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FREQUENTLY ASKED QUESTIONS ON SSL ACQUISITION, SELECTION AND USE

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FP7-ICT-2013-11-619249

ACCELERATE SSL INNOVATION FOR EUROPE

FREQUENTLY ASKED QUESTIONS ON SSL ACQUISITION, SELECTION AND USE

AUTHORS:

Reine Karlsson, Lund University
Jos Kunen, TNO
Yvonne de Kluizenaar, TNO
Pieter Jan Bolt, TNO

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SUMMARY

This report consists of a compilation of questions concerning solid-state lighting (SSL), posed by city and council representatives at various workshops organised within the framework of the FP7 SSL-erate project in the period spring 2013 to autumn 2015.

The SSL questions have been structured into three categories, namely:

1. General information about LED lighting;
2. Application areas, such as e.g. education (schools) or the workplace (offices);
3. Practical information.

For each question answers are provided, aiming at non-specialists in lighting.

The answers have been provided by the SSL-erate consortium members

GENERAL INFORMATION

1

1 | GENERAL INFORMATION

Recent developments in lighting technology have brought many new possibilities and have widened the field of light applications, but have also increased the information need for specification and decision-making. Digital lighting, based on LED lighting, has become shapeable and user adjustable and provides great opportunities in terms of energy saving, manageability, and adapting light to various human needs.

Currently however, most commonly applied products and system solutions on the market do not yet exploit these opportunities. Furthermore, the properties and qualities of the lighting products that are currently available on the market vary. Consequently, it has become more difficult to make appropriate choices of lighting design, systems and products. It is difficult, for example, to find explicit guidance for how the light ought to be varied to make optimal use of the value enhancing potential.

1.1 WHAT IS LED LIGHTING?

Lighting applications that use light emitting diodes (LEDs) are commonly known as LED lighting. LEDs contain a solid-state object (a semiconductor) that emits light through electroluminescence, hence the name solid-state lighting (SSL) is also used. Thus, the light source differs from incandescent lighting (using an electrically heated wire filament in vacuum) or fluorescent lighting (using a gas). The colour of the light that can be produced by LEDs depends on the semiconductor materials. Different types of LEDs are available, which can provide light of different colour (or colour composition). A common and energy efficient technology to generate white light is to use a blue light emitting LED, surrounded by materials that convert the blue light partially into yellow and/or red light. This results in (to the eye) white light.

Beside LEDs made of inorganic semiconductor materials, also organic light-emitting diodes (OLED) have been developed. The terms LED lighting and SSL are both used throughout this brochure, but here SSL mainly refers to (inorganic) LED lighting.

1.2 WHY USING LED LIGHTING?

SSL systems have a number of significant advantages compared with traditional forms of lighting. Some prominent advantages are described hereafter.

1.2.1 Energy Savings

A strong argument for choosing LED, is the energy efficiency of solid-state light sources and thereby its energy saving potential. LEDs produce light very efficiently, consuming less electricity than, for instance, incandescent lighting.

1.2.2 Light design and controllability

The improved controllability of the LED and ability to modify colour tones is another unique selling point. LED based digitalization of light allows for intelligent lighting control which can make indoor and outdoor environments more attractive and functional.

It should be noted that the ability to get the right light, in the right place, at the right time is very much dependent on the lighting and system design, i.e. the ability to position the right luminaries in the right place and to enable a user adapted lighting control.

1.2.3 Health / comfort

How does light affect us?

Light is required for vision: The ‘image forming effects’ of light (IF). However, it also affects our well-being and health much more than most people realize. Light affects our mood, alertness, attention and the body’s internal biological clock, helping to wake up in the morning and fall asleep at night, our immune responses, appetite and many more of our functions and behaviours. This is partly emotional (psychological) but also biological: the non-image forming (NIF) effects of light (such as the effect on melatonin production). The International Commission on Illumination (CIE henceforth) proclaims that “we now know conclusively that photoreception in the eye leads not only to vision, but also to effects on human physiology, mood and behaviour, often summarized as non-visual effects of light.”

Dynamic lighting by smart variation in colour (spectral) composition and intensity, provides great opportunities for adapting lighting to human needs, to enhance health, wellbeing and productivity (human centric lighting).

What is 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.

The lighting profession has started to recognize the importance of designing lighting installations that takes also non-visual effects of light into account.

This includes to make use of the SSL controllability to vary a number of lighting attributes related to intensity, spectral composition, duration and timing of the light exposure. While innovative ways to beneficially affect human health, behaviour and comfort has started to be used, the market readiness and market awareness of HCL needs to be further developed to benefit from its full potential.

How can SSL lighting help?

SSL can be easily controlled digitally. The adaptability of digital solid-state light to the user’s physical or social needs is a large advantage over other types of lighting. With SSL, lighting has become more easily adjustable in colour and level. The colour and intensity of artificial light can be designed to imitate the natural light variation and restore some of its beneficial effects on our biological systems. Solid-state digital light can be programmed to this purpose, far beyond light regulation through simple dimming or presence detection alone.

Why important in indoor environments?

Nowadays, people spend most of their time in indoor environments with relatively little daylight. Consequently, people are not only exposed to lower light intensities, but also lack exposure to daylight from the sun. This lack of daylight can interfere with the body's natural cycles. Furthermore, blue-rich light and cool tones of white light (high colour temperatures) should be avoided in the evening and night time. Suboptimal indoor lighting conditions can adversely affect our wellbeing, mood, alertness, attention as well as our sleep-wake cycle. It may thus adversely affect cognitive performance in schools and at work. Disturbances in the circadian rhythm have been linked to chronic diseases such as insomnia, hypertension, diabetes, and depression and should be prevented.

Why important for outdoor environments?

Outdoor lighting, such as street lighting, can encourage outdoor activity, social life and recreation, and can be used to promote well-being, safety and a pleasant atmosphere in cities. The digital control possible with SSL can help to provide a better 'city nightscape' (enhancing aesthetics, ambience, attractiveness, liveliness). Examples of such applications include outdoor illumination of buildings and focusing light on natural objects, such as the greenery (which may enhance the perceived safety, restorative capacity and preference of pedestrians). Furthermore, digital SSL allows adapting the lighting better to the needs of the citizens (using human centric lighting principles); One such example is the possibility to limit the emission of blue-rich light to control potential adverse effects of light (circadian effect, discomfort glare, photophobia and sky glow) at night-time.

SSL also offers the possibility to design flora and fauna friendly (green) lighting solutions: lighting which is better in tune with the ecosystem and more fauna friendly. This implies for example that designing green dominating lighting in parks (and other green environments) should be promoted. This would enhance the natural colours of the environment and at the same time it may produce less sky glow and attract fewer insects as compared to blue rich light sources. Furthermore, it may have less disorienting effect on migrating birds as compared to long-wavelength (red rich) light. Such a spectral content would also enhance (mesopic) vision in low but not quite dark lighting situations, and may limit discomfort glare. (see "Lighting for health and wellbeing" brochure on www.lightingforpeople.eu).

Examples in practice

One and the same fixture can provide several light colours and intensities, which can be useful to enable multipurpose uses of a room. An examination room at the hospital can be converted into a comfortable and welcoming office. At the touch of a button a bright neutral light can become soft and warm.

A day room at the elderly care centre can be given a dynamic atmosphere in the morning to encourage activity (activating light), but imitate natural light shifts during evening time and become a place of calm (de-activating light), helping patients come to rest.

Need to strengthen evidence on benefits in practice?

Research in 'real life settings' should be strengthened to extend the knowledge base for what "optimal illumination" is for the non-image forming effects of light. Specifically, well-designed large representative field studies (intervention studies) are needed, to allow quantification of benefits, preferably in terms of relevant 'Key Performance Indicators'. It would help the industry if many (human centric lighting) projects were properly followed after installation for their results, also in terms of benefits to the users, so that a database of 'quantified' proof can be created.

The right light at the right time: which recommendations can be given?

Research has already brought important insights that can be used, and are already used to improve lighting conditions both in indoor and outdoor environments. More knowledge is expected to come available on how to optimize lighting for individual needs which may differ between people (e.g. by age), and by time of the day, time of the year, type of task, etc. Knowledge coming available in years to come, will allow further optimization of systems. Based on current knowledge, application recommendations for biologically effective lighting can be found in the brochure "Recommendations and opportunities for implementation of Human Centric Lighting" on www.lightingforpeople.eu.

