European Commission

Preparatory Study on Light Sources
for Ecodesign and/or Energy Labelling Requirements
('Lot 8/9/19').

Final report, Task 3

Use of Light Sources

Energy

Prepared by:

VITO, in cooperation with VHK
Date: 31 October 2015

Prepared for the European Commission, DG ENER.C.3
Contact person: Ruben KUBIAK
SPECIFIC CONTRACT No ENER/C3/2012-418 LOT1/07/SI2.668526
Implementing Framework Contract No ENER/C3/2012-418-Lot 1

Main contractor:
Consortium of VITO NV, VHK BV, Viegand & Maagøe ApS, Wuppertal Institute for Climate, Environment and Energy GmbH, ARMINES, represented by Dirk Fransaer, Managing Director VITO

Technical Team Leader: René KEMNA (VHK)
Contract Manager: Caroline LEMEIRE (VITO)

Other Participants:
Roy VAN DEN BOORN, Leo WIERDA (VHK)
Stuart JEFFCOTT (external collaboration)
Lieven VANHOOYDONCK, Paul VAN TICHELEN, Dominic ECTORS (VITO)
Wai Chung LAM (VITO, Quality Control)

Status: Final report

This report was ordered and paid for by the European Commission, Directorate-General for Energy.

Contents

EXECUTIVE SUMMARY

This document covers MEErP Task 3, which focuses on the resources consumption and environmental impacts of light sources during the use-phase. Light sources are mainly Energy-using Products, and consequently the major part of the report is dedicated to their electricity consumption. Light sources as Energy-related Products (for space heating), health aspects, and end-of-life are also addressed. The major part of the chapter on local infrastructure is dedicated to the compatibility between dimmers and LED lamps. This includes Task 2 (markets) and Task 4 (technical) aspects, but it has been preferred to present all information together.

Results from MELISA regarding energy consumption (chapter 2)

The Model for European Light Sources Analysis (MELISA) has been introduced in the Task 2 report as regards sales and installed stock of light sources in the EU-28 for the period 1990-2013. Chapter 2 of this Task 3 report continues the presentation of MELISA as regards the lighting energy consumption in the EU-28 for the same period. This presentation anticipates some information that would normally be presented in later MEErP tasks. The reason for this is that the study team would like to receive comments from the stakeholders on the MELISA model as soon as possible.

The following points are highlighted:

- Installed lighting capacity (lumen)
  From 1990 to 2013 the total installed lighting capacity in EU-28 shows a continuously rising trend, from 5.6 Tlm in 1990 to 10.8 Tlm in 2013 [1].

  In 2013, 37% of the total lighting capacity is installed in the residential sector. This corresponds to an average of 20200 lm installed per household, of which 7000 lm supplied by CFLs and 6700 lm by halogen lamps.

  The lighting capacity trend shows a clear shift from incandescent lamps (GLS) to CFL and halogen lamps (HL). The share of lighting capacity provided by LED-lighting in 2013 is estimated around 1%.

- Installed lighting power (watt)
  The total installed lighting power in EU-28 increased from 266 GW in 1990 to 354 GW in 2007. After that year the trend is decreasing, reaching 304 GW in 2013.

  In 2013, 63% of the total lighting power is installed in the residential sector. This corresponds to an average of 966 Watt per household, of which 521 W for halogen (54%).

  In the non-residential sector 47% of the installed power is for LFLs.

- Operating hours
  From 1990 to 2013 the total lighting operating hours in EU-28 show a continuously rising trend, from 4.7 Th in 1990 to 9.3 Th in 2013 [1].

  In 2013, 34% of the total operating hours is made in the residential sector. This corresponds to an average of 16130 operating hours per household per year, of which 6800 h for CFL and 5700 h for halogen.

[1] Tlm = Tera lumen; Th = Tera hours. Tera = 10^{12}.

- Energy consumption

  The annual electrical energy consumption for lighting in EU-28 shows a continuously rising trend, from 276 TWh in 1990 to 397 TWh in 2007. In the period 2007 - 2011 the energy consumption is almost constant, around 400 TWh/year, while in the last two years it tends to decrease, reaching 382 TWh in 2013.

  In the residential sector the peak energy consumption for lighting was reached in 2007 (near 110 TWh) and since then the trend is continuously decreasing. In 2013 the estimated consumption is 93 TWh, which accounts for 24% of the total lighting energy. The residential values imply an average of 467 kWh per household per year in 2013, of which approximately 240 kWh for halogen lamps (51%) and still 120 kWh for incandescent lamps (GLS)(26%).

  The 2013 lighting energy consumption in the non-residential sector (indoor and outdoor) is estimated at 290 TWh (220 TWh when special purpose lamps, controls and standby are excluded). In the non-residential sector 58% of the energy is used for LFLs, 29% for HID.

- Energy cost

  In 2013 the EU-28 total lighting energy cost amounts to 43.7 billion euros. This is 0.33% of the EU-28 GDP in the same year.

  In 2013, approximately 40% of the expenses is made for the residential sector. This corresponds to an average expense for lighting energy of 89.3 euros per household per year.

  In 2013, 51% of the residential energy costs is for halogen lamps, and 58% of the non-residential energy costs is for LFL.

  Considering the period 2007-2013, the residential electricity prices increased by 14% from 0.167 to 0.191 euros/kWh, while the total EU-28 consumer expense for lighting energy decreased by 4% from 18.3 to 17.7 billion euros. In other words, if the lighting energy consumption had remained constant, the expense in 2013 would have been 20.9 billion euros, while it is 17.7 billion euros: a saving of approximately 15%.

  In the same period, for the non-residential sector, the 20% increase in electricity price from 0.099 to 0.119 euros/kWh, more or less corresponds with the 22% increase in total expense from 21.2 to 26.0 billion euros.

Data on lighting energy parameters (chapter 3)

Chapter 3 presents information from various sources on the basic parameters used for the estimate of energy consumption by lighting, such as operating hours, average power, luminous flux, and efficacy. The reported data form the basis for the data currently used in MELISA. The more recent data are also used to perform an auto-critical examination of the MELISA data.

