Barriers and Benefits; Building Energy Regulation and Certification

T50.A2

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

May 17, 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.*

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- 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)
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A Technical Report of Subtask T50-A.2

IEA SHC Task 50: Advanced Lighting Solutions for Retrofitting Buildings

May 17th, 2016

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PPP

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Lighting Clusters

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 Many countries face the same situation: The majority of the lighting installations are considered to be out of date (older than 25 years).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

Benefit should be addressed in a broad manner: energy saving, increased value (and rental value), improved functionality, human and social benefits. A possible way is to *compare benefits* of lighting retrofit with benefits of *other types of retrofits or actions* (change of furniture, change of floor, etc.).

A first step, we try to approach the issue of lighting retrofits in a more holistic way. This means that there are many other aspects beyond lighting to take into account, based on current practice. We collected evidence on existing reasons for conducting lighting retrofit today, which may not be solely related to improvement of lighting performance (there are other benefits). We also identify various barriers which lead to postponement of lighting retrofits, even when they are needed and cost effective.

But buildings are build in a context of standards, regulations or labels. The normative context of the building concerning energy performance suggests performance indices for lighting installations. Such specifications are not always coherent and consistent with other aspects. For instance, facade window dimension and technologies are directly or indirectly suggested, but optimal performance (daylighting, heat gains, heat losses) cannot always be achieved in respecting codes.

Therefore in a second step we conduct a critical analysis of regulation and certification documents, to identify some possible incoherence and also opportunities for progress. We propose some adjustment of these reference documents.

This leads to an identification of the possible actions dealing with retrofitting: typical budgets for investments, typical payback period, and also the relation between the expected performance and the acceptable costs. This will be covered in the last sections of this report.

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1. Introduction

Operating costs associated to electric lighting is in general considered as rather low, but costs are rather significant if we relate them to other energy related expenses. It is also important to integrate the scale of the concern: human scale, scale of a space, of building, of a company, or a city.

The annual cost for lighting of an office worker is equivalent to about one hour of his (or her) salary to his (or her) employer. It is small in comparison of the benefit associated to lighting, which is indispensable. These costs are comparable to TCO's of office furniture and miscellaneous expenses (20-30€ per worker and per year)

But at the level of a city or a country, producing 10 to 20% of electricity only to meet the lighting needs leads to important consequences. In the electrical network.

Production of electricity for lighting contributes also to emissions of CO_2, mainly for countries using fossil fuels to produce electricity.

2. Lighting costs versus other costs

There are many other aspects beyond lighting to take into account, based on current practice. The reasons for conducting lighting retrofit today are most of the time not only linked to energy performance.

More generally, retrofits are conducted

- When the building does not provide the requested service (old finishes, old electrical installation)
- For safety reasons (electrical, fire)
- For a desire of the owner to go up in standing (very common in households)
- For a global desire to reduce energy consumption, if consumption perceived as largely excessive (this can be stimulated with tax incentives)
- Because of new desires by owners or occupants
- To increase comfort (change of windows or heating system, for instance).

Various barriers lead to postponement of lighting retrofits, even when they are needed and cost effective. Retrofit can be delayed, or distributed over many years, delaying benefits related to energy efficiency. However, there are large amount of benefits to achieve by a lighting retrofit. Table 1 list the potential benefits for different building scenarios.

Table 1: Possible benefits associated with an improvement of lighting installations

	Typology / best solutions	TCO of lighting €/m^2	Electricity costs* kWh/m^2	Value benefit	Energy benefit	Function benefit	Human benefit
1.	**Offices**	36,7 €/m^2	11 kWh/m^2 1.4 €/m^2	2000 €/m^2(value) Rental 200-600 €/m^2·year	2 €/m^2.yr (lighting) 4€/m^2.yr (cooling & lighting)	Higher productivity 300€every year is about 1% improvement in productivity or 30 €/m2 is one worker per 10m^2	Less stress Extra hours of comfortable work. Check with medical staff. €/m^2

2.	**Schools**	36,7 €/m^2	3 kWh/m^2 0.4 €/m^2	€/m^2 (value) €/m^2 (efficiency of education)	.5 €/m^2.yr	Faster learning 1 % of total costs, including staff (200 €/m$^{2)}$ is 2€/m^2.	Less stress Higher concentration Extra hours without glare €/m^2
3.	**Industrial buildings**	14 €/m^2	16 kWh/m^2 2 €/m^2	Rental value	1 €/m^2.yr	Gains in productivity % of income 3€/m2 if one worker per 100 m2.	Higher comfort Less stress due to daylight Extra hours of comfortable work €/m^2
4.	**Shops**	36,7 €/m^2	33 kWh/m^2 4.3 €/m^2	> 1% of income	5€/m^2.yr	Higher % of income	Daylit shopping area, increased attractiveness by customers
5	**Supermarkets**	36,7 €/m^2	33 kWh/m^2 4.3 €/m^2	€/m^2	1€/ m^2.yr	Higher % of income	Daylit shopping area, increased attractiveness by customers €/m^2

** calculated for electricity price 0.13 €/kWh*

3. Barriers to lighting retrofit

Buildings have been refined and made more and more technically complex. For this reason, many new specialist and professional categories have emerged in the construction process. This means the need for information increases, as does the need to keep together and coordinate the various skills that are required in order to put a sustainable building in place.

Contract and leases structure

The traditional rental agreement between the property owner and user does not favour a holistic approach to the building. An example from the area of lighting is that investment in the building is paid for by the building proprietor while making the lighting installation more effective benefits the user who pays the electricity bill. This requires active cooperation between the parties so that life-cycle thinking will have an impact.
Another problem on contract between tenant and owners of a building can cause problems. An example of the problem can be when the owner of the building are responsible for the investment in the lighting system. The tenant takes the cost for energy and for maintain cost. The contract stipulates that changing the light sours is maintenance. Then putting in fixed LED system fails if you can’t change the separate LED chips.
So the structure of the contract and leases must be updated in line with technological developments.

Long term and short term profits, duration of leases

Getting the most out of an investment in the shortest amount of time can be in conflict whit the goal to save the most energy.

Communicating problems

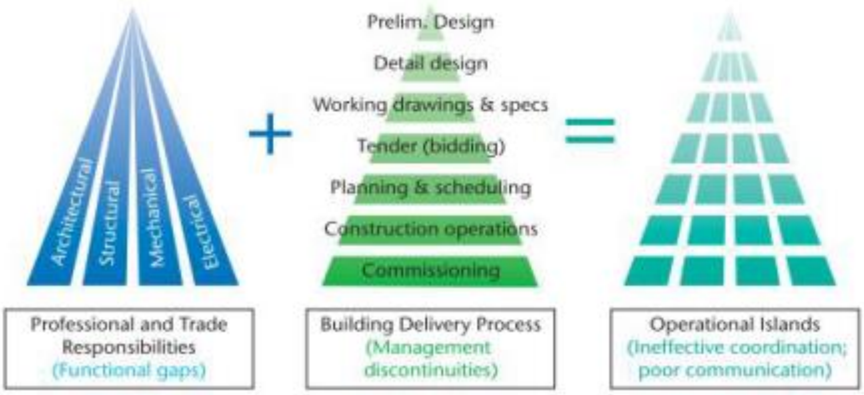


Figure 1 Players and practices in the building market, source: htto://www.wbsd.org/

In many respects, time and resources are two sides of the same coin. If you allocate a lot of resources, various tasks can be carried out in a shorter time. Nevertheless, we often see time and resources as two different, albeit connected, matters. Of course, the documents for a project contain both budgets and timetables.
A common view in the proses of building and retrofit is that timetables drawn up, particularly in the early stages, are often too optimistic but that they are still not revised when, for example, the date of the business moving in has been decided at an early stage and remains fixed despite delays to the project.

Having too little time has, in turn, its' consequences:

- Errors in documents and a lack of coordination between documents occur more frequently where there is time pressure.
- There is less scope for checking that things are really being done right and correcting errors and there is pressure to turn a blind eye to minor deviations. The application of self-inspection is not always absolutely reliable.

Synchronization with refurbishment plans
Very seldom it´s interesting to talk about retrofitting the light by itself. It is done when you do a bigger refurbishment or a structural change.

Technical compatibility of lighting equipment
It must be ensured that the new installation work whit the old system. Can the old control system still work? Can you get different manufactures fixtures to talk to etch adders over a Dali protocol? We can already se how you may have to changes the dimmer depending on the lower installed effect. It´s critical that this is not an issue.

