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Preparatory Studies for Eco-design Requirements of EuPs

Lot 19: Domestic lighting- Part 2
Directional lamps and household luminaires
Final Task Report
Task 6: Technical Analysis BAT And BNAT

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Important note:
This report contains the updated draft results of research by the authors and is not to be perceived as the opinion of the European Commission.
This is an updated draft document intended for stakeholder communication.

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0 PREFACE

VITO and its partners are performing the preparatory study for the new upcoming eco-design directive for Energy Using Products (EuP) related to domestic lighting, on behalf of the European Commission (more info http://ec.europa.eu/enterprise/eco_design/index_en.htm).

The environmental impacts of Energy-using Products such as domestic lighting take various forms, including: energy consumption and the related negative contribution to climate change, consumption of materials and natural resources, waste generation and release of hazardous substances. Eco-design, which means the integration of environmental considerations at the design phase, is arguably the best way to improve the environmental performance of products.

The creation of a coherent framework for environmental product policy avoids the adoption of uncoordinated measures that could lead to an overall negative result; for example eliminating a toxic substance from a product, such as mercury from lamps, might lead to increased energy consumption, which could in total have a negative impact on the environment. A Community framework also ensures that divergent national or regional measures, which could hinder the free movement of products and reduce the competitiveness of businesses, are not taken. It is not the intention to decrease the quality of domestic lighting.

The objective of this interim draft document is to present preliminary data for discussion with stakeholders related to the EuP preparatory study for the lot 19.
You can follow the progress of our study and find general information related to lot 19 on the project website when you register as stakeholder: http://www.eup4light.net
Please, also consult the website for timing and organisation of the tasks.

Important remark:
It must be clearly stated that this part 2 of the study relies on the draft regulation resulting from part 1 of the study on non-directional light sources. Specific items on non directional lamps that were discussed in part 1 will not be repeated in this part 2. Items that are related to all light sources can be repeated, only to improve the readability.

1 PRODUCT DEFINITION

For more info see website www.eup4light.net.

2 ECONOMIC AND MARKET ANALYSIS

For more info see website www.eup4light.net.

3 CONSUMER BEHAVIOUR AND LOCAL INFRASTRUCTURE

For more info see website www.eup4light.net.

4 TECHNICAL ANALYSIS EXISTING PRODUCTS

For more info see website www.eup4light.net.

5 DEFINITION OF BASE-CASE

For more info see website www.eup4light.net.

6 TECHNICAL ANALYSIS BAT

Scope: This entails a technical analysis and description of the Best Available Technology (BAT) and Best Not yet Available Technology (BNAT) that can be implemented on product or component level. The described BAT is in many cases already available on the market, but is less frequently or not yet used because of the purchase price. It partly provides the input for the identification of part of the improvement potential (task 7), i.e. especially the part that relates to the best available technology. In chapter 7, also cost, intellectual property and availability are taken into account for the selection of options. This is not the case in this chapter and many of the presented technologies are intellectual property or linked to individual companies. The input of this chapter is partially the result of an organised visit to the Light and Building trade fare in Frankfurt 2008 (see also chapter 9 stakeholder consultation). Additional information was collected by consulting manufacturer's catalogues, technical publications and the information that was provided by stakeholders as a comment on the draft published chapters. Much research is ongoing and information is not always publicly available, therefore this chapter can never claim to be complete but aims to give a general overview. For commercial reasons brand names are avoided in the text as far as possible.

This chapter also focusses on technical data[1] that influence the use phase i.e. the energy consumption. As demonstrated in the eco-reports in chapter 5, this phase is much more important than the production phase. For the BOMs, no significant differences with the base case lamps can be noticed. The production phase (including the BOM's) will be examined only for LEDs; the eco-reports for these light sources will be calculated in chapter 7.

6.1 BAT State-of the art

Because the sockets in the installed luminaires (existing stock) have a big influence on possible improvement options for lamps, the BAT and BNAT options are listed in accordance to the cap type.

6.1.1 Mains voltage halogen lamps with Edison (E27/E14) or Swan (B22d/B15d) cap

Improvements for the efficacy of blown reflector halogen lamps type R50, R63, R80 etc. can be classified in:

- improvement of the reflector by changing to a PAR reflector,
- improvement of the reflector by changing to a dichroic or silver coated parabolic reflector,
- improvement of the efficacy by xenon gas filling,
- improvement of the efficacy by optimized filament wire design,

[1] Technical data in this chapter were collected from different sources e.g. www.olino.org , ELC-members, stakeholders, etc.

- improvement of the light output by using anti-reflective coating on the cover glas,
- Incorporating a transformer in a parabolic reflector lamp and using IRC low voltage halogen bulb.

Figure 6.1: Blown reflector R63, PAR20 and PAR20i lamp.

6.1.1.1 Halogen lamps with PAR reflector

Compared to the blown reflector base case lamps R63, GLS-R as well as HL-MV-R, the efficacy of halogen PAR20 reflector lamps is much higher. The reason for this is the poor optical matching of a MV halogen bulb in the blown reflector. PAR reflectors are aluminium coated pressed glass reflectors, optimally made of borosilicate glass, and have the following advantages compared to blown reflectors:

- better beam control by the facetted reflector,
- no use of satinated front cover and therefore a higher % of the luminous flux in the 90° cone,
- much less (spilled) light backward.

In most fittings, blown reflector lamps R63 can easily be replaced by PAR20 halogen lamps without changing the luminaire.
These lamps have an excellent colour rendering (CRI=100) and can easily be dimmed as long as the wattage is above the minimum required wattage of the dimmer.

The technical data for these lamps are shown in Table 6.1.

6.1.1.2 Halogen reflector lamps with xenon gas filling

As already explained in part 1 of the study, efficacy of halogen lamps can be improved by replacing the normal halogen gas filling of the bulb by xenon gas. This is of course also the case for halogen reflector lamps.
These improved lamps are already available on the market for the blown reflector base case lamps and even for the PAR lamps.
These lamps have the same properties as all halogen lamps: excellent colour rendering and normal dimmability.

The technical data for these lamps are shown in Table 6.1.

Important remark:
It must be stated that the improvement due to xenon can not be concluded from the measurements that were performed on market samples for R63 halogen lamps. This mainly confirms the earlier statement that the optimal position of the halogen bulb in a blown reflector lamp can not be guaranteed in normal, continuous production.

6.1.1.3 Halogen parabolic reflector lamps with dichroic or silver coated reflector

Dichroic coating is a multilayer coating which selectively transmits portions of the spectrum[2] (in this case IR); the technology is based on interference filters. High efficiency in visible light can be obtained. Similar multilayer technology is used for 'infrared coated lamps', see also 6.1.3.
The evaporated aluminium coating of the PAR reflector can be replaced by this dichroic multi-layer coating as it is already common practice for low voltage halogen reflector lamps. This dichroic reflector causes an improved reflection[3] for visible light compared to a normal aluminized reflector and gives also a cool beam. A cool beam means that it contains less infra-red radiation or heat. These dichroic reflectors that are common practice for low voltage halogen reflector lamps are also on the market for mains voltage halogen reflector lamps but with a GZ10 cap that differs from the normal GU10 cap. Because the IR-radiation is evacuated on the backside (cap-side) of the lamp, the luminaire has to be suitable to resist this heat. As a consequence a one-to-one replacement from a GU10 capped lamp by a GZ10 capped lamp is not always allowed.
A silver coating on the reflector can have the same result with regard to optical efficacy and avoids the evacuation of heat backwards, of course without providing a cool beam. Silver coating is also more expensive than dichroic coating.
In the range of parabolic reflector lamps with Edison or Swan cap, the dichroic (or silver) coated reflectors are B(N)AT.
A possible problem with dichroic reflectors on Edison or Swan capped lamps could also be the heat problem as mentioned for the GZ10 capped lamps. If the existing luminaire is not designed for this changed heat transfer, these lamps could cause damage and maybe fire risk.
To solve this problem the dichroic coating could be applied on an aluminized reflector or a silver coating can be used.

All the common properties from halogen lamps are maintained.

The technical data for these lamps are shown in Table 6.1.

6.1.1.4 Mains voltage halogen reflector lamps with optimized filament wire design

The design of the filament wire has a strong influence on the light output and light distribution of a mains voltage halogen reflector lamp. The more compact the filament is, the more homogeneous and better the light output of a reflector lamp is.
Compared to a low voltage halogen lamp, the filament of a mains voltage halogen lamp is much longer and focussing this wire in a reflector is not easy. By optimizing the design of the filament, an improved efficacy can be obtained.
All the properties from halogen lamps are maintained.

The technical data for these lamps are shown in Table 6.1.

[2] (IESNA(1993)): 'Lighting handbook' (ISBN 0-87995-102-8).
[3] In literature, values of 5 till 10% are given.

6.1.1.5 Mains voltage halogen reflector lamps with anti-reflective coating on the front cover glass of the lamp

Glass not only transmits light but also reflects it, especially when the ray of light is not perpendicularly entering the glas. In a reflector lamp, this reflected light is reflected again by the reflector, but as this reflection does not have an efficiency of 100%, the efficacy of the lamp drops with every reflection. An anti-reflective coating on the cover glass avoids reflection and as a consequence, efficacy of the lamp raises. Measurements on coated cover glasses show an improvement in the 180° and 120° cone of 3% for one-sided coating and 5% for both-sided coating; this improvement even amounts to 6% in the 90° cone for both-sided coated cover glass.

The technical data for these lamps are shown in Table 6.1.