The following points are highlighted:

- Operating hours per lamp per year

  In the residential sector MELISA uses 450 h/a for GLS and HL and 500 h/a for CFLi and LED, including a rebound effect. Comparable values in other sources range from 224 h/a to 576 h/a.

  In the non-residential sector MELISA uses 1600 h/a for CFLi, 2200 h/a for LFL, 4000 h/a for HID and from 984 to 1500 h/a for LED. Comparable values for indoor lighting of buildings in other sources range from 80 h/a to 3984 h/a, depending heavily on the type of building and on the type of room/zone.

- Average lamp powers
  Compared to IEA 4E 2014 data [2] the average lamp powers assumed in MELISA seem slightly high for incandescent lamps, and slightly low for CFLi and mains voltage halogen lamps.
  For LED lamps an elaboration of the IEA 4E 2014 data gives an average power of 5-6 W for retrofit lamps and 4-5 W for dedicated LED lamps. This is in line with the values used in MELISA for the year 2013.

- Number of lamps per household
  In 2013, the MELISA model gives an average of 33 lamps per household (was 21 in 1990). Comparable values from other sources range from 10 to 55 lamps per household.

- Power densities
  In 2013, the residential lighting energy consumption is 966 kWh/household/year in MELISA. This corresponds to approximately 11 W/m^2. Comparable values from other sources range from 6 to 24 W/m^2.

  According to MELISA the total EU-28 installed lighting power in the non-residential sector in 2013 is 112 GW. In a rough estimate, all HID-lamps (13 GW) are assumed to be used in outdoor lighting, leaving approximately 100 GW for the indoor lighting of buildings. The total EU-28 non-residential building area is estimated in 11517 Mm^2. This implies a lighting power density for non-residential buildings of 8.7 W/m^2. Note that this is the installed power, not average power consumption. Comparable values from other sources range from 5 to 19 W/m^2.

- Lumen densities
  The MELISA estimate for the lighting capacity density in the residential sector is 190 lm/m^2. For the non-residential indoor lighting this density is estimated around 500 lm/m^2. These values are at light source level, not at task level. The values seem reasonable but further work will be done in an attempt to verify them.

- Average efficacy
  Compared to IEA 4E 2014 data, the average lamp efficacy assumed in MELISA seems on the low side for incandescent lamps and halogen lamps.

- Specific energy consumption
  According to MELISA, in 2013 the total EU-28 consumption of electric energy for lighting in the residential sector is 93 TWh. In the same year there are 198.6 million households (Eurostat), which implies 467 kWh/year/household. This compares well to values from other sources. Dividing the total energy consumption by the total estimated residential building area of 21218 Mm^2, an average of 4.3 kWh/m^2/year is obtained. Comparable values from other sources range from 3.3 to 12 kWh/m^2/year.

  According to MELISA, the 2013 lighting energy consumption in the non-residential sector is estimated in 290 TWh. Excluding special purpose lamps, controls and standby, this reduces to 220 TWh. In a rough estimate, all HID-lamps (63 TWh) are assumed to be used in outdoor lighting, leaving approximately 160 TWh for the indoor lighting of non-residential buildings.
  The total EU-28 non-residential building area is estimated in 11517 Mm^2. This implies a lighting energy density (LENI) for non-residential buildings of approximately 13.4 kWh/m^2/year.

[2] "4E Mapping Document, European Union, Domestic Lighting". Available through: http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5

Comparable values from other sources range from 2 to 28 kWh/m^2/year, depending heavily on the type of building and on the type of room/zone.

Light sources in relation to space heating (chapter 4)

As reported in the EU building heat demand report [3], the total internal heat gain (due to lighting, appliances, and body heat) in 2010 is believed to contribute 2.3 °C to the target temperature of the household spaces to be heated. If, as projected, there is a 16% decrease in energy for lighting and appliances by 2020 (compared to 2010), this contribution will decrease to 1.9 °C. This is a 0.4 °C deficit that has to be filled in by space heaters.

The contribution of lighting products to these figures is less than 20%: this gives an indication for the order of magnitude of the heating effects related to lighting in households.

Health aspects (chapter 5)

There is little news with respect to what was already reported in the Stage 6 review study [4]. The report adds a summary of the 2014 IEA 4E report on the health aspects of Solid State Lighting (LEDs) [5] , that did not find serious negative health aspects of LED lighting, but made some recommendations regarding glare and photobiological safety.
In revision 1, documents from LightingEurope, Global Lighting Association and Ökopol have been added. These documents clarify the legal context for health aspects of light sources and how the high level requirements have already been implemented in the standards for the specific lighting products. For general lighting purposes there is no reason for concern, and most light sources can be declared low risk without further investigation. For specific applications further investigation may be required, in particular as regards the blue light hazard.

End-of-life aspects (chapter 6)

The Eurostat WEEE statistics on lighting products indicate that around 30% of the discharge lamps is being separately collected and of this collected weight 75-80% is recycled or reused. These percentages hardly changed from 2008 to 2012.

For all other lighting equipment, excluding discharge lamps, 4-5% is being collected and in 2012 around 75% of the collected weight was recycled or reused. The collection percentage hardly changed from 2008 to 2012.

The underlying data show a considerable number of gaps, so the figures should be used with caution.

Dimmer – Lamp compatibility (chapter 7)

A good dimming behaviour of LED retrofit lamps and integrated LED luminaires is important for the introduction of the LED lighting technology in the market, and for the realization of the energy savings

[3] "Average EU building heat load for HVAC equipment", final report, René Kemna (VHK) for the European Commission, August 2014, http://ec.europa.eu/energy/efficiency/studies/doc/2014_final_report_eu_building_heat_demand.pdf

[4] "Review study on the stage 6 requirements of Commission regulation (EC) No 244.2009 Final Report", VHK (pl) / VITO for the European Commission, Delft/Brussels 14.6.2013, SPECIFIC CONTRACT No ENER/C3/ 2012-418 LOT 2/01/SI2.645913 Implementing Framework Contract No ENER/C3/2012-418-Lot 2. http://www.eup-network.de/fileadmin/user_upload/Technical_Review_Study_by_VHK_VITO.pdf?PHPSESSID=a60a9114e01af59471374f5814656e0c

[5] IEA 4E Solid-State Lighting Annex, Potential Health Issues of Solid State Lighting, Final Report, 24 September 2014, http://ssl.iea-4e.org/task-1-quality-assurance/health-aspects-report

that are expected from daylight-dependent and occupancy-dependent dimming by lighting control systems.

