Newsletter 1

Overview and first results

March 2015

IEA SHC Task 50: Advanced Lighting Solutions for Retrofitting Buildings

DAYLIGHTING – ELECTRIC LIGHTING – LIGHTING CONTROLS

BACKGROUND AND OBJECTIVES

Lighting accounts for approx. 19 % (~3000 TWh) of the global electricity consumption. Without essential changes in policies, markets and practical implementations it is expected to continuously grow despite significant and rapid technical improvements, like solid-state lighting, new façade and light management techniques. With a small volume of new buildings, major lighting energy savings can only be realized by retrofitting the existing building stock. Compared to existing installations, the majority of new solutions allow a significant increase in efficiency – easily by a factor of three or more – going along with highly interesting payback times. However, lighting refurbishments are still lagging behind compared to what is economically and technically possible and feasible.

With the activities in Task 50, we aim at improving the lighting refurbishment process in non-residential buildings in order to unleash energy saving potentials while at the same time improving lighting quality.
The overall objective is to accelerate retrofitting of day-lighting and electric lighting solutions in the non-domestic sector using cost effective, best-practice approaches, which can be used on a wide range of typical existing buildings.

This includes the following activities:

- Develop a sound overview of the lighting retrofit market
- Trigger discussion, initiate revision and enhancement of local and national regulations, certifications and loan programs
- Increase robustness of daylight and electric lighting retrofit approaches technically, ecologically and economically
- Increase understanding of lighting retrofit processes by providing adequate tools for different stakeholders
- Demonstrate state-of-the-art lighting retrofits
- Develop as a joint activity an electronic interactive source book including design inspirations, design advice, decision tools and design tools

This newsletter presents first results of IEA Task 50 addressing current topics in lighting retrofits.

Content

By-Passing Barriers for lighting retrofit

IS Solid State Lighting already changing the game?

Marc Fontoynont, Aalborg University, Denmark

By comparison with lighting solution using fluorescent sources, Solid State Lighting (LED) comes along with different technical, operational (maintenance) and economical parameters compared. Work within Subtask A of IEA Task 50 studied the impact of these fast changing parameters on lighting retrofits – intending to give profound advice to decision makers.

A large fraction of existing lighting installations is more than 10 years old, and often there is no plan to retrofit them before the end of life or on the occasion of a major refurbishment of indoor environment (ceilings, floors and wall finishes). In Subtask A of IEA-SHC Task 50 possible opportunities to anticipate lighting retrofits to benefit, as early as possible, of new and highly energy efficient lighting installations were investigated.

There are some "low hanging fruits", which are existing installations of poor efficiency with no plan for retrofit on the short term. In some cases, return on investment is below 2 years, when counting only the benefits on electricity consumption. However, in many cases, return on investment is in the range of 3 to 6 years, which is usually considered too long to motivate investors. Information from stakeholders was gathered, to identify on which terms and under which conditions, they would be interested in accelerating retrofitting operations.

These stakeholders are: owners, tenants, facility managers, contractors (and installers), local authorities, industry sellers, designers –consultants, users, broker agencies, financial groups, and energy service companies (ESCOs). Some of these stakeholders are interested

- in low investment costs, others
- in reduction of installation time ,
- reduction of maintenance,
- extended guaranties on products,
- reduction of use of electricity,
- optimal life of the products or
- in opportunities for radical change of appearance of the space.

We see that gain on energy efficiency is only one parameter among others. The good news is that with the reduction of costs of LEDs, Solid State Lighting options become more and more attractive: as there is not only a possible gain in energy efficiency by improved system efficiency, but also a possibility to reduce maintenance.

Life Cycle Cost(LCC) approach: shifting cost shares

Assessing Life Cycle Costs (LCC) of lighting installations, the share of costs due to electricity is typically half of the total LCC value (in areas where costs of electricity are rather high, above 0,15 €/KWh). Investment is more than a quarter of the total cost, and installation less than half the investment (Figure 1). The LCC is therefore very sensitive to the evolution of electricity costs. In the next 10 years, the combination of increases in energy efficiency and reduction of cost of equipment are anticipated to stabilize these costs, but major gains will be achieved in reduction of maintenance.

Figure 2 shows the comparison of the evolution of cumulated costs in €/m² of a classical fluorescent installation and of an installation using LEDs. Benefits in costs due to improved energy efficiency lead to a reduction of the general slope. LED based lighting does not require change of light sources every 15 000 hours as it is the case with fluorescent sources. But the whole