1.2.4 Smart lighting

What are the advantages of smart lighting?

Through its digital technology, SSL allows the light output to be controlled in a precise manner, adapting to changes in the users' needs as well as in its own performance. An example of the latter is the constant lumen output programming. The luminaire's digital driver starts at a certain power to produce a given amount of light, and progressively increases in effort to compensate lumen loss in aging LED chips - to boost the tired LEDs, so to speak. This technology, enables a park of fixtures to deliver a constant amount of light regardless of when the individual fixtures were installed. This presents big advantages from a maintenance point of view.

From users point of view, smart lighting systems (with sensors, advanced data processing and control loops and interoperability with e.g. entertainment, security, or building management systems) allow light to dynamically be adapted to the needs of the users.

Balancing natural daylight

Light intensity can be controlled in a way to balance the total lighting in e.g. an office or a street with natural daylight resources. An interior light level can be made to vary seamlessly, to compensate or imitate fluctuating sunlight.

Smart use of sensor information

By treating the lighting on system level (instead of as a set of individual lamps) including for example sensors, supporting interface and control protocols will multiply the functionality.

This system approach needs to address the issue of (future) interoperability with other systems (e.g. building management systems, smart city infrastructure) from the start and needs to be open for the ever more advanced digital advantages like intelligent maintenance and information transfer.

Smart lighting could use sensor data to assure that the right lighting is provided where and when needed. Some data will need to be stored like the average lighting level over a specific period, burning hours, etc. This data can also be used for long-term policy making on installation / procurement of lighting systems in, for instance, offices and schools.

1.2.5 New directions

At the start of the market introduction of SSL, much effort was spent on creating imitations of existing lighting (retrofit lamps), which did not exploit its opportunities to its potential, and thereby masked the true qualities of SSL on the public consumer market. But the different physical and control properties of modern lighting technology in comparison to classic (incandescent or fluorescent) sources technology enable a broad field of new applications and much more flexibility in terms of adaptions to varying user needs.

Because solid-state light sources produce less heat than conventional sources they can be installed in more confined spaces (up to a limit since LEDs cannot function without sufficient cooling). The miniature technology contributes to this advantage, but also allows for new configurations. For example solid-state linear light lines can, due to their small components, be bent in a way that neither fluorescent nor neon lines could be bent in, which opens up for entirely new design possibilities. Less fragile by nature than most light bulbs or other glass enveloped sources, SSL presents an advantage.

Solid-state lighting combined with numerous other kinds of ICT has great potential in open-ended system development.

1.3 PROCUREMENT/BUSINESS

1.3.1 Cost metrics

What are appropriate metrics for expressing costs for lighting in cities (e.g., costs per inhabitant, per year, per km road length, etc.)?

Cities will generally start with the budget available (euros) and try to get accomplished as much as possible with that. After reserving a part of this budget (the required budget for energy use and regular maintenance), a part of the remaining budget is available for improvements. The city lighting people will then generally look at the Total-Cost-Of-Ownership (TCO) and the city finance department will look at the Return-On-Investment (ROI). If the ROI is not satisfactory and investment can bring bigger benefits in another domains than lighting, it could be that they prefer that. However, other considerations become increasingly more important drivers for action. Retrofitting street lighting for more energy efficient alternatives, can contribute to achieve CO_2 reduction targets. In addition, light innovations can provide a better 'city nightscape' (enhancing aesthetics, ambience, attractiveness, liveliness). This can contribute to encouraging outdoor activity, social life, and recreation, and thus promote well-being, safety and a pleasant atmosphere in cities. Furthermore, this can increase city attractiveness for inhabitants and tourists.

Indeed, an important metric that is currently missing in TCO evaluations is the added value that better/smart lighting can bring. Indicators of this new significant added value should be developed and added to the current ways of evaluation. (See also the question about 'added value of intelligent lighting' in Section 1.3.5.)

1.3.2 Scientific evidence and the business decision process for HCL

How to deal with lack of evidence on benefits in terms of Key Performance Indicators in the business decision process?

There are still many unknowns, e.g. in terms of a lack of large representative field studies (studies outside the laboratory under real life conditions). It is difficult to quantify the effects of light on user related key performance indicators (e.g. sick leave, productivity etc.). Yet, however, a large amount of research is available, that allows providing a range of practical recommendations for lighting design to substantially improve lighting conditions, which currently often are sub-optimal (see www.lightingforpeople.eu, documents: "Lighting for health and wellbeing" and "Recommendations and opportunities for human centric lighting").

How to deal with the customers desire for (more) successful examples in practice?

In business practice this will mean that some potential customers will not be willing to buy such a system at this stage, while others - early adaptors - are willing to try.

Successful application examples should be demonstrated and be made more widely known to inspire people (on platforms such as www.lightingforpeople.eu) to take similar steps towards improving lighting conditions. It will be useful to make a satisfaction assessment of the installed lighting system for a better validation / quantification of the benefits. Of interest are the user results. It should be noticed that steps have been made towards metrics for lighting planners and specialists. This methodology provides recommendations (standards how to measure light) that are important to make assessments of various kinds of lighting solutions comparable (see www.lightingforpeople.eu: "Report on metric to quantify biological light exposure doses").

1.3.3 Practical advice and information

Which practical information may aid lighting planners and specialists to comply with customer requirements to vary the lighting conditions in accordance with human needs?

- Practical application recommendations: SSL-erate has formulated a range of practical application recommendations based on current knowledge, for different application areas (see "Lighting for health and wellbeing" and "Recommendations and opportunities for implementation of Human Centric Lighting" brochures on www.lightingforpeople.eu).

  In addition, steps have been made towards metrics for non-image forming effects of light from spectral and illumination data for lighting planners and specialists. (see www.lightingforpeople.eu: "Report on metric to quantify biological light exposure doses"

- Guidance document(s): A guidance document is available on how to practically start optimizing lighting for human needs (Human Centric Lighting, HCL application) for lighting professionals: The DIN-SPEC 67600, written by DIN (2013), with input from an expert panel. This document was published originally in German, however currently an English version is being elaborated: "Biologically effective illumination - Design guidelines". This will encourage lighting professionals and lead users to get started with HCL implementation.

1.3.4 Markets

Is there a market for off-grid lighting, in Europe?

As the electrification in Europe is very high and off-grid power/generation storage is still quite costly, off-grid lighting is not a mainstream business opportunity. However, photovoltaic solar panels and compact batteries are decreasing in price and ever more combinations of small light sources with this kind of power supply are becoming available. These kinds of units are starting to become interesting for places where installation is difficult, as well as for remote locations.

What are examples of 'low hanging fruits' and SSL solutions in retrofits?

For the consumer market the low hanging fruits are already there in replacement (retrofit) lamps.

Stakeholders expressed a need for development and increased availability of 'easy to use', 'easy to implement' systems including control panels (proven to be reliable and to work well in practice), particularly solutions allowing 'easy retrofit', e.g. 'plug and play' solutions: 'ready to use' solutions which can be installed easily in existing buildings, without having to change the existing system and/or to make related structural adjustments (cabling, wiring, ceilings, electricity supply, etc.).

1.3.5 Technological progress and procurement

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

One approach is to aim for completely open solutions with appropriate modularization allowing for flexible solutions and scalable systems. But this is not an easy road to follow. 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 lighting standardization, regulations, codes and certifications. To get a reality-based learning process, it is important to invest in early demonstrations and disseminations, as a base for mutual learning's.

Another approach is to strive for standardized interface solutions. The Zhaga consortium for example, aims to accomplish such an exchange solution in lighting systems for components of different suppliers (see http://www.zhagastandard.org/). The TALQ consortium aims to develop an internationally accepted, standardized software interface to manage outdoor lighting systems of different vendors. More information about these solutions can be found in the Section 3.1.2 and 3.1.3, respectively.

Can a plug and play approach make SSL more attractive?

On system level, plug-and-play will be a means to bring down cost and complexity: at the start of a project (ease of installation) but also during the years of operation (ease of updating and/or connecting the lighting system e.g. with building management systems).