In the current situation there are significant problems with the dimming of LEDs, in particular as regards the dimming of LEDi retrofit lamps on phase-cut dimmers already installed in the households. These problems include:

- Flicker (on/off of lamps, at a frequency that is perceived by the consumer).
- Shimmer (variations in light intensity, at a frequency that is perceived by the consumer).
- Stroboscopic effects (when objects are moving fast with respect to the light source).
- Dead travel (changes in dimmer position do not lead to perceived changes in light intensity).
- Pop-on (raising the dimmer from the off-position, the light suddenly pops on at an unexpected high intensity level).
- Drop-out (lowering the dimmer, the light suddenly shuts off while the consumer expected a further intensity decrease).
- Impossibility to reach low dimming levels (related to drop-out).
- Noise, buzzing (from the dimmer, the control gear or the lamp itself)
- Ghosting (the lamp continues to glow in the off-position)
- Reduced lifetime or abrupt failure of one of the system components (dimmer, control gear or LED-module).

The background and some possible reasons for these problems are explained in this report.

Standardization activities are ongoing, to resolve compatibility problems between phase-cut dimmers and LED lamps in the future, and to define minimum performance standards for dimming, thus implicitly defining what ‘dimmable’ exactly means. The implementation of these standards is expected for 2017/2018. Theoretically, after the introduction of this standard, any <u>new</u> dimmer would be compatible with any <u>new</u> LED lamp, without the need to test each combination. However, it will be impossible to make these new lamps backwards compatible with all old dimmers. Consequently there is a risk that consumers will have to substitute their old dimmers by new ones.

Reliable data are scarce, but it is estimated that in 2010 there were more than 120 million phase-cut dimmers installed in the EU-28, of which 60% leading-edge phase-cut dimmers and 40% trailing-edge or universal phase-cut dimmers. 75% of the dimmers was installed in households and 25% in the non-residential sector. The share of trailing-edge dimmers is increasing in recent years because this technology is deemed more suitable for LED lamps.

Consumer reaction to energy labelling of lamps (chapter 8)

The report provides an integration to existing European studies on this topic by presenting the findings of two recent studies in the USA. Among others, one of the studies found that:

- Consumers are willing to pay $2.63 more for CFL bulbs than for incandescent bulbs.
- For every 1000 h of lamp lifetime increase, consumers are willing to pay $0.52 more per lamp when annual cost information is NOT provided, and $0.66 more when such information IS given.
- For every 10 W decrease in lamp power, consumers are willing to pay $0.46 more per lamp when the annual cost information IS shown.

1. INTRODUCTION

This document covers MEErP Task 3, which focuses on the resources consumption and environmental impacts of light sources during the use phase. Light sources are mainly Energy-using Products (EuP), and consequently the major part of the report is dedicated to their electricity consumption. This document follows the same philosophy as the Task 2 report, i.e. the results from the MELISA model are discussed first and the data sources on which the model is based or to which it can be compared are presented next.

Light sources are also Energy-related Products (ErP), mainly because they produce a certain amount of heat that influences the heat balance of the space they are used in. Therefore the interaction between space heating and light sources is briefly addressed. In addition some non-energy-related environmental aspects are discussed (health aspects, light pollution).

As prescribed by the MEErP (see details in Annex B) this report further deals with the End-of-Life phase for light sources and with the local infrastructure. In this study, the latter topic mainly regards the interactions between the light sources and related lighting products such as luminaires (lock-in effect) and lighting controls (dimmers), taking into account that this will be more extensively covered by the parallel Lot 37 study on lighting systems.

Revision 0 of this document, as presented during the 1st stakeholder meeting of 5 February 2015, was preliminary, with paragraphs 7.4 and 7.5 still to be written. In revision 1 these gaps have been filled in, and the comments received from stakeholders on the original document have been incorporated. For convenience, the following table provides a survey of the paragraphs that have been changed in revision 1. Changes that are only editorial have not been included in this table.

paragraph	Description of change(s) in revision 1
2.1	Added IALD comment regarding diversification of MELISA for Member States
2.2	Clarified definition of luminous flux for directional lamps in MELISA
3.2.1	Added IALD comment regarding use of operating hours from EN-15193
3.2.3	Added IALD comment regarding the need for a new study on domestic lighting
3.3.2	Added IALD comment regarding lifetimes, in particular of fluorescent lamps.
3.4.5	Added DEA proposal to require maximum 0.3 W standby power for smart lamps
3.5.2	Adapted text and added reference to par. 2.2
5.1	Introduced paragraph subdivision
5.1.1	Added IALD comment regarding need for additional research on flicker and strobing
5.1.2	Added IALD comment regarding glare from SSL products
5.1.2	Added further explanation from EIA 4E on reasons for increase of light exposure.
5.1.3	Added summary of LightingEurope guide on photobiological safety
5.1.4	Added summary of Philips position paper regarding test methods for TLA (flicker)
5.1.4	Added IALD comment regarding flicker test methods and acceptable limits.
5.1.5	Added summary of Global Lighting Association white paper on optical and photobiological safety of light sources
5.1.6	Added summary of Ökopol report on health aspects of LEDs
7.1	Added UBA proposal for luminaire labelling to avoid overheating of LED lamps
7.2.1	Added reference from IALD comment regarding flicker being perceived up to 2 kHz
7.2.2	Added IALD comment on mixed mode control gear
7.2.3	Added IALD comment regarding 3-wire dimming solution from Lutron
7.2.9	Added CECAPI statement regarding use of smart lamps vs. traditional dimming
7.3	Added DEA opinion to keep PF>0.5 as criterion.
7.4	Completely new text
7.5	Completely new text

2. MODEL FOR EUROPEAN LIGHT SOURCES ANALYSIS

2.1. Introduction to MELISA

In the context of this preparatory study, the study team has developed and will continue to develop the 'Model for European Light Sources Analysis' (MELISA). This model has been introduced in the Task 2 report. Current data in MELISA are preliminary and may be updated as the study proceeds, also following comments on this draft report. At the end of the study, in MEErP Task 7, MELISA will be used for the scenario analyses.