6.1.1.6 Mains voltage halogen reflector lamps PAR20 with dichroic or silver coated reflector, anti-reflective coating on the front cover glass and an integrated electronic transformer, using a IRC low voltage halogen bulb

These lamps use the same technology that was explained in part 1 of the study. A low voltage halogen bulb is mounted in the housing of an halogen PAR 20 lamp where also an electronic transformer is incorporated. The E27/B22d cap allows a one to one retrofit with a similar incandescent lamp and the energy consumption reduces to about half of it.
If the low voltage halogen bulb should be coated with an IRC reflective layer, and the reflector should be dichroic or silver coated and the front cover glass anti-reflective coated, efficacy could still rise. Altough IRC technology and dichroic reflectors are common practice in different lamp applications, the application for this specific lamp is not yet available on the market but could be introduced very soon because all technologies are available B(N)AT.

The technical data for these lamps are shown in Table 6.1.

6.1.1.7 Summary of technical data for Edison or Swan capped mains voltage halogen lamps

Table 6.1 summarizes the main improvement data for Edison or Swan capped reflector lamps.

As already written in part 1 of the study, it must be taken into account that efficacy of lamps in the same family rises with the wattage i.e. a lamp of 50W will have a higher efficacy than his family member of 35W with the same technology. It must be noted that some lamps are available with different life times and as mentioned in part 1 there is a trade off between lamp life and lamp efficacy[4].
The relation between lifetime and efficacy is shown in Figure 6.2.

Some lamps are indicated as B(N)AT, they are not yet on the market due to current low market demand however their production is technically obvious and feasable.

[4] (IESNA(1993)): 'Lighting handbook' (ISBN 0-87995-102-8) p. 186

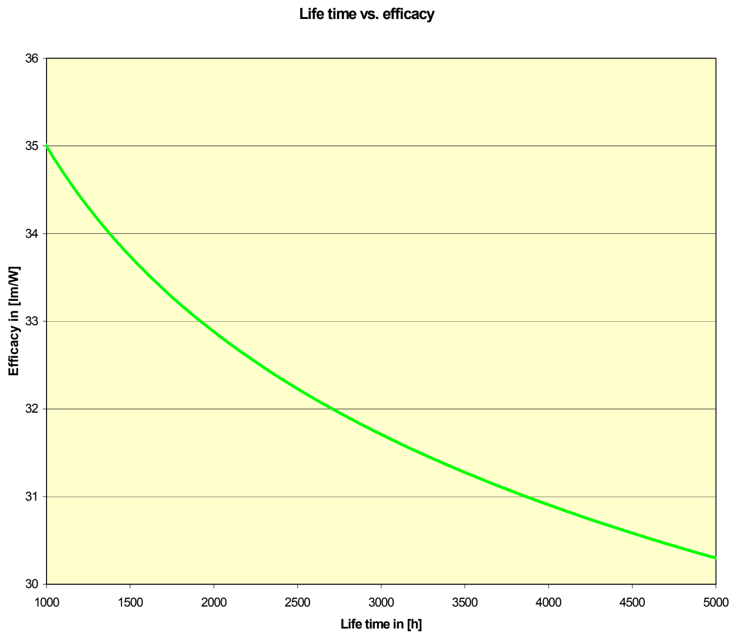

Figure 6.2: Lifetime of lamps versus efficacy[5]

[5] Received as a comment and discussed at the 3rd stakeholder meeting

Table 6.1: Data for lamp efficacy, cost and life time of Edison or Swan capped halogen lamps (source: ELC members and other stakeholders)

Lamp type **Acronym**	**Wattage**	**LWFt**[6]	**Beam angle**	**Intensity**	**Luminous flux in a solid angle of 2π**	**Luminous flux in solid angle π (angular beam 120°)**	**Functional lumens in an angular beam of 90°**	**ηlamp(90°) @25 °C**	**Life time**	**Unit price (for end user)**
	[W]		**[°]**	**[cd]**	**[lm]**	**[lm]**	**[lm]**	**[lm/W]**	**[h]**	**[€]**
Halogen reflector lamp, PAR20, E27 (B22d) **HL-MV-R**	50	1	25	1056	405	391	353	7.1	2000	12
Halogen reflector lamp, R63, E27 (B22d), xenon **HL-MV-R**	42	1	30	629	384	323	247	5.9	2000	3.0
Halogen reflector lamp, PAR20, E27 (B22d), xenon **HL-MV-R**	50	1	30	1161	446	420	388	7.8	2000	11.0
Halogen reflector lamp, PAR20, E27 (B22d), xenon +optimized filament wire design **HL-MV-R**	40	1	30	1043	340	319	296	7.4	2000	11.0
Halogen reflector lamp, PAR20, E27 (B22d) transfo inc **HL-MV-R**	20	1	25	1200			270	13.5	5000	22.0
B(N)AT[7] Halogen reflector lamp, PAR20, E27 (B22d), xenon +optimized filament wire design + dichroic **HL-MV-R**	40	1	30	1126	367	345	320	8.0	2000	13.0
B(N)AT[8] Halogen reflector lamp, PAR20, E27 (B22d), xenon +optimized filament wire design + silver **HL-MV-R**	40	1	30	1126			320	8.0	2000	14.5
B(N)AT[9] Halogen reflector lamp, PAR20, E27 (B22d), xenon +optimized filament wire design + dichroic/silver + anti-reflective **HL-MV-R**	40	1	30	1183	386	362	339	8.5	2000	15
B(N)AT Halogen reflector lamp, PAR20, E27 (B22d) transfo inc + IRC **HL-MV-R**	20	1	25	1300			303	15.1	5000	24
B(N)AT Halogen reflector lamp, PAR20, E27 (B22d) transfo inc + IRC + dich/silv **HL-MV-R**	20	1	25	1400			327	16.4	5000	27

*The **B(N)AT** values are calculated.*

[6] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see section **Fout! Verwijzingsbron niet gevonden.**).
[7] Intensity, functional lumen and efficacy are only calculated, based on estimated improvement as mentioned.
[8] Intensity, functional lumen and efficacy are only calculated, based on estimated improvement as mentioned.
[9] Intensity, functional lumen and efficacy are only calculated, based on estimated improvement as mentioned.

6.1.2 Mains voltage halogen reflector lamps with GU10 cap

Four similar improvements as for Edison or Swan capped lamps can be considered for GU10 capped lamps (GU10 capped halogen lamps already use PAR/MR reflectors):

- xenon gas filling,
- improved filament wire design,
- dichroic reflector,
- anti-reflective coating of the front cover glass.

The description of these improvements were already given in the preceding section.

Important remark for dichroic reflector lamps (see also 6.1.1.3):
Because a dichroic reflector evacuates the heat backward, this lamp has a specially adapted cap, the GZ10 cap. Interchangeability with a GU10 cap in the same luminaire is not always possible. If the luminaire has a GZ10 holder, a GU10 capped as well as a GZ10 capped lamp can be placed but if the luminaire is fitted with a GU10 holder, no GZ10 capped lamp can be placed. By this measure, the risk for damage and fire is eliminated.

All properties of halogen lamps are also maintained for these lamps.

The technical data for these lamps are shown in Table 6.2.
It must be noted that nearly all lamps have a relative short life time of 2000 h. Lamps with longer lifetime are rarely found on the market due to the negative impact on lamp efficacy[10]. Some lamps are indicated as B(N)AT, they are not yet on the market due to current low market demand however their production is technical obvious and feasable.

It is important to note that infra-red coating (IRC) on mains voltage halogen lamps, working on the European standard voltage of 230V, has no improvement potential on the efficacy of these lamps. If such improvement claims are found in literature, they are based on American mains voltage lamps, working on 130V.

[10] See Figure 6.2 and (IESNA(1993)): ‘Lighting handbook’ (ISBN 0-87995-102-8) p. 186 relation between lamp efficacy and life time

Table 6.2: Data for lamp efficacy, cost and life time of GU10/GZ10 capped halogen lamps

Lamp type **Acronym**	**Wattage**	**LWFt**[11]	**Beam angle**	**Intensity**	**Luminous flux in a solid angle of 2π**	**Luminous flux in solid angle π (angular beam 120°)**	**Functional lumens in an angular beam of 90°**	**ηlamp(90°) @25 °C**	**Life time**	**Unit price (for end user)**
	[W]		**[°]**	**[cd]**	**[lm]**	**[lm]**	**[lm]**	**[lm/W]**	**[h]**	**[€]**
Halogen reflector lamp, MR16, GU10, xenon **HL-MV-R**	42	1	30	826	340	319	285	6.8	2000	7.0
Halogen reflector lamp, MR16, GU10, xenon + optimized filament wire design **HL-MV-R**	40	1	25	1571	386	367	348	8.7	2000	7.0
B(N)AT[12] Halogen reflector lamp, MR16, GU10, xenon + optimized filament wire design + silver **HL-MV-R**	40	1	25	1697	417	396	376	9.4	2000	7.7
B(N)AT[13] Halogen reflector lamp, MR16, GU10, xenon + optimized filament wire design + silver + Anti-Reflect **HL-MV-R**	40	1	25	1782	438	416	398	10.0	2000	8.1

*The **B(N)AT** values are calculated.*

6.1.3 Low voltage halogen reflector lamps

For these lamps, there are two improvement options that are currently on the market:

- xenon gas filling of the bulb,
- xenon gas filling and applying an infra-red coating on the bulb.

These are again improvement options that were explained in part 1 of the study, but now implemented on low voltage halogen reflector lamps.

A third improvement option is the anti-reflective coating of the front cover glass as explained in 6.1.1.5; lamps with this technology are currently not yet available on the market but the technology exists and can easily be applied. The improvement for low voltage lamps however is lower than for mains voltage lamps because the filament wire is much more compact in a LV lamp than in a MV lamp. As a consequence the rays of light are much more concentrated and are reaching the front cover glass already more perpendicularly; the measured improvement of an anti-reflective coating on HL-LV-R was only 3%.

It is important to note again that efficacy of low voltage halogen lamps can also be improved by shortening the lifetime as already explained in 6.1.1.7.