How can the added value of intelligent lighting be taken into account in the decision making process?

The Total Cost of Ownership (TCO) – a financial estimate intended to help potential buyers to determine the direct and indirect costs of a lighting system – plays an important role in the decision making process whether to install such a system. A TCO analysis includes total cost of acquisition and operating costs as well costs related to replacement or upgrades at the end of the life cycle. The acquisition cost of an SSL lighting system can be high, whereas the operating costs, especially electricity and maintenance costs, can be low compared with a conventional lighting systems.

The added value of digital lighting (resulting from its controllability, adaptability to specific needs and interoperability), is, however, difficult to include in the decision making process. Use experience with the new systems is still quite scarce hampering monetization of the added value. Fortunately, development and application of intelligent lighting systems is advancing rapidly. It is expected that the benefits of intelligent lighting on user-related key performance indicators such as reduction in absenteeism, rise in productivity etc. can be quantified within a few years enabling the monetization of these benefits and the inclusion in cost-benefit analyses. Furthermore, intelligent lighting provides the opportunity to open up for the digital age and to stimulate the networking and competence development that is needed to get ready for these developments.

For the time being, the future benefits of new lighting systems should be included as explicitly as possible in the economic evaluation. Moreover, qualitative information on added value relating to e.g. promoting the image of a company or city and increasing the satisfaction of employees or citizens etc. should complement the quantitative information.

It is important to ensure that the total methodology provides insight in the bigger picture, including all relevant costs and benefits, to enable decision makers to make better informed, well balanced choices.

1.4 Metrics

What is needed in terms of metrics to allow comparison of products and systems?

LED lighting systems, with the associated energy reduction potential and the digital opportunities for control, adaptability and interoperability of the systems, changed the lighting industry. Consequently, new metrics are required for comparison of products, since the existing metrics are not sufficient anymore to adequately describe these new features.

Methods to address the costs and benefits/gains are discussed, especially for SSL in cities, in Section 1.3.1, and, more generally focussing on the added value of SSL, in Section 1.3.5 and in Section 3.4.

The performance metrics of traditional lighting need to be extended for SSL systems. For example, light output (lumen), efficacy (lumen per watt), lifetime, number of switching cycles, colour temperature (Kelvin) and colour appearance (correlated colour temperature, CCT) of the emitted light are important for the new lighting systems. Besides the colour rendering index (CRI) as unit for colour appearance of illuminated objects other appearance metrics are needed (and under development). See also Section 3.1.1 on performance of SSL.

Metrics for the possible occurrence of discomforted lighting phenomena, such as flicker and glare, need to be improved; see also Section 3.1.1. on flicker and glare.

Attempts are being made to quantify the biological effects (non-image forming / NIF effects) of light in order to make optimal use of HCL. More information can be found for example in "Report on metric to quantify biological light exposure dose" on www.lightingforpeople.eu). When more insight has been obtained in the possible NIF effects, a metrics framework needs to be developed to enable the comparison of intelligent lighting products in terms of user-benefits.

APPLICATION AREAS

2

2 | APPLICATION AREAS

2.1 Workplaces

How to encourage office developers to use new light solutions in both office new-builds and refurbishments?

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

Ergonomists (once they are well informed with respect to the importance of optimal lighting conditions) can play a role as advocate of the concepts of optimal lighting conditions in the workplace, and can disapprove of ergonomically suboptimal working conditions in the interests of the user.

Other approaches may be required with respect to encouraging intelligent lighting solutions, in view of its benefits, e.g. through selling an integrated concept to Chief Executive Officers (CEO) (who's interests include: supporting the company's image, the company's employees satisfaction etc.) and Chief Financial Officers (CFOs) (responsible for the company's finances: economic valuation is of importance) of companies, may be a way to promote the uptake of advanced lighting solutions (CEO and CFO should become involved as partner).

How to encourage design consultants to use new light solutions in both newly built and refurbished offices?

The basis is almost the same as for the office developers, i.e. there is a growing market advantage for offices with advanced lighting and thereby an even earlier market advantage for the design and lighting consultants that develop and show renewal oriented lighting competence. One thing societal actors can do is to build a "scene" for positive story telling about advanced lighting examples, e.g. by networking events.

2.2 Education

2.2.1 Implementation

How to implement human centric lighting in schools (from a school perspective)?

As a **first step**, to assure knowing what to ask for in the next steps of the process, it is important to get well informed on what SSL and HCL is and what the possibilities of HCL are. Sources of information can be found in Section 1.3.3.

As knowledge about HCL possibilities is still limited, as well as successful examples in practice (certainly within schools), a school should seek in the **second step** the assistance of a lighting professional/agency with knowledge on and/or affinity with intelligent lighting, HCL in particular, and the willingness to innovate in order to define together the lighting design project.

The project plan should, at least, contain:

- the aims of the lighting project (e.g. improvement of educational environment, improvement of school image, cost reduction, ...);
- the (integration) possibilities and obstacles within and around the school (such as the electrical and ICT infrastructure of school and the surroundings, ...);
- an assessment of the interests of important stakeholders (e.g. students, teachers, other school staff, the building owner (e.g. the municipality, if not the school itself, ...);
- other topics (such as how the HCL system addresses the aims, features and lifetime of HCL system, warranty, maintenance, after-delivery of components, ...).

In the **third step**, the lighting professional/agency should elaborate the lighting project definition plan into a plan of action specifying the detailed design, the requirements and the test program for acceptance and optimisation of the school HCL system to the needs.

The procurement process for which the school is responsible in the end, should be part of this plan too.

After approval of the plan by the school the potential suppliers of such a HCL system have to be approached in the **fourth step**. During this step the plan of action might need some revision. Depending on the estimated magnitude of the order, either a European tender has to be launched or the best quotation can be accepted.

In the final, **fifth step**, the HCL system has to be installed and can, after thorough testing, be accepted.

2.2.2 Control

What design recommendations can be made?

An intelligent dynamic HCL school lighting system should function as a tool designed to enhance the working conditions for both the students and the teacher, and also to facilitate the teacher's work.

One suggested design principle is to aim for an HCL system which automatically mimics an optimal natural light variation pattern, possible complemented with additional features (e.g. to prevent an after-lunch dip). In addition, it should be possible to manual override the pre-programmed variation with pre-defined lighting conditions and to switch off the system.

The automated light variation (sometimes called circadian variation) can support optimal usage of the alerting effect of more intense and higher colour temperature light, as well as of the potential to reduce feelings of distress and fatigue. This kind of variation can also be interesting from energy effectiveness point of view (but not necessarily so).

The manual override option allows to select the lighting setting that is desired in a specific situation (e.g. concerning certain activities, conditions, or time of the day) during the school day requiring different lighting than imposed by the circadian setting. For example, pre-defined settings for use of a smart board and/or video projector and for activities requiring concentration should be available. Of course there also is need for a switch-off option, both manually and automatically (controlled for instance by presence sensors).

How can the teacher overrule automatic functions when required for a specific activity?

The control unit of the HCL lighting system should have pre-defined lighting settings for manual override possibility, to provide the lighting wanted during a specific situation, that can be imposed by a user friendly control panel (e.g. by pressing a button or using switches) (see also 'design recommendations' answer above).

What to do if class schedule is changed?

The class schedule as such is not the control parameter for the lighting in school. From a basic circadian point of view the natural approach is to use a generic variation that is adapted to the time of day. The variation also may include some adaption in relation to the normal time of lunch and other breaks. The daily adaptions to what happens in the classroom has to be controllable by the teacher (e.g. like changing the light setting when using a smart-board). (see 'design recommendations' answer and 'overrule automatic functions' answer above).

2.2.3 Required training of personnel

What kind of education does the teachers and maintenance personnel need?

There are two levels of educational needs and opportunities:

- to increase understanding on how to make optimum use of the potential that the new technology enables;
- to build awareness among the students, about how important the variation of the light is for health and wellbeing.

When the HCL system has been installed, they need information about the specific lighting system in their facilities, e.g. how to turn it on and off, how to change mode etc. They also need information about the specific aims with the various lighting modes and variations, e.g. regarding health and performance. To avoid dissatisfaction, specifiers and installers should meet with teachers and maintenance personnel after the installation to make sure that everything is working according to their wishes and preferably again after some months of operation (e.g. after 6 months and/or 1 year), since most questions may arise after some time of use.