Need for changes in electrical architecture

Need for modification of ceiling type.
As an investor in new light in your facility you often need to fit the new lighting system in to the old ceiling. The cost

Lack of standard when it comes to LED
LED technology expands the technical opportunities in many ways. But the rapid progress in LED make it most uncertain for an investor to get the same light nest time he´s refurbish. Colour temperature, CRI, glare, flicker, sockets, drivers and much more may still changes quite raptly. This leads to unsureness when it comes to sett a system for buildings. LED is now being developed further with, for example, Organic LED (OLED), a technology that provides bright surfaces and is available for smaller applications. The next step is on the way and this is LED with nanothreads. This would make LED even more effective but at the same time make the time to set a standard even longer.

Lack of knowledge and commitment among the project managers, architects and consultants engaged
Knowledge and commitment are important criteria in the selection of the different advisers and experts required in the process. But when selecting advisers, it is often the hourly rate that determines the selection, i.e., not competence and project experience. The measurable factors outcompete those that are difficult to measure, particularly in the case of public-sector clients. Badly and vaguely written tender documentation also contributes to this. There is a tendency for some consultants to choose a solution they are used to and not spend much time thinking about whether this is right on this particular occasion. It is often a shortage of time that lies behind this, which, in turn, is connected to a poorly paid procurement exercise. Where there is a shortage of time, it may also be the case that the consultant focuses on the wrong aspects in the process. Documents are sometimes poorly coordinated between different categories of consultants. This may, in turn, be due to the fact that all the documents are often produced in parallel and there is too little time for coordination. Sometimes, however, it may be more difficult to decide whether, for example, errors in documents are due to too short deadlines, too few resources or consultants who lack commitment. Often there are problems with the transfer of information and knowledge between different stages and between different actors in the process. This particularly applies when working under time pressure with poor payment and where, partly as a result

of this, there is limited commitment from the consultants of different kinds that have been engaged.

Regulation and standards
Our rules and regulations lay down requirements for lighting at different "levels" with regard to a building and its use. The BBR building regulations (Health Chapter), which govern how a building will be designed by the participants in the construction process do not contain any actual requirements for lighting to serve as guidance. These requirements are instead contained in a lighting standard SS-EN 12464-1:2011, which states minimum requirements.

In conclusion, it is clear that stakeholders raise questions globally: buildings should meet standards, be energy efficient (to keep value on the market over long term), and be attractive to clients / users.

But for interest for retrofitting lighting installation would raise more rapidly if:

1) there is clear evidence of (visual) defaults (aging, faults, etc.)
2) regulations are not respected (illuminances to low for instance)

In these two cases, almost all stakeholders could be motivated tio act.

4. Benefits

Improving the lighting environment leads to various benefits, beyond energy savings. Identification of these benefits may ease the decision process of decision makers.

Some benefits have been identified for users, others for owners, managers, etc.…
There are benefits with respect to reduced LCC, improved value, improved functionality, enhanced image, improve use,

The most direct benefit is the improvement of working conditions related to an environment offering a higher satisfaction with respect to visual requirements. Here the benefits are largely higher that the cost affecting more than 1500 hours of work for a cost of one hour of salary only for the employer.

A building value (purchase and rental) depends, for a given location, on the general quality aspects of spaces, such as architecture and finishes. But on the market, it depends also on the long term operating costs, which includes energy requirements and use lighting electricity. A building with low energy requirements tends to sell better on the market, and represent a more secure investment.

Light has been known for a long time to enable sight, safety and orientation. But light can do more than enabling vision. Light has the power to energize, relax, increase alertness, cognitive performance and mood. Light is the most powerful regulator of the day-night-rhythm of people. Every day again, light exposure adjusts and stabilizes the duration, and timing, of our sleep-wake cycle. Moreover, light is known to be an effective treatment for a variety of conditions that include mental disturbances such as Seasonal Affective Disorder (SAD) and certain kinds of sleep disorders.

The ability of light to achieve these various non-visual effects depends on the spectrum, intensity, and temporal pattern of the light, as well as the light-exposure history and preceding sleep behavior of the individual. Therefore, the optimization of a Human Centric

Lighting solution for a given non-visual effect is only possible when this user context is accounted for.

Health and Wellbeing at Workplaces
The effect of light on employees' mental wellbeing, performance and health is dependent on the intensity level experienced during the workday. Research has shown that exposure to more intense light may boost employees' feelings of alertness and vitality. Moreover, the light intensity may influence individuals' ability to sustain attention and cognitive performance. In addition to the potential beneficial effects of light on mental wellbeing and performance during working hours at night, nighttime exposure to light can reduce melatonin secretion and affect the timing of sleep. There are also some indications that the experienced light levels during daytime working hours can influence sleep during the subsequent night. The light level may also affect working environment appraisal, but individuals' preferred light settings showed some substantial variations.

Health and Wellbeing in Education
Positive effects of artificial light in classrooms on physical and mental health are achievable. This is especially feasible in classrooms with a low level of natural light or during days with a low level of natural light. Especially lighting in morning hours with higher illumination levels and higher color temperature can have positive effects on academic performance, social behavior, and also on physical and mental health. The absence of light having blue spectral proportions in the morning can delay the circadian clock. Finally, light is a modulator on physical parameters such as blood pressure and body growth and humoral circadian rhythms (Vick, 2014).

Better lighting in schools has the potential to improve learning results, reduce the number of mistakes and achieve a better social climate. It is popular to install motion sensors to reduce the energy consumption, but in order to create real interest to invest in SSL we need to shift the focus from energy savings to healthier light environments. It is important to think about the possible effects on users, e.g. that automatic light can be disturbing for sensitive individuals. Dynamic light with more gradual changes could be a solution.
A barrier for the development of new light in schools is the challenge to find funding for switching to intelligent SSL, another the low awareness of possibilities.

Lighting in schools is still adapted to the old work situation with paper and pen whilst in the current work situation screens are often used. Glare and reflections in the screens have become a common but unwanted phenomenon. In the classrooms of today it is hard for children to find their own space. Many children need their own space and the new lighting technology provides a possibility to create such small spaces in the big room (Karlsson, Karlsson, & Johannesson, 2014).

5. Lighting and building energy regulation

Focus on building energy efficiency regulation had in many countries initially been on reducing heating (and cooling) energy consumptions only. In the process of a reduction of these loads, a thereby induced stronger relative portion of lighting in the overall energy balance, and still progressing ambitious energy saving goals, lighting energy consumption has gained higher attention also in regulative processes.

In consequence regulations on lighting energy have in several countries been no longer implemented than for a period of 5 to 10 years, in parts being based on standards developed in roughly the same period. For instance, in Europe: The “Energy Performance of Building Directive (EPBD)” than triggered the development of different systematic approaches, and requested member states to regulate energy for lighting as well. The European standard CEN 15193 was developed. It is so far not mandatory, but used in some smaller countries of the union, whereas bigger countries mainly developed and employed own approaches. Some of the underlying methods are now coming into the phase of revision adding gained experience from the first years of practical application. On international level ISO standards (TC 274 ISO/CD 20086: "Energy performance of lighting in buildings") are emerging. Last but not least, the fast technological development made it necessary to adapt to advances in LED, but also façade technology.

The approaches can generally be structured into component and system related approaches.
Table 2 gives an overview including a discussion of different approaches. In subsections 6.1 throughout 6.3 detailed descriptions of promising (most relevant) approaches are provided. This representation follows the same scheme: Short description", „Technical background", „Proposals for requirements", „Ways to verify / control", „Example" (where it exists), „Discussion", „Literature / references". Other measures for instance for loan / support programs can be found in [1]. Figure 2 provides an overview.

Table 2 Overview of general approaches taken in lighting related energy regulations.