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[11] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see section **Fout! Verwijzingsbron niet gevonden.**).
[12] Intensity, functional lumen and efficacy are only calculated, based on an improvement of 8%.
[13] Intensity, functional lumen and efficacy are only calculated, based on an improvement of 5 or 6%.

Currently lamp manufacturers are bringing low voltage halogen reflector lamps on the market with only xenon filling and almost the same efficacy of the ones with xenon and IRC, however with lifetimes of 2000h instead of 5000h.

All these lamps only differ from the normal low voltage halogen reflector lamps by the form of the halogen bulb, the thin layer of the infra-red reflecting coating and the filling gas.
There are no differences with the base case lamps neither regarding the reflector that is already a multi-facetted dichroic reflector nor regarding the filament wire that has the same compact dimensions that optimally fits in a reflector.
As a consequence the BOM's will not noticeably change compared to the BOM's showed in chapter 4.

Price and efficacy data about these lamps are included in Table 6.3 hereafter. These data will also be used for the improvement options assessment in chapter 7.

Table 6.3: Data for lamp efficacy, cost and life time of HL-LV-R improvements

Lamp type **Acronym**	**Wattage**	**LWFt[14]**	**Beam angle**	**Intensity**	**Luminous flux in a solid angle of 2π**	**Luminous flux in solid angle π (angular beam 120°)**	**Functional lumens in an angular beam of 90°**	**ηlamp(90°) @25 °C (LWFt not incl)**	**Life time**	**Unit price (for end user)**
	[W]		**[°]**	**[cd]**	**[lm]**	**[lm]**	**[lm]**	**[lm/W]**	**[h]**	**[€]**
Halogen reflector lamp, MR16, 12V, GU5.3, xenon **HL-LV-R**	25	1.06	36	862	421	398	367	14.7	2000	6.8
Halogen reflector lamp, MR16, 12V, GU5.3, xenon **HL-LV-R**	35	1.06	36	1992	584	558	524	15.0	2000	6.8
Halogen reflector lamp, MR16, 12V, GU5.3, IRC + xenon **HL-LV-R**	20	1.06	36	1110	418	374	321	16.1	5000	7.0
Halogen reflector lamp, MR16, 12V, GU5.3, IRC + xenon **HL-LV-R**	25	1.06	36	862	421	398	367	14.7	5000	7.0
Halogen reflector lamp, MR16, 12V, GU5.3, IRC + xenon **HL-LV-R**	30	1.06	36	1486	605	588	533	17.8	5000	7.0
Halogen reflector lamp, MR16, 12V, GU5.3, IRC + xenon **HL-LV-R**	35	1.06	36	1898	655	631	565	16.1	5000	7.0
Halogen reflector lamp, MR16, 12V, GU5.3, IRC + xenon **HL-LV-R**	45	1.06	36	2530	991	949	853	19.0	5000	7.0
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic **HL-LV-R**	20	1.06	36	1166	439	393	337	16.9	5000	7.5
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	20	1.06	36	1200	452	404	347	17.4	5000	8.0
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	20	1.06	36	1284	484	434	371	18.6	2000	8.0
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic **HL-LV-R**	35	1.06	36	1993	688	663	593	16.9	5000	7.5
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	35	1.06	36	2053	708	682	611	17.5	5000	8.0

[14] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see section **Fout! Verwijzingsbron niet gevonden.**).

B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	35	1.06	36	2196	758	730	654	18.7	2000	8.0
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic **HL-LV-R**	45	1.06	36	2657	1040	988	896	19.9	5000	7.5
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	45	1.06	36	2736	1071	1018	923	20.5	5000	8.0
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	45	1.06	36	2928	1146	1089	987	21.9	2000	8.0
B(N)AT Halogen reflector lamp, MR16, 36°, 12V, GU5.3, IRC + silver/dichroic + Anti-Refl **HL-LV-R**	45	1.06	36	3119	1221	1160	1052	23.4	1000	8.0

Remarks: The LFWt for the improvement options takes into account that the EuP study on External power supplies proposes a (BAT) value of 1.06.
*The **B(N)AT** values are calculated.*

6.1.4 LED retrofit lamps for replacing incandescent and halogen reflector lamps

White-light emitting diode (WLED) solid state lighting (SSL) lamps have been recently becoming available on the market with increasing efficacy (up to 94 lumen/W for an LED die ((Härle (2007)) and increasing life time as a result of decades of semiconductor research and progress. WLEDs that currently could serve as retrofit solutions in this study have much lower efficacy but the rate of improvements is very high, the lower performance can in part be explained by power supply losses, additional optical losses and temperature effects.
Also applications where coloured light is required benefit from LED's, e.g. traffic and other signs (applications with a low power density). LED's can be dimmed easily if the power supply is adapted for this function. WLED's are available in a wide range of lamp efficacies from the same manufacturing production line, these LEDs were sorted during manufacture by their actual efficacy. This efficacy sorting is also called 'efficacy binning'.
WLED's that are nowadays on the market are mainly Solid State Lighting (SSL) devices, that rely on semiconductor material. For this SSL technology, efficacy and life time rapidly decrease with ambient temperature, therefore no high power densities or compact light sources can be obtained. SSLs are therefore primarily produced as discrete devices they are mainly available in low wattages (typical 1 to 5 Watt) and the main market products nowadays are mobile appliances (48 % in 2006, Steele (2007)). They are also sold as LED replacement lamps for existing reflector lamps.
Dr. Shuji Nakamura is the inventor of the white LED which took a composite YAG phosphor coating on top of a blue LED and converted it to white light. This technique is nowadays nearly used by all WLED manufacturers. A theoretical limit in efficacy can be expected in the range of 135-150 lm/W with lens and without power supply losses (Härle (2007). The

spectrum of some white LEDs differs significantly from incandescent light. There is a strong dependency of maximum efficacy on colour temperature colour coordinate (up to 20% increase) (Härle (2007)). The most efficient WLEDs appear blue (e.g. CT 6000 K) and do not meet the CRI > 80 colour rendering requirement for office lighting (EN 12464-1). It must be noted that there are also UV based WLEDs on the market. The light spectrum and solid state physics follows the laws of quantum mechanics. Generally, quantum mechanics does not assign definite values to observables. Instead, it makes predictions using probability distributions. As a consequence, UV will never be totally absent for any white light source, it is only a matter of more or less. Moreover, the total absence of UV cannot be measured according to the the Heisenberg uncertainty principle.
The SSL dependence on solid state semiconductor material could keep the price relatively high for these sources and the environmental impact of the production should be followed up in the near future. WLED semi-conductors are crystals comprised of combinations of typically two or tree inorganic elements, such as gallium phosphide (GaP), gallium nitride (GaN), gallium indium nitride (GaInN) or gallium indium phosphide (GaInP). It should be noted that LEDs in general, thus not only WLED, are included in the environmental impact unit indicators in the MEEUP methodology report (table 29 material 48) and herein the production energy requirement or GWP per kg is very high compared to other materials. This can be explained by the high energy (GWP) and environmental impact that is typical for the production of semiconductor material, see also material 47 (ICs SMD) in table 29 in the MEEUP methodology report. The WLEDs in particular make use of the rare raw materials gallium and indium that are used in many other high tech applications (PV panels, monitors, LCD displays with coatings of indium tin oxide) ('Only united are we strong: supply problems await areas other than silicon', Photon International, July 2006). The world annual indium production was estimated(2005) at 455 ton at 650 €/kg with about 6000 ton global reserves only(US Geological Survey, Mineral Commodity Summaries, January 2006). The indium price did rise with a factor 8 from 2002 to 2005. The world annual gallium production is estimated in 2005 at 208 tons at 410 €:kg and the global reserve is more difficult to estimate. Gallium occurs in very small concentrations in ores of other metals and is produced as a byproduct (e.g. bauxite). Based on the world resource of bauxite the reserve exceeds 1 million ton but probably only a small percentage of this metal is economically recoverable (US Geological Survey, Mineral Commodity Summaries, January 2006). The required energy (GWP) and material for the particular high efficacy WLEDs can only be modelled very approximate nowadays because it is unclear how many % of the production reach the high efficacy rating and there are many different and new production processes involved from which no data is made available due to intellectual property concerns. In this study the environmental impact will be modelled with the unit indicator (material 48 'SMD/LED's Avg per kg') from the MEEUP methodology (table 29). It must be noted that also GaAs and AlGaAs semiconductor is used for LEDs (Schurbert (2003), pp.4-7)[15], the are mainly used for red or infrared LEDs. Arsenic is a well known toxic material. For visible red/orange light currently AlGaInP/GaP is used (Schurbert (2003), p. 213)[16], Infrared LEDs can still rely on these materials however they are not used for products in the focus of this study. Due to the high rate of innovation it cannot be excluded that arsenic compounds will reappear in LEDs for general lighting. It is also clear from the unit indicator in the MEEUP methodology that environmental impact from the production may not be neglected in future assessments.

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[15] Schubert (2003): 'Light-Emitting Diodes', second edition, ISBN-13 978-0-51-86538-8
[16] Schubert (2003): 'Light-Emitting Diodes', second edition, ISBN-13 978-0-51-86538-8

The rate of innovation is still very high and results in a significant amount of intellectual property (IP). A query for ‘LED’ in the European patent database[17] results in 1320 filed European patent claims and 9 patent claims were filed in the first trimester of 2009.

More details about LED quality are included in chapter 3. The values included in this section were the best found on the market (5/2009). It should be noted that many products had a lower efficacy and it was reported that many of them do not fulfil their package claims[18].

Even though this part of the study does not look in detail into retrofit LED NDLS lamps that appeared as replacement lamps for NDLS incandescent bulbs since the completion of part 1 of the study, these statements relating to the efficacy, quality and BOM of retrofit LED DLS lamps as compared to other DLS lamp technologies are also largely valid for retrofit LED NDLS lamps compared to other NDLS lamp technologies.

