Global Economic Models

T50.A1

A Technical Report of IEA SHC Task 50
Advanced Lighting Solutions for Retrofitting Buildings

May 19, 2016

IEA Solar Heating and Cooling Programme

The Solar Heating and Cooling Programme was founded in 1977 as one of the first multilateral technology initiatives ("Implementing Agreements") of the International Energy Agency. Its mission is *"to enhance collective knowledge and application of solar heating and cooling through international collaboration to reach the goal set in the vision of solar thermal energy meeting 50% of low temperature heating and cooling demand by 2050.*

The members of the Programme collaborate on projects (referred to as "Tasks") in the field of research, development, demonstration (RD&D), and test methods for solar thermal energy and solar buildings.

A total of 54 such projects have been initiated, 44 of which have been completed. Research topics include:

- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44, 54)
- Solar Cooling (Tasks 25, 38, 48, 53)
- Solar Heat or Industrial or Agricultural Processes (Tasks 29, 33, 49)
- Solar District Heating (Tasks 7, 45)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52)
- Solar Thermal & PV (Tasks 16, 35)
- Daylighting/Lighting (Tasks 21, 31, 50)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- Standards, Certification, and Test Methods (Tasks 14, 24, 34, 43)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- Storage of Solar Heat (Tasks 7, 32, 42)

In addition to the project work, there are special activities:

- SHC International Conference on Solar Heating and Cooling for Buildings and Industry
- Solar Heat Worldwide – annual statistics publication
- Memorandum of Understanding – working agreement with solar thermal trade organizations
- Workshops and seminars

Country Members

Australia	Germany	Singapore
Austria	France	South Africa
Belgium	Italy	Spain
China	Mexico	Sweden
Canada	Netherlands	Switzerland
Denmark	Norway	Turkey
European Commission	Portugal	United Kingdom

Sponsor Members

European Copper Institute	Gulf Organization for Research and Development
ECREEE	RCREEE

For more information on the IEA SHC work, including many free publications, please visit www.iea-shc.org

Global Economical Models

A Technical Report of Subtask A T50. A.1

IEA SHC Task 50: Advanced Lighting Solutions for Retrofitting Buildings

May 19, 2016

AUTHORS

Primary:
Marc Fontoynont (SBI-Aalborg University, Denmark)

Additional (in alphabetical order):
Jan de Boer (Fraunhofer Institute for Building Physics, Germany)
Johan Röklander (WSP Ljusdesign, Sweden)
Karen Guldhammer (SBI-Aalborg University, Denmark)
Nanna Sofie Gudmandsen (SBI-Aalborg University, Denmark)
Yasuko Koga, (Kyushu University, Japan)

Distribution Classification: unrestricted

AUTHORS

Marc Fontoynont
SBI-Aalborg University
A.C. Meyers Vænge 15,
2450 Copenhagen, Denmark
mfo@sbi.aau.dk

Karen Guldhammer
SBI-Aalborg University
A.C. Meyers Vænge 15,
2450 Copenhagen, Denmark
karenguldhammer@gmail.com

Nanna Sofie Gudmandsen
SBI-Aalborg University
A.C. Meyers Vænge 15,
2450 Copenhagen, Denmark
nsg@sbi.aau.dk

Jan de Boer
Fraunhofer Institute for Building Physics
Nobelstr. 12
70569 Stuttgart, Germany
jan.deboer@ibp.fraunhofer.de

Johan Röklander
WSP Ljusdesign
Jönköping och Stockholm
Box 2131
550 02 Jönköping, Sweden
johan.roklander@wspgroup.se

Yasuko Koga
Kyushu University
6-10-1 Hakozaki, Higashi-ku,
Fukuoka, 812−8581,Japan
koga@arch.kyushu-u.ac.jp

KEYWORDS

Light Quality

Light Benefits

Health benefits

Productivity

Life Cycle Costs

Life Cycle Assessment

Solid State Lighting

Roadmaps

Lighting Efficiency

PREFACE

Lighting accounts for approximately 19 % (~3000 TWh) of the global electric energy 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. Many countries face the same situation: The majority of the lighting installations are considered to be out of date (older than 25 years). Compared to existing installations, new solutions allow a significant increase in efficiency – easily by a factor of three or more – very often going along with highly interesting payback times. However, lighting refurbishments are still lagging behind compared to what is economically and technically possible and feasible.

IEA SHC Task 50: Advanced Lighting Solutions for Retrofitting Buildings" therefore pursues the goal to accelerate retrofitting of daylighting and electric lighting solutions in the non-residential sector using cost-effective, best practice approaches.

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 ("Lighting Retrofit Adviser") including design inspirations, design advice, decision tools and design tools

To achieve this goal, the work plan of IEA-Task 50 is organized according to the following four main subtasks, which are interconnected by a joint working group:

Subtask A: Market and Policies
Subtask B: Daylighting and Electric Lighting Solutions
Subtask C: Methods and Tools
Subtask D: Case Studies
Joint Working Group (JWG): Lighting Retrofit Adviser

ABSTRACT

This documents presents financial data relative to lighting installations, before and after retrofit operations. Data are calculated over a large number of years to combine installation costs, maintenance ,and energy use

The general principe was to compare the running costs of the “do nothing” approach (keeping the installation as it is and let it die gradually) , and the costs associated with a retrofit with highly effiient equipment.

For these reasons, long term costs of installation are quite sensitive to the initial cost, and the combined cost of electricity and energy efficiency. Total Cost of Ownership (TCO) of lighting installations has been calculated for various types of buildings: offices, schools, homes and industrial buildings..

The data we supply attempt to answer to the following questions:

Which installations are low hanging fruits (with shortest payback time)

For which type of building are retrofit operation more profitable

How do various parameters influence the payback time (investment costs, efficacy of luminaires and sources, cost of electricity, etc.)

Then we have investigated various financial models to initiate successful investments in retrofit operations

Direct investment by the user, with significant benefits after the payback time

Investment by the user with specific loan. This extends payback time, but doe nor require too high of a financial contribution at the beginning.

Leasing of the entire installation: the building owner does not own the installation. The lighting installation is rented (installation and operation is supplied by a third party)

From our experience, it appears that leasing options are the best way to trigger lighting retrofit to overcome the barriers associated to investment.

However such possibilities requires the benefits associated to lighting retrofit to be sufficiently high: large number of operating hour, large reduction of electric power density, high electricity rates.

Table of Contents

1. Introduction

Lighting technology can be seen as the downstream element of a global lighting system. Two upstream elements (electrical power generation and electrical distribution) are the aspects which are often forgotten by the consumers, but not by authorities and large stakeholders.

Lighting uses about 19% of the electricity produced in OECD countries. It varies significantly from country to country, mainly as a function of the importance of other usage of electricity (for heating for instance, in Norway or France).The energy mix has to be taken into account in the estimation of impact of lighting on the production of CO2, For instance, in , since in countries using mainly hydro or nuclear power, impact of lighting retrofit will be small on the emission of CO_2. (Norway, Swizzerland, Sweden, France, etc.)

Life Cycle Assessment of lighting products shows that most of the environmental impact of lighting occurs during the stage of use, through the consumption of electricity (IEA 4E-SSL Annex). It also shows that the initial investment costs in lighting products are increasing today, when energy efficiency increases. However this may rapidly change, and new generations of lighting products may become both more efficient and cheaper.

This evolution of lighting products may lead to some structural changes in the way lighting is provided. One evolution is the possibility of leasing of installations, with maintenance provided by a third party. In this case, retrofitting could be included in the service. Another approach is the retrofitting as part of services provided by ESCOs (either with external assistance, or through a shared-saving model).

The question which is raised is:

“What are the potential global economical and social benefits of conducting retrofit of lighting installations?”

and a possible related question is:

“Is there any action governments could take to stimulate lighting retrofit, beyond the development of energy codes?”

The simple and most shared argument in favour of retrofit stands in the replacement of existing lamp and luminaires by a new generation of products, often 30 to 60% more energy efficient. The criteria referred to in this process to assess gains (for the client) is the comparison of Total Cost of Ownership (TCO) between the former installation and the new one. TCO adds up investment costs, installation costs, maintenance and operating costs and costs related to the management of the end of life. In lighting, operating costs used to be the dominating costs in most office installations, but this share tends to be reduced to the increasing costs of new generation, high efficiency luminaries.

This model seems to concern mainly the clients. On the global economical side, the questions are:

“How can lighting retrofits contribute to governmental objectives (reduction of CO_2 , Kyoto objectives, EC goal 20-20-20, etc.”

and

"What could be other benefits at a large scale?".

2. The Importance of Lighting Quality

Providing electricity production in developing countries has become a first priority for many organizations, and below a couple of the initiatives are described.

Approximately 1.3 billion people live in places which are off-grid and where electricity in the traditional way is not a possibility. The Canadian non-profit organization 'Light Up The World' (LUTW) enforces this initiative and is seen as a pioneer in illuminating the lives of remote and underserved communities. Villages in the developing countries are illuminated by using LED technology powered by renewable energy.

By providing electricity production to off-grid communities the lives of the villagers are changed dramatically. The electricity production is gained by using renewable energy which will result in a healthy and safe home environment, enhancing opportunities for education and contributing to economic development by increasing disposable income and encouraging entrepreneurship.

The focus of the organization is not only short termed, but initiatives are made to ensure that the communities are empowered to keep the initiative going and move towards a more sustainable future. The initiative to ensure this is focus on training local technicians as well as developing the capacity of local service providers. Table 1 gives an indication of how the LUTW is constructed and what focus areas are present.

Table 1: Benefits of providing lighting to remote and underserved communities (Light Up The World, n.d.).

 **EDUCATION** Energy facilitates education.	 **ECONOMIC DEVELOPMENT** Living without electric light is expensive.	 **ENVIRONMENT AND WELL-BEING** Clean energy is an investment in health.
In remote communities the length of the day is strictly related to the presence of daylight. This means that children's' work and chores are done before and after school, and this leaves little time in the evening in the dim light of a	The lack of electricity leads to a large usage of inefficient lighting sources like candles and kerosene wick lamps. This usage means that as much as one third of the monthly income is used for inefficient lighting solutions. With renewable	The toxic by-products released by burning fuels for light present a number of health and environmental issues and are a primary source of greenhouse gas emissions. Years of inhaling noxious gases can lead to severe respiratory illness and an

kerosene wick lamp. Quality home lighting immediately improves conditions for education in the home.	energy systems that cost much less than burning kerosene on a daily basis, families have more disposable income they can spend on other priorities such as school fees, health care or a small business.	open flame in the home increases the threat of fire and burns. Clean energy greatly reduces health risks.

Even for communities with electricity production challenges are present in form of inefficient lighting. The electricity for lighting is approximately 15 per cent of the global power consumption and 5 per cent of the worldwide greenhouse gas (GHG) emissions. With an initiative of a global transition to efficient lighting the stated emissions could be reduced by over one-third. Only few actions could reduce carbon emissions as cheaply and easily as the phase-out of inefficient lighting. This makes it one of the most effective and economically advantageous ways to combat climate change.

Inefficient lighting products often compromise the effectiveness of energy efficient lighting programs and policies. These products can breach technical regulations and intellectual property rights and are often sold at too low prices that exclude fair competition. The products can pose serious threats to human health and safety as well as generate pollution and contribute to environmental degradation. The *en.lighten* initiative has been established to amplify this initiative. The idea is to accelerate global market transformation to environmentally sustainable lighting technologies by developing a coordinated global strategy and providing technical support for the phase-out of inefficient lighting.

The initiative assists countries in an acceleration of market transformation with environmentally sustainable, efficient lighting technologies. To assists the countries in this several measurements are presented as:

- Promoting high performance, efficient technologies in developing countries.
- Developing a global policy strategy to phase-out inefficient and obsolete lighting products.
- Substituting traditional fuel-based lighting with modern, efficient alternatives.

