offer.

The cooperation with LiV resulted in Business Development Experiments (BDE) – public-private participatory testbeds on innovative lighting solutions, aimed at introducing innovative players and new stakeholders into the lighting business; and to strengthen links between public and private actors in the lighting value chain, to create opportunities, to promote quality, to identify new applications, and to support market deployment of novel lighting breakthroughs.

The BDE pilots tested in Bassano:

Lighting surface – Civic Museum – a pilot project launched in cooperation with three lighting/ICT companies Metalco, Hikari e Heliv (members of the lighting cluster Luce in Veneto). The "Lighting surface" project aims to protect and further enhance the historic facade of the Bassano's Civic Museum through the application of an innovative glass panel with the incorporated novel Heliv LIT solution that will allow the panel to activate a SSL light source. The official presentation of the "lighting surface" is planned for Summer 2016.

Lighting surface totem – a lighting panel in the Bassano's Martiri Street. This public-private cooperation led to prototyping of an innovative street furniture: a totem with a memorial lighting surface protected by a transparent sheet that with nightfall becomes a luminous element. The experimental technology is printed with transparent nanotechnological particles that emit light when stimulated by LED. The lighting totem commemorates the 48 victims (WWII partisans) of the Nazi massacre of 26 September 1944, whose names appear after the sunset as tenuous light spreading in the venue of the tragedy. The lighting surface is not only an innovative project but also an important tool to narrate the history of the city and a driver that triggered cooperation with the associations that keep alive the memory of those tragic events. The pilot project was inaugurated on 25th September 2015.

Furthermore, during the SSL-erate project, Bassano has increased its knowledge on Human Centric Lighting and its importance for people's well-being, mood and health. Bassano learnt how a HCL approach applied in smart lighting can improve concentration, safety and efficiency in workplaces and educational environments and how it can be applied to improve lighting in public buildings, e.g. offices, schools and hospitals. Since the knowledge generally is limited among the public, among politicians and also in the private sector, general discussions on this topic are often superficial and not driven by facts, Bassano and LiV introduced this issue during joint project local events, as workshops and seminars, involving thematic SSL-erate experts to study together HCL through an open innovative process.

Bassano is very interested in introducing the HCL approach in the planned refurbishment process of public schools located in the territory and therefore launched a participatory dialogue with local school stakeholders to raise awareness and collect their feedback. Through the local workshop entitled "Human Centric Lighting – The Influence of Light on Humans", the municipality launched in December 2015 an interactive and iterative multi-actor dialogue among key stakeholders as students and teachers of 5 important local high schools and technical institutes, city councillors and technicians, professionals as architects, engineers and lighting designers, Luce in Veneto and its lighting companies, aimed at triggering the discussion on HCL lighting and intelligent SSL lighting in the territory.
The capacity building process of the city of Bassano has been further enhanced by the specific knowledge and best practice transfer of the city of Malmö that exchanged experience in applying innovative SSL and Humanly Centric Lighting solutions in schools with Bassano's technicians.

5.1.3 Malmö experiences

The city of Malmö has, during the project time, become aware of and promoted application interest for human centric lighting. Particularly the possibility to enhance school results by changing traditional lighting standards to make better use of the potential of the new lighting is interesting for the city.

Malmö will during the next couple of years build approximately 35 new schools, and it is crucial that these schools will be built with good lighting conditions. It is a unique opportunity to show the city and the region what good lighting can achieve.

When interest was raised, a market analysis of the possibility to procure the components needed was performed. At that time, in 2014, it was difficult to find a reliable supplier of human centric lighting with automatic light variation. Instead it was decided to manage the design and installation within the city's internal development and service department. A human centric lighting system was selected as the way to go ahead. There were quite a number of interesting and challenging obstacles that had to be sorted out. Some obstacles were quite basic; What luminaires to use, where to buy those, where to get a concrete light variation schedule, how to programme the computer etc. The decision was to do as much as possible ourselves, so we bought the luminaires on a trustworthy web-side. The development manager had knowledge of Dali and Crestron interfaces, so he programmed the equipment, and the technical division at the Department of internal services put everything together. The only thing we needed some external help with was the lighting schedule, but luckily we found that within the project at Lund University and the Royal institute of technology, Stockholm. After a lot of work the test bed at the Lindeborg School was implemented. The universities have helped us to evaluate the resulting light variation, mainly by two different Master theses; one about design of human centric light variation and one about sleeping ability and the impact of blue light for younger people. The results from both master theses and the opinions of the teachers, pupils and parents are unambiguous. The human centric automatically controlled tuneable white lighting is considered to be superior to traditional fluorescent tubes.

Therefore the city of Malmö is working to include Human Centric Lighting in the planning instructions for construction of new school buildings.

Investments in schools are a common interest for many parties and in Malmö decisions about the policy for how to equip the classrooms are taken mutually. Therefore the living lab for human centric lighting at Lindeborg School in Malmö is a good showroom for creating mutual understanding among various stakeholders. Seeing is believing in many cases, and this is a possibility to create a wider discussion about the significance of the quality of lighting, in Malmö and in the region.

The city will also start processes to make use of Human Centric Lighting in elderly care. In the same way as for the school example, the elderly care will gain very much with good lighting, e.g. intense high colour temperature light in the morning to stimulate activation and to support the elderly's circadian clock function, which leads to better sleeping conditions and fewer risky situations. Probably the elderly and the pupils are the two groups that can benefit the most from the circadian lighting, but the needs are quite different for the two different groups. The elderly probably need a more individualised kind of lighting, than the pupils, due to the ageing of the eyes, diseases etc.

5.1.4 Vilnius experiences

Vilnius city has been involved in the SSL-erate through the Vilnius University Lighting Research Lab. The municipality of Vilnius and other state organizations are interested in new technologies, but the most important factors are limited to potential energy savings and renovation/expansion cost of current illumination system. Vilnius University scientists have been working closely with state organizations as well as with private actors for more than 10 years and the SSL-erate initiatives, reports and world-wide data collection become an effective tool for convincing the decision makers and society to pay more attention to the lighting quality and HCL aspects.

Vilnius City is now slowly executing a street lighting full renovation project where in addition to the energy and investment costs, quality, health and lighting pollution effects are being taken into account. The upper limit of the Correlated Colour Temperature (CCT) of the street lighting fixtures is agreed to be set at 4000 K and 3000K at industrial and old-town/household zones. Vilnius street illumination company has recently installed the demonstration field in Gelvonu str. (non-industrial district) where side-by-side comparison of 4000K and 3000K CCT street illumination is available. The municipality aims to involve the citizens in a subjective ranking and then prepare for full-scale renovation.

Vilnius city still has similar concerns and challenges of the new lighting systems as other cities going the same direction:

- Reliability and availability of the post warranty service/support. The lighting product and system market is evolving rapidly and it is very difficult to plan the installation and maintenance for 20 years ahead;
- Lack of standards for luminaires and especially control systems. Vilnius city already have ~7 different and not compatible control systems installed in several parts of the city by different vendors and those systems are not interconnected or included in a single API;
- Lack of competence to prepare qualified terms for public procurement tender and further supervision;
- Doubts whether to choose PPP (public – private partnership) or direct implementation. PPP benefits in the risk and competence share between public and private partners, but quality control of the lighting service and other supervision of the contract becomes complicated with limited action merits for the municipality;

- Never-ending discussions about "must have" and "nice to have" features of the smart lighting/city system. Currently with the labor costs of 2-3 times lower than in West Europe or Scandinavia the investments into automated systems look irrational but the future perspectives tend to change the situation;
- Limited finances.