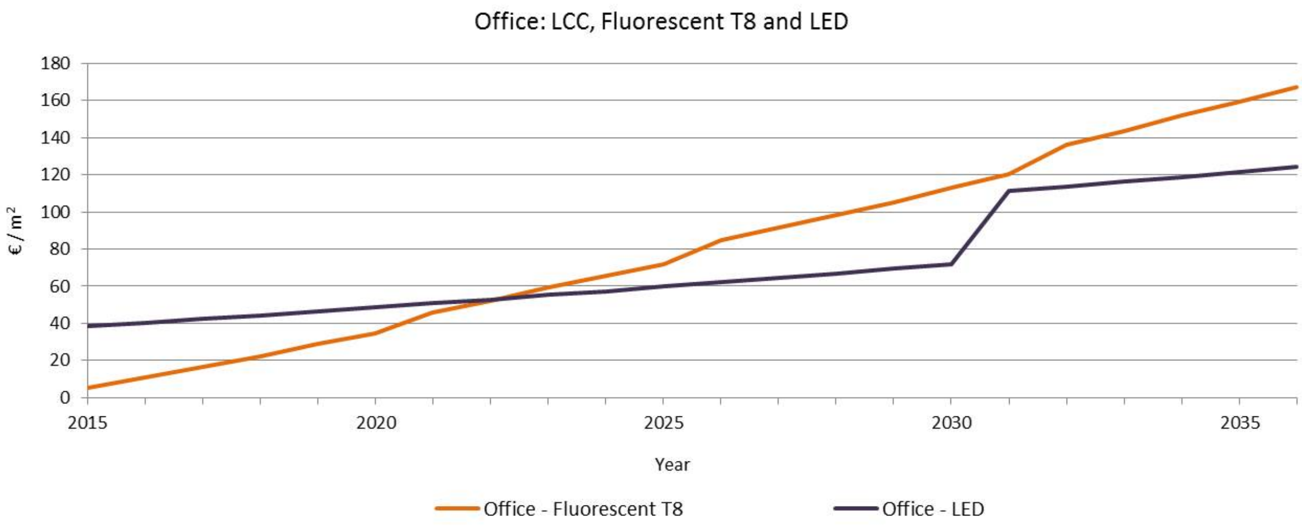


Figure 1: Evolution of cumulated costs over time, for classical fluorescent installationand new LED product.

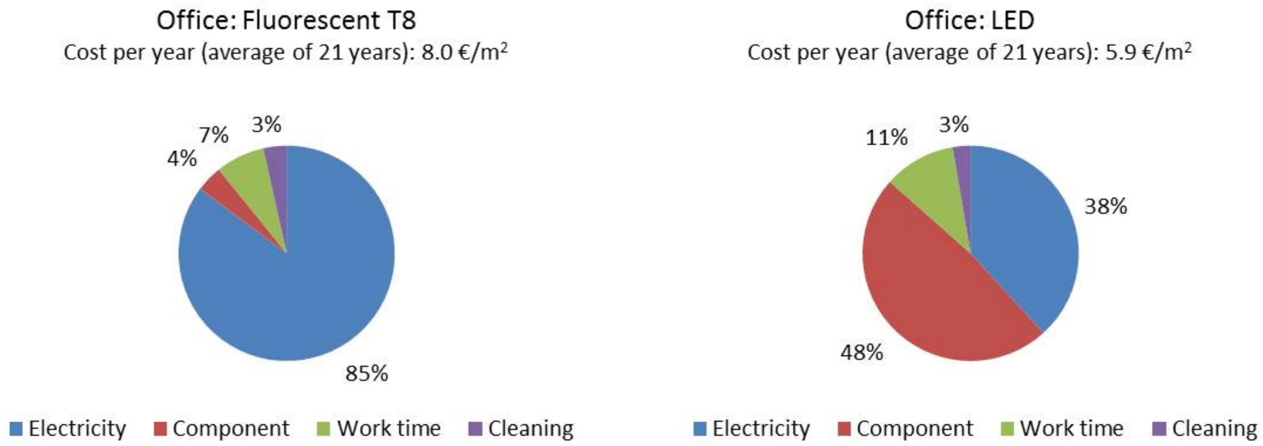


Figure 2: Life Cycle Costs of an office lighting installation using fluorescent tubes [€/m²].

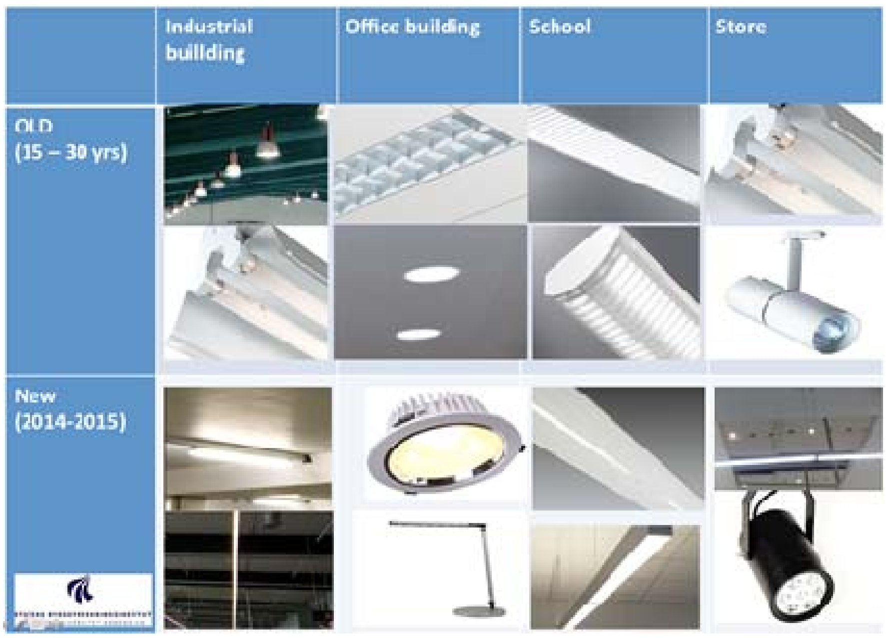


Figure 3:Typical existing 'old' electric lighting products found in existing buildings and highly efficient 'new' lighting products, mostly using LED technology.

luminaire has to be changed after 40 000 hours. It is expected that the re-investment in LED based lighting at the end of life will in fact be lower, due to a significant cost reduction of this technology over the next 15 years. The graph shows that operation of LED lighting requires no maintenance over the life of the products, except cleaning. However, to obtain significant benefits, it is important that the initial costs of SSL are not much higher than that of fluorescent systems.

Low hanging fruits

It was found that return on investment is easier and faster on installations with high annual duration of operation, for example in factories where lights are on a large fraction of the time (more than 5000 hrs/yr). Here, fluorescent tubes must be changed every two years, and SSL every 5 years. Furthermore, dirty environment in some factories suggests not to use equipment longer than 10-15 years, which is in line with the life span of SSL products.