2.3 Health care

2.3.1 Light and the ageing eye

There are studies that indicate that the effect of blue light may reduce with aging (http://dx.doi.org/10.5665/sleep.3314). Are there relevant experimental results available from 'field studies' (in representative 'real-life settings'), in elderly care?

The paper referred to above, presents results from a comparative study (in which individuals were alternatingly maintained in darkness or exposed to blue light). It shows that the effect of blue light on brain responses diminishes with aging in areas typically involved in visual functions and in key regions for alertness regulation and higher executive processes.

This may be explained, or the effect strengthened, by the yellowing of the lens with age, absorbing more of the blue light. This is mentioned in the "Lighting for health and wellbeing" brochure on www.lightingforpeople.eu):

"Another level of reduced light input relates to age-related changes in the eye. In order to obtain proper visual sharpness, the average 60-year-old person needs two to three times the light of a 20-year-old, and an 86-year-old person may require five times the lighting levels. These lighting level differences are due to age-related lens yellowing, opaque cataract or pupil narrowing (Winn, Whitaker et al. 1994; van de Kraats and van Norren 2007; Cuthbertson, Peirson et al. 2009), Van de Kraas, Winn...), creating a decline in retinal illumination, which makes the effective adaptation luminance lower for older adults (Veitch 2001). Therefore, older adults generally require better contrast and higher task luminance to obtain the same visibility level as a younger person."

Information on this phenomenon and compensation measures (without scientific references) can be readily found on internet. For example on http://www.sharecare.com/health/eye-vision-health/article/aging-eye.

Could white light with a considerable blue component be perceived as sterile?

Yes a bluish light environment may appear to be somewhat "sterile". But, it should be noted that the human visual system automatically adapts to the existing 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.

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, as emitted by 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, more mimicking the daylight character of the light.

Taking a deeper look, it can be noted that the spectral distribution of light from white LED light sources still may contain quite a lot of the blue light, with a wavelength around 450 nm. Not all (blue) light emitted by the blue diode (LED) is converted to other colours (longer wavelengths) in the creation of white light (by excitation of the fluorescent material on top of the blue diode). Some people have said that there is a "blue light hazard" with blue 450 nm 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.

2.4 Cities: outdoor

What are today's problems of cities regarding street lighting?

The problems of the city start with the financial situation: on the one hand they have to cut budgets, where energy costs form the major part of the lighting related expense. Changing to more energy efficient solutions requires investment, but cities may lack the money for such investments. Furthermore, there is a lack of examples in practice, and a lack of information on 'best practice', as well as a lack of expertise how to adequately approach such large scale retrofits. Clear examples are needed on how to effectively achieve this. Early adaptors on SSL products have had quality problems with products failing earlier than expected based on producer promises. Currently, a trend is visible with an increasing number of cities making progress in street lighting retrofits.

Which types of solutions can SSL offer to solve the problems cities are facing regarding street lighting?

To overcome the financial barrier of investment in a large scale retrofit of an existing 'light park', a gradual conversion to SSL is a common approach, where each year a small part of the 'light park' is being changed. Cities in most cases will not be able to realize the targeted CO_2/energy reduction in this manner, however. With the decreasing price of LED-luminaires, this barrier decreases in importance.

SSL offers the possibility to vary the light (both in intensity and colour spectral composition), which is also interesting in some outdoor applications, both as a signal, to be able to change the atmosphere, and to increase energy efficiency by providing the lighting dynamically where and when needed. Furthermore, SSL systems can be integrated in the infrastructure of a smart city because of its digital nature, whereas integration of conventional lighting would require costly adaptation of the analogue lighting system.

What are the investment advantages and obstacles?

Obstacles include: Many cities lack the money to invest themselves and they are usually also not allowed to borrow more money even if there is a very positive business case, because the debt of all public authorities is taken as part of the national debt, which is limited by EU agreements. Renting or leasing of light could overcome this through e.g. ESCO (Energy Service Company) models.

In practice, a number of elements are visible with respect to ESCO models and the like: a) when selling light one must be able to measure the light quantity and quality delivered in an accurate way; SSL in combination with communication makes it easier to do this; b) once the project has been tendered out, the flexibility of the city to make changes may be too limited; changes are sometimes very costly; c) lighting projects are in most cases too small to be interesting for such a complex contract – the ESCO organization considers a 1 million € contract a kind of minimum size, which might be much bigger than the normal lighting investment.

Lack of knowledge about the procurement process and of the possibilities SSL solutions have are major obstacles for many cities and municipalities to invest in SSL systems.

Is lighting a key driver of a Smart City approach? Or a minor aspect of it?

Lighting may not be a key driver of Smart City approach, but plays a key role to demonstrate or implement that approach.

A key challenge in the creation of a smart city is that improvement of operations and services will in many cases depend on actual, reasonably accurate data of what is happening at each specific moment and location. Getting the measured data requires an easy-to-roll out platform, which will in most cases require a sensor, a communication device and the power to drive them. Many parties in research and industry (from specialized SMEs to multi-nationals) see the light points as a very good platform to host these sensors. The role of lighting to enable cities to build wide sensor networks could create benefits/value that go beyond the impact of the lighting field alone.

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

The possibility to use the street lighting infrastructure of cables, communication and maintenance for several functions can be utilized to spread the 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 through sharing their differing perspectives. 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 consistency of the total infrastructure improves when people from different departments improve their mutual understanding.

How can local planning regulations for lighting be modified to mandate their use?

The motives to modify the local planning regulations have a similar basis as the motives to modify the national regulations. Due to the way the development processes for the international lighting regulation is set up, e.g. by CIE, the national actors in the CIE will have the best potential to clarify the scientific motives for modification of the national and local planning regulations. The local societal actors can engage in the local innovation processes in a more close way. One important aspect is to promote demonstrations of attractive Intelligent Human Centric Lighting.

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

The obvious technical basis is that communication electronics, software and ICT networks are required. Furthermore, a basic requirement is to clarify the ownership of data, and identify if there are any privacy issues.

From an interoperability point of view it is crucial to note that the development of interdepartmental collaboration and mutual understanding may be challenging.

2.5 Domestic

What are the advantages of LEDs in home spaces?

In the technical dimension, besides energy and cost savings, the advantage of LED is the potential to adapt the light to various demands. One suggestion is to use human centric lighting to increase domestic comfort and wellbeing. But it is not so easy to take full advantage of the HCL potential. Most people are not used to think of (how to) acquiring lighting systems that offer additional benefits by allowing smart adaptation (in intensity and colour composition) to serve user needs (e.g. during specific activities and/or time of day). situations and parts of the day. Consequently, the supply of LED products with diverse kinds of light and light variation so far is quite limited. Since there is no commonly agreed way of rating product properties in terms of the addressed 'HCL benefits', it is difficult for customers to compare products on their added value. Such evaluation framework would allow customers to select products addressing their specific individual needs. People tend to find it rather difficult to make choices between different products with advanced lighting and control characteristics.

Hence the most known LED advantage is still that the long lifetime and the low electricity consumption enables a low life-cycle cost.

How to verify and understand what LEDs types are the best for specific home spaces?

The LED technology enables a wide variety of light characteristics and ICT enables a wide range of variation patterns and user adaptions. To make optimum use of this potential there is a need for clear guidance about what to use in which room and in various situations.

One aspect is how to assess the functionalities (specification) that are wanted and needed in the different rooms. Another aspect is to stress that it is suitable to include circadian (daily rhythm) considerations into the specification of lighting.

In principle, the assessment of the needs and wishes can be translated into recommendations about normal choices for different kinds of rooms. To some extent this is already happening, but it is not so easy to find and interpret this information. In the end, especially domestic (interior) lighting is a matter of preferences and taste.

PRACTICAL INFORMATION

3

3 | PRACTICAL INFORMATION

3.1 Technical question

3.1.1 Performance

How well do LED products perform compared with conventional lighting systems and in time?