#	Approach	Name	Brief Description	Discussion	Country / System it is employed in	(Employed) Suited technical standard Reference
1	Component	Phase out of lamps & gear	Phase out of incandescent, inefficient fluorescent and inefficient high pressure lamps (i.e. also reduction of mercury in lamp technololgy). Phase out of inefficient ballast. Directive currently under further development: Within EU ban of general fluorescent lamps early 2020ties is in discussion.	**+** On supply side of market. Therefore very effective as manufacturers and retailers have to oblige to it. **+** Key instrument in the residential sector. **-** Substitute products have to be available at reasonable prices. **-** Effects installed powers, not operation times, i.e. covers only one aspect when it comes to rating the energy demand. Potentials by daylight use and absence detection are left aside.	European Union, Australia	EU Directives 244 / 2009 and 245 / 2009
2		Max. Power density for lighting	A maximum power density for a lighting installation is given. Compared to 1 "Phase out of lamps & gear", this approach is broader as it accounts for the efficiency of the fixtures and the influence of the space (geometry, room surface reflectances) and usage of zones (e.g. influencing illuminance levels)	**+** Accounts for influence of room parameters. I.e. includes some design criteria. **-** No pure product data. Calculation necessary as room properties have to be accounted for. **-** Specification for different usage types necessary (e.g. hall ways lower installed power densities than in office spaces) **-** Effects installed powers, not operation times (rf to #1)	European Union, Australia	EN 15193-1, 2016. Stipulated by the NCC
3		Minimum Luminaire system efficiency	Minimum efficiency requirement for the whole luminare system including the ballast by for instance specifying a luminaire luminous efficiency. <u>For Details refer to chapter 6.1.</u>	**+** Criterion addresses the efficiency of the fixture and the ballast as well (in contrast to 1 "Phase out of lamps & gear"). This will become the LED quantity to look at. It is easily available, as it is a quantity basically supplied directly by the manufacturer.	Sweden, UK	

				- Effects installed powers, not operation times (rf to #1)		
4		Taking old luminaires out of operation	In existing buildings often old, outdated highly inefficient lighting installations are found. The replacement often is very economical. For Details refer to chapter 6.2.	**+** Criterion addresses the efficiency of the fixture and the ballast as well (in contrast to 1 "Phase out of lamps & gear"). **+** The performance boost (new vs old) can be in the magnitude of factor 3 or higher. Depending on operation times short payback times. **+** Easily applicable, e.g. by usage of a picture table showing old installations **-** Effects installed powers, not operation times (rf to #1)	European Union, , Australia	
5	**System**	Max Energy demand for lighting in a building / space	Requirement for a maximum energy demand for the total lighting installation.	**+** Criterion accounts for installed power (i.e. luminaire system) and operating hours (i.e. architecture ->daylight, controls,..) **-** Requires a more detailed analysis. Software Incorporated methods nevertheless allow for a quick calculation. **-** has to make assumptions about the architecture		
6		Max energy demand on basis of reference techniques	Requirement for a maximum energy demand for the total lighting installation using a so called "reference technique". For Details refer to chapter 6.3.	**+** Criterion accounts for installed power (i.e. luminaire system) and operating hours (i.e. architecture ->daylight, controls,..) **+** Instead of providing a general maximum energy demand for a zone / building, reference techniques parameterizing an underlying physical model are defined. From this each zone / building specific maximum energy demands are. The approach thus does not rate the specific building architecture. If minimum the reference techniques are employed the maximum energy requirement for the specific zone / building will be met. + Advances in technologies can directly be addressed by adapting the reference technique. -Requires a more detailed analysis. Software Incorporated methods nevertheless allow for a quick calculation.	Germany, Luxemburg	DIN V 18599-4, EN 15193-1
7		Point System	Energy labels offer bonus points to rate the overall performance of buildings: this concerns for instance insulation, efficient boilers, efficient lighting. Architects and engineers have the freedom to push for hih efficiency in some	Labels do not provide high bonus for energy efficient lighting schemes. But it is a good approach to value a building for investors and clients It can show that high benefits regarding energy use can be	European Union (DGNB, BREEAM), Australia (Green star and Nabers)	DGNB, BREEAM, LEEDS, Green Star

			specific fields.	obtained with lighting at rather low cost.		

		2.3.2 Contracting		
		2.3.2 Contract design		
		2.1.2 Qualified lighting design		
		1.2.2 Specification based on expenditure figures		
		1.2.1 Specification based on reference technologies		
		1.1.7. Coupling of solar shading, artificial lighting control, seasonal		
Measure		1.1.6 Light management artificial light		
	2.3.2. Contracting	1.1.5 Daylight-oriented partitioning circuits		
	2.3.1 Contracting	1.1.4 Facade with daylight redirection		
	2.1.1 Consultancy vouchers for assessment / inspection	1.1.3 High transparency of the facade		
	1.1.2 Taking outdated luminaires out of service	1.1.1 Minimum luminous efficacy of luminaires on commissioning	2.2 Qualified commissioning	2.1.1 Consultancy vouchers for assessment / inspection
Project phase	Identifying potentials	Planning (Financing/ Contract design)	Implementation/ Commissioning	Operation
	Retrofitting	**New construction and retrofitting of existing buildings**		

Figure 2: Systematic overview of measures to improve lighting energy efficiency [1].

5.1. Minimum luminaire system efficiency

Minimum efficiency requirement for the entire luminaire system on commissioning (new building and retrofit).

Technical background of the measure
For conventional lighting systems, minimum luminous efficacies / efficiencies of the artificial lighting system are individually indicated using the component characteristics

a) Lamps: Luminous efficacy η_{Lamp}

b) Ballast: Efficiency factor f_{VG}

c) light output ratio (luminaire efficiency): η_{LB}

(see Figure 3). From this, the luminous efficacy of the luminaire can be determined and specified using the relation $\eta_{Leuchte} = \frac{\eta_{Lampe} \times \eta_{LB}}{f_{VG}}$.

In the case of integrated LED luminaires, however, it is rarely possible to separate the lamp from the luminaire (and from its thermal management, which affects the performance characteristics of the LEDs). As a consequence, the above-mentioned separation into single components is usually not an option; manufacturers will directly specify the luminaire luminous efficacy $\eta_{luminaire}$.

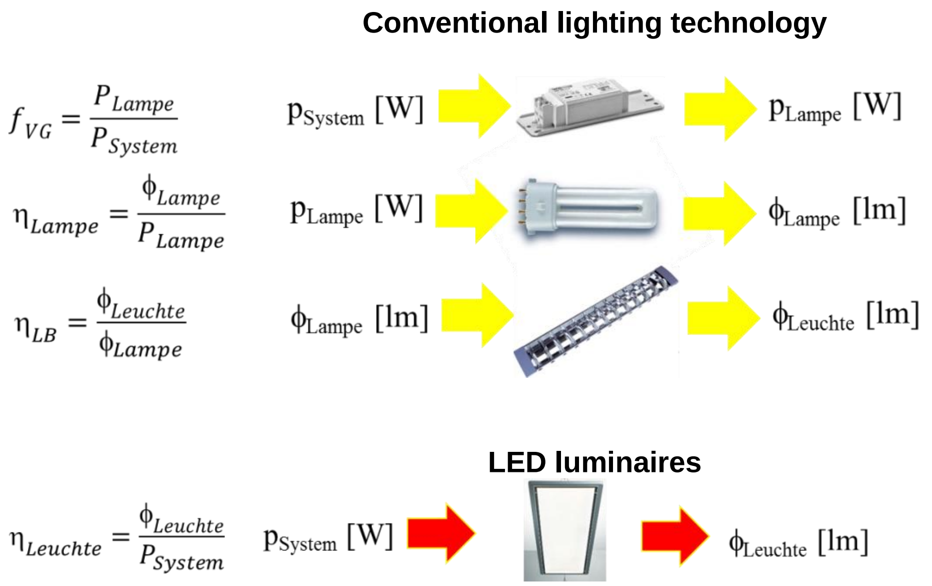


Figure 3: Systematics for evaluating the efficiency of conventional lighting technologies compared to LED luminaires.