To the contrary, in buildings such as schools, light is used more often for shorter periods, typically summing up to around 1000 hrs/yr, suggesting that fluorescent tubes should be changed every 15 years, and SSL every 40 years. Here, retrofit should clearly focus on possible savings in simplification of maintenance and improvement of lighting quality.

To account for differences like the above explained, typical approaches for four main categories of buildings were investigated: industrial buildings, office buildings, school buildings and department stores. In Figure 3 typical old and new lighting systems are compared.

Lighting retrofit and replacement of other building equipments

Development of cost models demonstrates that accelerating retrofit operations makes sense mainly for "low hanging fruits"; with "accelerating" meaning to conduct retrofit earlier than at the end of products life. However, often it is wise to wait for a major general retrofit (ceiling replacement, painting) since it could benefit from possible upgrade in the electrical architecture. Hence the importance, during field assessment, to identify possible times for general retrofit of indoor spaces. Lighting, as any other technical equipment (heating, ventilation, plumbing, etc.) has its own life. But evolution of products and reduction of prices should lead to higher replacement rates.

Towards a database of lighting retrofit technologies

Catalogue of Criteria – a holistic way to assess and compare retrofit solutions

Martine Knoop, Technische Universität Berlin, Germany

In practice often only the simplest retrofit solution is implemented, due to a lack of knowledge about often better options. Optimized, better suited solutions are left aside. Therefore a systematic – but still simple - approach to compare soluions on a holistic basis has been developed. One key element is the systematic definition of criteria for comparison. Theses criteria are currently used to characterize a set of 50 different daylighting and electric lighting technologies.

In a lighting retrofit, different lighting solutions can be applied to save energy, to reduce costs and to increase lighting quality. In practice, an optimized daylighting design, or the use of innovative daylighting systems or lighting control systems are rarely taken into consideration. Retrofit by means of simple lamp replacement is widely accepted, due to its effectiveness from an economic point of view, focusing on energy savings for electric lighting and payback times. On the other hand, retrofit approaches that take into account the usage of other components or a new design of the lighting installation often allow a (further) reduction of energy consumption while additionally improving the lighting quality.

The insignificant implementation of unconventional retrofit solutions is partly due to the abundance of approaches, and the great diversity amongst them. Another hurdle to take in considering alternative solutions in retrofit projects is the lack of an appropriate approach to compare solutions on a common basis. Previous projects that considered cost-related and lighting quality aspects, focused either on the evaluation of daylighting solutions or on the assessment of electric lighting solutions. The quality of electric lighting solutions is often described with features such as light output or lifetime. But these quality criteria used for electric lighting are usually not applicable or not sufficient to describe the quality of daylighting solutions or the effect on people. Resulting, to properly evaluate the impact of lighting retrofit decisions, a wide range of quality criteria should be considered, applicable for both, electric lighting as well as daylighting solutions.

Electric Lighting and Daylighting on an equal basis

Subtask B „Daylighting and Electric Lighting Solutions" of IEA SHC Task 50 is looking into the quality assessment of existing and new solutions in the field of façade and daylighting technology, electric lighting and lighting controls. The aim of Subtask B is to categorize lighting retrofits giving an overview of available retrofit strategies and solutions, to show their potential, and to offer a tool to look into and compare different retrofit strategies.

In order to evaluate a large variety of retrofit solutions on an equal and holistic basis, within Subtask B a Catalogue of Criteria was defined that can be used to:

- describe the holistic performance of retrofit approaches, and

function as a basis for a tool that allows for a quantitative comparison of retrofit possibilities.

Criteria

This Catalogue of Criteria contains over 50 quality measures that primarily focus on the following reasons to retrofit:

- to reduce energy consumption,
- to increase the light quality, and
- to reduce the cost of maintenance and energy consumption.

The Catalogue of Criteria concludes with aspects related to possible drawbacks of the retrofit solutions, such as the impact of the retrofit process, the duration and costs of the lighting retrofit, as well as thermal characteristics that could affect the overall building energy consumption (Figure 4).

The quality measures were taken from literature, standards and experience and consider

- aspects from an ecological and economic point of view, such as those related to acquisition of the system, energy consumption, and maintenance;

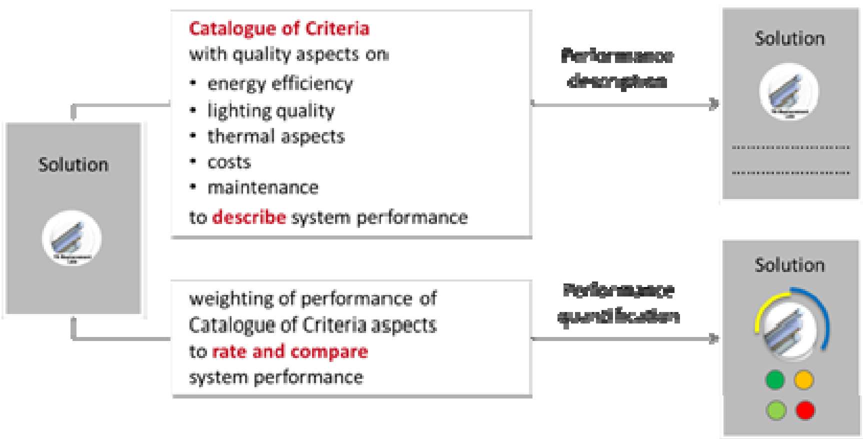
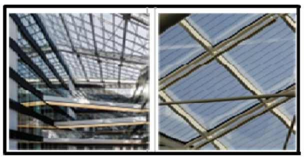


Figure 4:Graphic scheme depicting the structure of the catalogue of criteria, which enables comparable performance description and thus evaluation and comparison.