The aim of the project is stated on Enlighten's webpage as:

'The project aims to increase regional co-operation on efficient lighting, including the sharing of information and harmonization of standards, as part of a regional quality control system to increase consumer confidence in energy-efficient products, and lower their cost. The project will also involve quantitative and qualitative comparisons of the availability, performance and compliance of lighting products in the region, and the training of technicians and scientists.'

A new partnership ensures improvement of energy efficiency, reduction of electrical demand as well as lowering gas emissions across Asia. The efforts will focus on monitoring, verification and enforcement (MVE) activities and increase compliance. All these parameters are essential parts of ensuring a sustainable transition to efficient lighting and an example is seen below and in Table 2:

‘Indonesia alone could realize savings of over US$ 1.4 billion per year if a full transition to energy efficient lighting took place. For on-grid lighting, the shift to energy-saving replacement products for the major lamp types in all sectors would result in a savings of 9.3 terawatt hours in annual electricity consumption which is equivalent to 7 per cent of total national electricity consumption each year and equal to the power output of 3 large (500 MW) power plants. For off-grid lighting, the country would reduce CO2 emissions by 5.5 million tons which is equivalent to taking 1.4 million mid-size cars off the road’ (UNEP (United Nations Environment Programme), n.d.).

Table 2: Benefits of changing to energy efficient lighting with regards to financial, energy saving and climate change aspects (UNEP (United Nations Environment Programme), n.d.).

	Financial Benefits	Energy Saving Benefits	Climate Change Benefits
Indonesia	• *savings of over US$ 1.4 billion per year if a full transition to energy efficient lighting took place.*	• 9.3 TWh annual electricity consumption saved • Equivalent to power output of 3 large (500 MW) power plants	• *reduce CO2 emissions by 5.5 million tonnes annually.* • *Equivalent to taking 1.4 million mid-size cars off the road'*
China	• *savings of over US$ 21.6 billion per year if a full transition to energy efficient lighting took place.*	• 184.8 TWh annual electricity consumption saved • Equivalent to power output of 50 large (500 MW) power plants	• *reduce CO2 emissions by 133.8 million tons annually.* • *Equivalent to taking 33.5 million mid-size cars off the road'*
India	• *savings of over US$ 2.6 billion per year if a full transition to energy efficient lighting took place.*	• 41.3 TWh annual electricity consumption saved • Equivalent to power output of 11 large (500 MW) power plants	• *reduce CO2 emissions by 39.9 million tons annually.* • *Equivalent to taking 10.0 million mid-size cars off the road'*
Malaysia	• *savings of over US$ 554.9 million per year if a full transition to energy efficient lighting took place.*	• 5.7 TWh annual electricity consumption saved • Equivalent to power output of 2 large (500 MW) power plants	• *reduce CO2 emissions by 3.8 million tons annually.* • *Equivalent to taking 1.0 million mid-size cars off the road'*

3. Lighting and production of CO_2

Lighting electricity is currently said to use between 15 and 40% of the energy consumption in buildings, if expressed in primary energy. But we will see below that this strongly depends on the type of electrical power generation in countries.

On the government side, the interest in lighting retrofits is related to the reduced environmental impact linked to a reduced electricity consumption. The most relevant criteria are:

- Reduction of CO_2 production by electric power plants (when using fossil fuels)
- Reduction of mercury dissemination (linked to fluorescent and arc type lamps)
- Possible reduction in peak electricity demand (which in this case could affect capacity of power plants).

The carbon footprint related to electricity use varies significantly as a function of type of energy source used to produce electricity (Table 3).

Table 3: Grams of CO_2 produced when 1 kWh of electricity is produced from different sources.

Source	Grams of CO_2 produced for every kWh generated
Coal	955
Oil	893
Natural Gas	650
Nuclear Energy	60
Hydro Electricity	15
Solar Energy	40

One difficulty in the approach is that the "environmental" benefits are strongly related to the energy mix used by the electricity supplier.

A few observations related to the numbers presented in Figure 1:

- First, differences are huge, from almost 0 gr of CO_2 per kWh in Norway, to about 1000 gr in Estonia.
- In Norway, electricity is mainly produced by hydropower, with limited emission of CO_2. Here the use of high efficiency lamps and luminaires will have hardly any impact on the reduction of CO_2 emissions.
- In France, where 80% of the electricity is produced by nuclear power plants, the impact will also be very limited.

Impact associated with reduction of electricity consumption for lighting is maximum in countries using large quantities of coal (Greece, England, Germany and eastern European countries, for instance).

There are also discrepancies concerning the production of electricity per capita: Iceland produces 38000 kWh of electricity per year, Norway produces 30000, USA 13000, France 8900, Japan 8500, Germany 7000 (CIA World Factbooks 18 December 2003 to 28 March 2011, n.d.).

USA electricity generation is responsible for 39% of its production of CO_2, and 74 % of this is related to coal burning, 24% to gas (U.S. Energy Information Administration, n.d.).

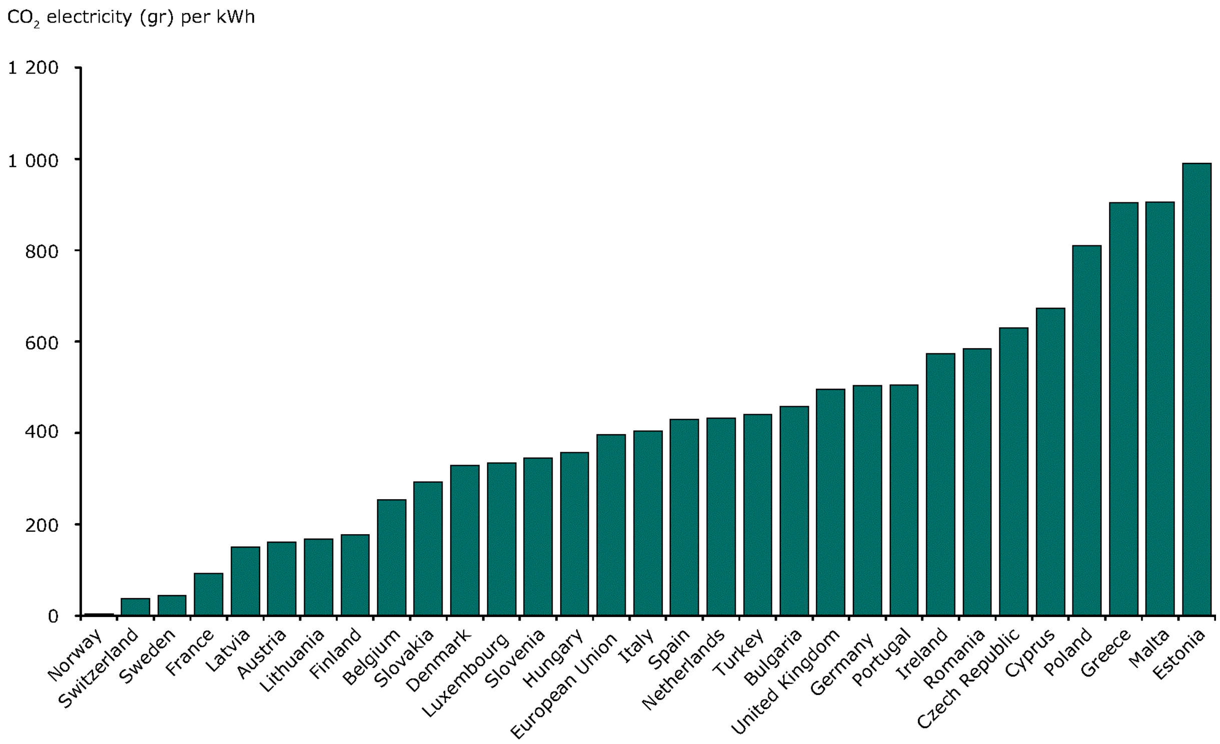


Figure 1: Production of CO2 to generate 1 kWh of electricity in the European Union

4. Opportunities and constraints related to rapid evolution of equipment

Progress in energy efficiency of indoor lighting products is mainly related to progresses in LED package, using phosphor coating (most of present LEDs) or color mixed. Gains of efficiency of about 50% are achievable with LED solutions in comparison with , in comparison with 2015 products (Figure 2) Campaigns of test of efficacy of products sold on the market show a huge discrepancy in performance (Figure 3).

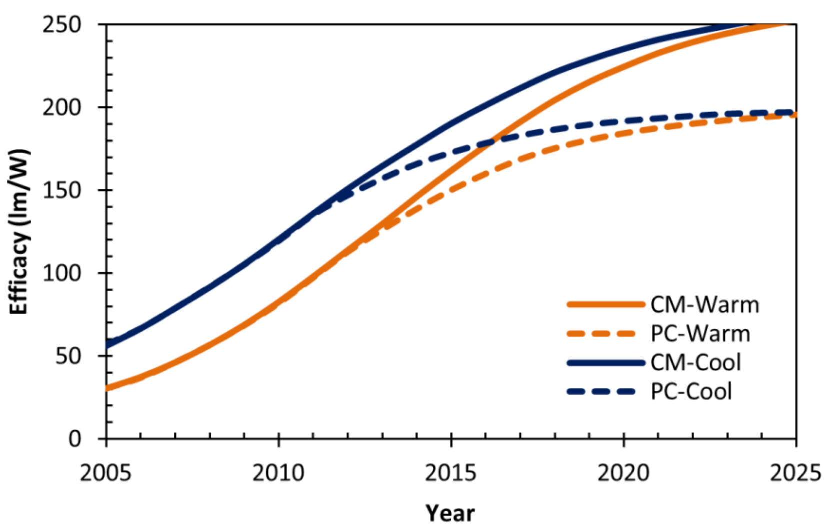


Figure 2: Actual and projected increases in the efficacy of color-mixed (CM) and phosphor-coated (PC) LED packages. CM-LED packages are predicted to have a higher maximum efficacy in the future, and the difference between warm white (CCT 2580 K to 3710 K, CRI 80–90) and cool white (CCT 4746 K to 7040 K, CRI 70–80) is expected to diminish (U.S. Department of Energy. Energy Efficiency & Renewable Energy, 2012).

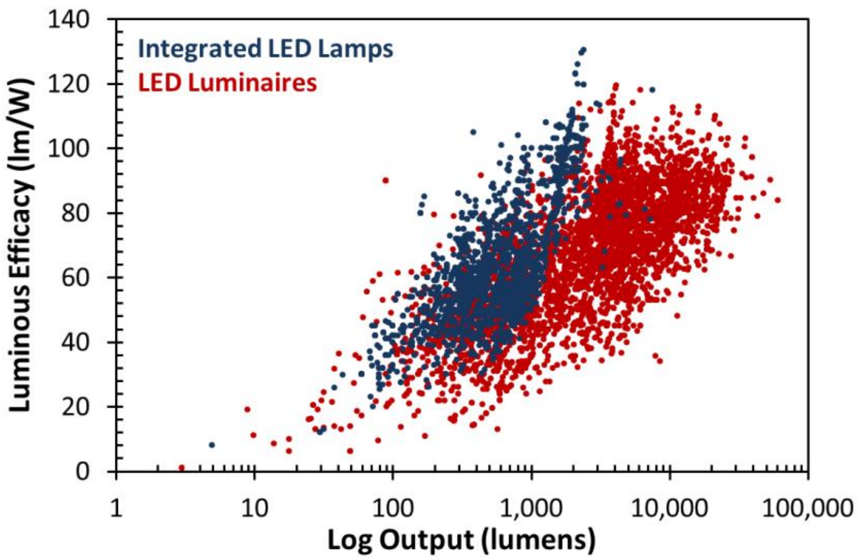


Figure 3: Efficacy versus output for integrated LED lamps and LED luminaires listed by LED Lighting Facts as of February 2013. The range in efficacy is similar for both types of products, but the potential for larger form factors in dedicated LED luminaires allows for more lumen output (U.S. DOE, n.d.).