MELISA data on sales, lamp life, operating hours, installed stock, lamp unit prices, consumer acquisition costs, and industry revenue have been presented in the Task 2 report.

The following MELISA-data, relevant for MEErP Task 3, are reported below for the period 1990-2013:

- Average power, efficacy and luminous flux per lamp technology type
- Operating hours [6]
- Total EU-28 installed lighting capacity (lumen)
- Total EU-28 installed lighting power (watt)
- Total EU-28 lighting use in operating hours
- Total EU-28 energy consumption for lighting
- Average EU-28 electricity costs
- Total EU-28 lighting energy costs for consumers (use)
- Total EU-28 consumer expense for lighting (acquisition + use)

In its comments on the Task 0-3 reports, IALD expressed the desire to express the broad range of climatic, social, geographical conditions and electricity generating mixes of all 28 EU states in the MELISA model [7].

2.2. Average light source powers, lumens and efficacy

Table 1 (non-LED) and Table 2 (LED) provide the basic data currently inserted in MELISA as regards average lamp power, average lamp efficacy and average luminous flux.

As regards the luminous flux for directional lamps, please note that MELISA does NOT use the definition from regulation 1194/2012 that prescribes measurement of the flux in a 90˚ or 120˚ cone. In principle, MELISA uses the total (omni-directional) flux also for directional lamps. As a consequence, the average flux and the average efficacy for directional and non-directional lamps of the same technology can be identical. The reason for this choice stems from the intended use of MELISA in the scenario analyses of Task 7. These analyses will mainly depend on the shift in sales from traditional lamp types to LEDs. During this shift, a governing principle is to maintain a lumen equivalence so that the total EU-28 lighting load (lumens) remains constant (except for a rebound effect, considerations on LLMF, general growth in number of lamps, etc.). During this shift it is anticipated that traditional NDLS lamps may be substituted by DLS LED lamps (for example LFL by LED tube). It would then be very confusing if lumen-definitions for DLS and NDLS lamps in the model would be different.

[6] Copy of the data presented in the Task 2 report, for ease of reference.

[7] IALD comment: "We would like to point out that with a single model it is challenging to cover the broad range of climatic, social, geographical conditions and electricity generating mixes of all 28 EU states. The MELISA model should be adapted and flexible enough to understand the variation across the EU 28; calculations based on this should be factored according to these variations. These differences impact lighting usage and therefore energy use."

For **non-LED lamps**, the values for power and efficacy have been derived from literature [8] and from the general experience of the study team in the lighting sector. Values for luminous flux (lm) have been computed as power (W) multiplied by efficacy (lm/W). For the period up to 2013 reported here, the power, efficacy and lumen values are constant throughout the years. This also implies that the same values are applied for new sold products and for the installed stock.

For **LED lighting** the model uses a more complex approach, to reflect the rapid year-to-year changes for these lamps. The governing principle is that the luminous flux of the LEDs should fit (match) that of the lamps they replace. This reference luminous flux (called 'Lumen to fit' in Table 2) is different for residential and non-residential use [9] and for directional (DLS) and non-directional (NDLS) lamps.

The average efficacy of newly sold LED lamps has been assumed to increase from 25 lm/W in 2009 to 80 lm/W in 2013 (top of Table 2, LED General). For a 500 lm light source this implies a power decrease from 20 W in 2009 to 6.25 W in 2013. As the efficacy of newly sold products changes with the years, the average efficacy of the installed stock in a given year is computed as the sales-weighted average over the preceding years. These values are reported in Table 2 as 'lm/W (average for stock)'.

Dividing the 'Lumen to fit' (lm) by the 'average efficacy for the stock' (lm/W), the corresponding power of the light source is obtained ('Watt to fit').

MELISA basic data	LFL					CFL		HL						GLS		HID		
	T12	T8 halophosphor	T8 tri-phosphor	T5 new (14 - 80w) including circular	All others (including T5 old types 4 - 13w and special FL)	Retrofit - CFLi	Non-retrofit - CFLni	Single ended, mirrored (low voltage) [M16, M25 etc.]	Linear (high voltage) [R7s]	LV halogen Capsule [G4, GY6.35]	HV Halogen capsule [G9]	Mains halogen (substitute for GLS and reflector)[E14, E27]	Other mains halogen - PAR 16/20/ 25/30 hard glass reflectors, GU10 etc.	Reflector	GLS (including clear/pearl, candles, coloured & decorative)	All mercury lamps (including mixed)	All sodium lamps	Metal halide lamps
Power (W)	35	32	30	25	12	9.5	12	35	250	35	35	36	35	54	54	250	140	160
Efficacy (lm/W)	70	75	80	91	86	55	55	14	12	14	12	12	12	9.5	9.5	40	95	82
Flux (lm)	2450	2400	2400	2275	1032	523	633	490	3000	490	420	432	420	513	513	10000	13300	13120

Table 1 Average non-LED light source power (W), efficacy (lm/W) and luminous flux (lm) currently used in the MELISA model, applied for all years.

[8] For many lamp types the values have been taken directly from "CLASP, Estimating potential additional energy savings from upcoming revisions to existing regulations under the ecodesign and energy labelling directives, feb. 2013, Appendix E and F" (http://www.eceee.org/all-news/press/2013/2013-02-19/eceee-clasp-report-estimating-potential). For additional information and other data sources see chapter 3.

[9] Due to the different mix of lamp types, for different types of tasks, substituted by the LEDs. In the residential sector mainly GLS, HL, CFL are substituted; in the non-residential sector mainly LFL and HID are replaced by LEDs.