In terms of lifetime and efficacy (light output per watt) LED products outperform conventional lighting systems, in terms of colour appearance LED systems are about equal to conventional systems and, because of the digital nature, they offer new possibilities concerning adjustability and interoperability (these aspects are addressed in other Sections, see, for instance, Section 1.2.4 on smart lighting).

a) Differences in lifetime

A LED system contains a LED light source, driver electronics and, nowadays, more and more control and communication electronics.

Unlike other light sources, the LED light source usually does not fail catastrophically, but fades out gradually. Market competition to comply with design requirements and to minimize cost makes the electronic parts, and often the driver, the weakest part of the LED systems. A well-designed LED system with good quality components and adequate cooling is expected to have a **useful lifetime** (emitting more than 70% of its initial light output) of, on average, about 25,000 hours. However, the lifetime of electric components (in drivers) varies significantly and can substantially shorten the lifetime of a luminaire. Moreover, design and quality of the driver can vary considerably between various replacement systems, and especially different retrofit lamps.

The lifetime of a typical incandescent lamp is about 1,000 hours.

b) Colour appearance

Key for high-quality light are the colour appearance of the light, described by the (correlated) colour temperature (CCT) and how the light affects the colour appearance of objects, quantified with the colour rendering index (CRI, expressed as CIE Ra value). A typical incandescent lamp has a CCT of about 2700 K and a Ra of 100.

LED light sources can have CCT values ranging from warm white levels (2700 - 3000 K) up to cool white levels (above 5000 K). Sometimes light emitted by white LEDs is perceived as light having a bluish tone. This might be the result of choosing a source with too high CCT, moreover, SSL offers the possibility to adjust lighting to one's preferences (see respectively also Section 2.3 on 'sterile' light and Section 3.1.2 on dynamic light).

Good LED light sources have quite acceptable Ra values of about 80 up to 95, although the high values come at a price. CRI is far from a perfect metric for LED light sources and new metrics have been defined (such as the fidelity index [Rf] and the gamut index [Rg]) described in IES TM-30-15. CIE have also realised the problem with the metric, and CIE technical committees (TC 1-90, TC 1-91) are working to find out new solution(s).

c) Light source efficacy

LEDs produce light much more efficiently than traditional incandescent lamps: The maximum LED light source **efficacy** (lumen/Watt) presently equals 168 lumen/Watt for cool white light sources and 137 lumen/Watt for warm white sources (2015 values). This is expected to rise even further: in 2018 respective values of 218 and 208 lumen/Watt are expected. The efficacy of a 60W incandescent lamp is as low as about 14 lumen/Watt.

More technical information on LED lighting can be found on the internet, for instance on http://energy.gov/eere/ssl/solid-state-lighting, a website of the USA Department of Energy.

Does LED lighting cause discomforting phenomena such as flicker and glare?

a) Lighting and flicker

All (alternating current) AC-powered light sources, even incandescent lamps, show some degree of 'flicker' (a periodic modulation of the light output). For many traditional lighting sources, in particular fluorescent lighting, flicker increases at the end of their lifetime.

The phenomenon flicker, has been studied in detail, because of the related discomfort. Flicker has been linked to negative physiological effects, such as headaches and migraines, epileptic seizures and can result in issues with the strobe effect.

Despite the research conducted, the existing industrial standard doesn't fully quantify flicker[1]. The Illuminating Engineering Society (IES) has defined two measures to describe cyclic variations in amplitude and shape of the waveform of the light source: In the IES' RP-16-10 Standard percent flicker is defined as a relative measure of the cyclic variation in the amplitude of a light source and flicker index as a measure of the cyclic variation considering the shape of the waveform. However, other factors important for the perception of flicker, such as illumination intensity, wavelength and degree of light/dark adaptation, are not addressed. The research presently conducted into the importance of these effects will hopefully result in an improved standard enabling a better comparison of products with respect to the amount of flicker produced.

The occurrence of flicker in the light of a LED luminaire is strongly related to the quality of its driver: Because the light output of a LED correlates closely with the output waveform of its driver, LED light often flickers at the ripple frequency occurring on the output of the LED driver, which is typically two times that of the input current. A well-designed driver (i.e., one with a small ripple, high frequency output current) can reduce the flicker produced by a LED lighting system. By adding sufficient capacitance to the output of the driver the AC ripple component can be reduced; this comes with the trade-off of potentially decreasing system reliability, especially if low-quality capacitors are used. In replacement lamps and other small applications, physical space constraints can be a challenge for designing the lighting system.

Another cause of flickering is compatibility issues with the dimming and control circuitry. Changing the input current for LED(s) in a luminaire to dim light output can cause the system to flicker. Problems can be caused as well by a faulty photo-sensor or timer. When designing and

1 See IEEE standard 1789-2015: 'IEEE Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers'. More information on the standard in http://energy.gov/sites/prod/files/2015/05/f22/miller%2Blehman_flicker_lightfair2015.pdf.

procuring LED lighting systems, it is important to specify and verify that the products are indeed compatible with the dimmers or other control circuits used in the lighting system. (Some SSL suppliers provide information about the compatibility of lightings systems and drivers.).

Flicker can also occur randomly or intermittently, possibly indicating a problem in the lighting system such as loose wiring and interconnections, or with the quality of the electricity supply. Suspecting those causes, more investigation is required to prevent any potential safety hazards.

b) Lighting and glare

Glare can be caused by all types of artificial outdoor and indoor lighting. Therefore, the quality of the light design and not the type of light source is crucial in preventing glare. However, the abundant and still increasing use of lighting, especially brought about by SSL systems (such as LED billboards), makes glare prevention a bigger issue.

The International Commission on Illumination (CIE) defines **glare** as:

'visual conditions in which there is excessive contrast or an inappropriate distribution of light sources that disturbs the observer or limits the ability to distinguish details and objects'.

Such conditions can cause three types of glare: (i) Discomfort Glare (brightness brings a sensation of light pain and discomfort, such as looking at a (LED) light bulb or a digital billboard), (ii) Disability Glare (eye becomes less able to discern other details particular in the vicinity of peak light, including drivers being blinded by oncoming traffic at night, and causes a reduction in sight capabilities), (iii) Blinding Glare (Strong light, such as sunlight, is completely blinding and leaves temporary vision deficiencies).

Everybody is susceptible for glare, but older people, from about 50 years of age, and in particular those with visibility problems like a cloudy vitreous body (the gelatinous mass that fills the eye ball), suffer most from glare conditions.

Glare prevention

CIE has issued the 150:2003 'Guide on the Limitation of the Effects of Obtrusive Light from Outdoor Lighting Installations'. The purpose of this Guide is to help formulating guidelines for assessing the environmental impacts of outdoor lighting and to give recommended limits for relevant lighting parameters to contain the obtrusive effects of outdoor lighting within tolerable levels. Appropriate design of outdoors lighting systems, e.g. with automated brightness adjustment to surrounding light, is the best approach to control obtrusive effects, however only applicable for new installations. The Guide does provide some advice to take remedial measures for existing installations as well. Individuals can wear protective glasses to lessen obtrusive effects.

For indoor applications protection against glare can be provided by special coatings on screens (anti-glare coating on TV screens) and special software in smart phones and tablets automatically adjusting brightness and colour temperature to more ambient light conditions.

3.1.2 Standards and directives

Will Zhaga become the new standard for components of LED lighting systems?

Zhaga[2] is a global lighting-industry consortium that aims to standardize LED light engines and associated components[3]. Zhaga aims to simplify the design and manufacturing of LED luminaires, and to accelerate the adoption of LED lighting solutions. Presently, Zhaga has 117 members, including luminaire manufacturers, LED module makers, suppliers of materials and components, and testing labs.

Zhaga is working on specifications for the mechanical, photometric (light output and distribution), thermal and electronic compatibility of LED modules and systems. These specifications do not cover the internal design of the light source, but focus instead on the interface with other components within the fixture, enabling the combination of components optimal for new and even existing lighting solutions and easier use of service parts available from different manufacturers.

Note that a Zhaga-compliant LED light engine installed in a lighting fixture does not make the fixture Zhaga-compliant. Both the light engine and fixture must be tested and should be verified as compatible. Zhaga does not yet cover dimming functionality or electrical connections between light source and separate driver.