The data in Table 4, which deals with the evolution of costs and efficacy of LED package, together with the high discrepancy of the performance of this technology, suggests that there will be an evolution of the actors of the value chain: with value of products going down and efficiency improving, lighting industry will have to enlarge its perimeter of action:

- Larger catalogue of products.
- Move upward to provide services.

Table 4: Prediction of evolution of LED Package cost and efficacy (U.S. Department of Energy. Energy Efficiency & Renewable Energy, 2012).

Metric	Unit	2011	2012	2013	2015	2020
LED Package Efficacy (warm white)	lm/W	97	113	129	162	224
LED Package Price (warm white)	$/klm	12.5	7.9	5.1	2.3	0.7
LED Package Efficacy (cool white)	lm/W	135	150	164	190	235
LED Package Price (cool white)	$/klm	9	6	4	2	0.7
Metric	$/klm	33	23	16.5	10	5

Notes:
Projections for cool white packages assume CCT=4746-7040K and CRI=70-80, while projections for warm white packages assume CCT=2580-3710K and CRI=80-90. All efficacy projections assume measurements at 25°C with a drive current density of 35 A/cm. Note that MYPP projections are based on price, not cost.

More information can be found in (McKinsey & Company, 2011).

To assess a possible evolution of the approach of lighting retrofit with a rapidly changing technology, we should investigate what is happening with telephone and computer technologies. Rapid changes tend to accelerate obsolescence of products, and suggests a reduction of life time. Products become disposable quickly.

Evolution of lighting techniques may follow the same route. Disposable products, with a life below 5 years should be easily changed.

Hence the question of standards. In the last 30 years, the lighting industry provided for instance ceiling mounted luminaires allowing the change of fluorescent tubes.

Will we have standard light engines for our luminaires, or should we consider the disposal of the whole luminaire every 5-8 years? In this case, we need standard dimensions (circular or rectangular systems in ceilings).

Anyway, the general directions is that SSL becomes more efficient, cheaper and that its attractivity will increase if energy price increase. It is also one of the energy saving technologies with the most attractive possible return on investment. A topic which we will address in this document

5. Life Cycle Cost of lighting (LCC)

Life Cycle Cost (LCC) of a lighting installation is a cost which is computed in adding:

- The investment cost (electrical installation usually not included, but this costs includes the equipment and the installation on site)
- The operating cost (electricity consumption, maintenance, change of lamps)
- The cost related to the end of life (when taken away from the building, with and without recycling costs).

The value of LCC is typically expressed in € or $ per meter square of floor, per year, or for the duration of equipment (5, 10, 15 years for instance). But TCOs can also be computed per lamp or luminaire, showing the global costs for the client, associated with a product during its entire life. Here, it can be expressed in $ or € per klmh (functional unit of lighting being delivered).

Figure 4: Example of two lighting installations in an office, using ceiling mounted circular luminaries, and task lamps. Left, with fluorescent, and right with LED solutions. LED solution is 50% more energy efficient, but LCC is lower only with long life LED systems.

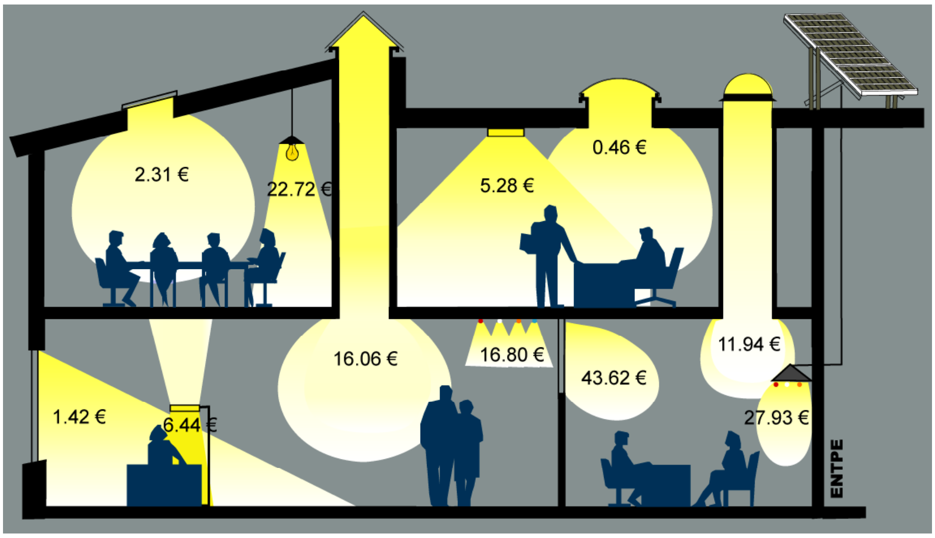


Figure 5: Comparison of LCC of various electric lighting and daylighting scheme. Here, selected functional unit is € per Mlmh per yr of usable light (on work plane). This type of display can quickly illustrate schemes offering lowest LCC for comparable lighting quantities being delivered (Marc Fontoynont, Lighting and Engineering, 2008)

6. Input data for Life Cycle Cost analysis

Table 5 to Table 10 show the hypothesis used in the LCC calculations. The most important parameters are the power density (W/m^2), and the number of hours of use per year (hours) But furthermore the shift of technology from fluorescent light sources to LED affects the frequency of maintenance tasks and life of products. For fluorescent light sources, ballasts need also to be changed. The tables below show that frequency of changes of equipment is not perfectly adjusted with life of luminaire. As a consequence, before retrofitting an existing installation, it is useful to record the time of the last changes (tubes/lamp and ballasts). For all scenarios the installed power is Fluorescent T8.

In offices, this comparison is based on the delivery of 500 lx on the work plane. We compared a classic 10 -20 years old installation with the best in class LED solution.

Table 5: Input data for LCC calculations for personal offices.

Personal Office		Installed, Fluorescent T8	LED
Power density	[W/m^2]	22	7
Usage hours per year	[h]	902	902
Maintained illuminance	[lx]	500	500
Area per luminaire	[m^2]	6	6
Change of luminaire (interval)	[h]	60000	40000
Change of tube/lamp (interval)	[h]	15000	-
Change of ballast (interval)	[h]	45000	-

Table 6: Input data for LCC calculations for open space offices.

Open Space Office		Installed, Fluorescent T8	LED
Power density	[W/m^2]	22	5
Usage hours per year	[h]	2148	2148
Maintained illuminance	[lx]	500	500
Area per luminaire	[m^2]	6	6
Change of luminaire (interval)	[h]	60000	40000
Change of tube/lamp (interval)	[h]	15000	-
Change of ballast (interval)	[h]	45000	-

In the industrial buildings, specified illuminance varies quite a lot. The table below suggests rather high illuminances, especially after the retrofit. It is also noticeable to observe the significant difference in usage hours due to the placement of roof lights.

Table 7: Input data for LCC calculations for industrial installations (using data shared within the IEA 50 members) .

Manufacturing Hall without Roof Lights		HID	LED
Power density	[W/m^2]	14	4
Usage hours per year	[h]	3949	3949
Maintained illuminance	[lx]	300	300
Area per luminaire	[m^2]	6	10
Change of luminaire (interval)	[h]	60000	40000
Change of tube/lamp (interval)	[h]	15000	-
Change of ballast (interval)	[h]	45000	-

Table 8: Input data for LCC calculations for industrial installations.

Manufacturing Hall with Roof Lights		HID	LED
Power density	[W/m^2]	14	4
Usage hours per year	[h]	2948	2948
Maintained illuminance	[lx]	300	300
Area per luminaire	[m^2]	6	10
Change of luminaire (interval)	[h]	60000	40000
Change of tube/lamp (interval)	[h]	15000	-
Change of ballast (interval)	[h]	45000	-

Wholesale retail spaces are used for a long period consecutive period of the year with a high power density for lighting.

Table 9: Input data for LCC calculations for wholesale retail.

Wholesale Retail		Installed, Fluorescent T8	LED
Power density	[W/m^2]	17	7
Usage hours per year	[h]	4801	4801
Maintained illuminance	[lx]	750	750
Area per luminaire	[m^2]	6	6
Change of luminaire (interval)	[h]	60000	40000
Change of tube/lamp (interval)	[h]	15000	-
Change of ballast (interval)	[h]	45000	-

In the classrooms the usage hours is low and the existing luminaire has a beginning low power density.

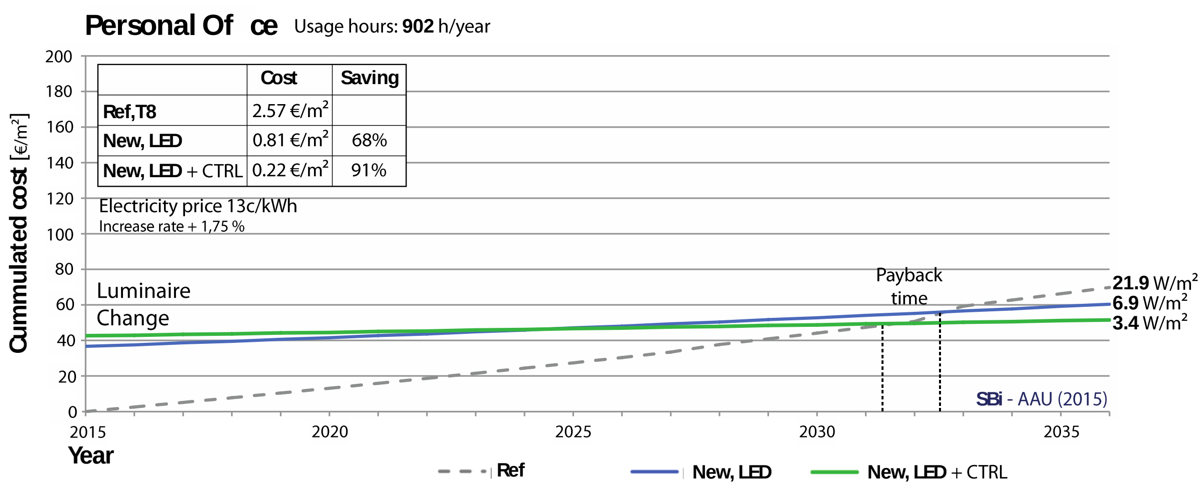
Table 10: Input data for LCC calculations for classrooms.

Classroom		Installed, Fluorescent T8	LED
Power density	[W/m^2]	11	3
Usage hours per year	[h]	932	932
Maintained illuminance	[lx]	300	300
Area per luminaire	[m^2]	6	6
Change of luminaire (interval)	[h]	60000	60000
Change of tube/lamp (interval)	[h]	15000	-
Change of ballast (interval)	[h]	45000	-

7. Results from Life Cycle Cost analysis

7.1. Personal Office

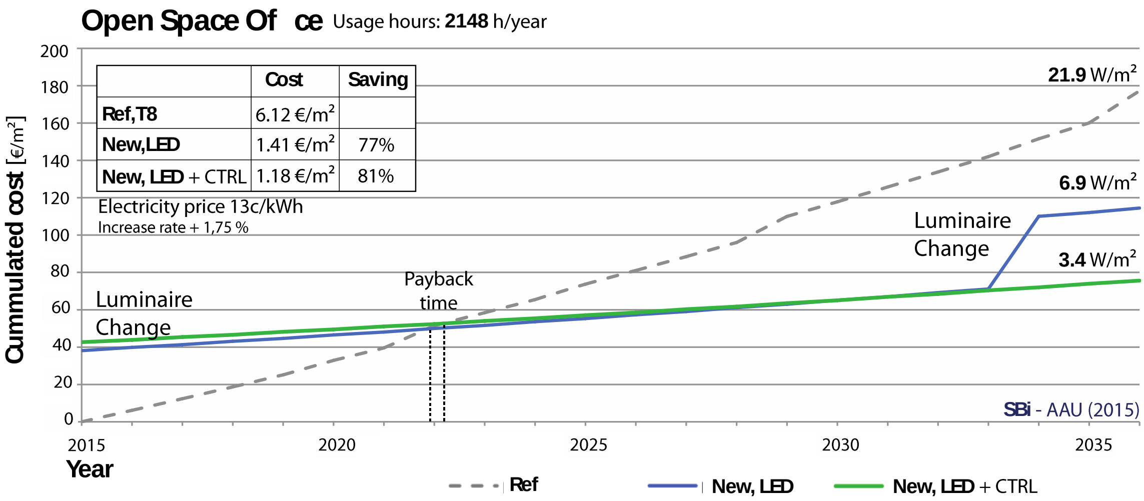
The retrofit of a T8 based lighting installation by LEDs requires an investment, which will not be amortized before 16 years. In personal office, payback time gets closer from life of lighting products