	Year	2009	2010	2011	2012	2013
LED General	**lm/W (for sales in year)**	25	30	40	60	80
	Watt @ 500 Lm	20.00	16.67	12.50	8.33	6.25
LED-NDLS (incl. LFL replacement) **Residential Use**	**Lumen to Fit (NDLS)**	500	550	600	600	600
	lm/W (average for stock)	25	28	35	49	68
	Watt to Fit (avg. NDLS stock)	20.00	19.37	17.03	12.13	8.83
LED-NDLS (incl. LFL replacement) **Non-Residential Use**	**Lumen to Fit (NDLS)**	1800	1800	1800	1800	1800
	lm/W (average for stock)	25	30	40	49	76
	Watt to Fit (avg. NDLS stock)	72.00	60.00	45.00	36.38	23.58
LED- DLS Residential Use	**Lumen to Fit (DLS)**	600	600	600	600	600
	lm/W (average for stock)	25	28	35	47	63
	Watt to Fit (avg. DLS stock)	24.00	21.15	17.34	12.83	9.55
LED- DLS Non-Residential Use	**Lumen to Fit (DLS)**	600	600	600	600	600
	lm/W (average for stock)	25	30	40	53	74
	Watt to Fit (avg. DLS stock)	24.00	20.00	15.00	11.33	8.08

Table 2 Average LED light source power (W), efficacy (lm/W), and luminous flux (lm) currently used in the MELISA model, period 2009-2013.

2.3. Average operating hours per lamp per year

MELISA's operating hours for light sources have been presented in the Task 2 report. It is recalled that these hours are full-power-equivalent hours. This means that for example effects of dimming are included in the operating hours [10]. For convenience the hour-data currently used for non-LED light sources are shown again in Table 3.

As further explained in the Task 2 report, the following operating hours are used for LED-lighting:

- Residential use : 500 hours/year (includes rebound effect)
- Non-residential, NDLS: 1500 hours/year
- Non-residential, DLS: 984 hours/year in 2013.

MELISA basic data	**LFL**					**CFL**		**TUNGSTEN**						**GLS**		**HID**		
Operating Hours for Light Sources	T12	T8 Halo-phosphor	T8 tri-phosphor	T5 new (14 - 80w) including Circular	All others (including T5 old types 4 - 13w and Special Fl.)	Retrofit - CFLi	Non-Retrofit - CFLni	Single Ended, Mirrored (Low voltage) [M16,M25etc]	Linear (High voltage) [R7s]	LV halogen Capsule [G4, GY6.35]	HV halogen Capsule [G9]	Mains halogen (Substitute for GLS and Reflector)[E14, E27]	Other Mains halogen - PAR 16/20/25/30 Hard glass reflectors, GU10 etc.	Reflector	GLS (Including clear/pearl, candles, coloured & decorative)	All Mercury Lamps (including mixed)	All Sodium Lamps	Metal Halide Lamps
Operating hours / year Residential	700	700	700	700	700	500	700	450	450	450	450	450	450	450	450	*700*	*700*	*700*
Operating hours / year Non-Residential	2200	2200	2200	2200	2200	500	1600	450	450	450	450	450	450	450	450	4000	4000	4000

Table 3 Operating hours for non-LED light sources (residential and non-residential) as currently used in the MELISA model. See par. 2.6 of Task 2 report and par. 3.2 for further details.

[10] For example a lamp that is used at full power for 250 hours/year and dimmed at half power for 400 hours/year would have 250 + 400/2 = 450 operating hours/year in the sense of MELISA.

2.4. EU-28 total installed lighting capacity in lumen

The total installed lighting capacity (Tera lumen) in the EU-28 is computed by multiplying the installed number of light sources (stock, see Task 2 report) by the average luminous flux per unit (par. 2.2) [11]. This is initially done per lamp technology subtype. Subtype values are then summed for the residential and non-residential sector, that together form the EU-28 total.

The total installed lighting capacity can be conceived as the user-demand for light and is important during scenario analysis: in principle, different scenarios should lead to the same lighting capacity (demand for light does not change between scenarios) [12].

MELISA's total light capacity values for **All sectors** are reported in Figure 1, Figure 2, Table 4 and Table 5. The values for the **Residential sector** are reported in Table 6 and Figure 3; those for the **Non-residential sector** in Table 7 and Figure 4.

From 1990 to 2013 the total installed lighting capacity in EU-28 shows a continuously rising trend, from 5.6 Tlm in 1990 to 10.8 Tlm in 2013 [13].

In 2013, 37% of the total lighting capacity is installed in the residential sector (4.01/10.8 Tlm). The residential values imply an average of 20200 lm installed per household in 2013, of which 7000 lm supplied by CFL and 6700 lm by halogen, see Table 8.

Table 9 shows the subdivision of the EU-28 lighting capacity per lamp technology type for the years 2008 and 2013. This table clearly indicates the shift from incandescent (GLS) to CFL and halogen (HL). The share of light provided by LED lighting in 2013 is estimated around 1%.

[11] In principle, the computed total is intended to be for new light sources (no lumen degradation taken into account). The reduction of luminous flux by luminaires in not considered.

[12] The other part of the demand side are the operating hours, that express the part of the installed capacity which is actually being used, on which level (dimming), and for how long.

[13] Tlm = Tera lumen (10^{12} lumen). For comparison, the sun at zenith on a clear day gives around 98000 lm/m^2. Multiplying this by the entire estimated EU-28 (lighted) building area of 32735 Mm^2, 3208 Tlm are obtained. The installed artificial lighting capacity in 2013 of 10.8 Tlm is then around 0.33% of the light that the sun would give on the same area.