Another area of recent interest is school lighting. The university presented a description of the present situation to Vilnius municipality and Ministry of Education and Science. In most of the schools in Lithuania fluorescent-tube lighting with electromagnetic ballasts resulting in 100 Hz flicker dominates. Modern LED lighting is still not allowed due to the strict light hygiene norm regulation that specify that the school lighting shall be fluorescent lighting technology. The steps toward the change of this norm have been made but still not successful enough due to a complicated bureaucratic system. Despite those difficulties the private initiative was realized and an application for the local business science initiative financing grant was submitted. If the process goes well the demo classrooms with conventional high quality and HCL with tunable CCT lighting systems will be installed and cognitive ability research performed. In particular vision acuity, attention concentration and reading speed tests will be performed at different illumination regimes, while more comprehensive cognitive ability tests like text reading and perception, math/logics exercises will be used for long term lighting effect evaluation. Those classrooms probably will remain as living labs of school lighting in Lithuania and hopefully will inspire further HCL developments in the education sector.

Finally, the public awareness of the lighting quality and non-visual effects of lighting has increased significantly due to the number of public posts, lectures/seminars and private communication with architects, journalists, lighting professionals as well as persons from the public sector.

It was quite remarkable that some private schools wanted to invest in more advanced school lighting considering the economic situation in Lithuania.

5.1.5 LUCI experiences

LUCI and SSL-erate outreach

LUCI's main role in SSL-erate has been to disseminate the outputs and learnings of the SSL studies and experiments conducted within the project, to gather information and feedback from cities, and to raise awareness within and beyond the LUCI network. LUCI has contributed to the SSL-erate outreach mainly in three ways:

- Organizing two awareness rising events in Bucharest and Dubrovnik
- Presenting the SSL-erate project and results, in 5-minute slots LUCI events in Bucharest, Helsinki, Glasgow and Gothenburg and in numerous contacts with the LUCI cities and other lighting related actors over the course of the project.
- Disseminating the SSLerate related information and outcomes in the LUCI Newsflash disseminated to 350 contacts each month, and "Cities & Lighting" magazine printed twice each year in 1000 copies each and disseminated to urban lighting related contacts worldwide.

Especially through the two dedicated SSL-erate events, LUCI has gathered input from various cities around Europe.

City LED Forum

This was organized by LUCI on 24 April 2015 during the LUCI "City under Microscope" event in Bucharest. 50 key regional sustainability actors and municipal decision makers attended the City LED Forum.

This included elected officials, lighting managers, technicians and other city representatives from 20 cities in Europe. The workshop format enabled front running municipalities such as Lyon, Eindhoven, Jyväskylä, Malaga, etc. to put forward and communicate on successful LED lighting practices to less advanced cities. It facilitated technical discussions and helped municipal lighting professionals get concrete answers from their peers.

Through discussions, valuable insight was obtained on some of the barriers that cities are facing regarding the large-scale deployment of LEDs and the issues that they need to take into account. These include: LED procurement and the tendering process; choosing the right luminaire; control systems and presence detection; LED lighting and social acceptance by citizens; financing solutions for LED lighting projects; energy grids as enablers for energy-saving, sustainable and smart cities.

Professional Training session on LED Lighting in Cities

This was organized by LUCI and the City of Dubrovnik on the 23rd and 24th May 2016 in Dubrovnik, Croatia. Gathering 25 representatives from 9 countries (Croatia, Romania, Slovenia, Bosnia & Herzegovina, Poland, Hungary, France, Netherlands and Sweden) mixing city professionals (from Bled, Brasov, Budapest, Dubrovnik, Eindhoven, Lyon, Koprivnica, Split, Zadar…), representatives from the lighting industry (Zumtobel, Philips Lighting), lighting designers and an expert from Lund university, the session was a good opportunity to hear from the best specialists and exchange ideas on LED lighting for cities.

The objectives of training session were to: learn about the state of the art information on SSL technology in an urban context; go into detail with examples from European city strategies; exchange about the issues and challenges with European counterparts; learn about the urban lighting strategy in Dubrovnik and visit its lighting installations.

Learnings from these activities

The above workshops and activities have enabled LUCI to provide information about experiences on how to enhance a city's motivation to invest in better lighting.

- Cross border and international dialogue is important for exchange of know-how and innovation.
- Collaboration between different departments in local governments is key to enhance the cooperation of local stakeholders towards better public lighting.
- A high level driver is therefore needed in any type of city enhancement project via light. LUCI as a forum for dialogue and exchange especially of policy makers, managers and experts from cities, can help to maximise stakeholder involvement.
- Another interesting dimension to attract cities to invest in better lighting is the attractiveness and comparative advantage that lighting can produce as an identity marker and a city branding opportunity.

Today, many small to medium sized cities are modernizing their public lighting, financed by public investments and/or infrastructure subsidies from the EU. One of the main targets is of course energy efficiency and reduction of public spending for electricity, but other aspects include the improvement of the quality of life and enhancing the city with a smart lighting system.

There is a strong interest for the development of smart city and correlated smart lighting concepts. For example, following the City LED workshop, the City of Bucharest asked its public lighting system operator to develop a smart city strategy and pilot project. In Dubrovnik, the participants were very interested by the new installations of a street enhanced by connected lighting (partnership between the city and telecom operator) and heard about major developments in Brasov (a 200 000 inhabitant city in Romania) with a lighting system integrated to the global IT system of the city.

However, cities are also strongly saying that there are more questions than reliable answers at the moment. Municipal lighting professionals have a strong need for concrete answers from their peers. Feedback on user experience is essential, and therefore site visits and on-site demonstrations are crucial to encourage uptake in other cities. Some topics pointed out by cities to take into account when implementing SSL lighting are:

- It is important to have an open dialogue of what is really needed. The starting point for the development of smart lighting solutions should be the real needs of cities.
- LED projects have to be planned carefully taking into account the context of each city. Citizens should be involved, particularly regarding what kind of ambiance they want in their city. It is important to elaborate on the needs of the users before the procurement phase.
- Maintenance aspects have to be taken into account from the very beginning of the project.
- The shift towards new "intelligent, smart lighting", which is different from previous public lighting, requires new competencies and skills in municipal staff that they do not currently have and will need to develop.
- New ways of functioning will also be required within municipalities. Smart city systems will require transversal cooperation between departments and not the "silo" functioning.
- There is a need for open solutions and interoperable protocols. Cities would like to ensure that there is inter-operability between different manufacturers' software for intelligent lighting control so that they are not limited to one manufacturer.
- The issue of data ownership and use needs to be addressed. The large amounts of data gathered in smart systems offer promising opportunities, but rules need to be established regarding who owns the data, who has access to it and how it can be used. Questions related to data gathered and privacy of individuals also needs to be addressed.

Developing a City task force to ensure the continuity of the work of SSL-erate

As a result of the dialogue within the SSL-erate project, between cities and other partners, LUCI today is involved with the dialogue on how to get started with a city task force for advanced indoor lighting.

Indeed, and especially given the new dimensions and use of lighting for health and wellbeing, cities may have developed strategies or aim to develop them soon for both indoor and outdoor lighting in the public realm (schools, local government offices, other public buildings). The plan is to organize the first step of the build-up process as a LUCI Commission.

5.2 SSL peculiarities

It is important to take it seriously that the LED light sources have different properties than incandescent bulbs. SSL enable a much larger freedom of action, but it has also become much more difficult to make a appropriate lighting choices. SSL based products has great potential to:

- Vary the product functionality and spectral composition to various needs, but it is vital to avoid bad electronics and bad system solutions.
- Dim the light, but it is crucial to avoid harmful (invisible) flicker due to primitive driver circuitry and electric instabilities
- Optically control the light flow and light design, but it is essential to avoid glare due to intensive light spots and optics that generate intense light.
- Long product lifetime, but it is essential to be trustworthy about the real-life product lifetimes.
- Intelligent SSL solutions enable low life cycle cost, but to harvest this advantage there is a need for proper investments.