MicroShade®
is transparent strips of micro lamellas that are mounted in the cavity of low-E glazing. Sunlight from low angles passes relatively unimpeded, while light from higher angles is blocked and thus creating visual and thermal comfort and reduce energy consumptions.

Energy efficiency
Lighting quality
Maintenance

- Stable performance, protection against high angle sun and at the same time view out. Low total cost of ownership
- Good light transmission and diffuse light distribution of light inside. Improved indoor climate
- No glare protection in winter, an addition glare control for winter is needed

Performance of MicroShade®
MicroShade® has been developed to effectively shade the direct sun and at the same time provide good daylight conditions and reduce energy consumption. This is obtained by a patented micro lamella system, that reduce or block the direct solar beam progressively with the height of the sun and hence reduce the energy consumption for ventilation and cooling during the summer and still allowing passive heating during the winter. A typical effective g-value for summer is 0.10-0.15 and measurements show that the temperature is lowered 4-5 °C. The reduced room temperature and beam shading has a positive effect on productivity. At the same time MicroShade® is transparent and allows a view to the outside and daylight into the building. The light transmittance is app. 50%. As the high intensity direct solar beam is shaded by the micro lamellas, the daylight passing through the MicroShade® will appear soft and friendly to the working environment. Dark shades, typical in positions near facades, are greatly reduced by MicroShade®. The light color is determined only by the glass in the glazing. For typical MicroShade® glazing the color rendering index is above 95%. MicroShade® requires no user interaction and delivers a proved, stable performance and hence ROI and TCO can easily be calculated. MicroShade® is maintenance-free and installs like other glazing. MicroShade glazing are available in various types for façade and roof applications. MicroShade® is produced from high grade steel and bonding material. All materials used are readily available and fully recyclable. The product reduces the energy consumption of the building and hence save CO_2. MicroShade® is installed and has proven its effect in a number of landmark buildings in northern Europe.

Used for façade and roof application where strong solar shading, weather independence and no maintenance is required (e.g. high rise, roofs and large glass facades).

MicroShade A/S, Gregersensvej 1F, 2630 Taastrup, Denmark
TAG3-HWR-1008-E10 (2010): Thermal and optical characterization of MicroShade, Fraunhofer ISE, Dr. H.R. Wilson
Comparative Investigation of micro lamella shading and alternative shadings (2013), E. Vangeloglou
REHVA Journal (2013): MicroShade® provides daylight and view out in the new Confederation of Danish Industry' building in Copenhagen, H.F. Rasmussen

Figure 5:Representation of an exemplary daylighting technique in the database (also becoming part of the Lighting retrofit adviser).

	Upgrade of existing situation	Use new components in existing situation	Redesign
Façade & daylighting technology	Add on to window plane: add simple daylighting system (e.g. light redirection blinds)	Window replacement: Add daylighting system (construction fits in existing window frame)	Redesign façade or façade elements, increase window size, add skylight, add daylighting systems
Blinds & shading technology	Add on to window plane: add shading devices (with or without control)	Window replacement: Improve glazing (e.g. electrochromic glazing, smart windows, double glazing with blinds)	Redesign façade or façade elements, add architectural shading elements Link to BMS – blind control to optimize with heating and cooling
Electric lighting solutions	Lamp replacement: improvement in lamp technology, or ballast technology, improvement of spectral quality of the light source	Luminaire replacement: improvement in lamp or ballast technology that requires a new luminaire, improvement in luminaire technology	Redesign of lighting installation: more efficient luminaires, use of task / ambient lighting, improvement in application efficacy), reduction of maintained illuminance levels
Electric lighting controls	Stand-alone controls: use time switch to reduce total switch-on time, use of occupancy sensors - switching	Luminaire based controls: controls for dimmable luminaires or motors: use of occupancy sensors – dimming, daylight dimming, manual dimming	BMS: install building management system to link electric lighting to heating and cooling (e.g. demand control), networked lighting
Changes to the interior	e.g. increase of surface reflectance	e.g. reduce partition height	e.g. increase ceiling height, remove walls
	→ for the retrofit solutions from the left to the right → in most cases: an increase of energy efficiency or visual comfort, as well as initial costs		

Figure 6: First outlook on the database in the way it will be presented to the future users.

- user requirements, such as psychological and physiological, visual and non-visual human needs;
- the impact of the lighting retrofit on the overall retrofit process; and
- the thermal behavior of daylighting systems, as well as
- the geographical and climatological applicability.

By allowing a high level evaluation of both, daylighting and electric lighting solutions on potential energy savings for electric lighting, on costs, lighting quality, and the retrofit process, a comparison of distinct different retrofit approaches on a common basis seems to be feasible. Within the Catalogue of Criteria also descriptive, qualitative, performance assessments of all retrofit lighting solutions are provided.
In order to allow for a quantitative assessment, set quality criteria are applied to assess the systems' performance for designated topics, which represent the main reasons to retrofit a lighting installation: 'Reduce energy efficiency' and 'Increase lighting quality', as well as the thermal impact of daylighting retrofit solutions. The relevance of each topic within the main categories is reflected in a weighting factor per item, which is used to determine the overall performance of a retrofit approach.

This Catalogue of Criteria will be available online by March 2015. In addition a tool based on this catalogue, using selected weighted quality criteria to quantify the performance of solutions will be included in the Lighting Retrofit Advisor.

Database of lighting retrofit technologies

The criteria will be applied to numerous retroftit technologies (electric lighting, daylighting, light management). Up to now more than 50 such technologies have been collected and are currently being entered into a database, which structures relies on the developed set of criteria.
Figure 5 shows with a rooflight solution an exemplary representation of a technology in the database of the lighting retrofit adviser.
Figure 6 provides a first outlook on the database in the way it will be presented to the future users.