In this chapter, three retrofit lamp types are studied:

- a LED-retrofit lamp for the R63-E27 5B22d) incandescent and halogen reflector lamps
- a LED-retrofit lamp for the MR16-GU10 halogen mains voltage reflector lamps
- a LED-retrofit lamp for the MR16-GU5.3 halogen low voltage lamps.

Price and efficacy data can be found in Table 6.4 and de BOM data in Table 6.5.

Lamps with a correlated colour temperature (CCT) of 2700 K were chosen because this is similar to incadescent lamps, 2700 K is also referred as ‘warm white’. Nevertheless it should be noted that most 4000 K LEDs are about 50 % more efficient compared to 2700 K LEDs, as can be concluded from manufacturers catalogue data. This efficacy difference is mainly for manufacturers that use phosphor to convert blue into white light, colour mixing LEDs might overcome this difference (as reported on the stakeholder meeting).

Figure 6.3: Some examples of LED retrofit lamps

[17] http://be.espacenet.com/

[18] Dutch Metrology Institure (2009): ‘OpgeLED Minder opbrengst dan verwacht’ (Be careful for LED performance is less than expected), available at www.vsl.nl

Table 6.4: Data for lamp efficacy, cost and life time of LED retrofit reflector lamps (data source: Olino[19] and ELC members)

Lamp type Acronym	Wattage	LWFt[20]	Beam angle	Intensity	Luminous flux in a solid angle of 2π	Luminous flux in solid angle π (angular beam 120°)	Functional lumens in an angular beam of 90°	ηlamp(90°) @25 °C	Life time	Unit price (for end user)
	[W]		[°]	[cd]	[lm]	[lm]	[lm]	[lm/W]	[h]	[€]
LED retrofit reflector lamp, R63, E27 (CCT 2700 K) **LEDi-R**	7.4	1.05	45	360			247	33.4	30000	40
LED retrofit reflector lamp, R63, E27 (CCT 4200 K) **LEDi-R**	6.4	1.05	26	788	275	249	226	35.3	45000	40
LED retrofit reflector lamp, MR16, GU10 (CCT 2700 K) **LEDi-R**	4.7	1.05	32	382			170	36.1	30000	35
LED retrofit reflector lamp, MR16, GU10 (CCT 3000 K) **LEDi-R**	3.8	1.05	24	657	181	160	143	38.2	15000	35
LED retrofit reflector lamp, MR16, GU10 (CCT 3000 K) **LEDi-R**	3.9	1.05	21	310	137	115	96	24.3	15000	35
LED retrofit reflector lamp, MR16, GU10 (CCT 4200 K) ** **LEDi-R**	3.3	1.05	11	963	75	57	49	14.8	35000	40
LED retrofit reflector lamp, MR16, GU5.3 (CCT 2700 K) **LEDi-R**	4.4	1.17	29	405			136	31	30000	30

*** not complete retrofit for GU10 halogen (lamp is much longer)*

19 www.olino.org

20 LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see chapter 4).

Table 6.5: Input data for the materials extraction and production of the lamps (expressed in g)

MATERIALS Extraction & Production	LED retrofit reflector lamp, R63, E27 – **7.5W**		LED retrofit reflector lamp, MR16, GU10 – **4W**		LED retrofit reflector lamp, MR16, 12V, GU5.3 – **4W**	**Category**	**Material or Process MEEUP**
Description of component							
Lens	10.1		10.1		10.1	7-Misc.	**13-PMMA**
Aluminium body for cooling	140		27.3		27.3	4-Non-ferro	**27-Alu die-cast**
Aluminium for caps	1.5					4-Non-ferro	**26-Al sheet/extrusion**
Copper for caps / connector pins			1.5		1.5	4-Non-ferro	**30-CU tube/sheet**
LED	1		0.7		0.7		**48-SMD/LED's avg**
Copper plate (heat transfer)	10		9		9		**30-CU tube/sheet**
Plastic insulation plate	10		2.2		10		**8-PVC**
Porcelain housing			16				
Printed circuit board, assembled	10		7.5		7.5		**53-PWB assembly**
Total weight							

6.1.5 Compact fluorescent reflector lamps (CFLi-R) with integrated electronic ballast

As can be concluded from the technical analysis and the data in chapter 4, most CFLi-R on the market can not be considered as a DLS. Only in the range of lamps with big dimensions, some lamps match the definition of a DLS. Moreover, their efficacy is very low, compared to non directional CFLi. The reason for this lower efficacy and the non conformity with the DLS criterion is caused by the dimensions of the light emitting discharge tube which makes it necessary to lay the folded tube in layers. The upper layer of the folded tube shields the light from the underlying. As a consequence, there is no optical control in small size reflectors.
Nevertheless, a stakeholder reported improved lamps with small dimensions that fulfil the requirements of a DLS. Although these lamps are not yet available on the market, his figures are listed in Table 6.6.
This table also includes data for lamps with big dimensions that are rarely used in domestic lighting but that could be used as a downlighter e.g. in corridors.

It is important to note that even if those lamps fulfil the requirements of a DLS and their efficacy is higher than the efficacy of the comparable lamps (GLS-R or HL-MV-R), the intensity of their beam angle will always be very much lower. Many consumers will be disappointed if they buy these lamps. Their benefit can only be found if they are used as a downlighter.

Table 6.6: Data for lamp efficacy, cost and life time of CFLi-R[21]

Lamp type Acronym	Wattage	LWFt[22]	Beam angle	Intensity	Luminous flux in a solid angle of 2π	Luminous flux in solid angle π (angular beam 120°)	Functional lumens in an angular beam of 90°	ηlamp(120°) @25 °C (without LWFt)	ηlamp(90°) @25 °C (without LWFt)	Life time	Unit price (for end user)	% face lumen output in solid angle π (angular beam 120°)
	[W]		[°]	[cd]	[lm]	[lm]	[lm]	[lm/W]	[lm/W]	[h]	[€]	
B(N)AT Compact fluorescent reflector lamp, R50, E14(B15d) **CFLi-R**	7	1.05	115	68	164	140	98	20.0	14.0	10000	15.0	85
B(N)AT Compact fluorescent reflector lamp, R63, E27 (B22d) **CFLi-R**	11	1,05	125	111	240	206	145	18.7	13.2	10000	15.0	86
B(N)AT Compact fluorescent reflector lamp, R63, E27 (B22d) **CFLi-R**	11	1,05	117	124	240	203	149	18.5	13.5	15000	20.0	85
B(N)AT Compact fluorescent reflector lamp, R50, GU10 **CFLi-R**	11	1,05	99	119	220	182	134	16.5	11.7	15000	18.0	83
B(N)AT Compact fluorescent reflector lamp, PAR30(R100), E27 **CFLi-R**	15	1.05	90	290	600	501	376	33.4	25.1	15000	26.0	84
B(N)AT Compact fluorescent reflector lamp, PAR38(R120), E27 *dimmable* **CFLi-R**	15	1,05	70	450	680	604	492	40.3	32.8	15000	30.0	89
B(N)AT Compact fluorescent reflector lamp, PAR38(R120), E27 **CFLi-R**	23	1.05	110	450	1200	980	711	42.6	30.9	10000	27.0	83

- Lamp 1 could be seen as a replacement (?) for the E14 capped 40W blown reflector incandescent lamp R50 that is not a base case lamp for us.
- Lamp 2 and 3 could be seen as improvement (?) options for the E27 capped 40/60W blown reflector lamps, incandescent as well as halogen (improved lamps with xenon filling 28 and 42W included).

[21] Data provided by a stakeholder (Megaman)
[22] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see chapter 4).

- Lamp 4 with a GU10 cap is in fact not a real replacement lamp for the GU10 capped HL-MV-R because the dimensions are different. It can of course also be made with a E14 cap and then it is a similar lamp to lamp 1 (replacing R50 blown reflector lamps)
- Lamps 5, 6 and 7 are replacement (?) lamps for the GLS-R-HW and HL-MV-R-HW.

6.1.6 Cold Cathode Compact Fluorescent Reflector Lamps (CCFLi-R) with integrated electronic ballast

Cold cathodes fluorescent lamps (CCFL) are fluorescent lamps that do not employ a cathode heater. Nowadays, miniature CCFL's are extensively used as backlights for computer liquid crystal displays or flat screen television sets. More recently reflector lamps for general illumination appeared on the market. Their manufacturers claim a longer life time, dimmability and improved light distribution. Compared to a normal CFLi-R it can be said that the smaller light emitting discharge tube could have as a consequence that the light output is higher in the 90° cone angle. It must also be stated that these lamps contain mercury. More technical information can be found in the final report of preparatory study for ecodesign of EuP products lot 5 for television sets[23].

6.1.7 White light HIDi-R lamps to retrofit high wattage reflector lamps

High wattage incandescent or halogen reflector lamps can be replaced by more efficient HID reflector lamps with integrated control gear (HIDi-R).

The main advantage compared to CFLi-R is that an HID burner is a point source that performs better when the light needs to be focused by optics, e.g. in reflector lamps or a luminaire. Normal HID lamps are mainly available in high lumen output versions (> 1000 lm) and hence users are also forced to use luminaires to prevent glare and distribute the light.
There currently exist HIDi-R lamp versions that directly offer cost effective integrated solutions for replacing high wattage PAR38 incandescent or halogen reflector lamps with E27 cap. These lamps are rarely used in indoor domestic applications. In outdoor applications (e.g. garden lighting) they are a good alternative. Compared to an incandescent reflector lamp PAR 38-120W the equivalent HIDi-R only needs 25W, with a high colour rendering Ra = 87 and a warm, suitable colour temperature of 3000K.
These HIDi-R lamps have of course the same warm up and restrike times of several minutes as the normal HID lamps that were discussed in the street lighting study; also dimming is not possible. This makes them not very suitable for indoor domestic applications with regular switch-on's and –off's. Nevertheless, for horeca and outdoor applications they provide an energy efficient, retrofit alternative without need to change the luminaire.
It is unlikely that much lower lumen output HIDi-R lamps will appear on the market in the near future. It is a strong technological challenge. Simply downscaling can compromise life expectancy. Obstacles are the thermal conduction losses from the arc and the electrode losses that become more important for low wattages
Also here must be stated that white HIDi-R lamps also contain mercury; for more information on HID lamps see the preparatory EuP-study on street lighting lot 9.