5.2.1 Blue light

The third receptor, the intrinsically photosensitive retinal ganglion cells, ipRGC was noted in the 1990ies and two decades of intense research has clarified why blue light is stimulating and awakening.

The impression of a higher or lower colour temperature (CCT), i.e. a higher or lower percentage of blue light seems to be a matter of taste and habit. In northern Europe most people tend to prefer a lower colour temperature, similar to traditional incandescent light bulbs. In everyday language this somewhat reddish light is denominated as "warm" light. In southern Europe most people tend to prefer a higher colour temperature, i.e. a daylight character of the lighting.

Taking a deeper look, it can be noted that the spectral distribution of light from LED light sources tend to contain quite a lot of the blue light, with a wavelength around 450 nm, from the blue diodes (LED) that are used for the excitation of the fluorescent material that generates the other colours, i.e. the longer wavelengths. Some people have said that there is a "blue light hazard" with LED light. The daylight in nature does not contain so much 450 nm light. Daylight contains more blue light with longer wavelengths. 480 nm light has the strongest effect on the circadian entrainment, i.e. awakening effect. This means the blue part of the LED light may appear to be a bit unnatural, in particular for low quality light sources that emit a high percentage around 450 nm and a low percentage around 480 nm.

One other factor that tend to complicate the selection of lighting intensity is that the blue light, in particular the shortest wavelengths are disregarded by the V(lambda) curve that is the basis for the calculation of the lux and lumen values that describes the light intensity. This means that at one and the same level of lux-value the impression is that the light with a higher percentage of blue light is more intense.

It should also be noted that the human visual system automatically adapts to the present light environment, and then this light appears to be normal. The main impression occurs when the light changes abruptly and when we enter a new light environment.

5.2.2 Flicker

The ambition that LED light shall be dimmable and the combination of various dimmers and various driver circuitry results in technical complexity and also a risk for invisible unpleasant and maybe harmful flicker. From functionality and flexibility point of view it is a great advantage that we are making it possible to combine SSL, user interfaces, control functions and ICT components. However, the complexity also means that there is a risk for technical malfunctions and shortcomings.

The first generation of LED were replacement bulbs for E27 and other traditional 240 V AC sockets. From user point of view these light sources are intended to give the same light and functionality as the incandescent lamps. But so far not all the LED lamps are dimmable so where there is a dimmer it is important to make sure that the selected light source is dimmable in an appropriate way. Most of the luminaries that have integrated LED's are designed for the normal AC net and have integrated drivers. Furthermore some LED replacement bulbs and in particular luminaries are controllable in more advanced ways, e.g. variable colour composition by means of an app. The LED controllability enable a much larger freedom of action and to start to make more advanced use of this potential there is a need to start to work with lighting as a part of integrated system solutions. These solutions may include a DC power supply and this may be very important to reduce the risk of flicker and to reduce the number of transformers.

During the autumn 2015, Sweden had a discussion about flicker risks also with LED products. The LED light source part of this can be avoided with proper high-quality non-flicker design of the electronics in the driver circuitry. But there are numerous LED products on the market that generate 300-500 Hz light variations. The risk for rapid light fluctuaions is also related to other electric instabilities. According to Martin Lundmark, Luleå Technical University there are three aspects that can contribute to the electric instabilities and flicker:

- Driver circuitry in the LED light source
- Dimmer electronics
- Disturbances from the net

Considering the risk of negative human effects from flicker it should be noted that there is a recent standard IEEE 1789-2015: IEEE Recommended Practices for Modulating Current in High-Brightness LED's for Mitigating Health Risks to Viewers.

5.2.3 Glare

A great potential with SSL is that LED makes it possible to optically control the light distribution in a very precise way. This is a valuable property that enables many kinds of very advanced light designs. But if this feature is used in a primitive way there is a risk that it may result in unattractive light environments. One way to increase the calculated efficiency is to limit the light distribution to a specified area. If the energy saving ambition is implemented as a limitation of the light to a roadway and without any light outside this area there is a risk that the street lighting will be dysfunctional and glary. This causes a risk for a serious functional shortcoming by not being able to see anything, e.g. animals, at the side of the road. The technical potential to optically control the light distribution is a great resource, but it is vital to take a starting point in thorough understanding of the needed light distribution.

The possibility to optically control the light flow is a powerful tool for advanced light design, but on the other hand there is risk that uneven light distributions result in glare.

5.2.4 Lifetime

One question about LED is if the life times that are specified on the packages can be trusted. One background here is that there are large differences in product quality. The LED and the driver electronics are also sensitive to heat, which means that the luminaire design and installation is crucial. Too high temperature may cause significant reductions of the functionality and lifetime. Furthermore there are risks for electric disturbances between light sources and other loads on the electric net.

One particular issue is that, numerous actors have a common interest in presenting a long lifetime to be able to calculate a favourable life-cycle cost. This means that the proponents of the LED energy saving tend to be rather uncritical about long stated life times. This also applies for customers that want to get started with LED. This means it is crucial to establish market mechanisms that promote honest market information, in particular about the product lifetime. To promote high quality, development of better light and more advanced functionality it is important that the customers are critical, as a driver that motivate such market developments that the stated product data can be trusted.

A high quality LED itself can have a lifetime of 30000 – 50000 hours or even more, when it is operated at sufficiently low temperature. However, an LED light source also contains driver electronics and more and more also control and communication electronics. The lifetime of a "lamp", i.e. a complete system of components, is governed by the component that has the shortest lifetime and there is some random variation in the lifetime of most components. LEDs and their electronics are solid-state components so they are mechanically robust also when they are on. But in particular in replacement light sources the design and quality of the driver circuitry varies quite considerably. The life times of LED light sources should be specified on the packages. It often is 15 000 h and this is realistic for high quality products in luminaires with appropriate ventilation and cooling, at a normal room temperature. A long lifetime appears to be very good for the life cycle cost/year, in particular considering the low need for maintenance work with replacements. But one basic question is how fast the efficiency improves. The future products will save even more energy. However the LED products now are so efficient and the prices are so low that the additional reduction of life cycle cost/year hardly motivates frequent changes of products. Consequently this hardly is a motive for shorter product life times.

5.3 SSL system considerations

What are the concerns that need to be taken into account when incorporating LED's into interior / architectural elements or furniture?

The traditional lighting design and user interface considerations are still important, and in fact even more important than before, because there is less general experience of how to make best use of the new technologies.
To get a good lifetime there is a need for adequate cooling.
For lighting that is integrated with facility management or some kind of smart system it is important to consider replace-ability and upgradeability. One new aspect is that the colour composition varies between different light sources. One major on-going change is that the light sources are becoming more and more efficient and that the light output tends to become higher for each new model.

Power grid and poles is just the start, what more can be integrated?

The possibility to use the lighting infrastructure of cables, communication and maintenance for several functions can be utilized to reduce cost. Another potential integration advantage is to pool resources to enhance functionality and dependability, e.g. by means of dual systems.
Another significant aspect is that when several earlier not collaborating departments' starts to talk to each other they can take advantage of learning from each other's different kinds of perspective. This may be used to find more suitable components, better positioning of various components and more advanced system solutions, by combined use of different kinds of proven knowledge. It is also a major potential advantage that the coherence of the total infrastructure improves when people from different departments improve their mutual understanding.

What is required to submit data from and to a streetlamp?

The obvious technical basis is that there is communication electronics, software and ICT networks. However, it is also basic to clarify the ownership of data and if there are some privacy aspects.
From interoperationability point of view it is crucial to note that the development of interdepartmental collaboration and mutual understanding may be more difficult than the technical compatibility.