Change of luminaire (€/m2)		**36.7** €/m²	**42.7** €/m²
Electrictiy consumption (€/m2) WATTAGE	**2.57** €/m²	**0.81** €/m²	**0.22** €/m²
Usage hours (h/year)	**902** h/year	**902** h/year	**494** h/year

7.2. Open Space Office

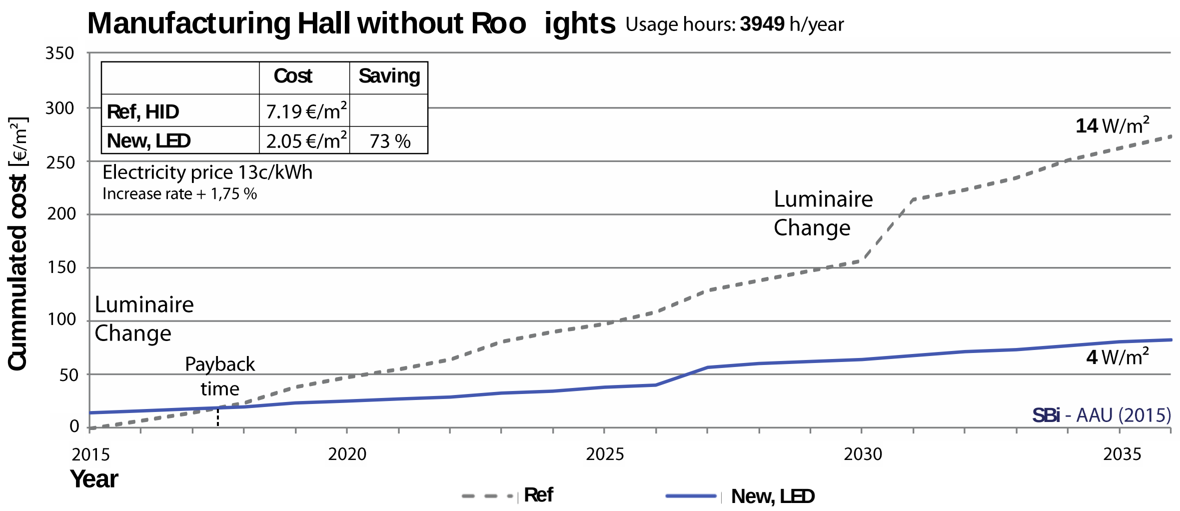
Investing in an open space office has a payback time, which is shorter than with a personal office, mainly due to the fact that general lighting is used for longer duration. As can be seen on the graph below, the payback time is approximately 7 years.



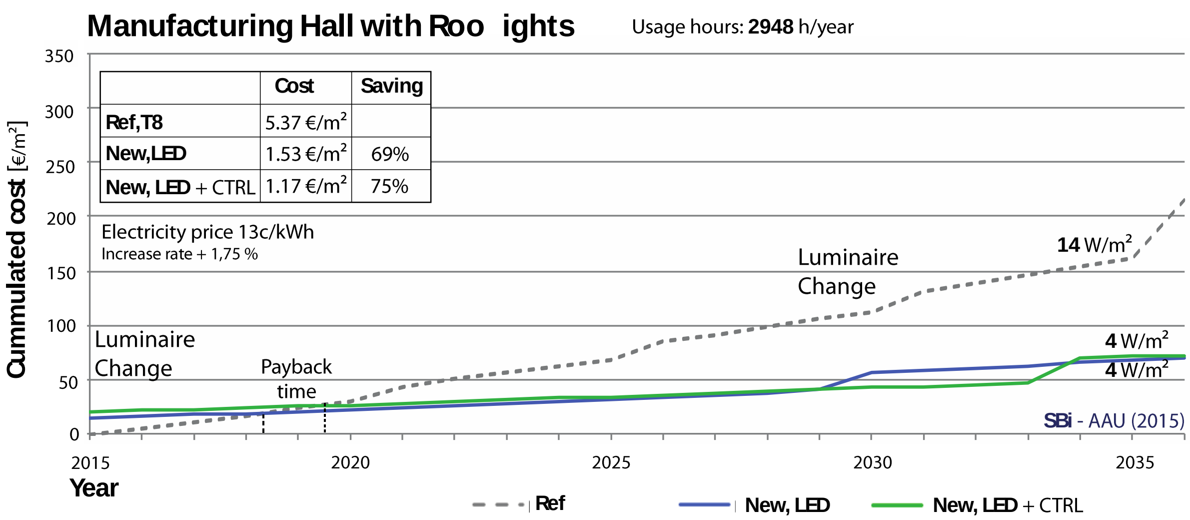
Change of luminaire (€/m2)		**36.7** €/m²	**42.7** €/m²
Electrictiy consumption (€/m2) WATTAGE	**6.12** €/m²	**1.41** €/m²	**1.18** €/m²
Usage hours (h/year)	**2148** h/year	**2148** h/year	**1798** h/year

7.3. Manufacturing Hall without and with Roof Lights

Manufacturing halls have a rather short payback time, but however a little bit longer if adding roof lights as the usage hours of electrical lighting decreases. In this case study, most of the gains are related to reduction in electric lighting power density, but in this case the cost of LED system is quiet low and thus has the shortest payback time.



Change of luminaire (€/m2)		**10** €/m²
Electrictiy consumption (€/m2) WATTAGE	**7.19** €/m²	**2.05** €/m²
Usage hours (h/year)	**3949** h/year	**3949** h/year

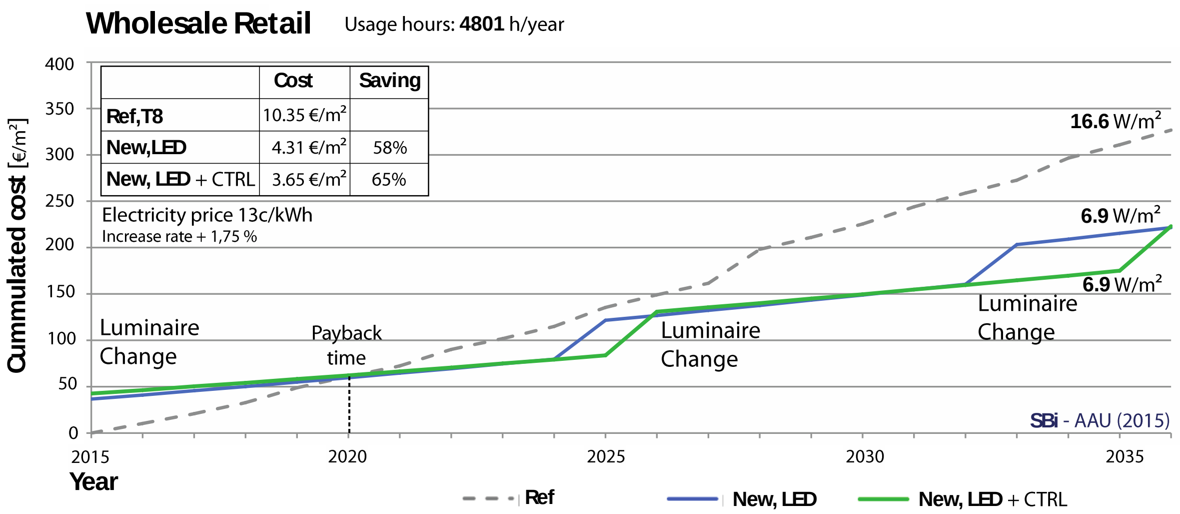


Change of luminaire (€/m2)		**10** €/m²	**16** €/m²
Electrictiy consumption (€/m2) WATTAGE	**5.37** €/m²	**1.53** €/m²	**1.17** €/m²
Usage hours (h/year)	**2948** h/year	**2948** h/year	**2252** h/year

7.4. Wholesale Retail

In department stores, although power density has been almost divided by 2, this reduction is still insufficient to lead to radical decrease in LCC. It is important to develop products with a power density inferior to 10W/m^2 for 750 lx delivered

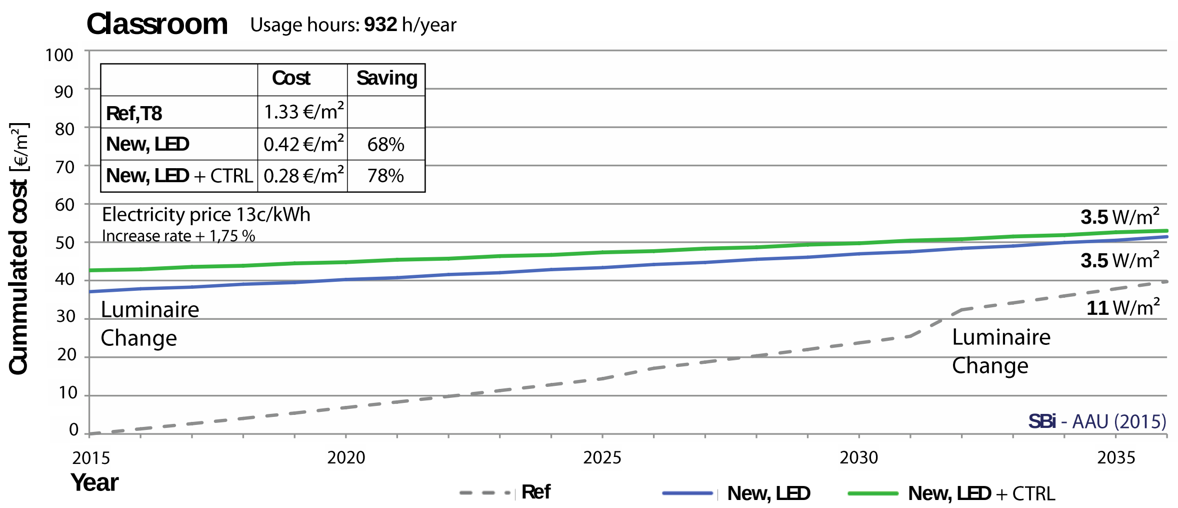
Payback time is short, due to the high number of usage hours.
Main benefit of daylight controls is to delay replacement of lighting equipment.



Change of luminaire (€/m2)		**36.7** €/m^2	**42.7** €/m^2
Electrictiy consumption (€/m2) WATTAGE	**10.35** €/m^2	**4.31** €/m^2	**3.65** €/m^2
Usage hours (h/year)	**4801** h/year	**4801** h/year	**4069** h/year

7.5. Classroom

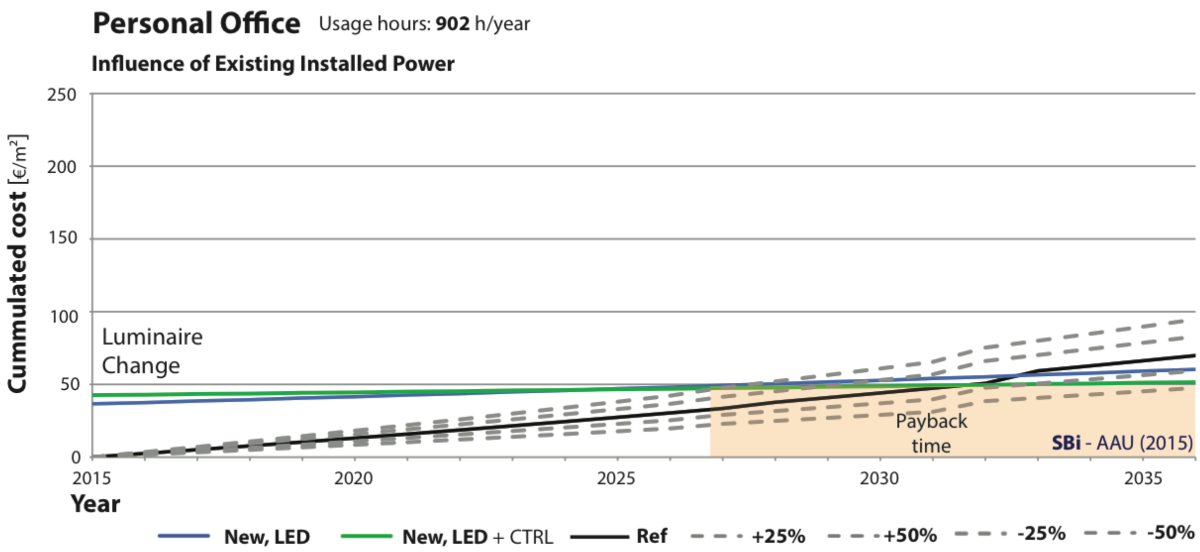
Replacing T8 fluorescent with LED technology does not lead to sufficient gains to justify an accelerated retrofit. Especially in classrooms due to the combination of low power density and limited duration of use every year. Classrooms are thus not used long enough to allow rapid payback for investment in lighting.