[23] www.ecotelevision.org

Figure 6.4: HID-reflector lamp with integrated control gear.

The efficacy data for these lamps are shown in Table 6.7

Table 6.7: Data for HIDi-R lamps

Lamp type Acronym	Wattage	LWFt[24]	Beam angle	Intensity	Luminous flux in a solid angle of 2π	Luminous flux in a solid angle of π (angular beam 120°)	Functional lumens in an angular beam of 90°	ηlamp(90°) @25 °C	Life time	Unit price (for end user)
	[W]		[°]	[cd]	[lm]	[lm]	[lm]	[lm/W]	[h]	[€]
HID retrofit reflector lamp, PAR38, E27 **HIDi-R**	25	1.05	10	26000	1275		1045	41.8	9000	40
HID retrofit reflector lamp, PAR38, E27 **HIDi-R**	25	1.05	25	5000	1275		1085	43.4	9000	40
HID retrofit reflector lamp, PAR38, E27 **HIDi-R**	25	1.05	40	2100	1275		1020	40.8	9000	40

The average LLMF for these lamps is 0.81.

6.1.8 DLS LED luminaire as improvement option to DLS luminaire + DLS lamps

Following the logic of Regulation 244/2009, integrated DLS LED luminaires would be considered as lamps and will have to comply with the requirements applicable to DLS lamps. Indeed, because of their integrated nature, they are an improvement option not only to luminaires (as discussed in section 6.1.9) but also to lamps, in the series of lamp improvement options started above. As the price is higher for retrofit the consumer might choose to replace the complete luminaire.
Compared to the use of DLS lamps (other than retrofit LEDs) in DLS luminaires, LED luminaires could bring the benefit of higher energy efficiency, reduced maintenance (lamps do not need to be changed) and as a consequence, reduced waste production.

[24] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see chapter 4).

Compared to the use of retrofit LED lamps in DLS luminaires, the main improvement through LED luminaires is brought by higher energy efficiency, thanks to an improved thermal design with LED modules and more efficient power supplies because they do not suffer from space limitations that similar retrofit LED lamps encounter.
A typical example is a downlighter luminaire, see Figure 6.4. The functional performance parameters are included in Table 6.8 and the estimated BOM (extra functional elements) in Table 6.9. Dimmable power supplies are available. As can be seen from Table 6.8 the approach of quantifying functional lumens in a 90 ° solid angle is less suitable compared to functional lumens in a 120 ° for luminaires with LED modules (see also chapter 1).

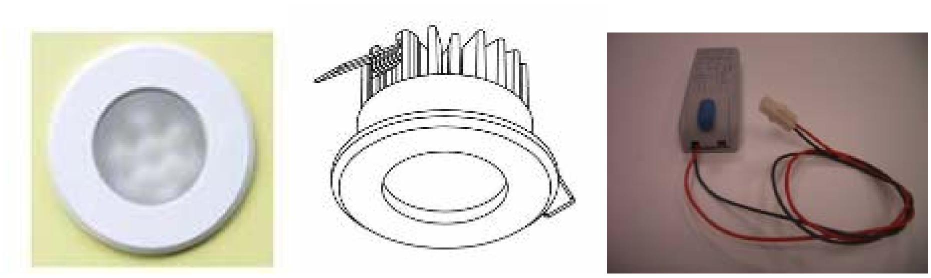

Figure 6.5: Sample LED downlighter incorporating a LED module and its dimmable external power supply

Table 6.8: Data for lamp efficacy, cost and life time of LED retrofit reflector lamps (source: manufacturer catalogue data)

Lamp type **Acronym**	**Wattage LED module (ecl. Power supply)**	**LWFt[25]**	**Beam angle**	**Intensity**	**Functional lumens in an angular beam of 180°**	**Functional lumens in an angular beam of 120°**	**Functional lumens in an angular beam of 90°**	**ηlamp(90°) @25 °C with power supply losses**	**Life time (as used in this study)**	**Unit price luminaire (for end user) (excl. power supply)**	**Unit price dimmable power supply (for end user)**
	[W]		**[°]**	**[cd]**	**[lm]**	**[lm]**	**[lm]**	**[lm/W]**	**[h]**	**[€]**	**[€]**
LED downlighter luminaire (CCT 3000 K) (32° beam angle) **LED module**	6.7	1.19	32	866	450	435	409	51	30000	99	44
LED downlighter luminaire (CCT 3000 K) (70° beam angle) **LED module**	6.7	1.19	32	866	450	395	309	38	30000	99	44

[25] LWFt = Total Lamp Wattage Factor = LWFp x LWFe (see chapter 4).

Table 6.9: Input data for the materials extraction and production of the LED module luminaire (expressed in g) (estimated)

MATERIALS Extraction & Production ***Description of component***	LED retrofit reflector lamp, R63, E27 – **7.5W**		**Category**	**Material or Process MEEUP**
Lens	15		7-Misc.	**13-PMMA**
Aluminium body for cooling	300		4-Non-ferro	**27-Alu die-cast**
LED	1.5			**48-SMD/LED's avg**
Copper plate (heat transfer)	15			**30-CU tube/sheet**
Plastic insulation plate	10			**8-PVC**
Printed circuit board, assembled	10			**53-PWB assembly**

6.1.9 Luminaires with reduced energy consumption (system level)

Scope of this section:
The purpose of this section is to evaluate how much energy can be saved with a particular improvement option taking into account that the compared luminaires should have an equal similar 'Light Output Function' (LOF) which is not the same as 'Light Output Ratio' (LOR) of the luminaire (see also discussion in chapter 1).

Remarks:
All figures in the tables in Annex 1 are estimated values based on the knowledge of CELMA[26] *members as of July 2009.*
The average luminaire was defined in chapter 2.
The column in data tables of improvement options about 'What proportion of the energy can be saved comparing worst to best practice' is only related to luminaires that can be improved as indicated in the previous column (see Annex 1).

[26] Source: 'National Manufacturers Associations for Luminaires and Electrotechnical Components for Luminaires', www.celma.org

6.1.9.1 Luminaire improvement options related to lamp efficacy improvements

Note on the quantification of these improvement options:
In this section these options are discussed qualitatively however they are related to the most important and essential saving potential 'Increasing the lamp efficacy'. The related energy saving is calculated in more detail in chapter 8 and is also related to lamp stock and sales data and the related improvement options. The potential energy savings were already approximately calculated in scenarios in part 1 without lock-in effect, i.e. 'Scenario option 1'. The potential saving could be even more taking into account benefits from CFLni or future ultra-efficient LEDs when implemented in new luminaires. In part 2 it is the scenario related to replacing HL-MV-R with BAT or BNAT lamps, see chapter 8.

Avoid the lock-in effect into low efficient lamps class C or lower

This is also related to lamp sales data and the related improvement option in the scenario analysis. In part 2 it is the scenario related to replacing HL-MV-R with BAT HL-LV-R, see chapter 8. The proposed rule is very simple, the designer should verify that the luminaire is able to host an energy efficient lamp, e.g. at least label B.

Design luminaires that create a positive lock-in effect into efficient lighting by using CFLni lamps or ultra-efficient LED modules

CFLni lamps can have an improved efficacy and life time compared to CFLi lamps, moreover it is a positive lock-in effect for the end-user because these sockets only accept the efficient CFLni lamps. When incorporating CFLni lamps it should be carefully checked whether dimming is needed, if so dimmable ballasts should be considered. The ballast should be electronic in combination with 4-pin CFLni lamp sockets, keeping in mind Commission Regulation (EC) No 245/2009.

The same objective can also be obtained when a luminaire is constructed with ultra-efficient LED's. One of the main benefits of incorporating the LED modules directly in the luminaires is the optimisation of the LED cooling that can be improved compared to luminaires that rely on retrofit LED lamps. LEDs match also very well with optics to provide a desired light distribution.
Example: An example LED down lighter is included in this study, see section 6.1.8. The efficacy was found to be superior compared to the one of equivalent retrofit LED lamps.

Use coloured LEDs to create coloured light

LEDs are able to produce directly the desired colour which can be an alternative to a white light source with a colour filter screen.
Example from a similar lamp solution(Source ELC): LED retrofits are available in coloured versions. These have power consumptions of lower than 1 W system power and thus no need for special cooling provisions. They readily replace coloured light bulbs of 25 W regarding light output and colour with the same lumen output. Hence, the use of coloured LEDs in luminaires can create a similar saving.

6.1.9.2 Design luminaires with appropriate and efficient control electronics

Design luminaires that incorporate or are compatible with dimmers

A luminaire is in normal circumstances only operated at maximum power for functional use in occasional situations or ‘scenes’. The rest of the time the luminiare can be dimmed. Situations that benefit from dimming are: change of ambient requirements, change of function (e.g. reading, watching TV, ..), change of age of users, change of mood, interference with other light sources or displays, lamp performance during lifetime (ageing), change in room reflectance, daylight entrance, etc. This improvement is applicable for external and internal dimmer systems. Special attention is needed when a CFLni ballast or LED power supply is incorporated in the luminaire as they are not always compatible with dimmers and could create lock in effects. When using filament lamps one should be aware about the reduced efficacy of the lamp. An option for filament lamps is to design a luminaire that can simply be dimmed by incorporating several lamps which can be switched on/off individually.