The future of Zhaga is uncertain, because many of the LED luminaires available today were developed prior to the introduction of Zhaga modules and because some LED light source and driver suppliers and fixture manufacturers continue to push proprietary designs in an attempt to secure market share. Eventually the interchangeability of Zhaga components might ascertain the viability of the Zhaga specifications.

The Zhaga website (www.zhagastandard.org) holds a (presently still limited) database of certified products.

Dynamic White a possible new standard lighting option?

Dynamic White concerns the change of illuminance and colour temperature of a white light source (from warm to cold) by blending and adjusting the light output of two white LED modules having different colour temperatures. A growing number of advanced luminaries with tuneable white or more colour components are being introduced. One application is to change the colour in a room similarly as the natural daylight during the day or to adjust it to the required mood (or activities in a room).

Whether Dynamic White will become a new lighting standard remains to be seen, as the spectrum of a white LED has a peak at a wavelength of approx. 450-460 nm which is absent in natural daylight. (This peak can, for instance, result in a disturbance of the sleep/wake cycle of people.) The more pronounced the peak is, the higher the colour temperature.

2 http://www.zhagastandard.org/

3 Zhaga defines an "LED light engine" (LLE) as the combination of one or more LED modules, together with an LED driver. Some LLEs contain an integrated driver, while others consist of one or more LED modules together with a separate driver.
An "LED module" is a unit containing one or more LEDs supplied as a light source. It may contain additional components, e.g. lenses or resistors or ESD protection devices but not the LED driver.
An "LED driver" is a unit located between power supply and one or more LED modules to provide the LED module(s) with an appropriate voltage or current. The driver may consist of one or more separate components, and may include additional functionalities, such as means for dimming, power-factor correction, or radio interference suppression.

Is there any international/European standard / quality labelling that evaluates LEDs performance and technical characteristics?

Yes, there are a few European directives that set requirements for performance and safety of LED lighting systems. However, the number of performance parameters is quite limited (most important ones: output, colour temperature, lifetime, switching cycles) and only minimum vales are set for the parameters[4, 5]. Other performance parameters (such as flicker or glare) are not specified. Moreover, for HCL specific features (such as circadian alerting effects by blue light) even new metrics have to be defined.

ECO-Design directive

The EU ECO-Design directive[5] prescribes functional requirements for LED lighting (see also Section 3.2.1 on the design implications) and the labelling of lighting products. On the package (nominal) light output, life time, colour temperature and number of switching cycles before premature failure have to be indicated.

The ECO-Design directive also gives procedures for verifying the requirements without linking to test methods. The Illuminating Engineering Society of North America (IESNA) and US Department of Energy (DOE) have worked together to establish tests to determine properties of LED lighting. The method, described in IES LM-80-15, to measure the light output and colour maintenance of LED packages, arrays and modules is often used to determine output and colour properties.

As the EC-design directive became mandatory September 1st, 2016, some performance properties might not be determined in an appropriate way and some labels might still be missing on packages.

CE-marking

The CE-mark, mandatory on packages for quite some time[6], indicates the (self-declared) conformity of the product with the relevant safety directives and regulations (viz. EU Low Voltage directive 35/2014, EU Electromagnetic Compatibility directive 30/2014, EU Directional Lamps, LED Lamps, Related Equipment regulation 1194/2012, implementing the EC Energy Related Products directive 125/2009, EU Restriction of Hazardous Substances (RoHS) Directive 65/2011).

Is there a standard for management of lighting networks?

The TALQ consortium[7], founded by leading lighting industry players, aims to develop a globally accepted standard for management software interfaces to control and monitor heterogeneous outdoor lighting networks. The TALQ interface is an open software interface. The TALQ protocol specifies an application language and protocol for operation and management of lighting networks. It can be implemented in different devices that are used in the systems. The TALQ interface makes sure that different devices in a lighting network understand each other, since they talk the same "language".

The TALQ consortium has initiated a program to expand its scope on setting standards to manage other Smart City and IoT (internet of things) applications.

4 In some countries voluntary top-end performance requirements are set (e.g. EST in UK, EnergyStar in the USA).

5 The EU Directional Lamps, LED Lamps, Related Equipment regulation 1194/2012 of 12 December 2012 implementing the EC Energy Related Products directive 125/2009 defines the ECO-Design directive.

6 EU Directive 2014/35, in force from 20 April 2016 on, prescribes the requirements for CE marking; before that date Directive 2006/95/EC and EC Regulation No 765/2008 were in force.

7 http://www.talq-consortium.org/

3.1.3 Communication and protocols

How to control and manage outdoor and indoor LED lighting systems?

The trend of (lighting) devices being smart, connected, or classified amongst the Internet of Things is very obvious. The push for connected lighting is not only driven by innovation and technological evolution but also by the cost saving and human centric lighting potential and, for outdoor city lighting, by regulatory influences as well. Connecting lighting systems with pre-programmed or programmable lighting controls is the first step. Cities are starting to go further making operational lighting decisions by using monitored lighting data, and, even, making higher level decisions after interconnecting the lighting domain to other city domains.

Communication is indispensable for such control and management (see also Section 3.1.2 on the TALQ interface).

Indoor control can be conducted locally (control by wire, IR, RF), although nowadays, apps on smart phones are available using the internet as carrier for the control signals. Controlling outdoor lighting can be done by power wire or wireless.

Communication protocols?

SSL systems offer the option of interoperablility. For successful integration communication and communication protocols are essential, which is about the protocol/semantics of the commands. The communication method can be modular as there will probably not be a-one-size-fits-all approach possible. So, the same language has to be spoken, but whether the communication signal goes via radio, line, fibre, internet is not important.

The protocols used should be as open as possible to enable service and extension of the systems by other companies that the original suppliers.

Indoor applications

For indoor lighting applications many protocols have been developed (such as DALI, DMX, Bluetooth, Wi-FI, ZigBee, 6LoWPAN, Li-Fi, Analog, Power line Communication, Power over Ethernet, EnOcean). According to Normasym, a Danish lighting company collaborating with the Technological Institute of Denmark, Philips, Samsung Electronics and lighting designers, Bluetooth, Wi-FI and ZigBee are the protocols that will dominate the future market.

Outdoor applications

Advanced lighting systems, generally referred to as outdoor lighting networks (OLNs), combine controls and connectivity to enable remote configuration, operation and monitoring of outdoor lighting sources over large areas. An OLN typically consists of light points (LPs) in the field communicating with a central management system (CMS) through a gateway. An LP is a uniquely identified unit within an OLN, consisting of luminaire, communication/ control modules and, possibly, also sensors. Connectivity between LPs and the gateway can be implemented with different technologies including wireless (802.15.4) and power line communication protocols. However, such protocols are often proprietary ones as existing off-the-shelf platforms are customized to improve efficiency and reliability. Network communication standards, such as TCP/UDP and IP, are the typical choices between gateway and CMS, and connectivity is provided with cellular modems (2G/3G/4G) to WiFi/802.11, Ethernet and even fiber optics solutions. Contrary to proprietary protocols, the management software interface under development by the TALQ consortium is an open interface. With TALQ, various suppliers of outdoor lighting control systems can be easily integrated with a compliant CMS. Furthermore, a customer can have a single CMS to manage OLNs from multiple vendors (see also Section 3.1.2) on standard for management of lighting networks.

3.2 Design and operational questions

3.2.1 Design

What are the implications of the EU ECO-Design directive for LED lightings systems?

The ECO-Design directive (see footnote 5) prescribes eco-design requirements for directional lamps, light emitting diode lamps and related equipment. The directive states minimum values for some performance requirements of LED systems (see Section 3.1.2. The lighting industry has to comply with the directive since September 1st 2016, assuring for customers a certain minimum quality level for these products.

Some functional requirements for LED lamps, as specified the directive, are:

- at least 90% of the total number of lamps should continue to operate at 6000 h;
- the luminous flux emitted by the lamp at 6000 h of operation should be at least 80% of the initial luminous flux;
- the number of switching cycles before failure should be at least half the specified lamp life expressed in hours;
- the starting time of the lamp should be less than 0.5 s;
- within 2 s after start-up the lamp should emit at least 95% of its stabilised luminous flux;
- the premature failure rate of the lamp should not exceed 5%;
- for outdoor and industrial applications the colour rendering index of the lamp (CRI, Ra value) should be at least 65, for other applications at least 80.