Are there open systems so we can submit devices from any company?

Theoretically yes, but in practice no, in a holistic perspective. From communication and ICT point of view there are numerous technical standards that are quite open. The ability to develop and maintain an open system is very much dependent on the user. As usual it is basic to clarify what it is that is needed and wanted. Which kind of openness is it that is required?
Also here it is important to note that a rapid development is going on. A functionality that is "open" today may become a restrictive hindrance for future openness.
One principle recommendation to enhance the ability to handle this is to develop internal competence and to keep an up to date network of expertise. One good way to do this is to engage in experimental system installations.

How can we be sure that we buy future-proof solutions?

The best is to aim for truly open solutions and appropriate modularization. But this is not so easy. To enhance the ability to navigate in this complicated field there is a need for competence development and networking among peers, including experts and independent business intelligence considering the evolution of various forms of open and hidden standardization. To get a reality-based learning process, it is important to invest in early demonstrations, as a base for mutual learning's.

It is very relevant to consider the upgradeability. But it is hardly possible answer this question in an explicit way without knowledge about what functional flexibility it is that is wanted. At the basic level there always is some almost unavoidable goal conflict between the aim to get an advanced functionality that can be used for very many different things and the opposing aim to get a readily understandable system that is easy to use, and also easy to install and maintain.

Of course it is necessary to use components that can communicate to be able to build a system and it is advisable to use open broadly used protocols. To be able to later expand the system with more advanced components it is important that the "system" knows and preferably also can identify new and existing components and what they can do.

5.4 Evidence based lighting design

Involve the users in the dialogue

When you aim for something significantly new one first basic step ought to be to involve potential users in the dialogue. To be able to get the right people interested in the new opportunities it is often important to make attention-grabbing demonstrations. To trigger interest in new things there is a need to show and describe the advantages of the new lighting. To avoid dissatisfaction, it is crucial to involve the staff, e.g. teachers, cleaners and to take their worries, feedback and suggestions seriously.

Define the goal

Just as in all other forms of engineering and procurement the starting point should be to clarify and define the actual goal. Concepts such as Smart Lighting and Human Centric Lighting include many different possible functions and interpretations.

Create a basic light variation pattern

This limitation is even worse for Intelligent Human Centric Lighting. One basic aspect is that it is unclear how to specify and find various kinds of spectral distributions. Research shows that light has significant effect on our health, but there is no consensus recipe for which spectral distributions, intensities, etc. that are those most beneficial for each individual and situation. It is also unclear which measures it is suitable to use and there is limited information in today's product data. It is also unclear how the light ought to be varied to get a good 24 h combination of various light intensities and various colour characteristics.

Light variation and design of the user interface. One suggested system characteristic for the early introduction is that the basic user interface ought to use/keep the same kind of basic on/off functions that the users are used to (so far mainly the normal on/off switch) and maybe also on/off and dimming based on some kind of presence sensors.

There are two basic control principles:

- Manual changes between a set of different static lighting modes, by means of some kind of switches on a control panel or maybe by an app
- Automatic variation of the lighting

In the manual mode the setting tends to be left in one and the same mode and then it is not a dynamic human centric light variation.

An automatic control has to relate to some kind of information about the lighting need at different points in time. One alternative is to relate to the daylight and time of day or to a schedule of different kinds of activities. Another way is to use a supervision system with some kinds of sensors to distinguish between different kinds of activities.

The basic advice to enable those mutual advantages, now and even more for the future is to aim for truly open systems.

To be able to be more specific the following focuses on school lighting as an application case. It is vital that the intelligent dynamic HCL school lighting is designed to enhance the working conditions for the pupils and the teacher, and also to facilitate the teacher's work. It is vital to enable smooth adaption of the light to various needs during the day – and the most straightforward way is to use switches for special pre-set functionalities. One such setting ought to be a light intensity and distribution that is adapted for use of a smart board and/or video projector.

To be able to make optimum use the alerting effect of more intense higher colour temperature light and also simultaneously avoid that some pupils feels distress and fatigue there is a need for some kind of more or less automated variation of the lighting. This kind of variation is also interesting from energy effectiveness point of view.

One suggested design principle is to aim for an automated circadian variation as default case and a manual override possibility to be able to get the lighting that is wanted in each specific situation. In addition to the circadian variation there also is a need for a traditional on/off by means of a normal switch or perhaps controlled by presence detectors.

Maintenance

Traditionally, both light sources and luminaires have been standardised commodity products and consequently most organisations do not have any specialized support staff, internally and hardly as established contacts either, for indoors lighting.

One aspect also is that lighting designers ought to be involved not only in the preparatory design phase but also in the specific choice of technology. Lighting is and should be considered as an integrated part of the building architecture and the building structure.

There is a need for development of new networks, new competence and new support functions.
The basic step is to start to take it seriously that lighting has become an advanced technology. It is important to involve appropriate technical and lighting expertise when something strange happens.

For example the caretaker for the facilities ought to have the authority to bring in appropriate expertise to be able to assess the situation at a proper level, at an early stage.
There is a large variation between various products and system solutions. It is important to involve facility management staff in the procurement decisions and the installation of new kinds of lighting. It is important to clarify who it is that has the responsibility to alleviate various kinds of problems when something happens.

As a preparation to be able to meet this challenge in a better way, by precautionary development of system solutions with lower and more manageable failure risks, there is a need for development of new competence and new networks, to have access to and find the needed expertise and to be able to make relevant assessments of the upcoming situations.

The long lifetime means that the need for maintenance is rather low. For high quality LED products the lifetime also is rather homogenous, i.e. similar for all the products of a certain version. This means that it is suitable to replace all the LED that belong to the same batch at the same time, i.e. in a planned replacement schedule.

It is quite common that there is some change in intensity and also spectral colour composition over time. The basic question is if the users will notice this and if the differences have any significant effect for the users. The basic method to minimize the differences and changes is to buy high-quality light sources.

But then there is another significant effect that should be noted. There are products with different colour tone (CCT= Correlated Color Temperature) and colour rendition (i.e. the appearances of different colours on the objects we look at) (CRI Color Rendering Index, Ra-value). Furthermore, there are other differences between different brands and product models, also between products with the same numbers for these parameters.

It should also be noted that the product development is very rapid. The best products are becoming better and better. This also means that the appearance of the light can change a bit.

Programming of changes in automatic light variation schedules
This is a principal problem for all facilities where the pattern of activities varies. From a basic circadian point of view the natural approach is to use a generic variation that is adapted to the time of day that also may include some adaption in relation to the normal time of lunch, etc.

The daily adaptions to what happens in the classroom has to be manageable for the teacher, like reducing the light level on a smart-board when that is used and then afterwards to increase the light level again. A main part of these kinds of technical adaptions can be automated. But to be able to meet the various more or less random things that happens there is a need for manual overrides, at least to turn various parts of the light on and off.

When there is a significant change of the class/room schedule it ought to be so easy to make the needed "reprogramming" that this can be handled by the everyday caretaker for the facilities. This means that the appropriate persons should be engaged in the commissioning of lighting installations with automatic light variations.

Cleaning considerations

LED-lamps are not as warm as incandescent lamps and fluorescent tubes so there is less risk for overheating and that the lighting "burn" the dust particles to smaller more dangerous size.

On the other hand the LED's and also the driver circuitry is heat sensitive so it is important to keep the lighting clean. Furthermore, the LED light sources have much longer lifetime and consequently the cleaning is more crucial.

The need for cleaning is very much dependent on the design and installation of the luminaires.