Lighting retrofit in current practice

Evaluation of a survey with more than 1000 participants

Bernard Paule and Jérôme Kaempf, Estia SA / kaemco LLC / EPFL, Switzerland

A questionnaire with 18 questions regarding lighting retrofit in current practice was send out to the lighting communities in the participating countries of IEA-SHC Task 50. The answers from more than 1000 participants give a profound view on used approaches but also barriers in practice.

Surveys and socio-professional studies carried out at national and international levels contribute to better understanding, in this case of the lighting retrofit process. Within the first work package *Analysis of workflow and needs* of Subtask C "Methods and Tools" an online survey dealing with lighting retrofitting in practice was developed. Its distribution was initiated in December 2013. After seven months, more than 1000 participants from all over the world answered the questionnaire. As the amounts of answers were not statistically relevant for most of the countries, the results were evaluated globally.

The survey's evaluation gives insights about the practical workflow of practitioners and leads to a better understanding of the real needs in terms of computer method and tools. First results were presented at the 4th Industry Workshop in Fukuoka, Japan on September 29th, 2014. This presentation is available on the Task's website (http://task50.iea-shc.org/). An online database containing the anonymous results of the survey will be set up at mid-2015.

In the following, some first relevant insights, e.g. about retrofit strategies, are introduced. One of the outcomes is that retrofitting strategies actually used in practice essentially deal with artificial lighting actions such as the use of sensors and the improvement of luminaires, whereas daylighting strategies are not rated as a priority (*Figure 7*). Another finding is that practitioners are most interested in user-friendly tools allowing quick evaluations of their project. The cost of the tools is also an important issue together with the accuracy of the results as well as the availability of features to produce nice reports and images (*Figure 8*).

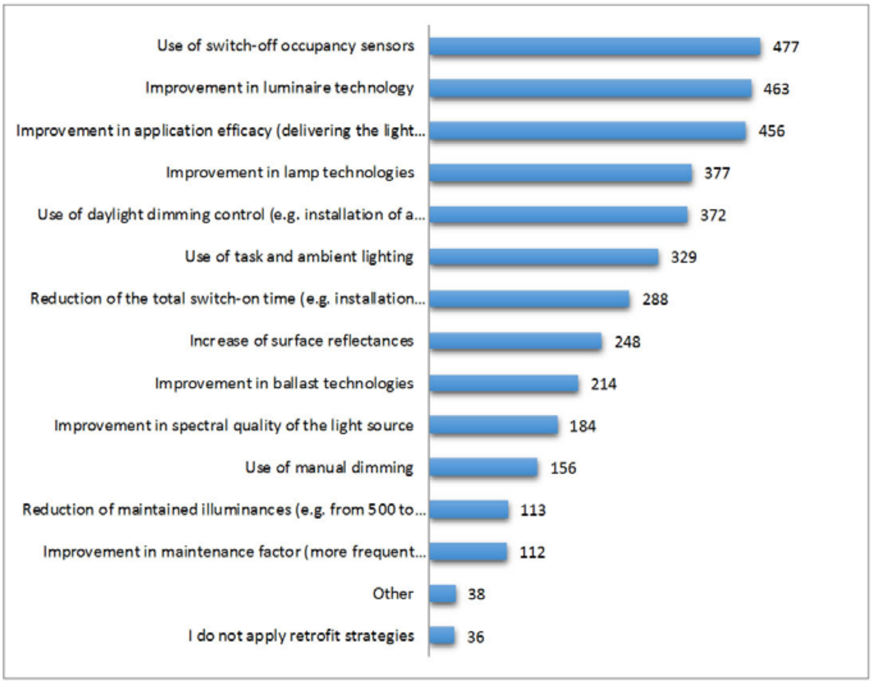


Figure 7: Evaluations of the questions on main retrofit strategies used in current practice.

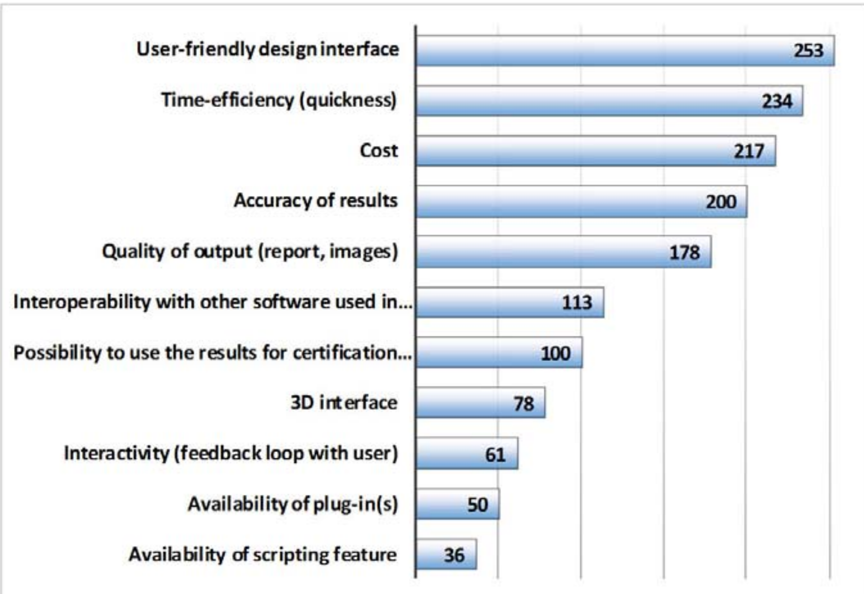


Figure 8: Evaluation of main factors influencing the choice of software.

Furthermore the survey's evaluation confirms that professionals mostly rely on themselves handling design and decision processes. However, from industry, lighting manufacturers are most strongly involved (*Figure 9*).