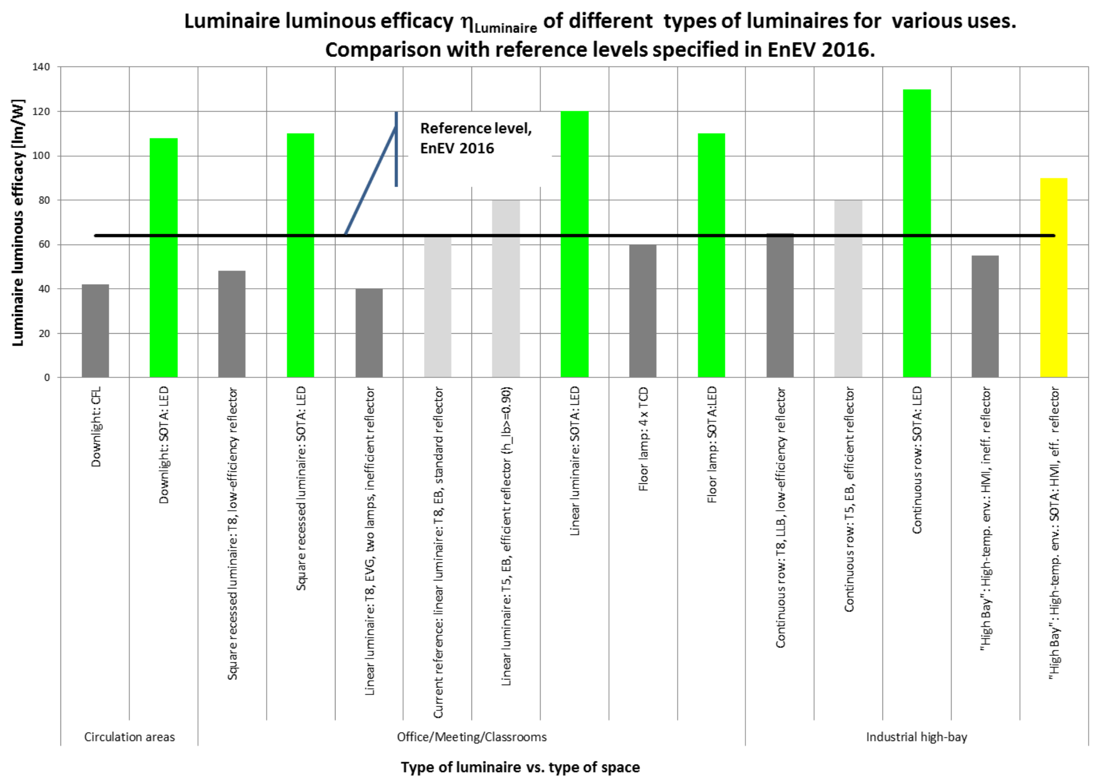


Figure 4: Luminaire luminous efficacy $\eta_{luminaire}$ for typical electric lighting solutions (representative low-energy luminaires: dark grey; state-of-the-art (SOTA) luminaires: green). Data captured 11/2015.

As becomes evident from Figure 4, LED luminaires have by now become much more efficient than solutions based on fluorescent lamps or high intensity discharge lamps. Regarding LED systems, also parts of new definitions regarding the maintenance/ preservation of the luminous flux across the entire life cycle of the product (luminous flux degradation and partial failures in LED modules) and the color quality (MacAdam ellipses for describing LED binnings) need to be considered. A comprehensive guideline issued by ZVEI [3] provides useful information in this context.

Proposed requirements

With a view to the technical development towards integrated LED luminaires, it is recommended to now use the luminaire luminous efficacy $\eta_{luminaire}$ as a characteristic value instead of referring to the individual characteristics $\eta_{luminaire}$ from η_{Lamp}, η_{Lamp}, f_{VG}. In the case of LED retrofit lamps, $\eta_{luminaire}$ can be determined using the previously applied systematics. Figure 4 contains a compilation of luminaire luminous efficacies, distinguished by types of usage. To better assess these figures, comparative values of existing installations have been included.

Table 3: Compilation of requirements for the total luminous efficacy of the luminaire, depending on common uses compared to benchmarks of older technologies.

Type of use (comparable uses)	Luminaire luminous efficacy $\eta_{luminaire}$			Comments
	Requirement for new installation	Benchmark for old installation		
		> 5 years	> 15 years	
	[lm/W]	[lm/W]	[lm/W]	
Circulation areas	> 110	35	30	High-quality LED downlights. Method of comparison: Downlight compared to CFLs.
Offices, meeting / classrooms	> 120	70	60	High-quality linear fluorescent lamps achieve values of up to 80 lm/W. A requirement exceeding 80 lm/W would thus no longer allow for these solutions and require exclusively LEDs.
High bay	> 130	80	70	Due to lower requirements on glare control and color rendering and (partially) color temperature (cold-white more efficient than warm-white light), LED systems for high-bay lighting are generally characterized by higher luminous efficacies. When using LEDs in industrial halls, special care must be given to requirements concerning the ambient temperature (partially high temperature under hall roofs). In these cases, at temperatures above approx. 45°C, high intensity discharge lamps should be applied (state of the art approx. 90 lm/W).

The main requirement can be accompanied by 'secondary requirements' regarding the quality of the lighting system, for instance:

- The maintenance/ preservation of the luminous flux of the applied luminaires must attain at least the following values: For LED luminaires ≥80 % (L80) at 50,000 burning hours, for any other types of lighting ≥90% at 16,000 burning hours.
- The color rendering index (Ra) of the lighting systems is required to be equal to 80, at least. For activities demanding stricter requirements with regard to color rendering, the specifications laid down in German standard DIN EN 12464-1:2011-08 shall be applied.
- 3-Step MacAdam ellipses should not be exceeded.

Surveillance / Verification

- For LED luminaires, the total luminous efficacy can be immediately determined on the basis of data specified by the manufacturers, see Figure 5.

– In the case of solutions without fixed integration of the illuminant with the luminaires, this parameter will be determined using the relation: $\eta_{luminaire} = \eta_{Lamp} * \eta_{Lamp} / f_{VG}$. Details of the individual characteristics are specified in the manufacturers' information on lamp and luminaire. If no values for f_{VG} are available, the following values given in German standard DIN V 18599-4 chapter 5.4.5 can be used instead (choice of further values included in the standard): fluorescent lamps (tubular or compact) with EB: there $k_{BG} = 1/f_{VG} = 1.1$; with CB 1.3. Compliance with the requirements would have to be proven by providing appropriate documents.

Figure 5: Verification of the total luminous efficacy of a luminaire $\eta_{luminaire}$ based on an exemplary excerpt from a luminaire catalog.

Examples

A comparable system of requirements has already been used in:

Source	Comment
BMVBS decree 'Energetische Vorbildfunktion der Bundesbauten – Vorgaben zur Umsetzung einer modernen und energieeffizienten Beleuchtung' as of 2013 [4] *[Government buildings as examples for energy performance – Specifications for the implementation of modern and energy efficient lighting.]*	For offices and comparable uses: Task lighting is required to have a system efficiency of the entire luminaire of at least 75 lm/W. The requirement 75 lm/W is based on the state of the art in 2013. In view of today's state of the art, this requirement would have to be tightened.
KfW Energy efficiency program 'Energieeffizient Bauen und Sanieren - Nichtwohngebäude' / *['Energy efficient building and retrofitting – Non-residential buildings']* as of 2015 [5]	The main requirement specifies a luminaire luminous efficacy (rated luminous efficacy) of the installed lighting systems of at least 100 lm/W. This is complemented by requirements on the maintenance/ preservation of the luminous flux across the lifespan of the product, on color rendering and requirements regarding the light management. It is recommended not to exceed 3-step MacAdam ellipses. Eligible for funding is the complete luminaire replacement including other ancillary work and components. Lamps that are intended for later installation or for installation in existing luminaires (e.g. retrofits, replacement lamps) are not eligible for funding.

Discussion

Criterion		Discussion
Costs / Benefits	Energy (CO_2) performance	Increase in efficiency of +30% up to +300%.
	Economic feasibility / Costs	Meanwhile often positive TCO for LED systems due to lesser energy use and reduced maintenance effort. The market situation is yet quite often restrained because of higher initial investments and expectations, efficiencies rising in short- / medium-terms and declining prices.
Complexity of (effort for) verification		Moderate.
Surveillance		Simple.

Comparable requirements from other trades		Requirements regarding the efficiency of boilers.
Misc.	Influence of luminaire design (Design issue)	Some explicitly requested luminaire designs (e.g. for representational areas) can reduce the light output ratio (luminaire efficiency). In this context, freedom of design may need to be considered when specifying requirements.
	Secondary requirements	Efficiency should be linked to minimum quality standards.

5.2. Taking old luminaires out of operation

Existing buildings often contain technically obsolete lighting systems, the efficiency of which is clearly inferior to state-of-the-art lighting systems and the replacement of which would be also economically expedient.

Technical background of the measure
In the last 20 years, the required values of installed power and, along with this, the energy demand of general lighting systems have decreased by (partly) more than factor three on account of various technical innovations (improved technology of lamps and ballasts, more efficient optics). Table 3 presents a compilation of technically obsolete and new solutions. Generally, individual components of the existing lighting systems (lamp technology, ballast) can be interchanged or the luminaires can be completely replaced.

Whether replacing individual components of the lighting system is expedient, strongly depends on the specific lighting system that is to be retrofitted. When there is a change of lamp technology, such as the change from T8 lamps to tubular LED lamps, different aspects associated with electrical engineering, safety and lighting technology must be considered as well as warranty claims. A guideline published by ZVEI [6] gives an overview of relevant issues to be taken into account. The interchange of ballasts – most of all the change from magnetic to electronic ballasts – must also be assessed with regard to the respective lighting system. In this context, average energy savings of 20 – 30% have to be weighed against the costs incurred for new ballasts and sometimes significant installation efforts (demounting the luminaires, replacing the ballast, mounting the luminaire).