Education of teachers and maintenance personnel

As long as a new kind of lighting solution is unfamiliar there is a need for information about the specific lighting system in the facilities, e.g. how to turn it on, how to change mode etc. The teachers also need information about the specific properties and effects of the various lighting modes and variations, e.g. regarding health and performance. To avoid dissatisfaction, the people that make the specifications and installation should meet with teachers and maintenance personnel after the installation to make sure that everything is working according to the specification and to collect feedback regarding their needs and wants.

5.5 The progress of more advanced used of SSL

The SSL-erate studies and dialogues verify that there is major business development potential for value adding Human Centric Lighting and Intelligent Lighting Systems. Cities can take advantage of SSL installations as a tool to improve productivity, health and wellbeing, e.g. in schools, offices, hospitals and elderly care centres, i.e. for sustainable social and economic development. SSL enables advanced lighting design and light variations, and this can be used to make the city premises more attractive, i.e. for city branding. Combined utilization of SSL and ICT also opens up local opportunities for the digital age of innovative business development.

Public institutions can lead by example in procuring advanced SSL and opening up markets for new products, lighting solutions and more sustainable business models. A green system solution with energy efficient lighting tends to have a higher procurement cost but saves operating costs throughout the life of the building. LEDs are efficient, and can have long lifetime and minimise maintenance cost. When the number of bulb replacements is reduced, the time workers spends on ladders and lifts is reduced, which leads to less injuries and working time. Smart Lighting is an attractive opportunity for global energy conservation, but in economic terms this opportunity is small compared to the financial benefits that can result from improvements in productivity, wellbeing and health of people working and living in optimized human centric lighting conditions. The main added value opportunity and also sustainable development priority is HCL and more effective and intelligent system solutions.

However there is limited public awareness about the significance of light for health and wellbeing. Another crucial hurdle is that the general idea is that the selection of lighting products is something that is very easy (and standardised) to handle. Most of the questions we have collected from city representatives and others have a background connotation that they want the selections and procurement to continue to be easy. This is quite natural, because, the earlier lighting products

have been standardised commodities and from user point of view the technical development rate has been very slow.

The SSL-erate studies show that there is a rather broad consensus that LED and Smart lighting can save significant energy. Numerous lighting experts are also confident that SSL can provide higher user value than the traditional lighting technologies.

The SSL-erate observations indicate that the user value considerations that are illustrated in Figure 5 are relevant to consider for SSL customers. Figure 13 is based on these user value distributions for traditional lighting and SSL. The business development opportunities are most obvious for the higher levels of user value. The risk for unsuitable choices and user values below the traditional minimum standard of lighting are also significant development concerns for the SSL market.

To motivate investments in value enhancing development of products, system solutions and business models it is crucial to develop a willingness to pay for higher quality and better user adaptions. Consequently, it is serious if questionable product characteristics, unfitting light design or unsuitable product choices results in dissatisfaction and distrust. If people are exposed to the bad LED experiences that are illustrated by fields 3 and 4 in Figure 13 it is very difficult to build confidence that SSL can be trusted to build much higher user values. One reason is that it tends to influence professional judgements also when people have bad experiences of LED as private product users.

Looking at this in a broader perspective, the above is only one side of the comparison of SSL with earlier technologies. There are lots of low quality worn-down conventional luminaires, e.g. T12 fluorescent tubes with magnetic ballasts and thereby 100 Hz flicker, e.g. in schools. A too high percentage of the existing luminaries are too old and when the maintenance is inadequate this results in bad light environments. In many cases and countries this is a much worse drawback than the present quality variation for LED products. A basic requirement to get light environments that are appropriate for productivity, health and wellbeing is that the lighting is maintained, as it should. In this context it should be noted that investments in replacement of really old lighting with LED normally enhance the quality of light quite considerably.

Still it should be noted that there is a need to enhance the ability to make appropriate choices of SSL solutions. There are two sides of this:

1. One is to enable people to make correct choices. To do this it is necessary to understand the peculiarities of the new technology in relation to the own needs and wants. There is a need to enable people to experience the differences between different kinds of light. To motivate people to inform themselves there is a need for awareness rising activities.

2. The other side is that there is a need for readily understandable labelling of products and also market supervision to ensure that the labelling's can be trusted. The peculiarities of SSL and the new opportunities to vary the light mean that there is a need for broad education on how to interpret lumen and colour temperature values, and also other kinds of product information. To enable optimum utilization of HCL there also is a need for new measures, e.g. for the amount of activating blue light. To explain the meaning of various light measures there is a need for demonstrations and explanatory information. One opportunity is to use ICT tools to illustrate what various measures mean, preferably in relation to various needs.

Both these aspects are valid to enable proper investments in intelligent human centric lighting (field 1 in Figures 13) and at a basic level even more to enable people to avoid the shortcomings that are illustrated by fields 3 and 4.

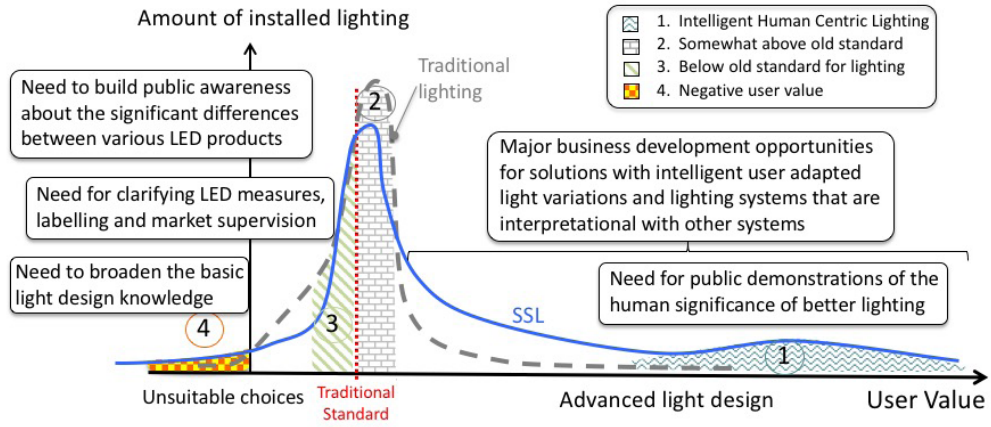

Figure 13 – User value variations between various kinds of SSL installations in relation to business development opportunities and light quality challenges.

In addition to Figure 13 there is a need to consider the evolution over time. In the first phase of LED introduction the LED light was often said to be inferior to the traditional light sources, this is illustrated by the perceived distribution (1) in Figure 14. During the latest five years the quality of the LED light has become significantly better, as illustrated in the right hand part of (2) in Figure 14. The interest in the quality of the light has also brought to the front that a large part of the old lighting is rather bad, as illustrated in the left part of (2). This means that SSL open up significant potential to increase the quality of light compared to the traditional lighting. The right hand part of the LED curve illustrates a significant improvement potential, but not how this potential can be activated.

To make things happen business development drivers are needed. One possible way is to introduce LED-adapted specifications for more advanced lighting, (3) in Figure 14. One way to develop and introduce new specifications is innovative procurement. To build interest and confidence in the evolving advanced opportunities there is a need for public demonstrations, at present in particular to show the significance of Human Centric Lighting. Demonstrations of advanced SSL are also important to clarify what to aim for, so that the mistakes illustrated by fields 3 and 4 in Figure 13 can be avoided. The curve in the bottom part (3) of Figure 14 illustrates that a new specification of a higher quality of light can be a driver for investments in various levels and kinds of more advanced lighting. These specifications ought to clarify some specific reasons for why it is vital to invest in better lighting. Two ways to get moving with specifications of more advanced lighting is innovative procurement and demonstrations of the resulting light environments. The resulting awareness also tends to influence the product choices for more ordinary installations and shift the LED distribution curve to the right.