In conclusion, the overall answers to the questionnaire showed that the main barriers in using the simulation tools are essentially still their complexity and the amount of time it takes to complete a study. Practitioners are furthermore keen to use tools in preliminary design and would like to be able to estimate the cost and other key figures (energy consumption and lighting levels) already in an earlier project stage.

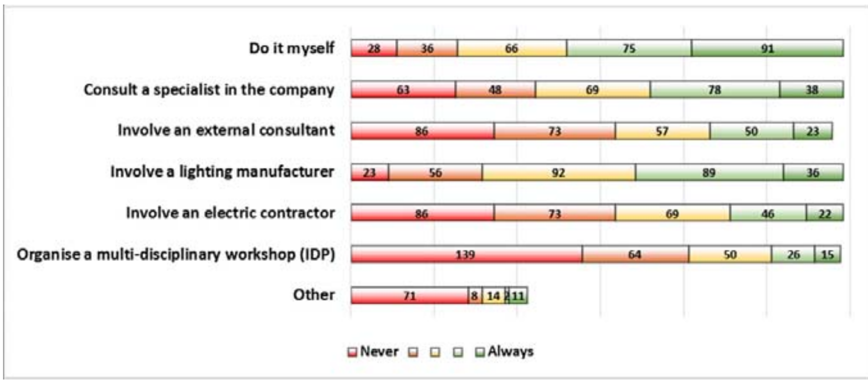


Figure 9:Evaluation of the question on handling of design and decision processes concerning the integration of lighting technologies in retrofit projects.

Assessment of lighting retrofits in practice

First application of a new monitoring protocol

Marie-Claude Dubois and Niko Gentile, Lund University, Sweden

A new monitoring protocol to assess lighting situations before and after retrofits has been developed. It covers the four key aspects: energy efficiency, costs, light environment, and users' satisfaction. The protocol has been tested on a first building in Stockholm and is currently applied to more than 20 case studies within IEA Task 50 participating countries

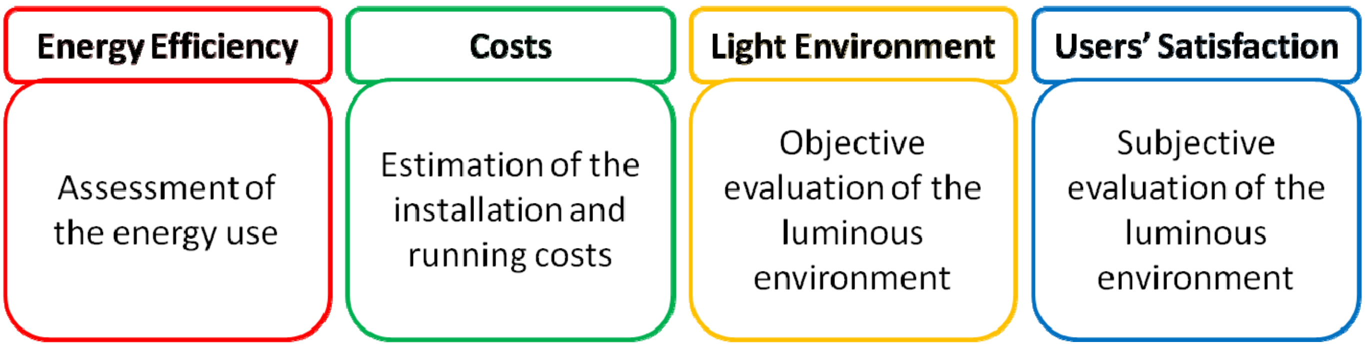


Figure 10:Key aspects covered by the monitoring protocol.

The development of a monitoring protocol for the evaluation of the overall performance of lighting and/or daylighting retrofit projects is an important part of Subtask D. A beta version of this monitoring protocol – which will also be addressed to the lighting industry – was released among the Task expert group in November and is currently being used as guide for the case study monitoring. This protocol assumes that buildings can be monitored both, before and after the retrofit or only post-retrofit with comparison to benchmark values. The protocol covers the following four key aspects (*Figure 10*)

1) energy efficiency,
2) costs,
3) light environment, and
4) users' satisfaction.

It is generally presented as a non-expert guideline document, following a 5-phase procedure (1. initial visit survey, 2. decision phase, 3. preparatory phase, 4. monitoring program, 5. analysis phase). Each phase is described in detail, including the required documentation for two distinct monitoring levels: 'basic' and 'comprehensive', depending on the ambition and budget of the monitoring team. The protocol was first used, among others, when monitoring a recently retrofitted open-plan office in Stockholm, Sweden. As the retrofitting is ongoing, two floors, representing *pre* and *post* retrofit, could be monitored at the same time (see *Figure 11*).

The initial results indicate that, despite a positive first impression of the retrofitted space, due to a new design and new furniture, the lighting quality was not improved as much as expected. While the daylight was drastically enhanced, thanks to higher surfaces reflectance and to the removal of some architectural obstacles, the energy use for lighting was just slightly reduced. Although the new lamps are more efficient, the lighting control system did not work as expected. The light fixtures over the working spaces were on most of the time, even with sufficient daylight or with unoccupied space. Some additional light spots on the retrofitted ceiling were continuously on, even though they did not contribute to enhance lighting in the space. The external surface, including glazing, was not changed in the renewed space. On the east side, glaring issues occurred in the morning. This was objectively measured through HDR photography, and confirmed by a users' satisfaction questionnaire. The glaring due to electric lighting was reduced in the retrofitted floor, thanks to opaque working space partitions.

The questionnaire assesses the subjective experience of lighting quality, so that the measured objective lighting metrics (e.g., illuminance, luminance, …) can be compared with the users' perception. For example, in *Figure 12*, the answers on perceived light distributions are depicted. The employees are pretty neutral in both floors, though they report a slightly higher appreciation of the lighting in retrofitted space (question "how well can you see in this light?").