In many cases, replacing the complete luminaire seems to be the most reasonable solution today. In the case of a 1:1 replacement, i.e. retaining previous light points while keeping the same lighting concept, the installation effort is however limited. Compared to LED retrofit lamps / conversion lamps, the efficiency of pure LED luminaires is superior; safety and guarantee issues are subject to the liability / warranties of the luminaire manufacturer. Some solutions are offered especially for retrofitting projects. In the case of recessed luminaires, for instance, manufacturers offer substitute products featuring the same design / shape such as LED recessed luminaires for standard ceiling grids. Furthermore, manufacturers provide fitting pieces for adaptation when replacing downlights with compact fluorescent lamps (usually larger diameter) by LED downlights with smaller diameters. In this way retrofitting can take place without expensive modifications. In the case of continuous row luminaires, it is possible to exchange only the light engine. This option allows retaining the load-bearing structure and the ceiling pattern, thus avoiding additional expenditure for installation.

Proposed requirements
For example, requirements can also be specified on the basis of an image table, see Table 3. This image table could be used immediately on site, for instance during a building inspection. When establishing requirements for decommissioning, it is absolutely necessary to consider the expected operating time of the particular area / space in the building that will be retrofitted.

In the case of short usage times (for instance in server or storage rooms), only minor potential energy savings could be achieved, and decommissioning requirements would thus have insufficient impact. Standard operating times are laid down in German standard DIN V 18599-10 [7]. During on-site building inspections it might be helpful to include the experience of e.g. facility managers in the decision making process. With their assistance, the effective operating times can be estimated (as in

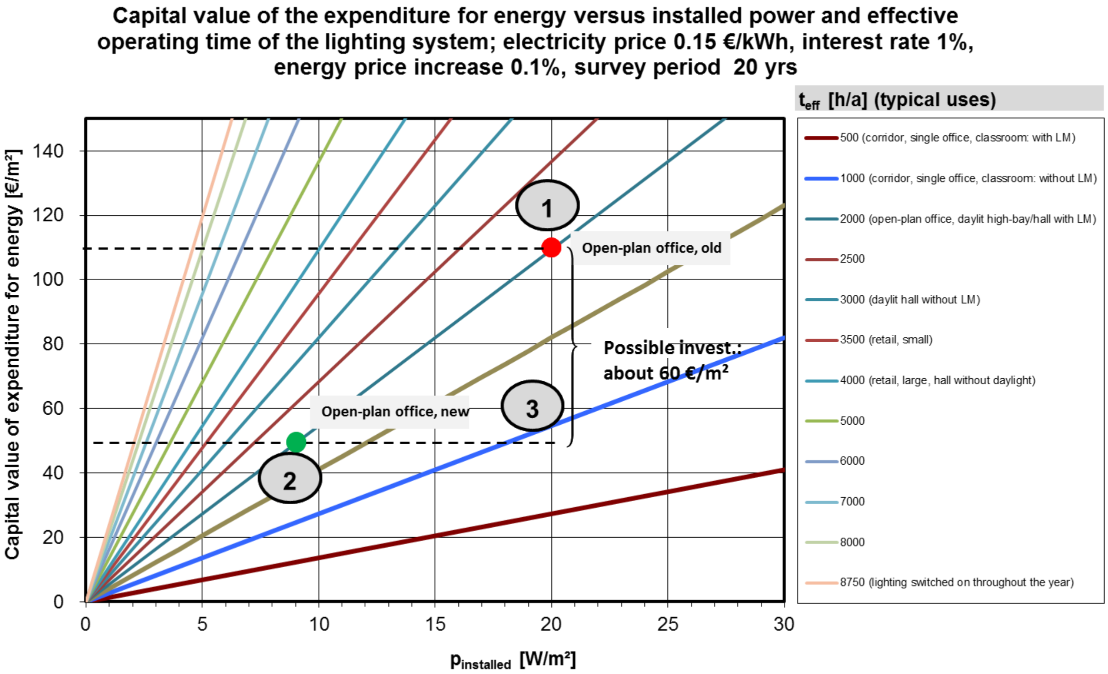
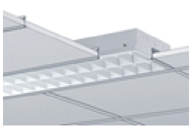


Figure 6) in order to enable engineers to quickly decide whether decommissioning would have any impact in conjunction with the determined switch-on times. It is expedient to connect the decommissioning process directly to a commissioning requirement (see the measure described in chapter 6.1), in order to fix the level of the replacement technology.

Table 4 Compilation of exemplary product classes for a possible requirement for taking old luminaires out of operation, comparing the luminaire luminous efficacy of old and new lighting technologies.

Product class to be taken out of operation			Luminaire luminous efficacy: Existing installation lm/W	Luminaire luminous efficacy: Comparison new installation lm/W	Efficiency increase	Comment on replacement
Recessed luminaires	Halogen downlights in various designs		10 - 15	Up to 110 (LED)	approx. 3	For recessed LED luminaires, bezels are offered, which ensure that the new technologies are compatible with the existing ceiling plan.
	CFL-based downlights		30 - 40	Up to 110 (LED)	approx. 3	
	Luminaires with simple white glare protection louver with (T12-) T8-, CB lamp technology		40 - 60	Up to 110	approx. 2 - 3	

Surface-mounted luminaires	Prismatic diffusers with (T12-) T8-, CB lamp technology		approx. 40	Up to 110	approx. 2 - 3	
	Surface-mounted opal diffuser luminaires with T12 light source and LLB		approx. 50	Up to 110	approx. 2 - 3	
row luminaires	Continuous-row luminaires with T12 light source and CB		40 – 60	Up to 130	approx. 2 - 3	Many manufacturers offer conversion kits for retrofitting LEDs to existing continuous-row luminaire systems, which allow making further use of the - usually expensive - bearing structure.
High Bay	High-bay fitting, like mercury vapor lamp.		50 - 60	90 - 100 (HMI) to 140 (LED)	1.5 - 2.5	

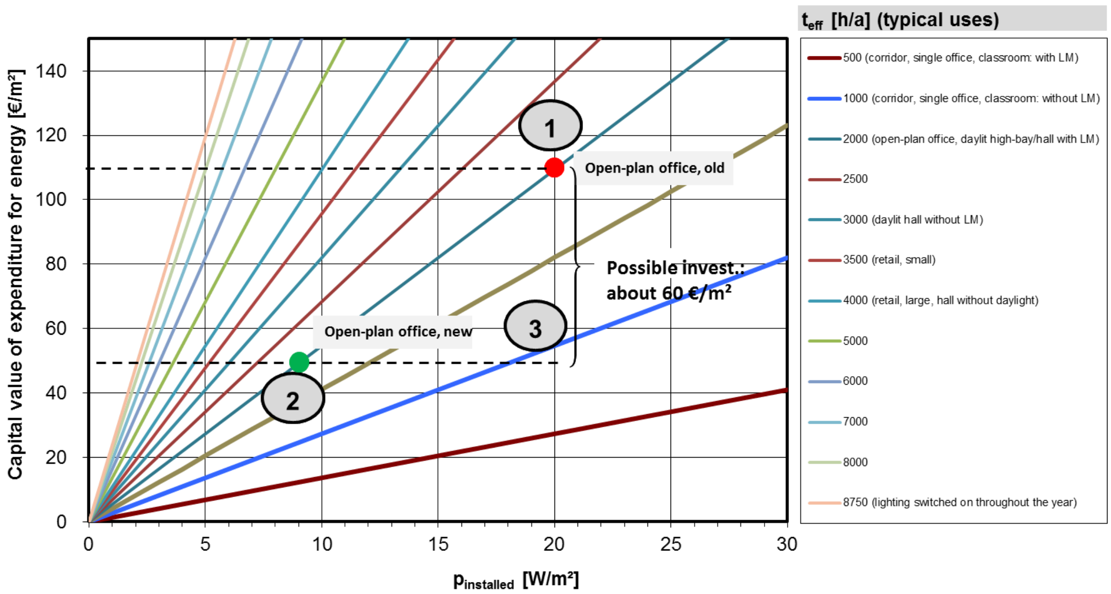


Figure 6: Capital value of the expenditure for energy as a function of the installed power and the effective operating time of the lighting system. Exemplary description of three steps for approximately estimating a potential investment framework [Source: FHG – IBP].