Figure 14 shows a one-dimensional quality value. However it should be noted that a quality measure should show the adaption to the customers' needs and wants, and these lighting considerations are multi-dimensional. It is possible to vary the light in very many different ways and there also are other kinds of characteristics. The Section 3.3 presentation of the LCA quotient denominator explains a number of aspects that ought to be considered to build a solution that is really good for the social and economic dimensions of sustainable development. The presented LCA quotient includes several dimensions of customer values.

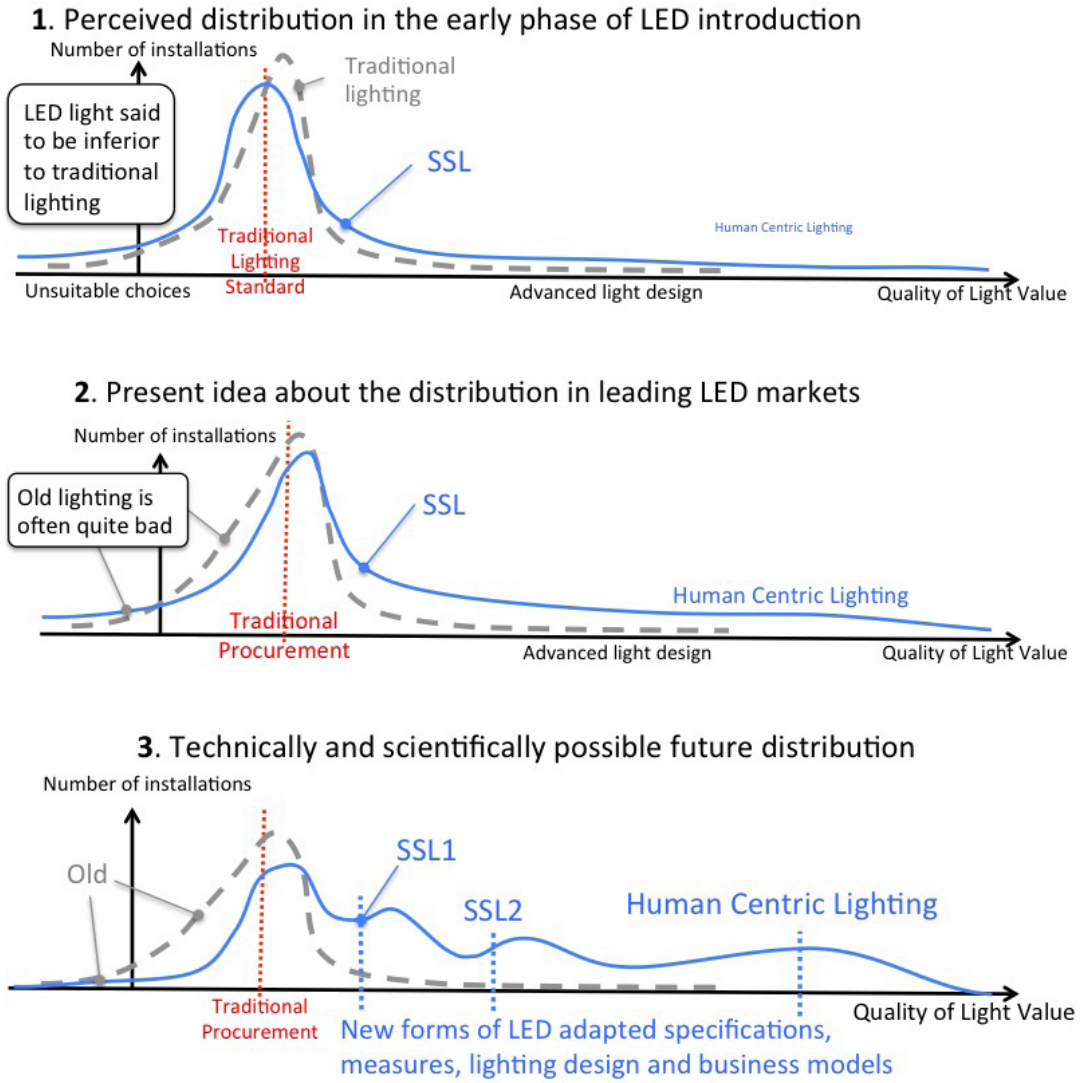

Figure 14 - Three phases of the introduction of SSL. In the first phase (1) there was skepticism. The growing interest in the quality has made people aware that a large part of the old lighting is quite bad (2). The prospective view (3) includes three generations of LED light specifications as drivers for deployment of lighting with higher user value.

Figure 15 illustrates how the introduction of a new specification drives development of lighting that is somewhat better than that minimum requirement. The different specifications may focus on different kinds of user values.

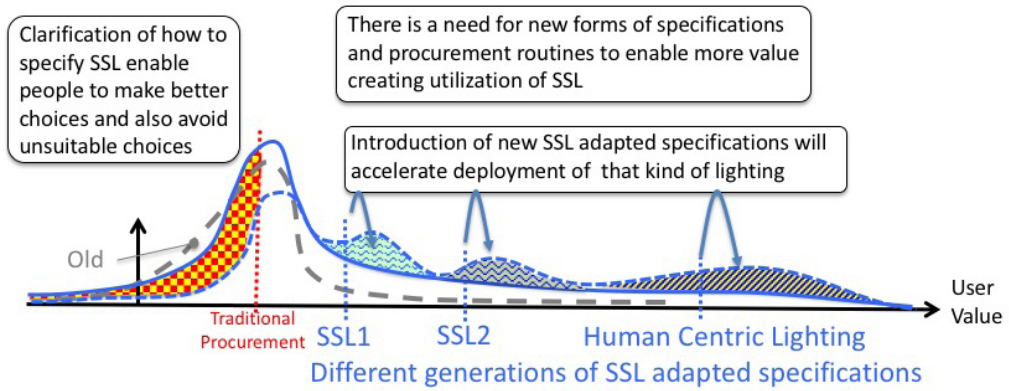

Figure 15 - Three dimensions (or generations) of LED lighting specifications as drivers to accelerate deployment of a broader set of high quality (user adapted) lighting solutions.

The start-up of markets for more advanced lighting can be enabled by green public procurement and, in particular, Public Procurement for Innovation (PPI) and Pre-Commercial Procurement (PCP). PPI and PCP aim for new solutions to address a perceived need or societal issue. PPI can also aim to commercialise inventions that already exist, but are not yet put on the market. For further information on green public procurement see also 'Sustainability issues for SSL' (downloadable from www.lightingforpeople.eu)

The new EU Directive on public procurement and the related tools can be used to support development of processes for early deployment of intelligent lighting solutions. Energy analyses can be used as a guidance to design of solutions with user adapted spatial and temporal light variations. This is crucial to make sure the money that is invested in green SSL solutions is used in such a way that we promote intelligent human centric lighting, i.e. solutions that are appropriate in relation to the social and economic dimensions of sustainable development.

5.6 Lighting specifications and procurement routines

There are a lot of routines and specifications that has been established during the use of the earlier lighting technologies. The existing way of thinking is a mental inertia that tends to be a hindrance for new solutions. Many parts of these routines have their basis in practices that were established several decades ago. The specifications and tools for the planning of the lighting have a basis in large international standardization processes based on earlier research and at the basic scientific level organized by CIE. This material has been used as a basis for development of building norms and procurement requirements that include main norms such as 500 lux at work areas. Concerns of health are rarely linked to light (vs air quality, chemicals, noise, etc.) in the procurement.