The energy saving of this improvement option has been estimated in consultation with CELMA members and is included in Annex 1.

Design Luminaires with incorporated motion sensors where appropriate

Specific luminaires can have low operational hours and should only be operated when the luminaire is approached. This is often the case in corridors where wall/ceiling mount luminaires are used (Figure 6.6). The benefit of incorporating the sensor in the luminaire is that the full power supply (230 VAC) is always available and no leakage current through the lamp is needed as explained in part 1 section 3.4.5 on the ‘Electrical wiring and control system lock-in effect’. This lack of lamp leakage current lowers the standby power requirement for this application. When incorporating motion sensors the standby power requirement should be carefully examinated.

Figure 6.6: Luminaire with incorporated motion sensor

The energy saving of this improvement option has been estimated in consultation with major CELMA members and is included in Annex 1.

Design outdoor luminaires with incorporated day/night sensors

Outdoor luminaires should mainly be operated from dusk till dawn. The benefit of incorporating the sensor in the luminaire is that the full power supply (230 VAC) is always available and no leakage current through the lamp is needed as explained in part 1 section 3.4.5 on the 'Electrical wiring and control system lock-in effect'. This lack of lamp leakage current lowers the standby power requirement for this application. When incorporating day/night sensors the standby power requirement should be carefully examined (Figure 6.7). This option can be combined with dimming when the natural light level is insufficient, e.g. in workplaces where a minimum illumination level is required.

Figure 6.7: Outdoor luminaire with day/night sensor and motion detector

The energy saving of this improvement option has been estimated in consultation with major CELMA members and is included in Annex 1.

Eliminate standby losses when power supplies are incorporated in luminaires

It is important to install the switch before an incorporated lower voltage power supply instead of after the power supply. Also detectors or electronic ballasts could create losses without any light output.

According to CELMA only very few luminaires (less than 0.1%) do have today this standby loss, hence the impact is negligible.

Use electronic gears instead of magnetic (conventional) gears for CFLni and low voltage halogen

Please note that these savings were already documented and calculated in previous EuP preparatory studies on external power supplies (lot 7) and office lighting (lot 8). Magnetic ballasts are also covered by EC regulation 245/2009.

6.1.9.3 Options to increase the optical efficiency of luminaires

Use material with increased light transmittance for visible parts that are transparent / translucent

Significant differences can occur in light transmittance for visible parts that are transparent / translucent. This material is often used in luminaires to diffuse the light and luminaires can be improved with materials that have an increased light transmittance and still provide a similar outlook. Hence the Light Output Ratio (LOR) of the luminaire can be increased, see Figure 6.9: and Figure 6.10.
Examples are opal glass that has a significant lower light transmittance compared to surface treated glass, e.g. sand blasted or etched glass. Another example is white colouration PMMA (plexi-glass) that often can be replaced by satinated PMMA (see Figure 6.8). When assessing diffusor materials not only light transmittance counts but also the light reflection on the inner surface should be evaluated to avoid that the light gets 'trapped' within the luminaire . The best solution is to apply antireflective coatings at the inner surface of the diffusor, the same way as explained for halogens, see also section 6.1.2.

Figure 6.8: Left satinated PMMA and right white colouration PMMA diffusor material

Figure 6.9: Luiminaire(left) having LOR = 83 with special finish on the PMMA screen for direct&indirect lighting Luminaire (middle) with LOR = 70 having a glass diffuser with satin finish for direct lighting versus Luminaire (right) with LOR =62 having a white colouration PMMA screen for direct lighting

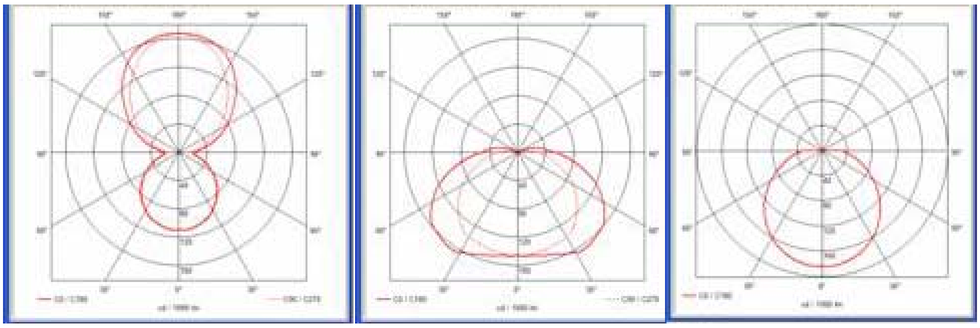

Figure 6.10: Light distribution for luminaires in ***Fout! Verwijzingsbron niet gevonden.*** *left is for direct and indirect lighting while middle and left are for direct lighting*

The energy saving for this improvement option has been estimated in consultation with major CELMA members and is included in Annex 1.

Use materials with increased reflectance for invisible parts that are not transparent/translucid

Significant differences can occur in light transmittance for visible parts that are not transparent / translucent, see Figure 6.1. This material is often used in luminaires to direct the light in a desired light distribution and can also be used to recover light from invisible parts. Hence the Light Output Ratio (LOR) of the luminaire can be increased.

Figure 6.11: Lampshade (left) with high internal reflectance (silver) and lampshade (right) with very low internal reflectance (black)

Related to this improvement option it should be noted that the lighting industry is working on a new EN standard within CEN/TC 169/WG 10, *'Performance of reflecting surfaces for luminaires'*.
The current proposal contains 10 efficiency classes vs total reflection in %, see Table 6.10.

Table 6.10: Proposal for reflection classes

Class	Total reflection in %
10	97 - 100
9	94 - 96.9
8	88 - 93.9
7	81 - 87.9
6	75 – 80.9
5	70 – 74.9
4	60 – 69.9
3	50 – 59.9
2	25 – 49.9
1	< 24.9

Note: The total reflectance ρtot measurement in accordance to Annex A (includes the relevant measurement procedure of CIE 130:1998).

The highest class 10 can only be achieved using advanced multi-layer coating techniques (final report lot 8, p. 168) (97%). Normal anodised aluminium for lighting applications has a total reflectivity of up to 87% (class 7) while standard white painting is about 80 % (class 6). To increase or enhance this total reflectivity to a higher level, several nanometre-thin optical coatings must be applied to the aluminium surface in a vacuum. This highly reflective surface allows the lighting manufacturer to achieve 5 up to 15 % increase in Light Output Ratio (LOR or CEN flux code). Especially luminaires that create a narrow beam and have multiple internal reflections to redirect the light from an NDLS can benefit from these materials. Therefore LOR or related LER requirements were formulated less stringent for narrow beam luminaires in lot 8 (final report lot 8, p. 185-189).

The energy saving of this improvement option has been estimated in consultation with major CELMA members and is included in Annex 1.

Summary of related LOR data found for domestic luminaires in simulation software

Important notice about LOR (see also chapter 1):

Luminaires that are used for functional lighting in the tertiary sector (e.g. office and street lighting) have photometric data that include the LOR. This approach to quantify the luminaire efficiency by its LOR cannot be applied one to one on decorative luminaires used for lamps within the scope of this study. The main reason is explained in section 1.1.5, i.e. part of the light transmitted through the luminaire shield is used to provide luminance on the decorative ornaments (of different transmittance) of the luminaire itself (another part of the light is absorbed in the luminaire and lost as heat). Moreover the reproduction and reliability of LOR data of decorative luminaire that rely on hand crafted parts (painting, glass, ..) will be very unreliable. Please note also that LOR might also rely on the used lamp type.

It is also not common practice to provide LOR data for those luminaires (CELMA communication in 2009), only very few manufacturers do so and mainly for the purpose of application in photometric simulation tools with high end architectural luminaires.

The next data (Figure 6.12, Table 6.11) contain collected LOR data found in electronic catalogues for about 49 typical domestic luminaires. It should be noted that this data is hard to find, only few manufacturers have this data and provide it in photometric simulation tools with high end architectural luminaires. There seems to be a plateau above LOR =60. Some sample luminaire pictures of this analysis are in Figure 6.13.

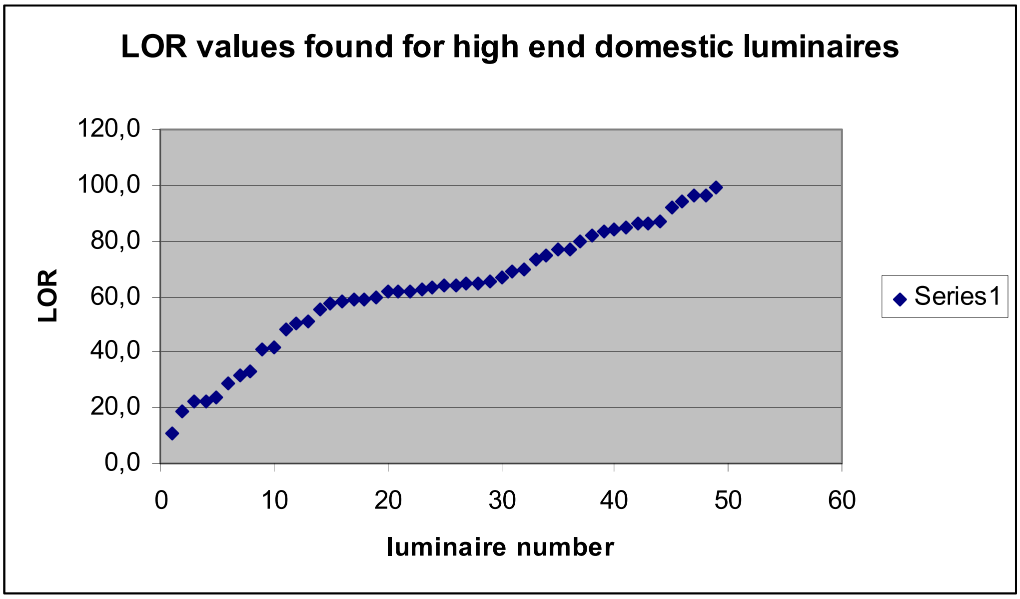

Figure 6.12: LOR found in electronic catalogues for different domestic luminaires.