Surveillance / Verification

During on-site inspections of existing buildings, outdated luminaires can be identified e.g. by using an image table, see Table 3. Light sources can be categorized either by directly reading the labels in the case of open luminaires (such as louver luminaires, open downlights) or after the luminaire has been demounted or opened by an electrician. The type of ballast can be identified when the device is switched on. In the case of a built-in CB or LLB, the device will start slightly delayed and there will be flickering light; if the device already has been equipped with an EB, there will be neither flickering nor delays. For

instance, on-site building inspections can be linked to BGV [8] Tests A3 'Electric systems and equipment.
Once the old luminaires have been taken out of service, this can be proven by submitting a photo documentation (situation before/ after replacement). Verification of the newly installed technology (if necessary, compliance with coupled commissioning requirements, compare to section 6.1.) can be provided according to the measure applied (documentation including appropriate product documents.

Examples
For instance, a comparable system of requirements was already used in the:

Source	**Comment**
German Energy Saving Ordinance (EnEV): Provision regarding outdated heating systems [9].	Heating systems installed before 1985 have to be replaced in due time. Exceptions apply if the owner lived in the house already before 2002.

Discussion

Criterion		**Discussion**
Costs / Benefits	Energy (CO_2) performance	Efficiency increase of up to approx. 300%.
	Economic feasibility / Costs	The economic feasibility also depends on the operating time.
Complexity of (effort for) verification		Low.
Surveillance		Simple.
Comparable requirements from other trades		Heating systems.
Tendency / Trend		LED prices are expected to further decrease while efficiency will continue to increase. Replacement will become more worthwhile.

5.3. Maximum energy demand on the basis of reference technologies

Specification of a maximum energy demand based on a reference technology for lighting systems.

Technical background of the measure
For instance, so-called reference technologies for describing the energy efficiency of a system are used in the German Energy Saving Ordinance (EnEV). On the basis of a calculation method (in this case on the basis of German standard DIN V 18599) the technical building systems are parameterized using reference technologies. This parameterization results in the energy demand for a specific building, which must not be exceeded in order to ensure compliance with the EnEV requirement.
This approach can be used in single cases for lighting with higher requirements, which exceed EnEV requirements, conjunction with funding measures. Tightened provisions compared to EnEV requirements are possible with regard to:

- Improved reference technologies.
- Inclusion of previously unconsidered technologies used in the areas of facade and light management.

The reference technologies approach provides the opportunities to combine measures pertaining to electric lighting, facade and light management. As the specification defines only one energy standard/ level, the planner can compensate the individual technologies (e.g. more efficient facade technology using light redirection, but moderate efficiency levels of electric lighting).

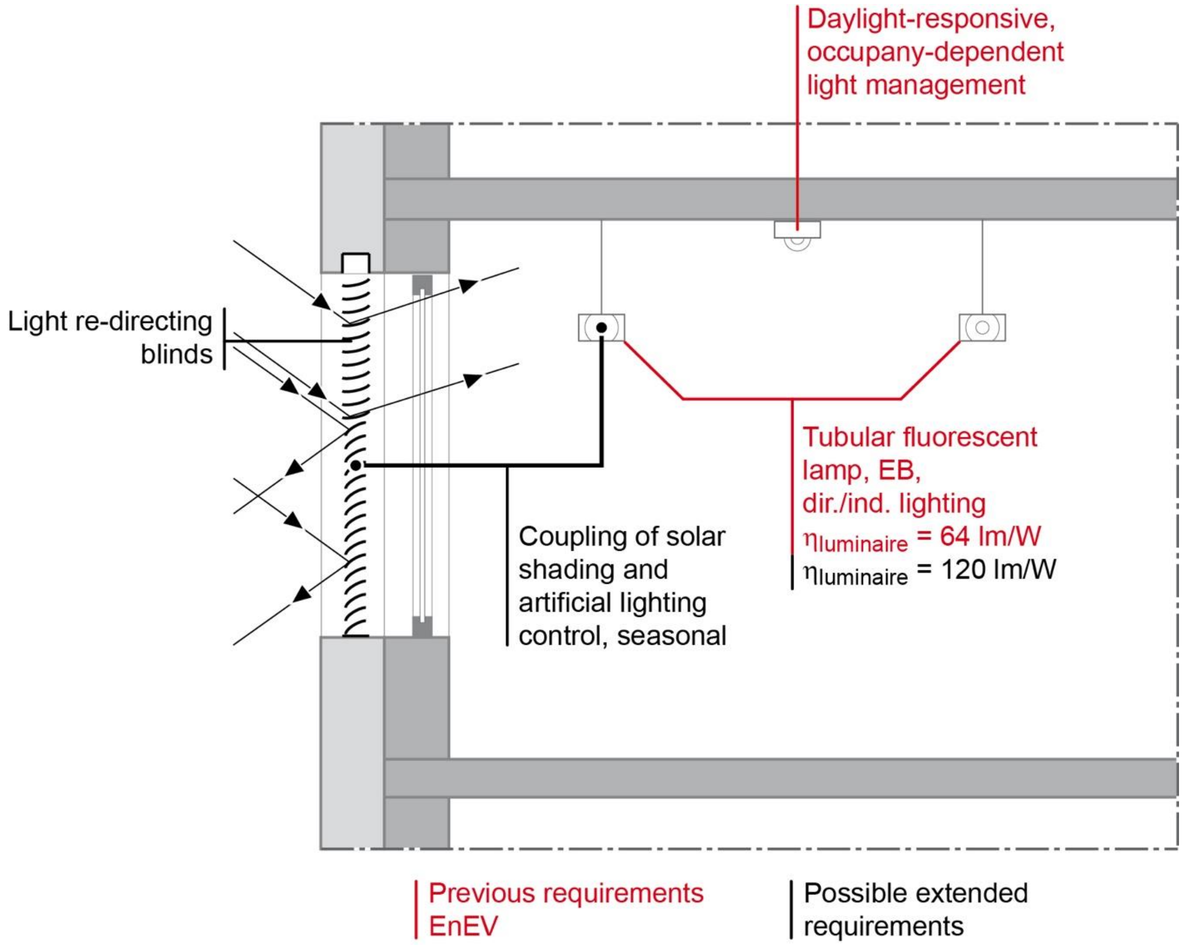


Figure 7: Previous reference technologies according to EnEV. Possible extended requirements.

Proposed requirements

Table 5 Compilation of comparative requirements as specified in German regulation EnEV 2016 and conceivable extended requirements.

Reference technology		Comparative requirement EnEV 2016		Extended requirements
Electric lighting	Lamp	Tubular fluorescent lamp	$\eta_{luminaire}$ = 64 lm/W	LED systems, see measure [10]
	Ballast	EB		
	Luminaire	Direct / Indirect, η_{LB} = 0.8		
Daylight	Glazing with high light transmission	-		> 75 %
	Light redirection	-		See light redirection as defined in DIN V 18599-4: also see measure [11]
Light management	Presence	For uses characterized by long periods of absence		As in EnEV
	Daylight	For uses characterized by good daylight supply		As in EnEV
	Linking artificial light control and facade control (seasonal)	-		See seasonal shading as specified in DIN V 18599.

Surveillance / Verification
Documentation of the calculations.
Verification of implementation (photo documentation, bills/invoices).

Discussion

Criterion		**Discussion**
Costs / benefits	Energy (CO2) performance	High, depending on the parameterization of the reference technologies. Potential for improvement compared to the current EnEV level: up to more than 100%.
	Economic feasibility / Costs	Depending on parametrization, see also other (individual) measures.
Complexity of (effort for) verification		Medium.
Surveillance		Medium.
Comparable requirements from other trades		Reference technologies have also been introduced in other trades. They are systematically used to establish stricter requirements.

6. Sustainability labels / certifications

6.1. Overview

Beside regulations and codes, sustainability labels have evolved worldwide over the last decades addressing among others lighting aspects. Figure 8 gives an overview of different labels; Figure 9provides a release history. Employing sustainability levels is in many cases not mandatory. It rather follows private contracts in the real estate market to document and compare different quality levels in sustainable building design. Anyhow in parts, like for instance in Germany, the public sector requires nowadays for public buildings, minimum sustainability levels. This is requested for new built and major retrofits as well.

Other than other standards and / or regulations the labels certificates are not “single issue”, meaning they address broader spectra for certain criteria. In lighting in most cases energy and visual comfort including view out aspects are addressed, generally considering electric lighting, daylighting as well as light management aspects. Appropriate sustainability labels can therefore be considered as a valuable “multi criteria” instrument, going beyond the scope of just energy related aspects.

As technology and also standards / codes (on which the labels in part rely on) have been and are still being developed further quite forcefully, updates of labels should be considered. Recommendations are given at the end of this section.