So far most actors continue to use their old lighting specifications also for SSL and smart lighting. The resulting effect is that most LED so far is used for replacement installations that aims to produce the same static lighting as before. This is a hurdle for deployment of solutions that make more advanced use of the controllability of LED in combination with today´s ICT. The main potential improvements with using dynamic LED´s etc. are therefore so far difficult to achieve.

How can local planning regulations for lighting be modified?

There are many instances and experiences that demonstrate that many construction stakeholders will only change their ways of working when planning regulations are changed. To provide an effective trigger for change it is suggested to build awareness among those responsible for setting and maintaining planning regulations for lighting, both for construction and refurbishment.

This message needs to involve the Local Authority Planning Departments for setting and maintaining lighting requirements.

How to encourage office developers to use new light solutions?

One effective way is by clarifying that lighting improvements is a most cost effective tool to make the working environments more functional and attractive. It is also relevant to mention that leading innovation actors aims to integrate intelligent lighting with facility management, sensors and ICT systems and that this message is communicated by leading societal development actors, e.g. in Lighting the Cities.

Office developers must adhere to national building standards and local planning requirements. That said; there is still a lot of flexibility about how the standards and planning requirements are met in practice.

How to encourage design consultants to suggest more advanced SSL?

One thing societal actors can do is to build a "scene" for positive story telling about advanced lighting examples, e.g. by networking events. Lighting for People presents numerous case studies.

How to encourage professional bodies and research associations working in the lighting and building services sectors to use more intelligent solutions?

Professional bodies and research associations provide state of art guidance to many different stakeholders associated with lighting and facility management systems in office buildings. By providing forward-looking guidance and advice concerning the benefits, specification, procurement and installation of intelligent SSL systems, both professional bodies and research associations can be effective triggers for renewal.

Demonstrate new functionalities

It is vital to show actual examples of what it is possible to achieve with todays SSL in combination with intelligent system functionalities. It is also crucial to consider how new learning's can be utilised in procurement of more installations. As in all other forms of professional engineering it is crucial to test the new functionalities in such a way that there is free access for measurements, corrections and further improvements.

Involve appropriate expertise

It is important to involve appropriate expertise in the selection and basic description of the goals, and also to get trustworthy competent advice regarding possible complications. This is not easy, because the lighting technology now include aspects that are quite different from how it used to be, only a few years ago.

It should be noted that the new knowledge on health and wellbeing shows that that there are motives for light variations that are quite different from how lighting used to be. The new technology is enabling quite new functionalities, and most of the established lighting professionals have limited knowledge about the new technology. There is a risk of misunderstandings. One and the same word may mean different things for different people, e.g. "dynamic" may be intended to mean an automatic variation or alternatively a possibility to use a set of buttons to vary the light. Most lighting professionals are not used to work with control systems, and vice versa. There is a risk that we think that the people we talk to have knowledge and experiences that they don't yet have. This is also difficult from contractual point of view.

It is crucial consider that we now have very many quite different lighting related products on the market. The light characters, functionalities and qualities vary quite considerably. It is important to use reliable knowledgeable suppliers. When you aim for new functions, radically new products, more economic solutions and energy saving it are vital to check with trustworthy experienced persons. For example, the LED market so far includes products that are glary and flickering. It is prudent to assess the products, e.g. together with light designers and persons that are knowledgeable in lighting related electronics, and preferably also make measurements before procurement.

From a procurement point of view this means that lighting changes from a standardized commodity to an advanced and rapidly developing systems technology. Lighting design becomes even more crucial than before because of the many simultaneous changes that are occurring. New is that electric installers and their customers have to be aware of is a considerable and growing need for integration with control system functionalities.

Introduce lighting early in the planning and building process.

At a higher-level, lighting has been a minor part of the building sector and often just been added at the end of the planning and installation processes, In the worst case the lighting equipment is selected and added at the end of the process, when the house is almost ready.

5.7 Summary of what cities can do

The SSL-erate project observations correspond with earlier observations that it is technically, visually, biologically and emotionally possible to generate a significantly higher user value by means of SSL. The needed acceleration of the deployment of more advanced SSL solutions has started. The SSL-erate results provide guidance for how the acceleration can be enhanced.

To be able to improve the management of the present situation it is important to take it seriously that SSL is significantly different from the earlier lighting technologies. In many respects lighting is becoming a part of electronics and ICT (Information and Communication Technologies). It is becoming possible to vary the light in very many different ways and there are significant differences between different products. Several products on the market are rather immature and the product development is much more rapid than for the earlier generations of lighting. It is crucial to build awareness about the differences.

Figure 16 summarizes what cities can do to enable better utilization of SSL as a tool for sustainable development. Most of these advices focus on improvements for the social sustainability dimension. It should be noted that these "tools" are intended for clarification of which light actually is desirable. This is an important basis to enable effective use of resources, including energy savings in concert with user value improvements.

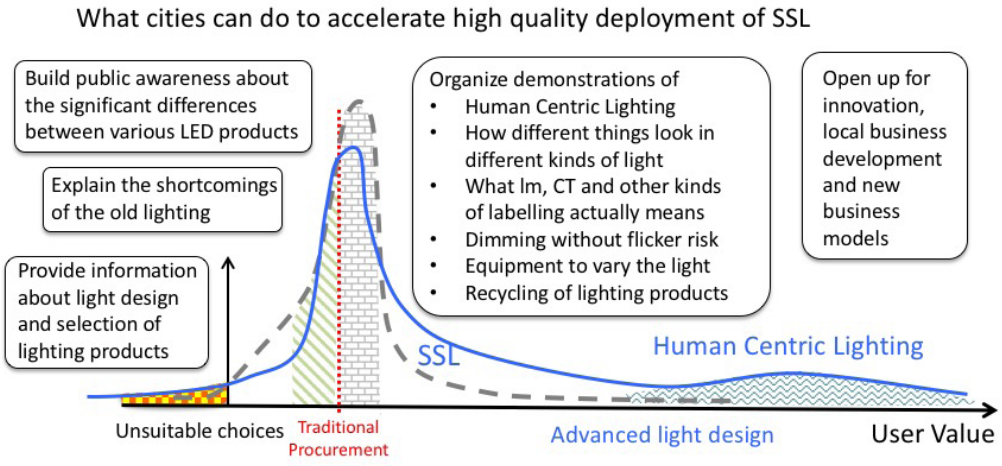

Figure 16 - Advices for how cities can pave the way for value enhancing deployment of SSL.

5.8 City motives for promotion of SSL

Some achievements by SSL-erate cities' and also their reasons to take interest in SSL and SSL promoting activities are described in 5.1 above.

The common motivation for the city experts' participation in SSL-erate is that they are convinced that SSL is a technology for the future and that intelligent lighting systems is a key to the digital age. The SSL-erate cities want to speed up their learning processes to be able to enhance their utilization of the evolving technical potential and knowledge about HCL.

It is vital to demonstrate more advanced SSL solutions and explain the advantages, to build awareness about the potential of SSL. In this respect SSL-erate has been quite successful. The participation in SSL-erate has stimulated internal build up of awareness and knowledge. More than 50 cities have participated in 24 workshops and outreach activities by cities and LUCI. The dialogues have been interesting.

The SSL-erate cities have used different strategies for their build up of awareness. At an early phase of the project Malmö decided to make a demonstration installation of human centric school lighting. This was enabled by Malmö's participation in the SSL-erate project. If Malmö had not been a partner in SSL-erate it would have been even much more difficult to motivate the allocation of the own internal resources that enabled this demonstration. Bassano del Grappa made use of the project momentum to engage local and regional media and schools in the build up of SSL interest. Stavanger has made use of the SSL-erate momentum to enhance the regional interest in more advanced deployment of SSL in outdoor lighting and more intelligent system solutions; in particular via the regional utility Lyse in dialogue with their 16 municipalities in Sør-Rogaland. The lighting researchers within Vilnius University have made use of the SSL-erate momentum to strengthen their role in a number of regional development ambitions. The persons that are involved in those processes has benefited from the SSL-erate exchanges of experiences about why human centric lighting is important and how to move ahead with open innovation processes.