Table 6.11: LOR statistics from 49 domestic luminaires

% of luminaires that have lower LOR	LOR
16	40
22	50
28	55
37	60
50	63
53	65
65	70
69	75

Figure 6.13: Luminaires with LOR = 19 (left), LOR = 62 (middle), LOR =84 (right)

Please note that the energy saving from this option has already been assessed in the two previous improvement options.

Use the correct category of luminaire for the correct application and provide appropriate user information

It is important that users are informed about the proper use of the luminaire.
Important application related issues that have an important influence on energy consumption are:

- Avoid the use of spotlights for general illumination by informing the consumer;
- Provide information on luminaire cleaning when diffusers, reflectors and/or dimmers are applied;
- Avoid continuous dimming with halogen lamps and change if possible to lower lamp power. This avoids lamp blackening with permanent efficacy decrease, moreover dimming also reduces efficacy;
- Do not put further shades on the products to reduce the light emission (it is possible to use those, if any, provided by the manufacturer and already evaluated;
- Warn users that indirect lighting is only beneficial with bright walls/ceiling;
- Warn users that indirect lighting needs an appropriated distance from the ceiling/walls, not to far but also not to close;
- Inform users about the light distribution for spot lights, e.g. beam angle;
- Warn the users for outdoor luminaires that have a high upward light flux (ULOR). This might create a high spilling of light and moreover creates light pollution (see also lot 9 on street lighting) (Figure 6.14).

The energy saving of this improvement option has been estimated in consultation with CELMA members and is included in Annex 1.

Figure 6.14: Example luminaire(left) that can createa spill of light when used against the open atmosphere versus an optimised luminaire(right) solution

6.1.9.4 Other luminaire related improvement options

Design outdoor luminaires with photovoltaic panels

Incorporating photovoltaic (PV) panels in outdoor luminaires could create a synergy and environmental benefits. Nevertheless a positive impact depends strongly on the application and is not always obvious. It will depend on the orientation, shading, seasonal variations in sunlight, the battery capacity, the battery life time and lighting needs. The 'saved' energy needs to be evaluated against the important environmental impact from PV panel production or PV panel production needs, this is often called energy pay-back time calculations[27].

Therefore it could be recommended in line with Annex 1 of the directive:
1. The manufacturer provides the energy pay back time for the system expressed in hours of operation of the luminaire.
2. The luminaire manufacturer provides the hours of operation per EU27 capital at a sunny unclouded day at equinox in optimum orientation.
3. The luminaire manufacturer provides instructions on optimum orientation.
4. The luminaire manufacturer provides the country average on sun vs cloudy days (e.g. Belgium is about 20 % sunny).

Figure 6.15: Outdoor luminaire with photovoltaic(PV) panel

Conclusion:
Situations where such an improvement option is beneficial were estimated very rare (see data provided by CELMA in Annex 1).

Use a reflector lamp instead of luminaire with reflector for downlighters

Source ELC, best LOR for reflector lamps are LOR = 85 %.
This should be compared to LOR = 65 % for an equal recessed reflector luminaire with a NDLS.

Nowadays reflector lamps are far more often used in spot lights, hence no big saving can be expected.

6.2 State-of the art of best existing product technology outside the EU

The EU has premises of leading international companies in the field of lighting with also important R&D related to office lighting within the EU. For the cited BAT above, similar technology exists around the world, mainly in the US and in Asia. Many European companies

[27] Alsema (1998): 'Energy pay-back time of photovoltaic systems: present status and prospects', Vienna, 1998, see http://igitur-archive.library.uu.nl/copernicus/2006-0307-200042/98053.pdf

are also internationally active and it is difficult to allocate their activities and achievements exclusively to the EU. The production of CFL is often located in China.
On the longer term (above 5 years), the proliferation of more advanced electronic lamp technology and solid state lighting such as LED's could be allocated to technology resulting from Asian technological developments.

6.3 BNAT in applied research

6.3.1 Low voltage halogen reflector lamps with super IRC

A stakeholder mentioned in his comments and explained in the 3rd stakeholder meeting that there is still improvement potential by replacing IRC by super IRC and even super super IRC. Efficacy could still rise with more than 10%.

6.3.2 OLED lamps

OLED's (Organic LED) are a new upcoming technology but they are not intended to give directional light. The reason for this is that the light producing element has typically a flat surface and the amount of generated lumens per m² is rather low. Due to the dimensions, a directional light source based on this technology is unlikely. The future of OLED's can mainly be found as backlights in flatscreens and mayby also as a NDLS in general room illumination. As a consequence they will not be discussed in this part 2 of the study.

6.3.3 The road map for WLED development

As mentioned before LEDs are under contineous development and LED efficacy is expected to furher increase.

LED manufacturers are claiming that LED performance will still improve in the next years.
At the 3rd stakeholder meeting, ELC has distributed a road map with their expectations until 2017 about the future LED system efficiency improvement for 3000K retrofit lamps.

This road map is displayed in Figure 6.16: ELC road map for LE

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The National Electrical Manufacturers Association of the USA has also published their expectations for LED improvement. This road map is displayed in Figure 6.17: National Electrical Manufacturers Association road map for LEDs

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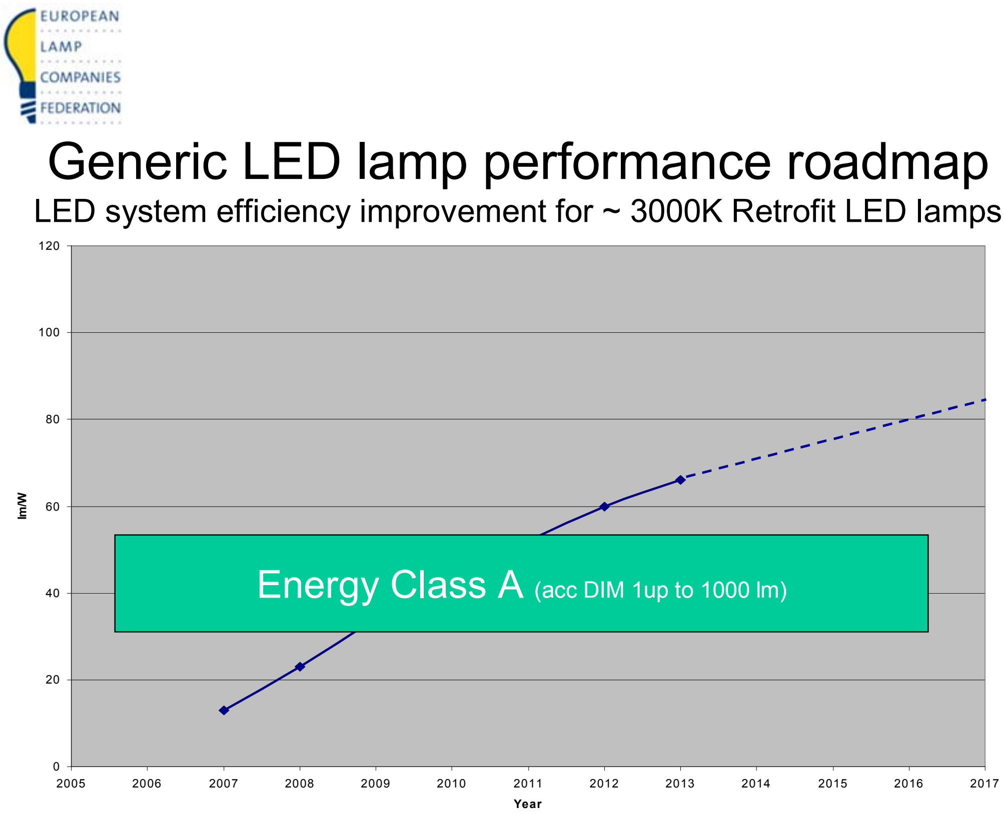

Figure 6.16: ELC road map for LE

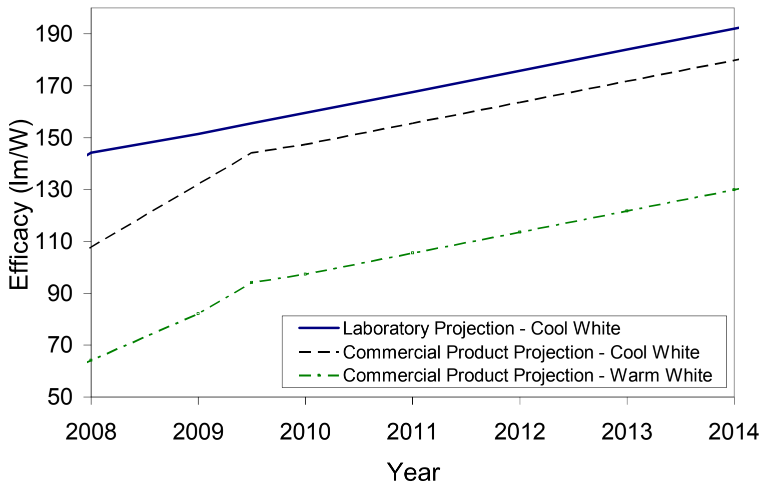

Figure 6.17: National Electrical Manufacturers Association road map for LEDs

Conclusion:

These projections suggest that the retrofit LED lamps that are discussed in section 6.1.4 could reach double lumen output and efficacy by 2016. In 2016 the total functional lumen output (90°) could be close to the base case halogen reflector lamps (HL-LV-R (GY5.3), HL-MV-

R(GU10)). Hence retrofit LED lamps with equivalent performance might become a realistic improvement option in 2016.