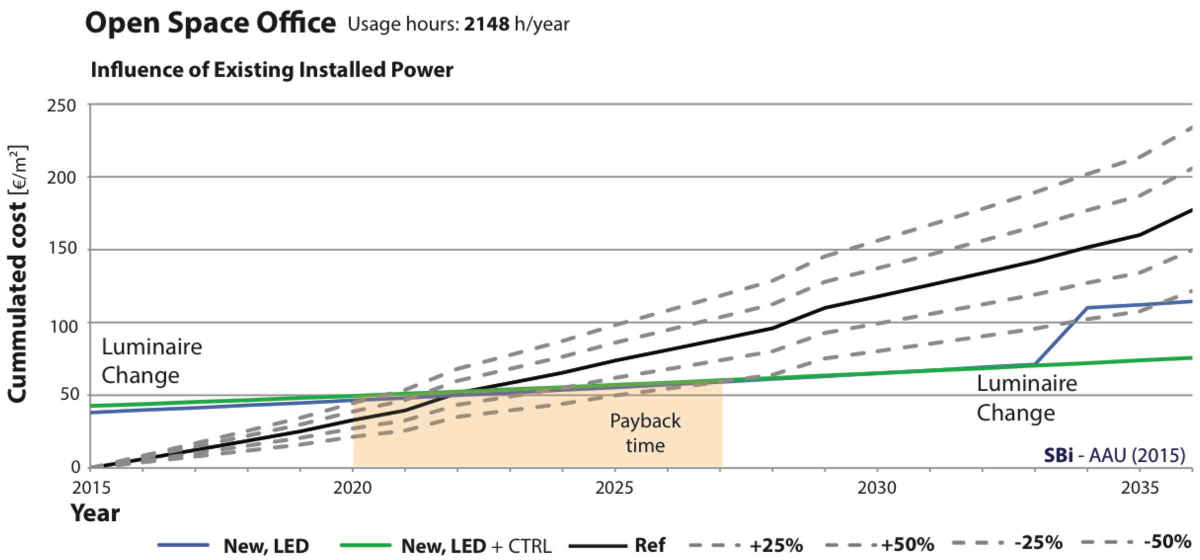


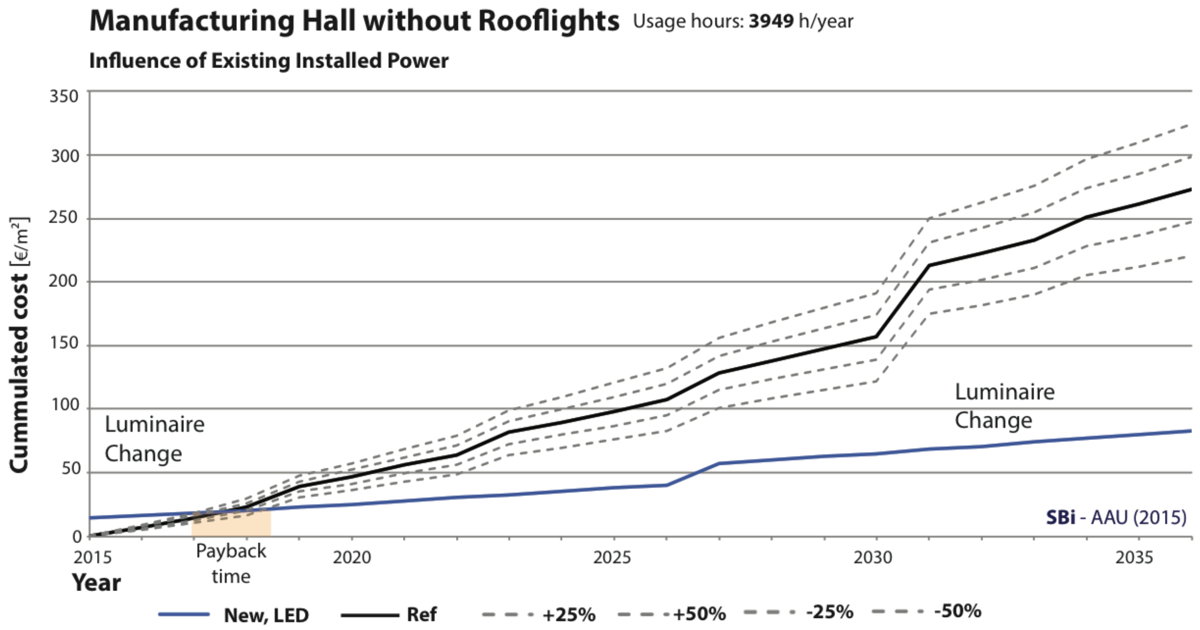
Change of luminaire (€/m2)		**36.7** €/m²	**42.7** €/m²
Electrictiy consumption (€/m2) WATTAGE	**1.33** €/m²	**0.42** €/m²	**0.28** €/m²
Usage hours (h/year)	**932** h/year	**932** h/year	**620** h/year

8. Parametric Studies

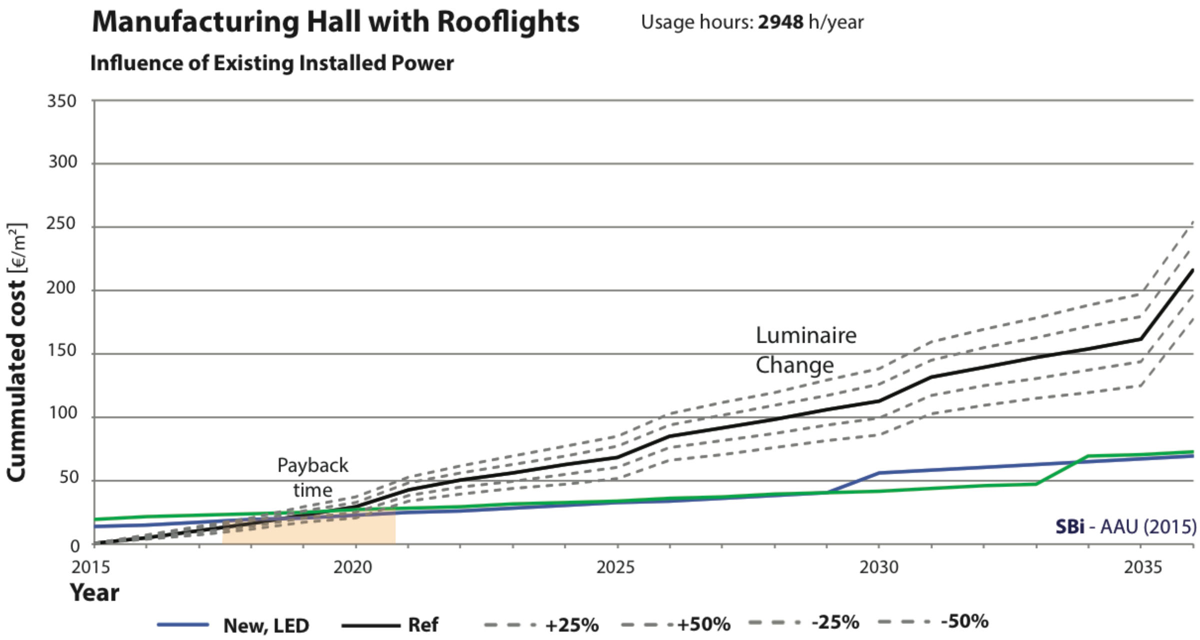
8.1. Influence of Installed Power on Payback Time



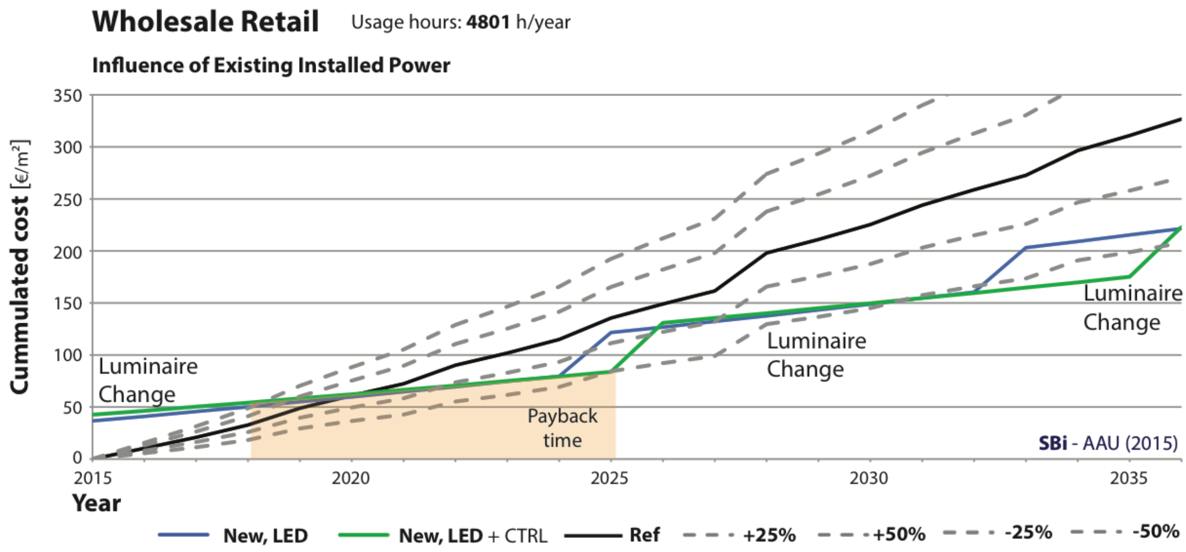




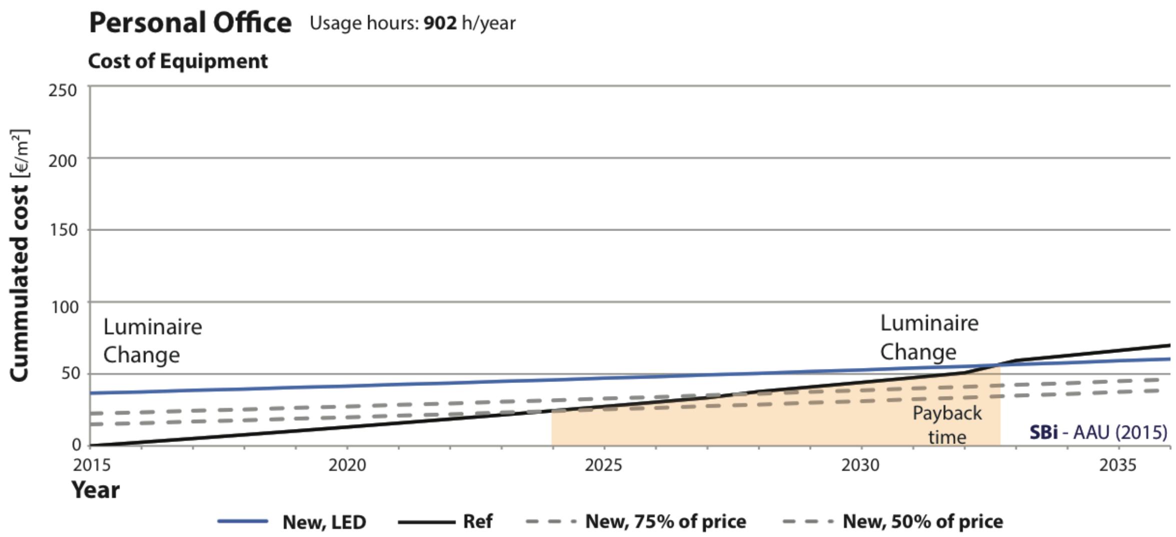
Manufacturing Hall without Rooflights
Usage hours: 3949 h/year
Influence of Existing Installed Power
Cummulated cost [€/m²]
Year
Luminaire Change
Luminaire Change
Payback time
SBi - AAU (2015)
New, LED
Ref
+25%
+50%
-25%
-50%