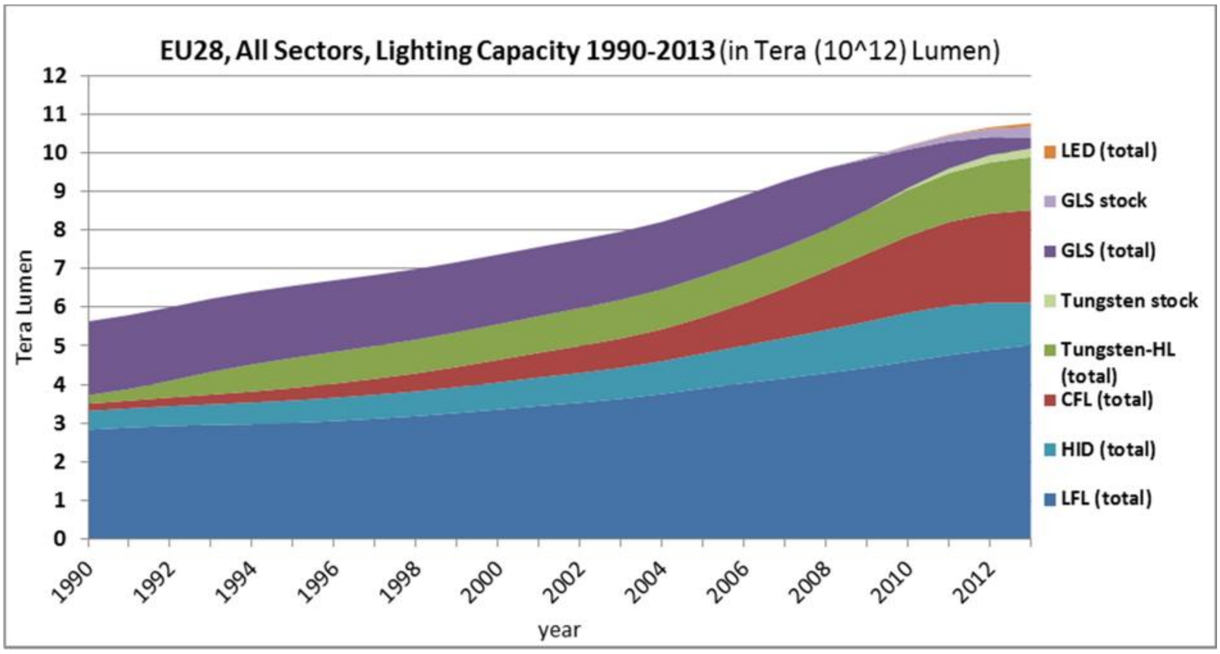


Figure 1: Installed lighting capacity, EU-28 cumulative total in Tera lumen (10^{12}). ALL SECTORS

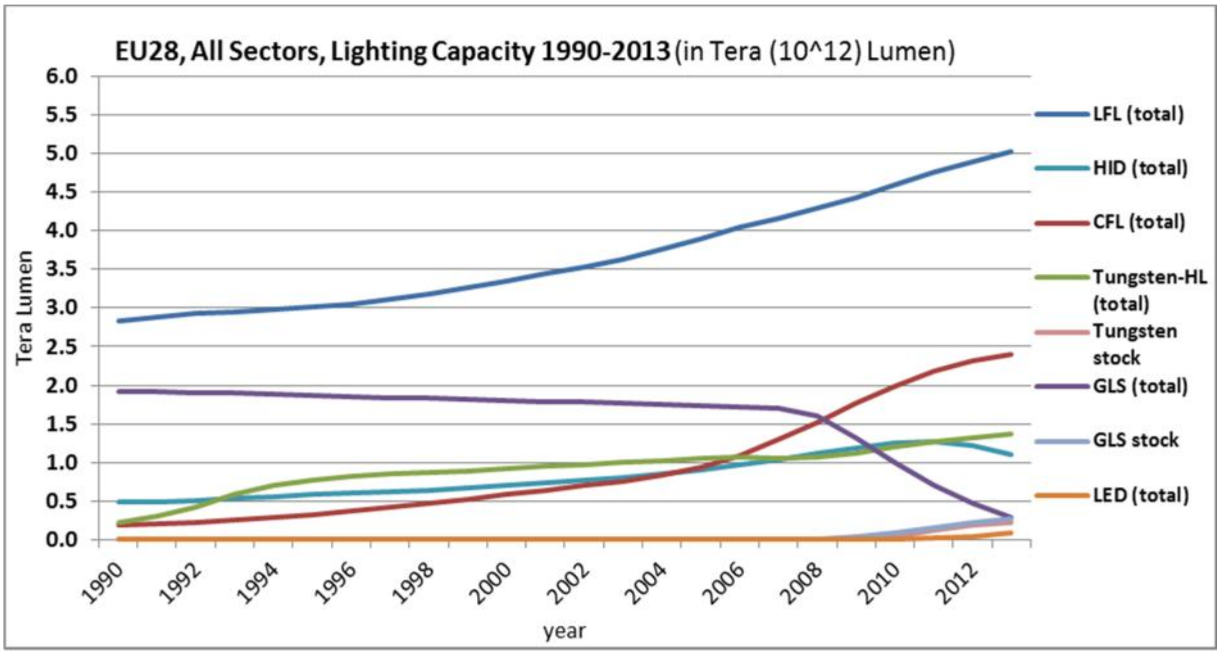


Figure 2: Installed lighting capacity, EU-28 totals per lamp type in Tera lumen (10^{12}). ALL SECTORS

EU-28 LUMEN SUMMARY, All Sectors Tera (10^12) Lumen	Average lm/unit	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL (total)	2256	2.8	3.0	3.4	3.9	4.0	4.2	4.3	4.4	4.6	4.8	4.9	5.0
CFL (total)	543	0.2	0.3	0.6	0.9	1.1	1.3	1.5	1.8	2.0	2.2	2.3	2.4
Tungsten-HL (total)	745	0.2	0.8	0.9	1.1	1.1	1.1	1.1	1.1	1.2	1.3	1.3	1.4
GLS (total)	513	1.9	1.9	1.8	1.7	1.7	1.7	1.6	1.3	1.0	0.7	0.5	0.3
HID (total)	12580	0.5	0.6	0.7	0.9	1.0	1.0	1.1	1.2	1.3	1.3	1.2	1.1
LED (total)	797	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
GLS stock	*513*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*	*0.2*	*0.2*	*0.3*
Tungsten stock	*504*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*	*0.2*	*0.2*
TOTAL	**1021**	**5.6**	**6.6**	**7.4**	**8.5**	**8.9**	**9.3**	**9.6**	**9.9**	**10.2**	**10.5**	**10.7**	**10.8**

Table 4: Installed lighting capacity, EU-28 totals per main lamp type in Tera lumen (10^{12}), years 1990, 1995, 2000, 2005 – 2013. ALL SECTORS