Other requirements for the LED lamp and control and installation equipment can be found in the online document: http://ec.europa.eu/growth/industry/sustainability/ecodesign/.

Furthermore, verification procedures for market surveillance purposes are given in the ECO-Design directive, whereas the national market surveillance authorities can be found here:

http://ec.europa.eu/DocsRoom/documents/17105/attachments/1/translations/en/renditions/nativemsa.

To what other systems can the lighting system be connected (building management system)?

There are two basic control principles that can be applied in a building:

- manual switches, between a set of different static lighting modes, on a control panel or maybe by an app;
- automatic variation of the lighting (e.g. sensor driven, a pre-programed pattern in time, or a combination).

An automatic control has to relate to an assessment of the lighting need at different points in time. One principle is to relate to a fixed schedule of different activities, another is to use a supervision system with sensors to detect different activities (or presence).

Supervisory information needed for human centric lighting may already be available in the facility management system. But, the other way round, situational information generated by sensors incorporated in new lighting systems can also be highly relevant for the facility management itself. The basic advice to enable those mutual advantages, now and in the future, is to aim for truly open systems.

What are the concerns that need to be taken into account when incorporating LEDs 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 ventilation/cooling of the LEDs. Ways to prevent a view of the light source and to minimize glare have to be considered.

For lighting integrated in larger equipment or a smart control system it is important to consider replace-ability and upgradeability (access to LEDs and wires). One new aspect is that the colour composition can vary 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.

Should dynamic lighting follow more closely variable needs?

Dimming the lights can save 30-50% of electricity compared to the situation that there is no dimming functionality available. Tailoring the lighting by advanced control to actual requirements is estimated to save up to 90% of the electricity in numerous cases.

Which variability of street lighting is acceptable, and desired?

Each European country has its own set of safety recommendations for street lighting applications. The national recommendations are often based on recommendations given in the EN 13201 standard 'Road Lighting' and the CIE 115 technical report 'Recommendations for the Lighting of Roads for Motor and Pedestrian Traffic'[8] . The elaboration of the safety requirements into basic (minimum) quality for lighting systems is not always done on national level, but sometimes carried out by regional and even local (city) authorities.

There are economic and environmental reasons why authorities may wish to reduce the amount of lighting. However there are safety reasons why lighting needs to be available. In some locations, a reduction in lighting quality may not increase the risk of an accident. However, there is the danger that an unconsidered removal or reduction in quality could actually increase accidents and their severity. Therefore, when considering removal or dimming of lights, location based traffic and accident evidence should be assessed.

8 Latest versions: EN 13201: 2015 and CIE TR 115:2010 (ed. 2).

What has to be specified to get LED-luminaires that can be adapted to the quick and fast technical developments (interconnectivity, interoperability, etc.)?

It is a very relevant to consider the upgradeability. But it is hardly possible to answer this question in an explicit way without knowledge about the wanted functional flexibility.

At the basic level there is always a conflict between a system with multiple functionalities and a system that is easy to use, and also easy to install and maintain. Of course, in order to build a system components are needed that can communicate, and it is advisable to use open and broadly used protocols. When expanding the system, in the future, with more (advanced) components, this is easier when it can identify and connect to these directly. (See also Section 3.1.3 on communication and protocols.)

3.2.2 Operation

What to ask for when buying LED lighting?

First of all the aim of the LED lighting project should be defined. On a basic technical level what matters are the efficacy (lm/W), spatial and spectral distribution (CCT and CRI) and lifetime of LED lighting, the dimmer quality and compatibility and control options. The application of human centric lighting systems can balance visual, emotional and biological benefits of lighting. As the knowledge increases, control possibilities for these benefits are introduced in lighting systems at an accelerating pace. Therefore, it is vital to talk with progressive suppliers.

The available choices are dependent on both the budget and the time frame, and whether the project is a standard procurement project or an innovative development or demonstration one.

It is important to remember that the procurement framing influence the way the specifications are made. In standard procurement it tends to be a challenge to introduce new specifications. For innovative activities and pre-commercial procurement there is a much larger freedom of action to use special specifications and also for open dialogue with suppliers. Off course, it always is possible to have an open dialogue with potential suppliers before the call for tender, also in processes that are intended to be a standard procurement of ordinary lighting.

Other questions to ask the LED lighting supplier are how the compatibility with products/systems/dimmers of other suppliers is assured and how future deliverable of the product is secured (see also next question).

The schematic description of the implementation process of lighting in schools, in Section 2.2.1, contains many items relevant here as well.

When considering the replacement of incandescent lamps this rule of thumb could be useful:

- a 100W incandescent lamp has an light output of about 1600 lumen;
- a 75W bulb has an output of about 1100 lumen;
- a 60W lamp has an output of about 800 lumen;
- a 40W bulb has an output of about 450 lumen;
- a 25W lamp has an output of about 250 lumen.

What aspects must be considered when replacing a standard light source with LEDs in a building retrofitting / requalification?

The most basic aspect is that the LEDs, driver circuitry and control functions should have appropriate quality. Furthermore, the light should be variable in such a way that it meets the needs.

But there is no readymade standard or method for how this should be considered. The old standards and procurement guidelines do not specify how the new lighting opportunities can be utilized in an optimum way.

LED-based products can be used to provide (almost) the same light as before with approximately the same setup of the installation, management and use as before.

There are different qualities of LED, what is the risk of choosing the wrong type?

The quality of the LED products presently on the market varies quite a lot and it is difficult to assess the quality; all products should have the CE-mark and the EU ECO-Design directive will improve that quality issue in the near future. The safest way to buy replacement lighting probably is to buy from a reliable knowledge supplier and to aim for high-quality brands. This is relevant also when aiming for more advanced products and system applications. But in this case it is more important to have a dialogue with knowledgeable persons.

Energy and cost saving is often the first aim. But it should be noted that SSL based products have also great potential to:

- vary the product functionality and spectral composition;
- optically control the light flow and light design;
- long product lifetimes.

In case of retro-fit LED lamps, there is a risk that these will not comply with existing dimmers, especially when other lamp types are also connected to the same dimmer. This may lead for example to excessive flickering.

Do LEDs for indoor use require specific power supply / drivers?

The first generation of indoor LED lamps were replacement bulbs, for example for E27, GU10 and other traditional 240 AC sockets, with integrated drivers. These light sources are intended to give the same light and functionality as the incandescent lamps. But not all the retrofit LED lamps are dimmable or match with existing dimmers (without introducing flicker), so it is important to check this.

Like the retrofit bulb type LED lamps, most of the luminaries with integrated LEDs are designed for the normal AC net and have integrated drivers.

Next generation LED replacement bulbs and in particular luminaries are becoming controllable in more advanced ways, e.g. variable colour composition by means of an app. However, to make use of the digital control potential of LEDs, not only the lamps should be replaced but also other parts of the lighting system. With regard to the power supply, a DC 24V or 42V grid would allow drivers without rectifiers and less transformers and would have a lower risk for flicker.

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

Theoretically it is possible to combine devices from different companies, but in practice it turns out to be difficult. 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 depends very much on the user. As usual it is basic to clarify what it is that is needed and wanted, and what kind of openness is required?

Also here it is important to note that a rapid technological development is going on. Functionality that is 'open' today may become a restrictive hindrance for future openness, as it may become too difficult/expensive to maintain compatibility.

Fortunately, standardization developments, specific for LED lighting systems, are going on also, both on component exchange and system interconnection level; see the description of the activities of the Zhaga and TALQ consortium in Section 3.1.2 on standards and directives.

One principle recommendation to handle this is to develop internal competence and to keep an up to date network of expertise. A good way to do this is to engage in experimental system installations.

How do we know that LEDs lights are safe?

From electric safety point of view, LED's and their driver and control circuitry is an electronics device that should obey the safety directives and regulations of CE-marking valid for this sector (see also Section 3.1.2 on standards and directives).

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 gives a new level of risk reduction. But as long as we keep the 240 V AC supply power we keep distributing electricity at this level over a grid to ever more points, with all related potential power loss and overheating issues.