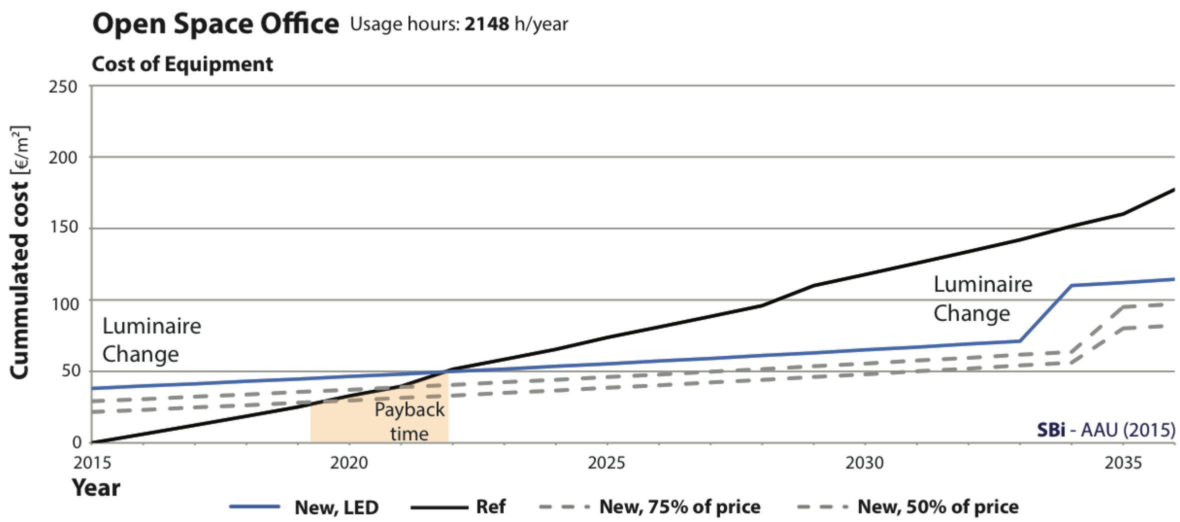


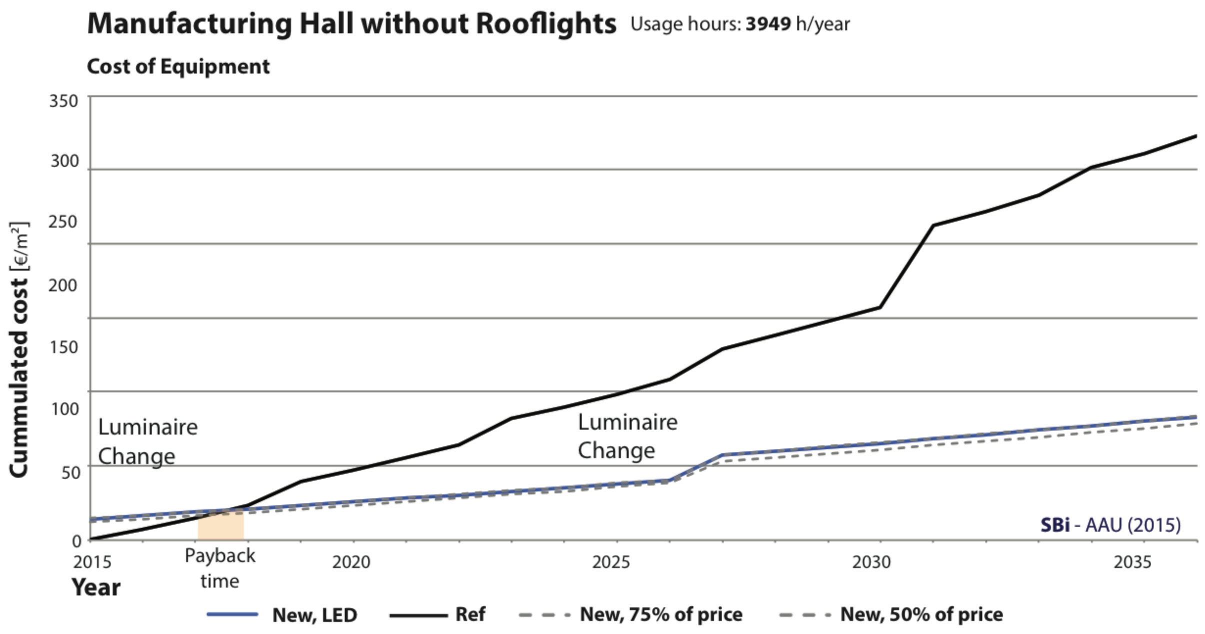
Manufacturing Hall with Rooflights
Usage hours: 2948 h/year
Influence of Existing Installed Power
Cummulated cost [€/m²]
Year
Luminaire Change
Payback time
SBi - AAU (2015)
New, LED
Ref
+25%
+50%
-25%
-50%

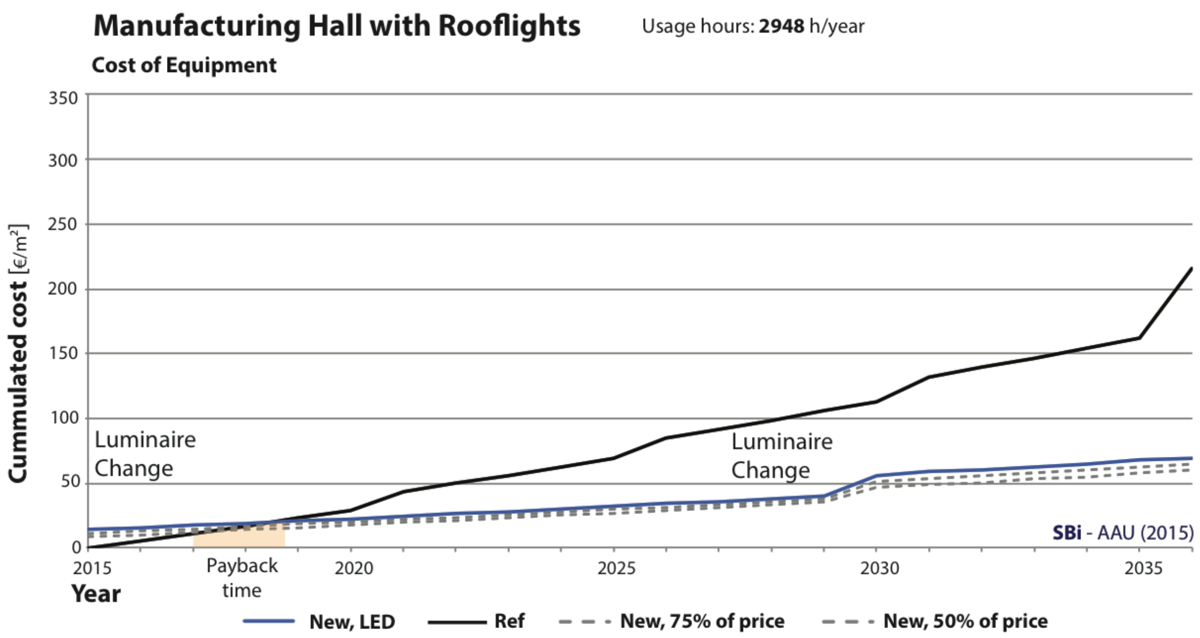


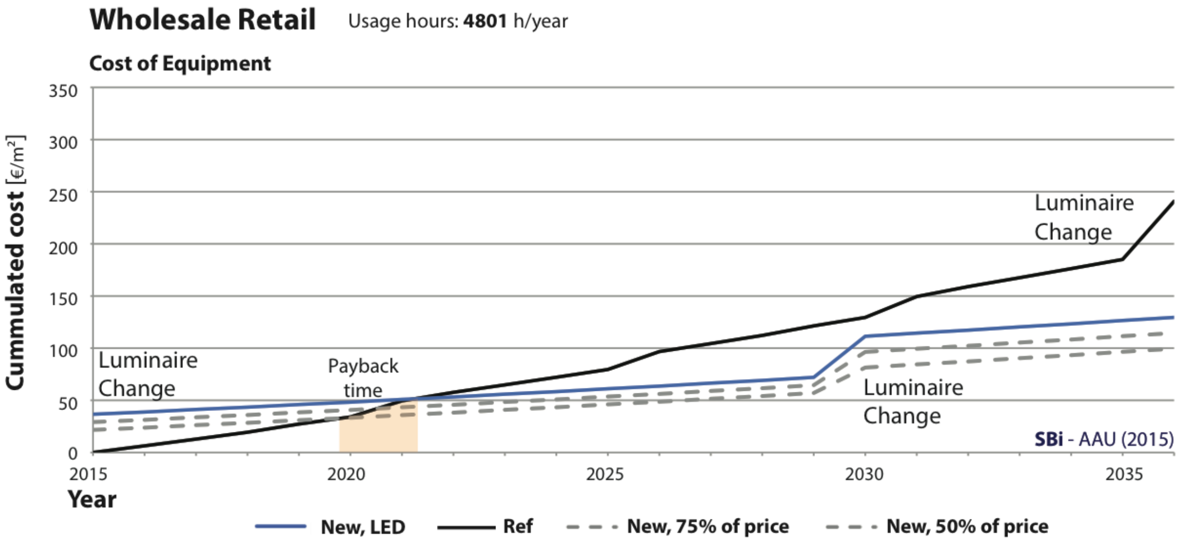
8.2. Influence of Cost of Equipment on Payback Time