	EU-28 LUMEN TOTAL, All Sectors Tera (10^12) Lumen	Average lm/unit	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL	T12	2450	0.79	0.59	0.37	0.21	0.19	0.16	0.14	0.12	0.10	0.08	0.07	0.05
	T8 halophosphor	2400	0.89	1.08	1.39	1.68	1.68	1.64	1.57	1.43	1.21	0.91	0.60	0.37
	T8 tri-phosphor	2400	1.04	1.20	1.42	1.67	1.76	1.85	1.98	2.15	2.41	2.73	3.05	3.30
	T5 new (14 - 80w) including circular	2275	0.00	0.00	0.00	0.12	0.19	0.28	0.39	0.52	0.67	0.84	1.00	1.14
	All others (including T5 old types 4 - 13w and Special FL)	1032	0.12	0.14	0.18	0.22	0.22	0.22	0.22	0.22	0.21	0.20	0.18	0.17
	LFL (total)		**2.83**	**3.01**	**3.35**	**3.90**	**4.04**	**4.16**	**4.30**	**4.43**	**4.60**	**4.76**	**4.90**	**5.02**
CFL	Retrofit - CFLi	523	0.10	0.20	0.40	0.69	0.82	1.01	1.21	1.43	1.62	1.79	1.92	2.00
	Non-retrofit - CFLni	633	0.08	0.13	0.18	0.25	0.27	0.29	0.31	0.34	0.36	0.38	0.39	0.40
	CFL (total)		**0.18**	**0.32**	**0.58**	**0.94**	**1.09**	**1.30**	**1.52**	**1.76**	**1.99**	**2.18**	**2.31**	**2.40**
TUNGSTEN (HL)	Single ended, mirrored (low voltage) [M16, M25 etc.]	490	0.03	0.09	0.17	0.26	0.27	0.28	0.30	0.31	0.31	0.32	0.33	0.33
	Linear (high voltage) [R7s]	3000	0.09	0.57	0.60	0.60	0.57	0.50	0.42	0.35	0.31	0.29	0.27	0.26
	LV halogen capsule [G4, GY6.35]	490	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.10
	HV halogen capsule [G9]	420	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.08	0.09	0.10	0.10	0.10
	Mains halogen (substitute for GLS and Reflector)[E14, E27]	432	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.11	0.17	0.23	0.28	0.35
	Other mains halogen - PAR 16/20/ 25/ 30 Hard glass reflectors, GU10 etc.	420	0.00	0.00	0.03	0.08	0.10	0.11	0.14	0.17	0.19	0.22	0.23	0.23
	Tungsten-HL (total)		**0.22**	**0.78**	**0.92**	**1.06**	**1.07**	**1.06**	**1.07**	**1.12**	**1.20**	**1.27**	**1.32**	**1.38**
GLS	Reflector	513	0.20	0.19	0.18	0.17	0.16	0.16	0.14	0.12	0.10	0.08	0.07	0.05
	GLS (including clear/pearl, candles, coloured & decorative)	513	1.72	1.68	1.63	1.57	1.56	1.55	1.45	1.21	0.90	0.63	0.40	0.23
	GLS (total)		**1.91**	**1.87**	**1.81**	**1.74**	**1.73**	**1.71**	**1.60**	**1.33**	**1.00**	**0.70**	**0.47**	**0.29**
HID	All mercury lamps (including mixed)	10000	0.15	0.18	0.18	0.15	0.14	0.13	0.12	0.11	0.10	0.09	0.08	0.06
	All sodium lamps	13300	0.29	0.32	0.36	0.45	0.49	0.53	0.57	0.61	0.62	0.60	0.58	0.56
	Metal halide lamps	13120	0.04	0.09	0.17	0.30	0.34	0.38	0.42	0.47	0.54	0.58	0.56	0.48
	HID (total)		**0.49**	**0.58**	**0.70**	**0.90**	**0.97**	**1.04**	**1.12**	**1.19**	**1.26**	**1.28**	**1.22**	**1.10**
LED	Directional	618	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.05
	Non-directional	969	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05
	LED (total)		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	**0.02**	**0.04**	**0.10**
	GLS stock	513	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.10	0.15	0.22	0.27
	Tungsten stock	504	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.12	0.19	0.22
	TOTAL		**5.63**	**6.56**	**7.37**	**8.54**	**8.90**	**9.27**	**9.60**	**9.88**	**10.2**	**10.5**	**10.7**	**10.8**

Table 5: Installed lighting capacity, EU-28 totals per lamp subtype in Tera lumen (10^{12}), years 1990, 1995, 2000, 2005 – 2013. ALL SECTORS

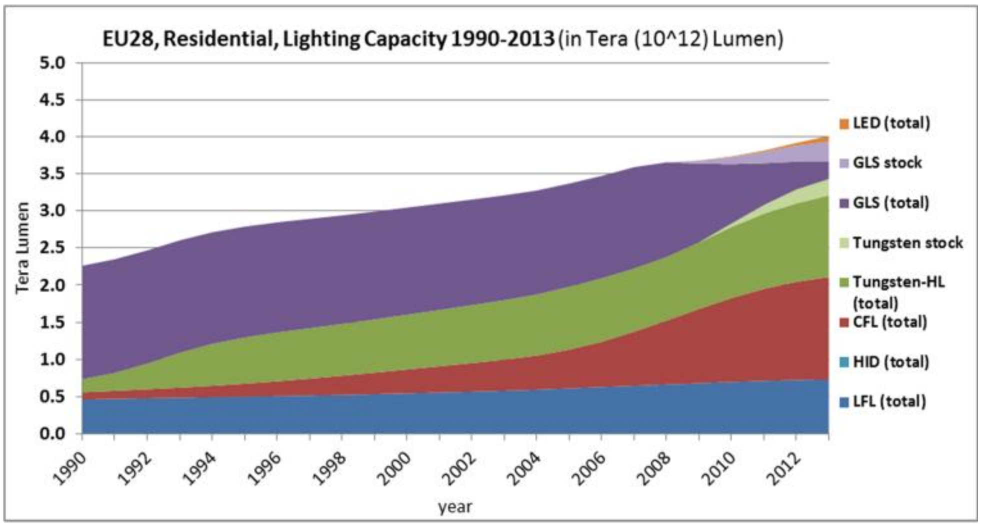


Figure 3: Installed lighting capacity, EU-28 cumulative total in Tera lumen (10^{12}). RESIDENTIAL