In the illustrated case, the improvement in the objective and the perceived daylight/electric lighting environment seems to not correspond in a significant reduction of energy and running costs, although final figures are not yet available.

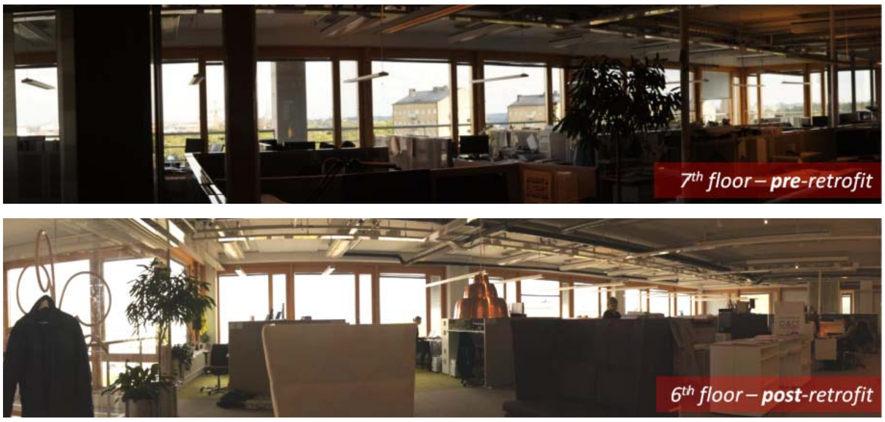


Figure 11:Photographs of the two floors monitored, representing pre- and post-retrofit.

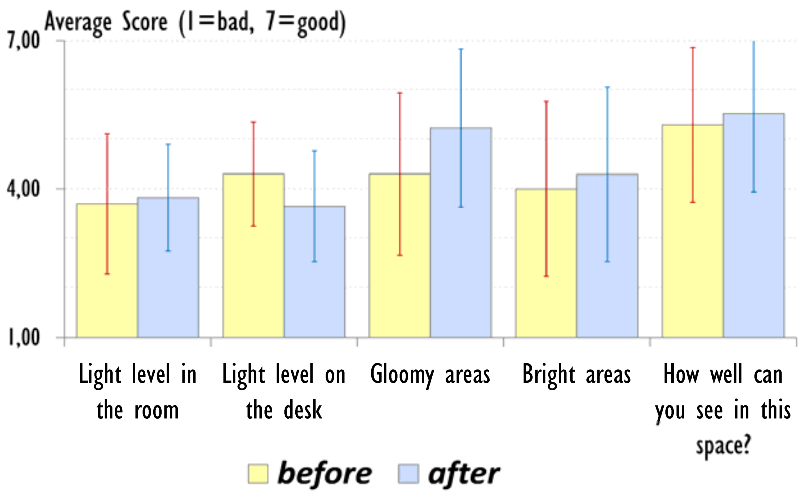


Figure 12:Example of the questionnaire's inquiries on perceived lighting on the monitoring day.

Thanks to the blended

objective/subjective approach with four different key aspects - energy, costs and light environment, users' satisfaction -, the lighting retrofit can be evaluated in a more rational way. Both an item-specific and overarching evaluation are provided. The retrofit is not classified through a simple "very good – very bad" verdict, but each action undertaken is reported. In this way, the case study assessment of IEA Task 50 will represent a useful guide for the decision makers, which need to deal with various aspects of lighting retrofit projects.

Outlook - Interactive presentation of results in an electronic source book

The Lighting Retrofit Adviser

Jan de Boer, Simon Wössner Fraunhofer Institute for Building Physics (IBP), Germany

An interactive source book – the Lighting Retrofit Adviser - will hold and communicate the major results of IEA Task 50 tailored to the needs of different stake holders. Aside targeted information also calculation features like quantitative assessment of retrofit potentials will be provided.

Besides the scientific work also the user friendly and easy to understand Dissemination of the results derived is a crucial issue, covered in a Joint Working Group developing an interactive electronic source book, where all results of the Task are collected (*Figure 13*). In addition calculation functionality to develop retrofit concepts will be provided. This tool will be available free of charge by download from the Task's website.

It is developed as a multi-platform application, accessible by different devices, such as PCs, tablets and smartphones on all relevant operating systems (*Figure 14*). An English and a German version will be made available. Participating countries can adapt the tool to their own languages. The navigation scheme is planned to be organized such that all components can be navigated separately and interrupted (memorizing its current state), e.g. when using links to further information.

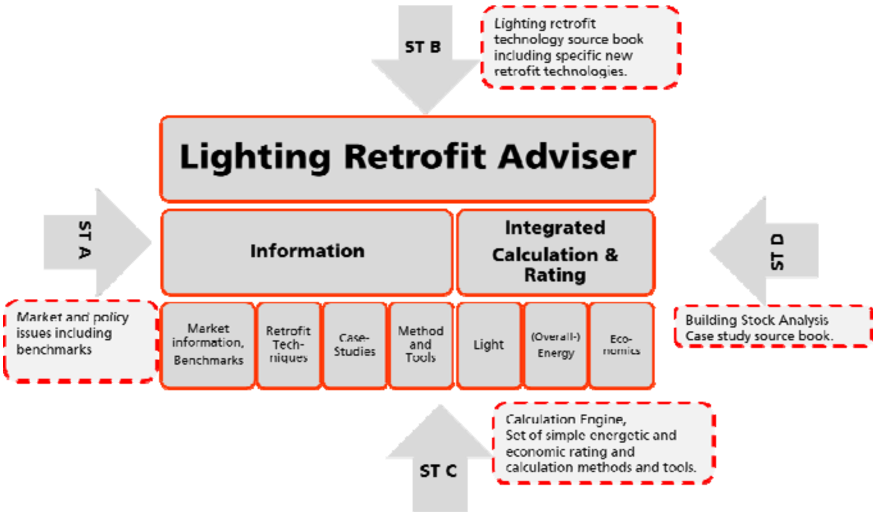


Figure 13:Structure and main components of lighting retrofit adviser. The LRA collects and dissiminates key results from the four subtasks.