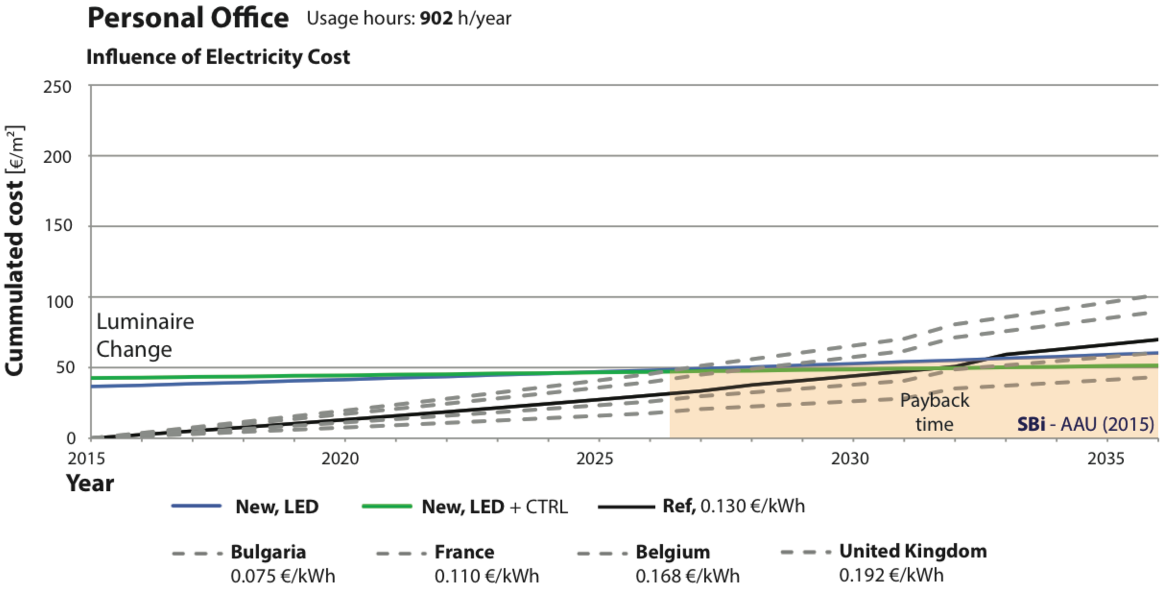


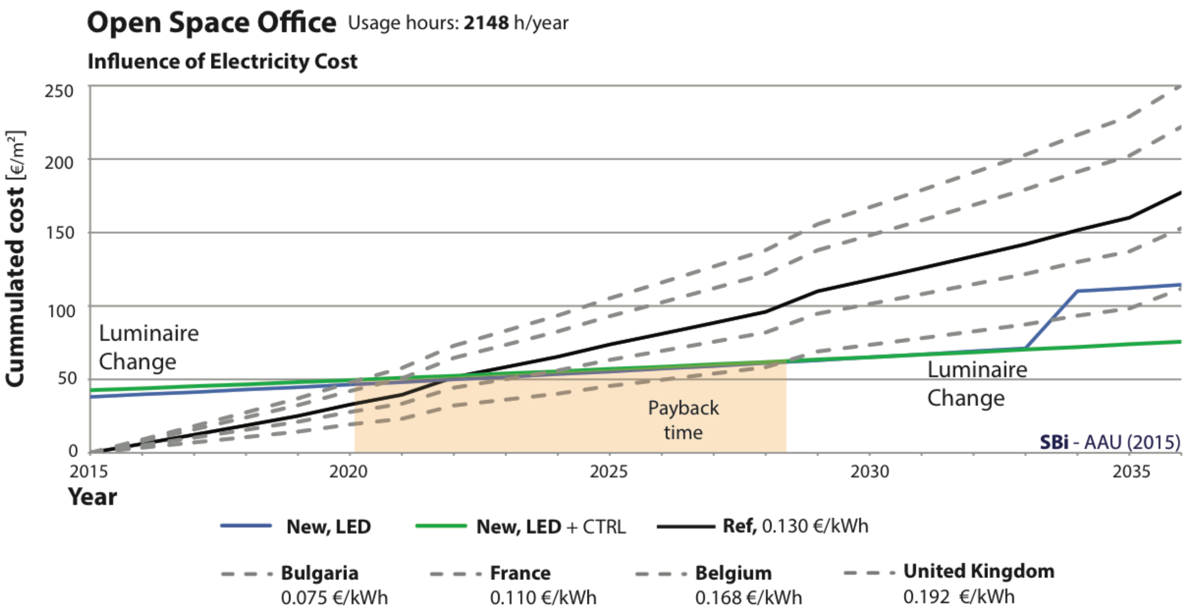

Manufacturing Hall without Rooflights
Usage hours: 3949 h/year
Cost of Equipment
Cummulated cost [€/m²]
350
300
250
200
150
100
50
0
Luminaire Change
Luminaire Change
SBi - AAU (2015)
2015
Payback time
2020
2025
2030
2035
Year
New, LED
Ref
New, 75% of price
New, 50% of price

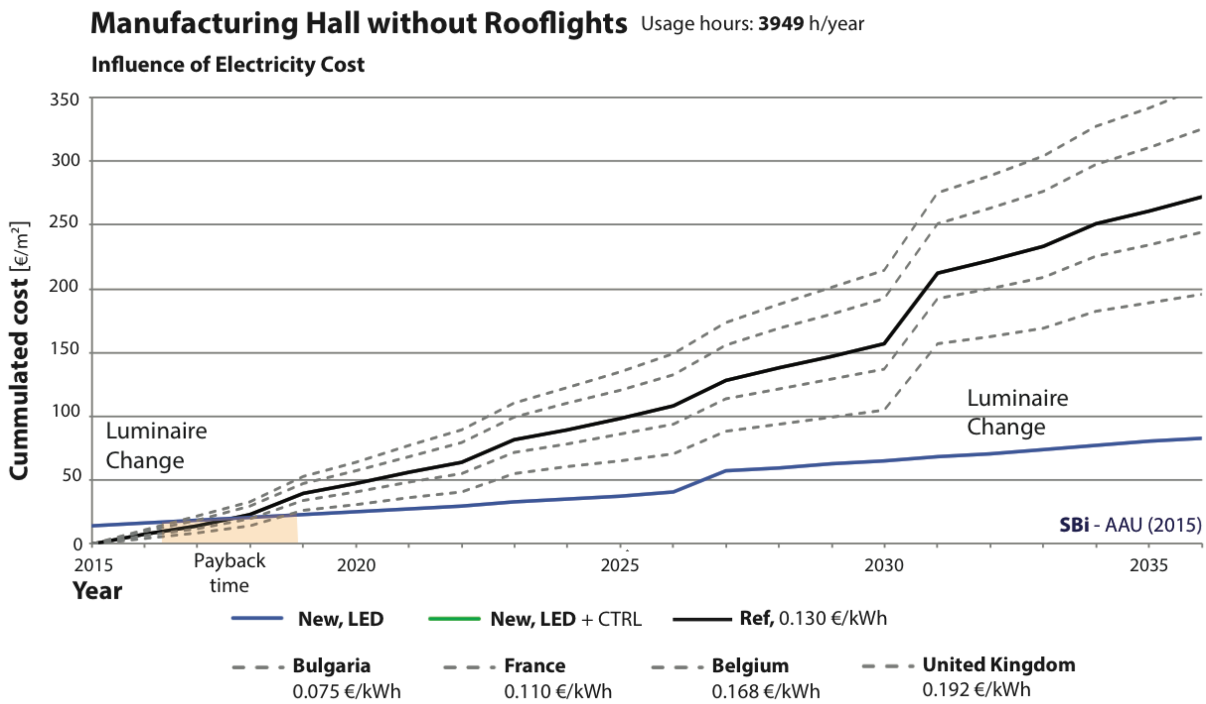

Manufacturing Hall with Rooflights
Usage hours: 2948 h/year
Cost of Equipment
Cummulated cost [€/m²]
350
300
250
200
150
100
50
0
Luminaire Change
Luminaire Change
SBi - AAU (2015)
2015
Payback time
2020
2025
2030
2035
Year
New, LED
Ref
New, 75% of price
New, 50% of price

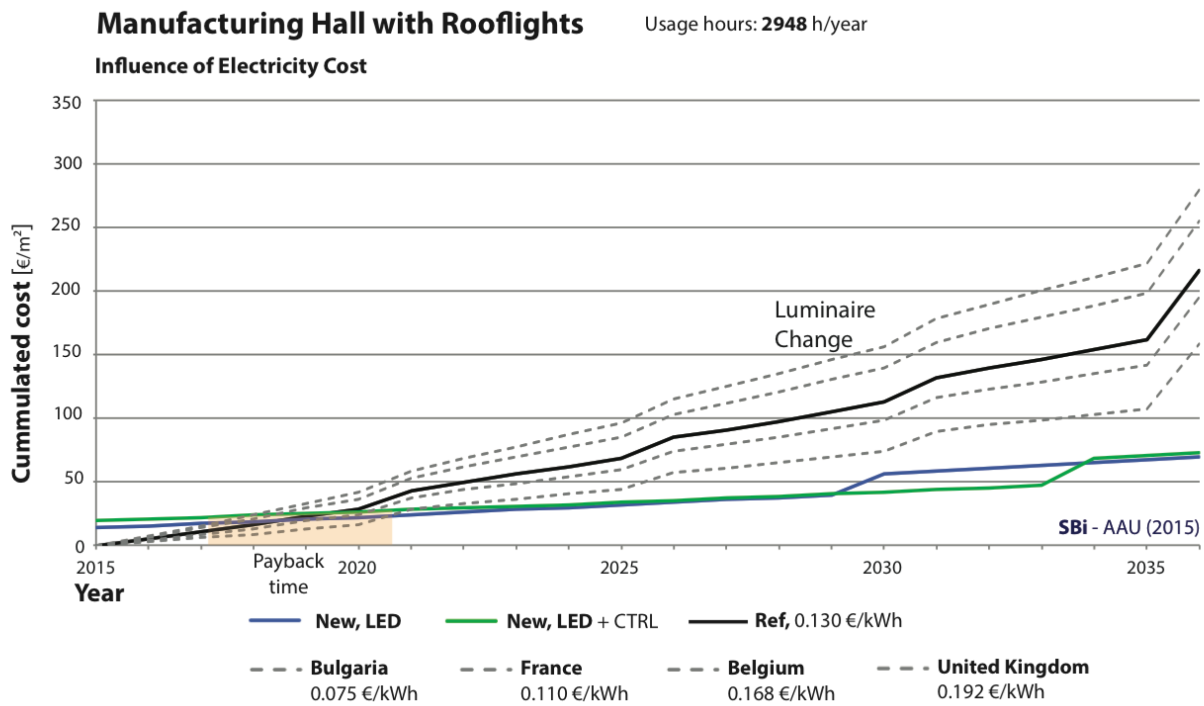

Wholesale Retail
Usage hours: 4801 h/year
Cost of Equipment
350
300
250
200
150
100
50
0
Cummulated cost [€/m²]
Luminaire Change
Payback time
Luminaire Change
Luminaire Change
SBi - AAU (2015)
2015
2020
2025
2030
2035
Year
New, LED
Ref
New, 75% of price
New, 50% of price

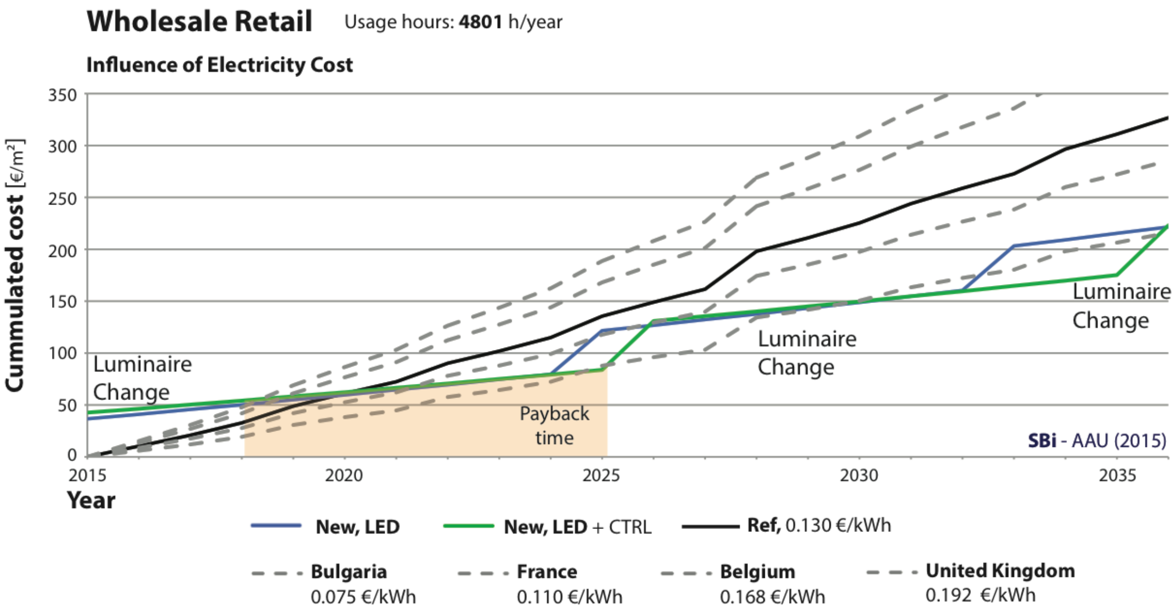
8.3. Influence of Electricity Cost on Payback Time