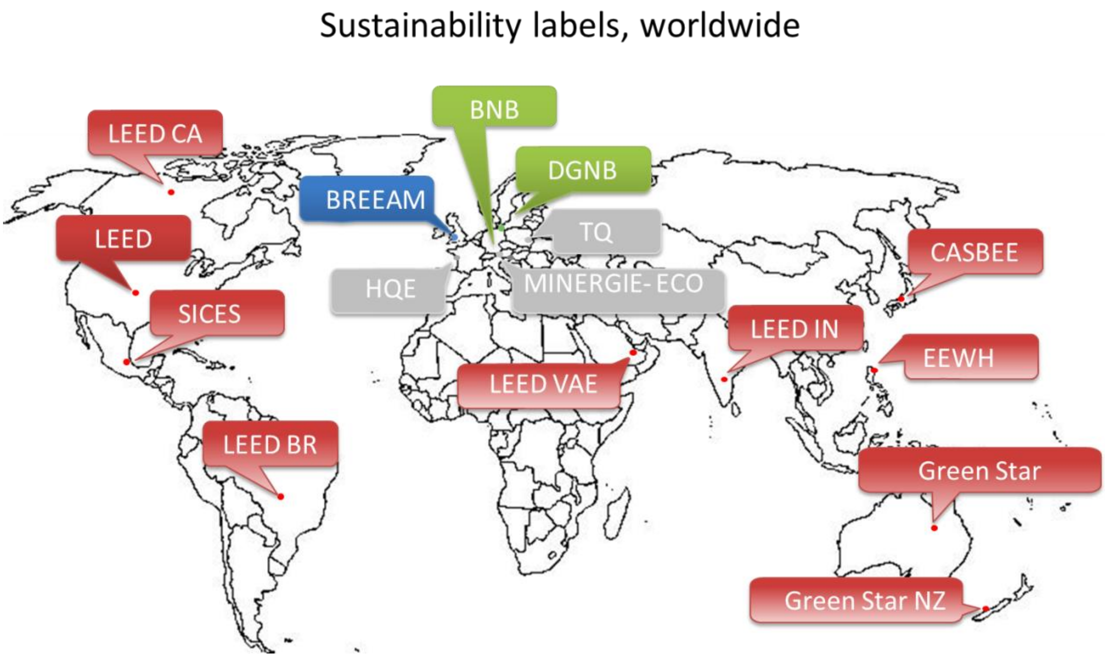


Figure 8 Overview on sustainability labels worldwide (based on data in [22]).

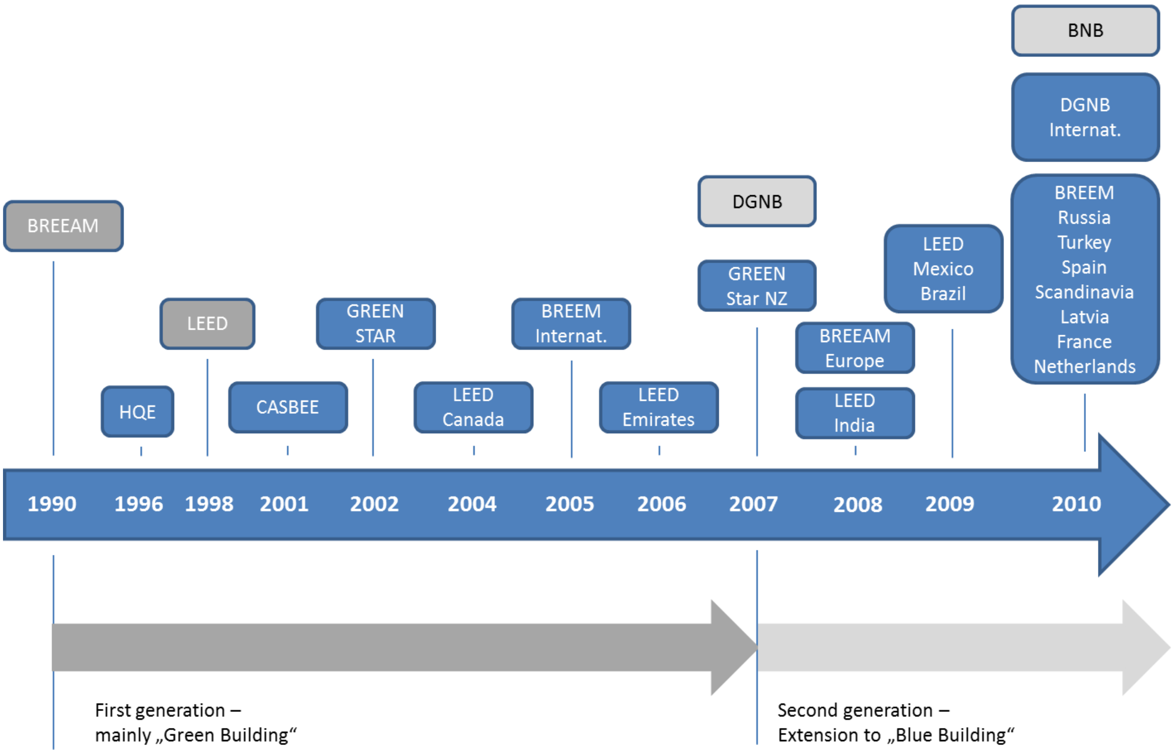


Figure 9: Historic evolvement of sustainability labels (based on data in [2]).

6.2. Comparison

Table 6, based on data in [2], gives a direct comparison of either qualitative or quantitative criteria and requirements of three selected, widely used, sustainability labels:

- LEED (Leadership in Energy and Environmental Design),
- BREEAM (Building Research Establishment Environmental Assessment Methodology), and
- DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen) in big parts similar to BNB (Bewertungssystem Nachhaltiges Bauen) which has been derived by the authorities from DGNB for public buildings in Germany).

The considered labels weigh lighting aspects in the range of around 2,5 % to 4 % of the overall rating. DGNB (BNB) has been developed latest and is with 7 single criteria the most comprehensive with respect to lighting (LEED: 3 criteria, BREEAM 6 criteria). Addressed are the following aspects:

Daylighting levels
Daylighting aspects are addressed by all approaches, where DGNB (BNB) provides the most elaborate. This requests as well the highest effort.

View out
View out aspects are addressed in all three, although in different approaches.

Electric lighting
Not addressed in LEED. In DGNB and BREEAM some requirements are listed. Generally the quality standards in electric lighting are high with respect to visual comfort (and energy

efficiency). Electric lighting is therefore obviously not in the main focus of the considered sustainability labels.

Lighting Control
High rating for automatic controls (DGNB / BNB, LEED), and separate control possibilities of workplaces near windows.

Colour Rendering
Colour rendering of electric light sources and façade components is only addressed in DGNB / BNB: For electric lighting minimum requirements from other the standard EN 12464-1 are set as baseline (i.e. nothing new). For façade components colour rendering indices for glazing and sun shading are requested. For glazing these are easy to be obtained. For glare protection systems no normative reference (standard procedure to obtain these quantities is known / proposed).

Retrofit
Only LEEDS directly addresses retrofits. Nevertheless, the described approach may of course be applied to bigger refurbishments, which with respect to lighting are in most aspects similar to new built.

The labelling systems are in big parts relating to standards or other documented requirements. For DGNB / BNB Table 6 illustrates this structural approach. Normally the minimum requirement for instance in a Standard is taken as baseline, better performance with respect to the criterion is honored extra.

Generally, the application of the labels is supported very well with guide lines and examples. Seminars and educational programs, in parts supporting tools are offered. Many of the requested lighting parameters are generated / calculated anyhow in the design process, such that they just need to be documented by designers / consultants (to be negotiated in advance). Nevertheless, for some criteria extra work may have to be contracted in order to evaluate the criteria.

Table 6: Comparison of systems – Example office buildings (based on data in [2]).