3.3 Maintenance

Since the lifetime of LEDs largely exceeds that of previous lighting technologies, the need of replacement maintenance is greatly reduced. However, due to the sensitive nature of the electronic equipment and the longevity of the installation, regular cleaning becomes more crucial for maintaining functionality.

How can maintenance of lighting products be simplified?

First of all it can be assured that there is no or only minimal maintenance required. Luminaires may have sensors to measure the light output in order to adjust automatically the driver setting (increase current) when the light output decreases due to ageing effects in the LEDs.

To simplify or allow maintenance, the interchangeability of functional modules (or luminaires) will be crucial. An example of what doesn't work is to make/buy a sealed-for-life luminaire with 50.000h life light sources and 12,500h life electronics; the complete product will have to be thrown away after 25% of the expected life time of the LEDs.

What are interesting new models for lighting installation maintenance?

Connection (wireless) to control systems for building or street lighting management, enables remote monitoring of the LED lamps, for example by the facility management hired building owners or cities. When more data is being gathered about the actual usage of individual fixtures and their electronic and output behaviour, preventive maintenance becomes possible. This includes the possibility to postpone replacement of a product at its rated life, but still could last a couple of years.

Who will support the maintenance system, what to do when the lighting fails?

Traditionally, 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 indoor lighting.

Lighting is now becoming an advanced system technology that will be more an integrated part of the building architecture and the building structure. This may not lead to a need for own specialised staff, but rather to further outsourcing of the maintenance and trouble-shooting of the lighting system to (external) facility management. These should have then authority to bring in appropriate expertise to be able to assess the situation at a proper level and at an early stage, and to solve the various problems that might occur.

There is a large variation between LED lighting products and system solutions. It is important to involve facility management staff in the procurement decisions and the installation of new kinds of lighting.

3.4 Costs

How can the lifetime cost for LED be described?

The most often used determination of the lifetime cost of a product is to divide the sum of procurement and energy costs by the lifetime.

However, it is more informative to use a cost benefit framing that also includes other differences between products. When there are differences in the delivered light or other functionalities this should be noted. With regard to Life Cycle Assessment analysis, one could calculate the Life Cycle Cost as a quotient of environmental cost and functional value, although it is difficult to express the functional value in a cost unit.

The situation at the end of product lifetime may be different from the situation before product installation. A bad choice may result in dead-end situations while future-oriented choices may result in valuable experiences and system improvements for the future.

Do higher investment costs per unit, compared to existing solutions, hinder a continuation of investment volume?

Ideally, the life-cycle cost should be evaluated in relation to the total functional value that is delivered during the product lifetime. One shortcoming in the current procurement evaluation is that the differences in functional value tend to be neglected. Another shortcoming is that it is difficult to assess if there are differences in the actual lifetime and the actual electricity consumption of products. When those aspects are neglected, the procurement framing tends to be limited to a comparison of investment costs, which so far is higher for LED lighting systems than that for the traditional lighting sources.

It should be noted that the basic challenge here is to clarify what it is that is being procured (i.e. needed and wanted) and to define a relevant and reasonably complete measure for that. In such evaluations everything that is not included as estimated values is in fact assumed to have zero value. In many cases it is obvious that there are differences in value and in those cases it is more correct to guess a value than to neglect the difference.

High purchase costs?

The product prices for LED-based replacement lamps have been much higher than the prices for incandescent lamps and fluorescent tubes. But the LED prices have fallen and are continuing to do so rapidly. The life-cycle cost is now below that of incandescent bulbs, due to the lower electricity consumption.

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 are needed and wanted. An advanced high quality Intelligent Human Centric Lighting solution offers a much higher user value than the traditional static lighting solution. A poor quality LED solution may result however in a lighting environment and functionality that is much worse than traditional lighting.

3.5 Issue/risk aversion

Unregulated markets

A rich variety of LED sources are readily available commercially. Since the development has been very rapid, regulations are still catching up, and as a result the available quality has been quite variable. The consumer retrofit products first available were often of inferior light quality but sold at a price dramatically higher than traditional light bulbs. As a result, they were interpreted by the public as the result of another bad regulatory measure just like the introduction of the compact fluorescent tube, and a compromising concession for the environment. Unfortunately this reputation largely still persists.

To add one more dimension, many of the available consumer retrofit solutions are not entirely compatible with existing fixtures. The incorporated gear (driver, heat sink) changes the geometry and thereby the centre of light is shifted, resulting in a modified light image once installed. The replacement solutions are not standardized, so no general rule of physical compatibility exits.

Today, the picture sketched above is improving: The quality of LED lighting systems is improving, while the LED technology is still evolving. The EU Eco-Design directive, now operative, will bring more market regulation. The mandatory CE-mark guarantees minimum performance requirements and provides safety protection according to the applicable requirements. (See Section 3.1.2 on standards and directives.)

Ownership and use of data: Privacy concerns

This is one of the key questions for smart cities right now. Smart city technologies and data developments are so quick and ubiquitous that official legislation may fall short for the decades to come. For the time being smart city governments could follow the approach proposed here http://www.sciencedirect.com/science/article/pii/S0740624X16300818, viz.:

- determine which privacy concerns for their citizens may be at stake with specific technologies and data practices;
- determine if and how these are subject to the EU General Data Protection Regulation 679/2016 which might take effect in 2018;
- develop a specific city policy on new developments that accommodates the concerns of citizens, beyond the bare legal necessities.

Is long lifetime desirable, considering the fact that the technological development is so fast?

Good question: 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 a basic question is how fast the efficiency will improve (and energy savings increase). Today's LED products are already so efficient and the prices are so low that the additional reduction of life cycle cost/year will hardly motivate frequent changes of products. Therefore, this hardly is a motive for shorter product life times.

Making an analogy with other kinds of "internet of things" products, it is not obvious that a very long product lifetime is good. For the most advanced LED products and systems the functionality, efficiency and qualitative potential to meet a variety of customer wants is improving very rapidly.

However, the main market volume so far is replacement light sources. The lack of information about the value enhancing potential and the focus on the long lifetimes tend to give the impression that the light sources will continue go give the same light and functionality as before. This way of thinking is not supportive for innovation.

Furthermore, on SSL packages often long lifetimes are stated. Because of resulting low life cycle costs/year environmental actors might not be (very) critical concerning the stated lifetimes, while many other people are quite skeptical about the trustworthiness of those values. For development of better light and more advanced functionality it is important that all customers are critical.

Are there problems that occur because LED lighting is a new product on the market?

As for any new product, the newness of LED lighting causes several forms of limitations and challenges. Some products are technically immature and 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. For a customer it is difficult to assess the quality of various products. An advantage, but also a challenge, is that there is a diversity of LED products with quite different properties.

An example is that there are products with different colour temperatures and spectral distributions. Lumen values don't indicate the contribution of the anomalous blue part in the spectrum of white LEDs, and consequently it is difficult to assess how the light will be experienced for various white light sources.

The new lighting technology is quite different from the old lighting. There is a diversity of new opportunities. To be able to make optimum use of LED lighting there is a need for a new conceptual framing. But so far the new situation is difficult to grasp for most people.

What are the main problems in current lighting systems for health and wellbeing? Consequences? Metrics and indicators?

Recently a fifth photoreceptor has been discovered in the human eye thought to be responsible for health and wellbeing effects of lighting. The knowledge about such effects of the (LED) lighting systems is still incomplete. In the last years claims about optimum lighting recipes have been made, although hardly proof existed. This is probably causing a lot of confusion.

In the "Report on metric to quantify biological light exposure doses" document on www.lightingforpeople.eu a method is introduced which allows for different light sources and different intensities the calculation of the five melanopic photoreceptor weighted light intensities. With these new metrics dose-response relationships can be determined, extending the knowledge about the health and well-being effects of light, and enabling the development of dedicated LED lighting systems promoting health and wellbeing.

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

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Malmö stad

UNIVERSITY OF OXFORD

rijksuniversiteit groningen

CITY OF STAVANGER

TNO innovation for life

UCL

VILNIAUS UNIVERSITETAS 1579 UNIVERSITAS VILNENSIS

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SEVENTH FRAMEWORK PROGRAMME

www.ssl-erate.eu

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