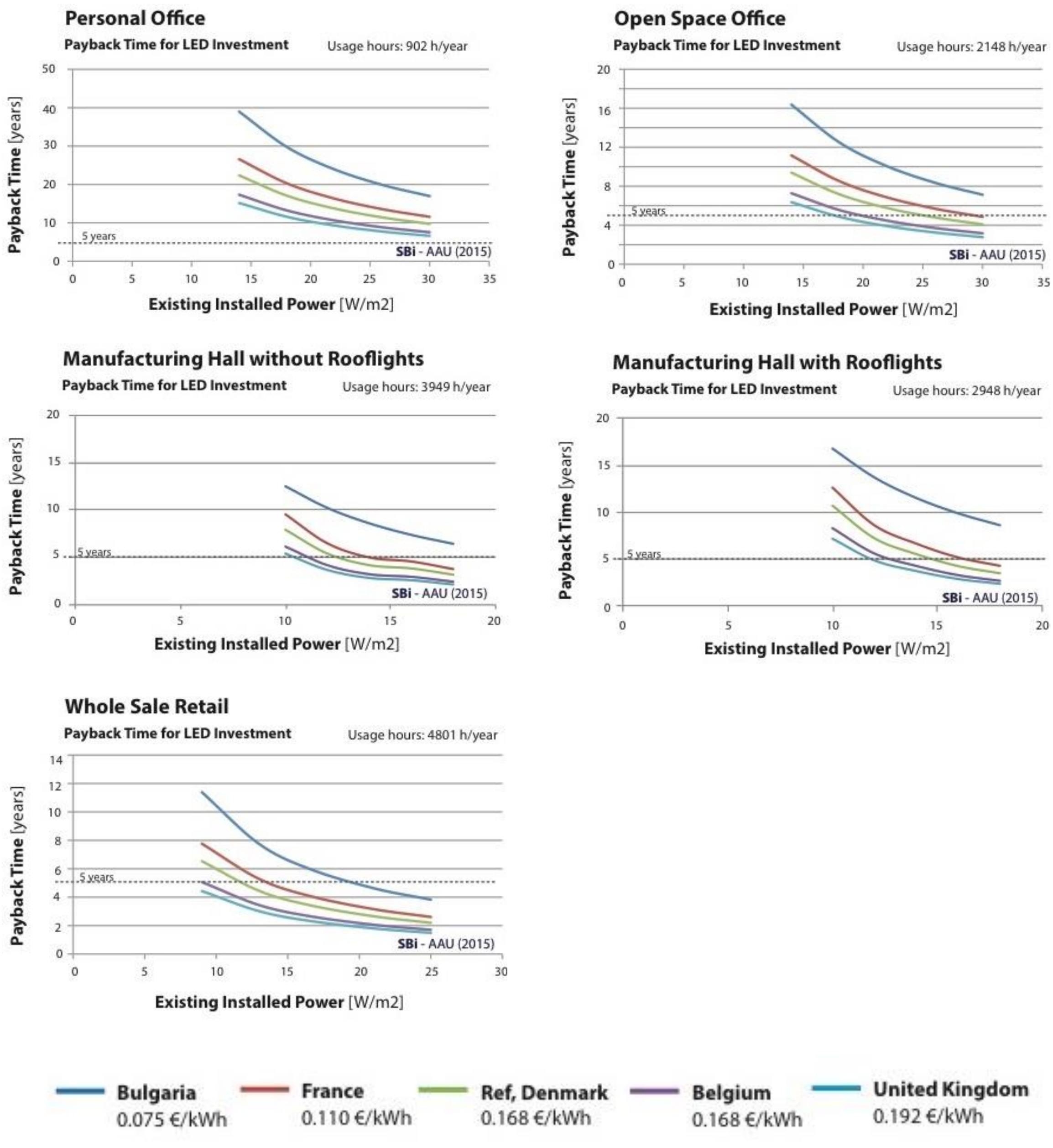

Manufacturing Hall without Rooflights
Usage hours: 3949 h/year
Influence of Electricity Cost
Cummulated cost [€/m²]
350
300
250
200
150
100
50
0
Luminaire Change
Luminaire Change
SBi - AAU (2015)
2015
Payback time
2020
2025
2030
2035
Year
New, LED
New, LED + CTRL
Ref, 0.130 €/kWh
Bulgaria 0.075 €/kWh
France 0.110 €/kWh
Belgium 0.168 €/kWh
United Kingdom 0.192 €/kWh


Manufacturing Hall with Rooflights
Usage hours: 2948 h/year
Influence of Electricity Cost
Cummulated cost [€/m²]
350
300
250
200
150
100
50
0
Luminaire Change
SBi - AAU (2015)
2015
Payback time
2020
2025
2030
2035
Year
New, LED
New, LED + CTRL
Ref, 0.130 €/kWh
Bulgaria 0.075 €/kWh
France 0.110 €/kWh
Belgium 0.168 €/kWh
United Kingdom 0.192 €/kWh

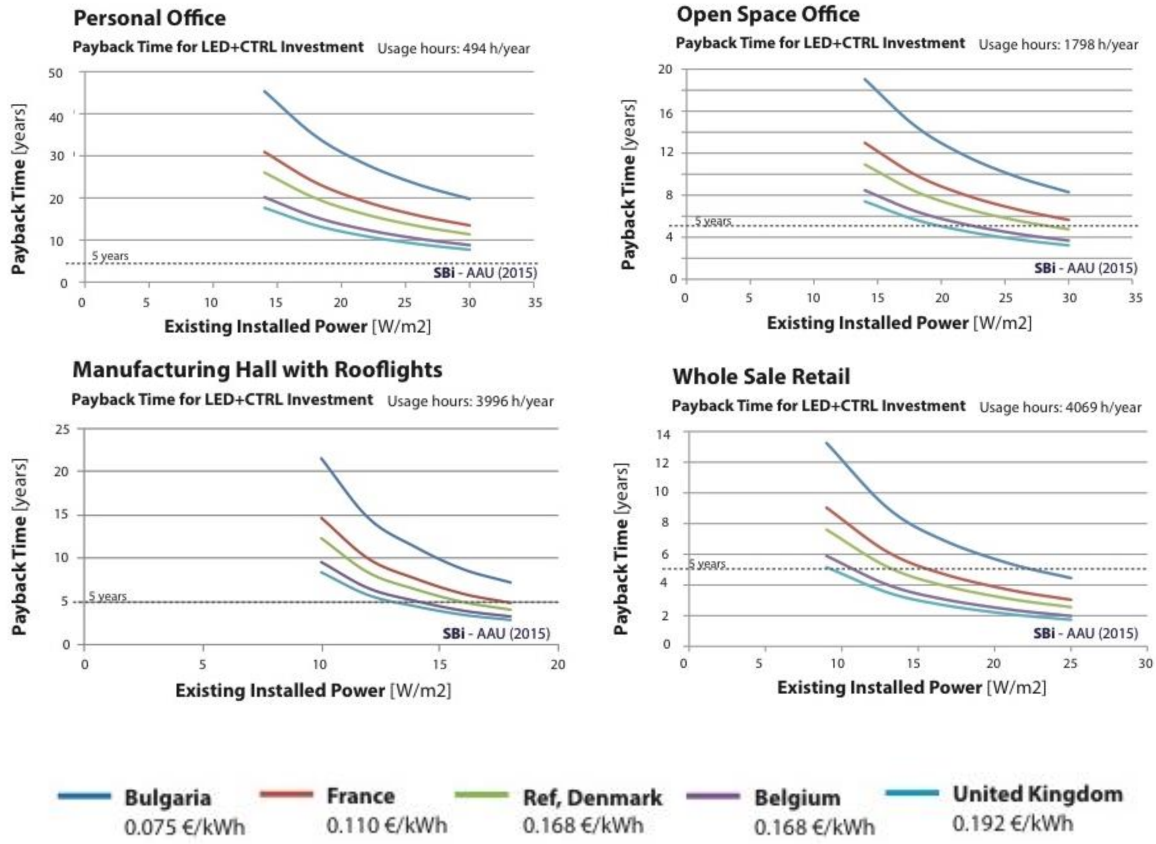


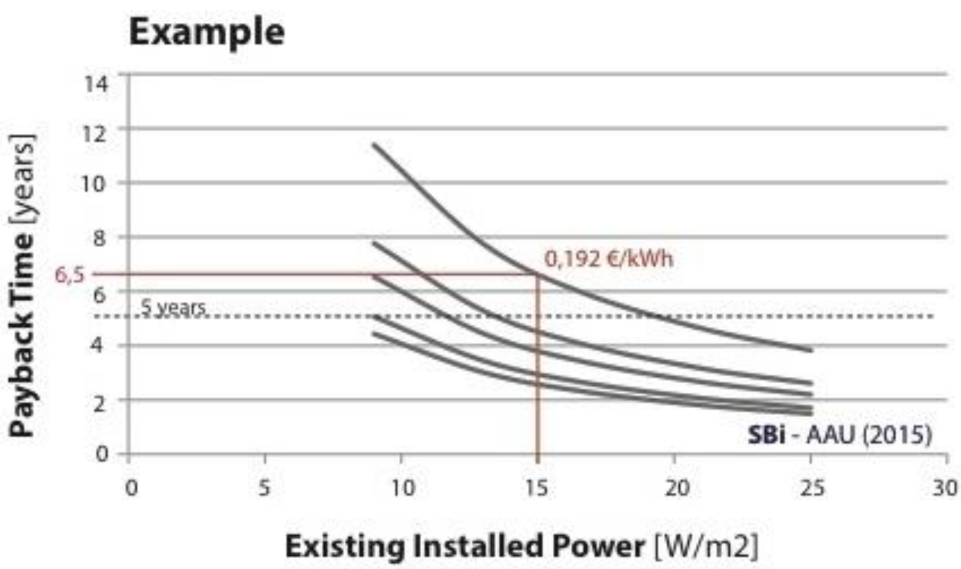
Electricity prices in Europe
Source: http://appsso.eurostat.ec.europa.eu/nui/show.do

8.4. Reduction of Payback Time for LED Investment



8.5. Reduction of Payback Time for LED + CTRL Investment





9. Conclusion

From the calculations, we conclude the following:

- In case of high electricity costs , and low cost lighting equipment, duration of payback time is below 5 years, which is attractive since new SSL equipment will operate from 5 to 20 years typically
- TCO calculations are very sensitive to parameters such as product lighting equipment cost, electricity rates , and annual duration of operation.
- In schools, refurbishment requires very low cost products (installation costs below 10€/m^2) since lighting equipment operates a rather short period of the time.

10.References

CIA World Factbooks 18 December 2003 to 28 March 2011. (n.d.). *CIA World Factbooks 18 December 2003 to 28 March 2011*.

Light Up The World. (n.d.). *Light Up The World*. Retrieved March 12, 2015, from http://lutw.org/why-energy/

McKinsey & Company. (2011). Lighting the way: Perspectives on the global lighting market.

U.S. Department of Energy. Energy Efficiency & Renewable Energy. (2012). *Multi-Year Program Plan. April 2012.* Retrieved from http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_mypp2012_web.pdf

U.S. DOE. (n.d.). *LED Lighting Facts*. Retrieved from http://www.lightingfacts.com/

U.S. Energy Information Administration. (n.d.). *How much of U.S. carbon dioxide emissions are associated with electricity generation?* Retrieved March 12, 2015, from http://www.eia.gov/tools/faqs/faq.cfm?id=77&t=11

UNEP (United Nations Environment Programme). (n.d.). *Enlighten Initiative*. Retrieved March 12, 2015, from http://www.learning.enlighten-initiative.org/