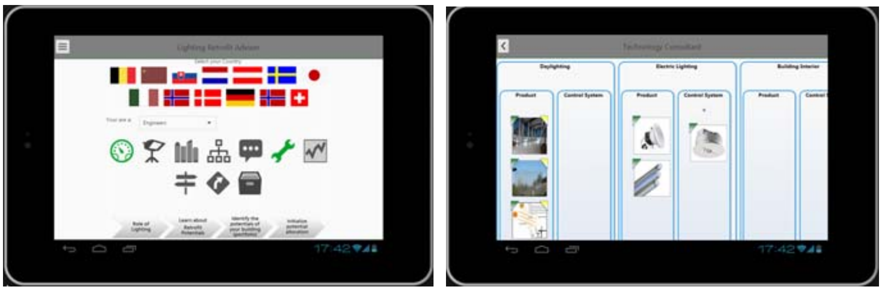


Figure 14:Tablet-view of home screen draft: Different access options are possible.

Information components

The Lighting retrofit adviser will contain information and calculation parts. Information is tailored according to needs of different stakeholders [Owner / Investors; Tenants [responsible for office space equipment]; Contractors; (Local) Authorities; Industry / Sellers; Designer / Consultances; Engeneers / Installers. The following information components are planned:

- Key information for stakeholders
- Legal frameworks
- Low hanging fruits and best solutions
- Benchmarking
- Technology Viewer
- Case Study Viewer
- Collection of tools and methods
- FAQs and recommendations

Calculation Components

The calculation part comprises on the building level a lighting assessment tool allowing to quickly rate existing installations with respect to their energy consumption. Here upon based retrofit solutions are proposed automatically / or can manually be developed including energy related and economic calculation and optimization functionality. Moreover additional detailed daylight rating functions are planned.

For owners or administrators of bigger real estate collections an additional calculation tool to estimate retrofit potentials in building portfolios is under development.

Further information on IEA-SHC Task 50

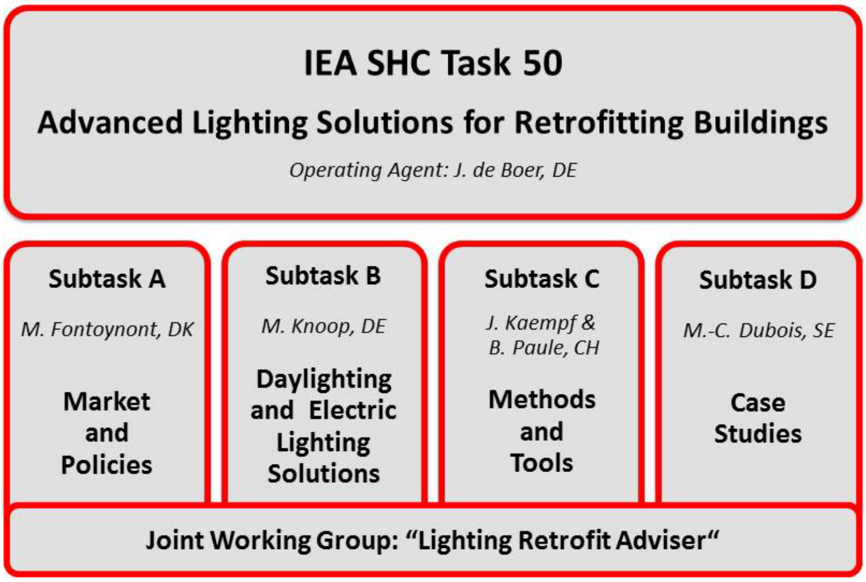


Figure 15: Structure of IEA SHC Task 50.

Figure 16: Participants of the 3rd Task meeting in Aldrans, Austria.

IEA SHC Task 50 officially started in January 2013 and it will continue until December 2015. IEA Task 50 is organized in four Subtasks and one Joint Working Group, in which with the Lighting Retrofit Adviser, an electronic interactive source book is developed (*Figure 15*). More information can be found under http://task50.iea-shc.org/.

Within IEA SHC Task 50, 36 lighting experts from 22 mainly scientific institutions of 13 countries are working together. Since the start of Task 50 four expert meetings have been held in Lund/Sweden (March 2013), Copenhagen/Denmark (Sept. 2013), Aldrans/Austria (March 2014, see *Figure 16*), Fukuoka/Japan (Sept. 2014). Each meeting was organized in combination with a public industry workshop to trigger experience exchange with practitioners. The next meetings are scheduled for Alesund, Norway and Brasilia, Brasil.

Participating countries and experts

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Wilfried Pohl
David Geisler-Moroder

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Belgian Building Research Institute (BBRI)
Arnaud Deneyer
Université Catholique de Louvain
Magali Bodart

Brazil
University of Brasilia
Prof. Cláudia Amorim

China
China Academy of Building Research
Luo Tao

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Aarhus University, Department of Engineering
Prof. Werner Osterhaus
Sophie Stoffer
Danish Building Research Institute (SBi)
Kjeld Johnsen
Prof. Marc Fontoynont

Finland
Aalto University
Eino Tetri

Germany
Fraunhofer Institute for Building Physics IBP
Jan de Boer
Berat Aktuna
Anna Hoier
Carolin Hubschneider
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Fredrik Martens Onarheim
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Niko Gentile
WSP Sweden / WSP Ljusdesign
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IEA SHC Task 50: Advanced Lighting Solutions for Retrofitting Buildings

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