The Malmö process is an interesting example. The interest to make this installation was initiated by the dialogue between Malmö City and Lund University, early in the SSL-erate process. Malmö managed to find a school setting with really interested persons. Then the city's Service Department initiated an open dialogue with the classroom teacher and others at the school and started to look for a suitable design and a technically possible system solution and products. It was decided to make use of tunable white luminaries and to use an automatic variation schedule for light intensity and color temperature. When Malmö started to talk with potential suppliers, both from the lighting sector and from the facility management sector, they did not find any supplier that was ready to deliver the kind of interoperation-able system solution that Malmö is aiming for. The Service Department decided to organize the system design and installation themselves and started to look for readily controllable luminaries, control system components and software. The basics of human centric lighting and the planned installation were presented for the classroom teacher and the pupils. It took a number of tries to find a working system solution, for example it was discovered that the available communication protocols were rather immature and closed. After a year of laboratory experiments and dialogues with various suppliers Malmö found a system solution that they could make use of. The installation was ready in October 2015. Malmö has continued to follow the market evolution and during 2015 and 2016 the supply of compatible products and communication protocols has improved considerably. On the ICT market there is an abundant supply of communication devices and possible user interfaces. Two success factors of the Malmö demonstration are that it has an automatic light variation schedule and a readily understandable user interface. The effects and appreciation of the installation has been evaluated in two Master projects in dialogue with the teacher and pupils. The results are coherent with the general scientific knowledge about HCL. The installation and experiences have been presented as a part of the SSL-erate results, e.g. at LuxLive and Light+Building. Olle Strandberg, Malmö City is now getting more and more requests to present the experiences from this demonstration and Malmö will make use of similar solutions in the new schools that are being built.

CONCLUSION

6 |

6 | CONCLUSION

The SSL-erate project experiences show that SSL enables sustainability oriented development opportunities for the cities that engage. The project cities have taken various kinds of lead in regional development processes.

The SSL market and uptake is growing rapidly. To broaden a more advanced utilization of this potential there is a need for policies, processes and networking that can be used to build momentum for renewal oriented activities and demonstrations. This means that there are great branding opportunities for the cities that take lead roles.

It should be rather straight forward for cities to start to make better use of SSL as a tool for sustainable societal development. Combination of the controllability of SSL and the ICT of today provides great potential to dynamically adapt the light to human needs and wants. The SSL-erate project clarifies that there are great business development opportunities, e.g. for schools, hospitals and for elderly.

The main political drive behind LED uptake is still energy saving. The lightings social and economic significance for sustainable development tend to be neglected. Procurement and the building sector are still normally using the lighting norms that have been used for the old lighting technologies.

Also, supply and demand are dominated by products that aim to simulate the light output of incandescent lamps. The market supply of more advanced high quality and readily useful products and open ready-made system solutions for e.g. human centric lighting is limited. This leads to the conclusion concerning green business development that there are opportunities, but these don't always lead to business because of lack of political support and of examples and products. However, this is changing as illustrated by Malmö HCL school case. At the start of SSL-erate no (lighting and ICT) systems were available satisfying their specifications, hence this was developed together with local entrepreneurs (in an open innovation collaboration). However now, few years later, market supply starts to materialize.

The product development is much more rapid than for the earlier generations of lighting. One consequence is that several products on the market are rather immature. It is crucial to build awareness about the differences that exist, between different products on the market.

The systemic development potential for smart systems and interoperationability is so far hardly utilized. It is still rather difficult to build open systems and the development of the lighting systems is normally not coordinated with the development of the cities ICT systems for other services.

The observations during the SSL-erate project show that the development now is accelerating. There is a rapid market development and for example it has become much easier to make use of Human Centric Lighting for schools and deployment of user-adapted lighting is becoming much more manageable and cost-effective.

SSL and Smart lighting control enable significant energy savings. Longer replacement intervals and operational advantages enable even larger cost savings. There are no known particular environmental risks with LED and the new lighting is an important aspect for development of a circular economy.

The main advantage for cities and sustainable development is that SSL can be used to enable living and working environments with better functionality, attractiveness and health and wellbeing characteristics.

The social and economic advantages, which are possible with SSL, means that, there is significant potential for green business development. SSL enable significant improvements of the working and living conditions, e.g. for children and elderly. It is a societal social responsibility for cities to make use of this improvement potential.

More people are starting to realize that light is vital for health and wellbeing. When more cities start to demonstrate more advanced lighting and takes it seriously that it is important to develop policies and specifications for more advanced lighting, this will result in a large market with higher willingness to pay for better lighting. This is a great opportunity for local innovation and green business development.

LITERATURE

LITERATURE

Other SSL-erate reports available via www.lightingforpeople.eu:

- Priority list of suggestions for demonstrations and business experiments
- Sustainability issues for SSL
- Lighting for health and wellbeing
- Recommendations and opportunities for implementation of Human Centric Lighting.
- Open Innovation Toolkit

REFERENCES

Govén, T, Raynham, P, Laike, T, and Sansal, E; The Influence of Ambient Lighting on Pupils in Classrooms-Considering Visual, Biological and Emotional Aspects as Well as Use of Energy, in Adjunct Proceedings (2010), p. 13 .

Joss, S (2015); Sustainable Cities: Governing for Urban Innovation. London: Palgrave Macmillan

OECD/IEA (2007); Mind the Gap, Quantifying principal agent problems in energy efficiency (https://www.iea.org/publications/freepublications/publication/mind_the_gap.pdf)

Richard Register (1987); Ecocity Berkeley: building cities for a healthy future, North Atlantic Books

UN, WHO (1949). Agreement between the United Nations and the World Health Organization. New York

WHO (2008). Commission on Social Determinants of Health. Closing the gap in a generation - health equity through action on the social determinants of health. Final report of the Commission on Social Determinants of Health. Geneva: World Health Organization

WHO (1946) Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19-22 June, 1946; signed on 22 July 1946 by the representatives of 61 States (Official Records of the World Health Organization, no. 2, p. 100) and entered into force on 7 April 1948.

Web references for Corporate Societal Responsibility (CSR):

Association of Chartered Certified Accountants
http://www.accaglobal.com/an/en/member/professional-standards/ethics/qualifiations-csr.html

European Commission
http://ec.europa.eu/growth/industry/corporate-social-responsibility_sv

Government of Canada
https://www.ic.gc.ca/eic/site/csr-rse.nsf/eng/h_rs00587.html

PARTNERS

Aalto University

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

CITTA' DI BASSANO DEL GRAPPA

Centre for Chronobiology
Psychiatric University Clinics Basel

Cicat

Cluster Lumière

University of Applied Sciences Munich

DTU

EINDHOVEN

ESADE
Ramon Llull University

KU LEUVEN

kamer van koophandel

LIGHTINGEUROPE
THE VOICE OF THE LIGHTING INDUSTRY

LUCEINVENETO

LUCI ASSOCIATION

LU OPEN
Lund University Open Innovation Center

LUX MAGAZINE

Malmö stad

University of Oxford

rijksuniversiteit groningen

CITY OF STAVANGER

TNO innovation for life

UCL

Vilniaus Universitetas 1579 Universitas Vilnensis

SSL-erate

SEVENTH FRAMEWORK PROGRAMME

www.ssl-erate.eu

lightingforpeople.eu