		System		
		DGNB / BNB	**LEED**	**BREEAM**
General	Version	DGNB: New construction office and administration buildings Version 2015 BNB: Version 2015	New Construction and Major Renovation Version 2009	BREEAM New Construction Nondomestic Buildings Version 2013
	Main criterion	Sociocultural and functional quality	Indoor Environmental Quality	5.0 Health and Wellbeing
	criterion	DGNB: SOC 1.4 BNB: 3.1.5 Visual Comfort + lighting in the overall energy context	Credit 8: Daylight and Views	Hea 01: Visual comfort
	share of lighting in the overall rating	DGNB: 3,2% BNB: 2,4%	3,6% (max. 4 / 110)	4% (4/15 credits, weighting „Health and Wellbeing“ 15%
Daylight entire	Requirement	Min. 50% of the usable floor area: DGNB: Min. 1,0% DF - 2% and higher DF BNB: Min. 1,0% DF - 2% and higher DF	-	-

	Evidence	DGNB: Simulation / measurement BNB: Simulation / EnEV	-	-
Daylight workplaces / continual used spaces	Requirement	All Workplaces: DGNB: min. 45% - 75% relative luminous exposure BNB: Min. 45% - 80% relative luminous exposure	75% of continual used spaces: Min. 270lux (Sept)	80% of continual used spaces: e.g. Ø 2% DF + Uniformity 0,4 or other options
	Evidence	Simulation / simplified in compliance with DIN 18599	Simulation / description Light transmission glazing + share of openings/ measurement	Simulation, measurement CIBSE Lighting Guide 10
line of sight	Requirement	DGNB: window area + solar-/ glare protection class 2 – highest BNB: window area + solar protection + view through activated solar protection with/without adjustment	90% of continual used spaces	Share of openings ≥ 20% - ≥ 35% of room surface and 95% of the area are within 7- ≥ 14 meters to a wall with windows or other openings
	Evidence	DGNB: area DIN 5034 solar protection. DIN 14501 data sheet / photo BNB: area DIN 5034 photo / plan of the office	Drawing line of sight	Plans / photos / confirmation
absence of glare trough daylight	requirement	Function of glare protection DGNB: class 1 – highest BNB: glare protection BschAVO / light directing with glare protection + shielding of direct light	-	glare control strategy with sufficient daylight for cloudy situations and situations without direct sunlight or
	evidence	DGNB: DIN 14501 classification, data sheet solar / glare protection BNB: photo	-	description inspection, photo
absence of glare artificial light	requirement	artificial light DIN 12464 yes / no	-	illuminance, max. luminance (national best practice lighting guides)
	evidence	DGNB: artificial light simulation BNB: documentation luminaires	-	specification, inspection, photo
colour rendering	requirement	colour rendering for artificial light + daylight (whole system) ≥ 80 - ≥ 90	-	-
	evidence	DGNB: spectral calculation according to DIN EN 410 manufacturer specifications BNB: DIN EN 12464 data sheets/ measurement or spectral characteristic values	-	-
light distribution	requirement	BNB: artificial light: compliance norm – combined direct-indirect lighting with control of single workplaces	-	uniformity
	evidence	BNB: DIN EN 12464 description + list of luminaires	-	-
possib le	criterion (differing)	DGNB: SOC 1.5 BNB: 3.1.6 Possible influence of the user	Credit 6.1: Controllability of Systems - Lighting	5.0 Health and Wellbeing (as mentioned above)

	requirement	DGNB: influence on solar / glare protection for 80% of the rooms of the main use per room or per group (max. 3 persons) BNB: per window / per zone (max. 3 persons) / per room	controlling is possible for 90% of the users / group of users	Max 4 workplaces controlled together, window workplaces can be controlled separately
	evidence	DGNB: data sheet, description BNB: description, explanatory report, photo documentation	-	-
evaluation	Minimum requirements lighting	Bronze ≥ 35% Silver ≥ 50% Gold ≥ 65%	-	requirement for certification: no fluorescent tube with electronic ballast
	strongest requirement	***	*	**

6.3. Recommendations for further development

The following recommendations for further development of sustainability labels / certificates can be given:

- Adaption to new standards: In Europe for instance a new daylight code is close to release, which will deal among others with issues like rating “view out” and “glare by facades”.

- Adaption to new technologies: Consideration of update to (recent) technological developments like:
    - Glare protection systems which offer glare protection and view outside as well.
    - New lighting control systems / approaches.
    - SSL (LED) higher efficiencies vs. fluorescent lamps.

- Further development of tooling: Improve tools, i.e. facilitate documentation of fulfillment of requirements.

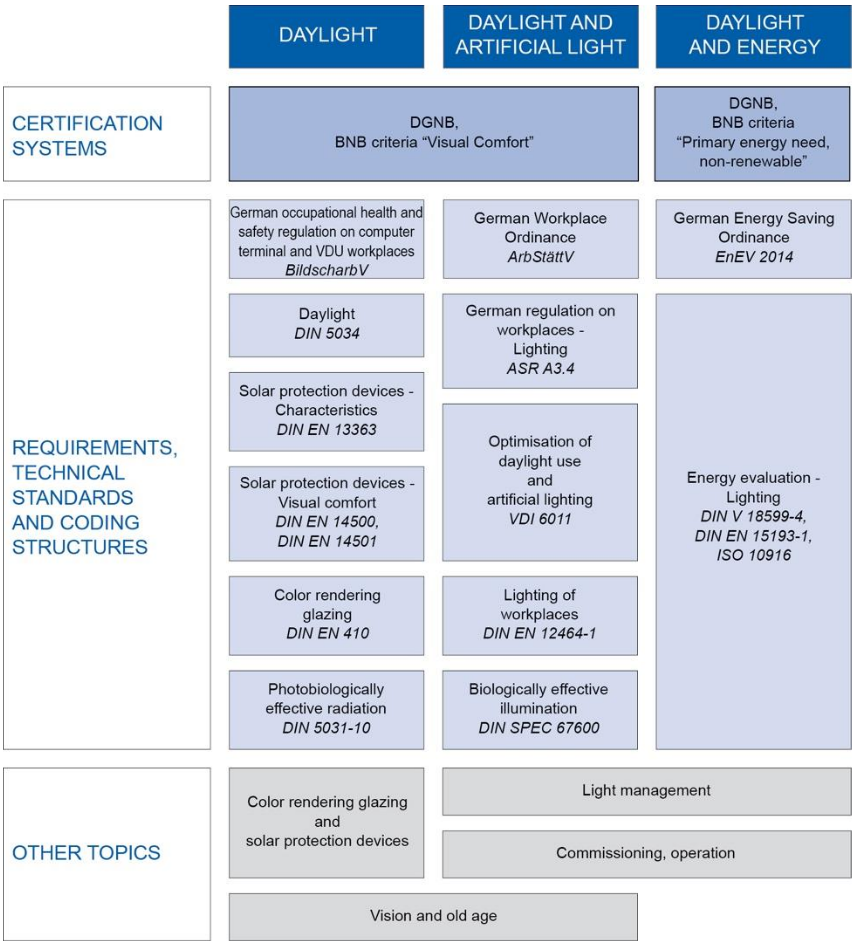


Figure 10 Graphic illustrating how sustainability labels with their criteria for lighting are embedded into standard / coding structures (example for DGNB, BNB).

7. Change of value of buildings with new retrofit lighting

There are several benefits to investing in a building retrofit, especially in regard to the value of the building. This could e.g. be higher productivity, health benefits, energy savings and creating better return on building investment[1].

At the moment energy prices are rather low and therefore high energy savings are not on top of the agenda. However, if an investor should choose to opt for a sustainability certification, they would guard themselves against any sudden increases in energy prices. This would be beneficial for long term investments where the probability is a little more uncertain. Furthermore, studies show that certified buildings have a higher sales value and have a higher ability of attracting tenants, and this allow the investor to set a higher renting price[2].

8. Identification of Obsolete Products

Various countries have implemented methods and regulations to phase-out the outdated incandescent lamps. This replacement often is very economical as the performance boost (new vs old) can be by the magnitude of factor 3 or higher. Depending on operation times it has a short payback time.

[1] *Exploring buildings of tomorrow, Sustainia, Monday Morning Publishers*
[2] The Business case for green building, World Green Building Council

It appears logical that countries promote the phasing out of lighting installations with low energy efficiency. But the only approach for countries are regulations and energy labels. For the global lighting installations, energy regulation seems the best approach, and it should be applied in all retrofit operations. Labels are incentives, and not mandatory: government can assist their promotion.

For equipment, the situation is more complex. Labelling is useful, but the label should be strong and respected by distributors (in the US, a rather good example is the label Energy Star). It appears more difficult to regulate products, beyond the safety requirements.

9. Conclusions and Recommendations

It is clear that the reference to “standard” is always useful, and the German approach of reference technologies for describing the energy efficiency of a system is an interesting approach. As long as it does not limit the interest (or the “bonus”) of solutions with higher efficiency.

The experience of labels shows the interest of a route with progressive rating: minimum, improved, high quality, super high quality.

It seems that regulations should not focus on minimum requirements, but also acknowledge installations with higher energy efficiency.

Such an approach has been proposed in draft of the new CEN standard on daylighting (CEN TC169-WG11) . Here three level are proposed, to avoid the case where tenders only rely to the least ambitious specifications.

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