6.3.4 Theoretical maximum lamp efficacy

It is important to note that the lamp efficacy has a physical upper limit; this is when all light is converted into visible electromagnetic radiation.
This maximum lamp efficacy is related to the colour due to the definition of lumen and the relative spectral sensitivity of the human eye that was taken into account.
The maximum lamp efficacy for a perfect cool white light source is 348 lm/W and the absolute maximum for monochromatic yellow-green light (555 nm) sources is 683 lm/W (IESNA (1993), p. 204).

7 IMPROVEMENT POTENTIAL

For more info see website www.eup4light.net.

8 SCENARIO- POLICY- IMPACT- AND SENSITIVITY ANALYSIS

For more info see website www.eup4light.net.

Annex 1 Luminaire improvement options data[28]

Option:	dimmable application								
Your country:	CELMA								
Saving method description	Luminaire is only operated at max power for functional use. The rest of the time the luminiare is dimmed. This is applicable for external and internal dimmer systems.								
Sample picture best practice		**Sample picture worst practice**							Energy
Category of luminaires	**Is this option applicable to this category or not**	**How big is the market share [EU27 sales] of improvable luminaires in its category**	**What proportion of the energy can be saved comparing worst to best practice**	**How many luminaires [EU27 sales] are among the worst 30 % performers in the category**	**How many luminaires [EU27 sales] are among the best 30% performers in the category**	**What proportion of the energy can be saved on average assuming all luminaires sold are in the range of 30 % best performers**	**Chararactertic parameter best performer**	**Chararactertic parameter worst performer**	
	Y/N	**%**	**%**	**%**	**%**		***max operational energy consumption (W)***	***min operational energy consumption (W)***	
Downlights (recessed mounted)	y	75	30	50	25	15	<=30	>=60	
Suspension (chandeliers)	y	75	30	70	10	21	<=30	>=60	
wall&ceiling	y	70	30	60	10	18	<=30	>=60	
Desk	n								
Table	y	30	30	80	20	24	<=20	>=40	
Floor	y	75	30	70	20	21	<=50	>=100	
Spotlights	y	75	30	80	20	24	<=30	>=60	
Outdoor	n								
							lower powerconsumption because used at 50% dimming or use of low wattage lamps	higher powerconsumption because of use of high wattage lamps in not dimmable applications	

Note: For dimmable applications cleaning is relevant since the consumer will use more energy in direct relation with the dust on the luminaire
Dimmability is focused on filament lamps, only a very small quantity of CFLI(ni) is dimmable today.

[28] All figures in the tables in Annex 1 are estimated values with the knowledge of CELMA members as of July 2009.

Option:	Motion sensors	
Your country:	CELMA	
Saving method description	Luminaire is only operated when luminaire is approached	
Sample picture best practice		**Sample picture worst practice**

Energy

Category of luminaires	Is this option applicable to this category or not	How big is the market share [EU27 sales] of improvable luminaires in its category	What proportion of the energy can be saved comparing worst to best practice	How many luminaires [EU27 sales] are among the worst 30 % performers in the category	How many luminaires [EU27 sales] are among the best 30% performers in the category	What proportion of the energy can be saved on average assuming all luminaires sold are in the range of 30 % best performers	Chararactertic parameter best performer	Chararactertic parameter worst performer
	Y/N	%	%	%	%	%	*max average operating time (h)*	*min average operating time (h)*
Downlights (recessed mounted)	y	5	80	80	1		<= 0.5	>= 3h
Suspension (chandeliers)	n							
wall&ceiling	y	30	80	80	1	64	<= 0.5	>= 3h
Desk	n							
Table	n							
Floor	n							
Spotlights	y							
Outdoor	y	50	93%	90	5	80%	<= 0.5	>= 12h

Note:

Option:	Day/Nightsensor	
Your country:	CELMA	
Saving method description	Luminaire is only operated when luminaire is approached	
Sample picture best practice		**Sample picture worst practice**

Category of luminaires	**Is this option applicable to this category or not**	**How big is the market share [EU27 sales] of improvable luminaires in its category**	**What proportion of the energy can be saved comparing worst to best practice**	**How many luminaires [EU27 sales] are among the worst 30 % performers in the category**	**How many luminaires [EU27 sales] are among the best 30% performers in the category**	**What proportion of the energy can be saved on average assuming all luminaires sold are in the range of 30 % best performers**	**Chararactertic parameter best performer**	**Chararactertic parameter worst performer**
	Y/N	**%**	**%**	***%***	***%***	**%**	***max average operating time (h)***	***min average operating time (h)***
Downlights (recessed mounted)	n							
Suspension (chandeliers)	n							
wall&ceiling	n							
Desk	n							
Table	n							
Floor	n							
Spotlights	n							
Outdoor	y	50	45	90	5	40,5	<=8h	>=12h

Note:

Option:	Used material							
Your country:	CELMA							
Saving method description	In some cases the material used to diffuse the light can be improved with a similar acceptable outlook							
Sample picture best practice		Sample picture worst practice						
Category of luminaires	Is this option applicable to this category or not	How big is the market share [EU27 sales] of improvable luminaires in its category	What proportion of the energy can be saved comparing worst to best practice	How many luminaires [EU27 sales] are among the worst 30 % performers in the category	How many luminaires [EU27 sales] are among the best 30% performers in the category	What proportion of the energy can be saved on average assuming all luminaires sold are in the range of 30 % best performers	Chararactertic parameter best performer	Chararactertic parameter worst performer
	Y/N	%	%	%	%	%	*LOR*	*LOR*
Downlights (recessed mounted)	y	15	20	10	70	2	100	50
Suspension (chandeliers)	y	30	20	10	70	2	50	30
wall&ceiling	y	50	20	30	50	6	70	50
Desk	n							
Table	y	30	20	5	80	1	60	50
Floor	n							
Spotlights	n							
Outdoor	y	20	20	20	70	4	80	65

Note: please estimate, collected data will be aggregated.

Option:	Relectors		
Your country:	CELMA		
Saving method description	Use reflectors or reflective surfaces to avoid light absorption in the luminaire		
Sample picture best practice		**Sample picture worst practice**	

Category of luminaires	**Is this option applicable to this category or not**	**How big is the market share [EU27 sales] of improvable luminaires in its category**	**What proportion of the energy can be saved comparing worst to best practice**	**How many luminaires [EU27 sales] are among the worst 30 % performers in the category**	**How many luminaires [EU27 sales] are among the best 30% performers in the category**	**What proportion of the energy can be saved on average assuming all luminaires sold are in the range of 30 % best performers**	**Chararactertic parameter best performer**	**Chararactertic parameter worst performer**
	Y/N	**%**	**%**	***%***	***%***	**%**	***LOR%***	***LOR%***
Downlights (recessed mounted)	y	10	30	5	80	1,5	>= 90	<=40
Suspension (chandeliers)	y	20	30	30	30	9	>= 70	<=40
wall&ceiling	y	70	30	70	10	21	>= 70	<=40
Desk	y	40	30	30	30	9	>= 60	<=40
Table	n					0		
Floor	y	70	30	20	30	6	>= 70	<=40
Spotlights	y	20	30	20	50	6	>= 90	<=40
Outdoor	y	20	30	5	80	1,5	>= 60	<=40

seen as the % lumenoutput of lumir

Note: please estimate, collected data will be aggregated.

Option:	Correct application of the luminaire		
Your country:	CELMA		
Saving method description	Use the correct category of luminaire for the correct application. Eg. Avoid use of spotlights for general illuminiation, by informing the consumer		
Sample picture best practice		**Sample picture worst practice**	

Energy

Category of luminaires	**Is this option applicable to this category or not**	**How big is the market share [EU27 sales] of improvable luminaires in its category**	**What proportion of the energy can be saved comparing worst to best practice**	**How many luminaires [EU27 sales] are among the worst 30 % performers in the category**	**How many luminaires [EU27 sales] are among the best 30% performers in the category**	**What proportion of the energy can be saved on average assuming all luminaires sold are in the range of 30 % best performers**	**Chararactertic parameter best performer**	**Chararactertic parameter worst performer**
	Y/N	**%**	**%**	**%**	**%**	**%**	***average applicable wattage in correct use***	***average applicable wattage in faulty use***
Downlights (recessed mounted)	y	80	20	30	70	6	45	60
Suspension (chandeliers)	n	80				0		
wall&ceiling	y	80	20	50	50	10	45	60
Desk	n					0		
Table	y	60	20	30	70	6	45	60
Floor	y	80	20	30	70	6	70	100
Spotlights	y	80	20	50	50	10	45	60
Outdoor	y	80	30	50	50	15	45	60
		is applicable to all		% of miss use				

Note: A lot of environments can improved to a more efficient system, with the color of the wall, kind of the use of luminaire.
As example: 'Don't use a desk lamp'', or 'only one table lamp for general lighting, it should part of the general lighting'

Option:	Solar	
Your country:	CELMA	
Saving method description	Luminaire is not connected to network.	
Sample picture best practice		**Sample picture worst practice**

Energy

Category of luminaires	Is this option applicable to this category or not	How big is the market share [EU27 sales] of improvable luminaires in its category	What proportion of the energy can be saved comparing worst to best practice	How many luminaires [EU27 sales] are among the worst 30 % performers in the category	How many luminaires [EU27 sales] are among the best 30% performers in the category	What proportion of the energy can be saved on average assuming all luminaires sold are in the range of 30 % best performers	Chararactertic parameter best performer	Chararactertic parameter worst performer
	Y/N	%	%	*%*	*%*	%	*max % net power consumption*	*min % net power consumption*
Downlights (recessed mounted)	n							
Suspension (chandeliers)	n							
wall&ceiling	n							
Desk	n							
Table	n							
Floor	n							
Spotlights	n							
Outdoor	Y	3%	100	100	0	100	0	100

Note:	combined with motion sensors/day-night sensors