EU-28 LUMEN RESIDENTIAL Tera (10^12) Lumen		Average lm/unit	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL	T12	2450	0.14	0.13	0.09	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.02	0.02
	T8 halophosphor	2400	0.14	0.17	0.21	0.26	0.27	0.28	0.28	0.27	0.26	0.24	0.22	0.20
	T8 tri-phosphor	2400	0.16	0.18	0.21	0.25	0.26	0.27	0.29	0.30	0.32	0.35	0.38	0.40
	T5 new (14 - 80w) including circular	2275	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.03	0.04	0.05	0.07	0.08
	All others (including T5 old types 4 - 13w and Special FL)	1032	0.02	0.02	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04
	LFL (total)		**0.46**	**0.50**	**0.54**	**0.61**	**0.63**	**0.64**	**0.66**	**0.68**	**0.70**	**0.71**	**0.72**	**0.73**
CFL	Retrofit - CFLi	523	0.06	0.12	0.24	0.41	0.49	0.60	0.73	0.86	0.97	1.08	1.15	1.20
	Non-retrofit - CFLni	633	0.03	0.05	0.08	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.17	0.18
	CFL (total)		**0.09**	**0.17**	**0.32**	**0.52**	**0.61**	**0.73**	**0.86**	**1.00**	**1.13**	**1.24**	**1.32**	**1.38**
TUNGSTEN (HL)	Single ended, mirrored (low voltage) [M16, M25 etc.]	490	0.02	0.07	0.14	0.21	0.22	0.23	0.24	0.25	0.25	0.26	0.26	0.27
	Linear (high voltage) [R7s]	3000	0.07	0.46	0.48	0.48	0.46	0.40	0.33	0.28	0.25	0.23	0.22	0.21
	LV halogen capsule [G4, GY6.35]	490	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.08
	HV halogen capsule [G9]	420	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.06	0.07	0.08	0.08	0.08
	Mains halogen (substitute for GLS and Reflector)[E14, E27]	432	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.09	0.14	0.19	0.23	0.28
	Other mains halogen - PAR 16/20/ 25/ 30 Hard glass reflectors, GU10 etc.	420	0.00	0.00	0.03	0.07	0.08	0.09	0.11	0.13	0.16	0.17	0.19	0.19
	Tungsten-HL (total)		**0.18**	**0.62**	**0.74**	**0.85**	**0.85**	**0.85**	**0.85**	**0.90**	**0.96**	**1.01**	**1.06**	**1.10**
GLS	Reflector	513	0.16	0.15	0.14	0.13	0.13	0.13	0.11	0.10	0.08	0.06	0.05	0.04
	GLS (including clear/pearl, candles, coloured & decorative)	513	1.37	1.34	1.30	1.26	1.25	1.24	1.16	0.96	0.72	0.50	0.32	0.19
	GLS (total)		**1.53**	**1.49**	**1.44**	**1.39**	**1.38**	**1.37**	**1.28**	**1.06**	**0.80**	**0.56**	**0.38**	**0.23**
HID	All mercury lamps (including mixed)	10000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	All sodium lamps	13300	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Metal halide lamps	13120	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	HID (total)		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
LED	Directional									0.00	0.01	0.01	0.02	0.04
	Non-directional									0.00	0.00	0.01	0.01	0.03
	LED (total)		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	**0.02**	**0.04**	**0.08**
	GLS stock	513	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.10	0.15	0.22	0.27
	Tungsten stock	504	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.12	0.19	0.22
	TOTAL		**2.26**	**2.79**	**3.05**	**3.37**	**3.47**	**3.59**	**3.66**	**3.68**	**3.74**	**3.81**	**3.92**	**4.01**

Table 6: Installed lighting capacity, EU-28 totals per lamp subtype in Tera lumen (10^{12}), years 1990, 1995, 2000, 2005 – 2013. RESIDENTIAL

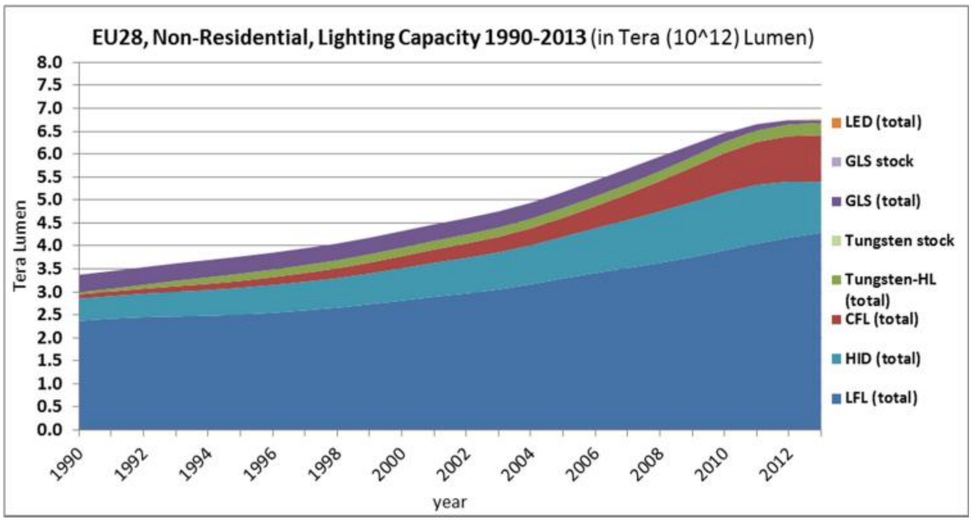


Figure 4: Installed lighting capacity, EU-28 cumulative total in Tera lumen (10^{12}). NON-RESIDENTIAL

EU-28 LUMEN NON-RESIDENTIAL Tera (10^12) Lumens		Average lm/unit	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL	T12	2450	0.64	0.46	0.28	0.15	0.14	0.12	0.10	0.09	0.07	0.06	0.04	0.03
	T8 halophosphor	2400	0.75	0.91	1.18	1.41	1.41	1.37	1.29	1.16	0.95	0.67	0.38	0.17
	T8 tri-phosphor	2400	0.88	1.02	1.20	1.42	1.49	1.58	1.69	1.85	2.08	2.38	2.67	2.90
	T5 new (14 - 80w) including circular	2275	0.00	0.00	0.00	0.11	0.18	0.26	0.36	0.48	0.63	0.78	0.94	1.06
	All others (including T5 old types 4 - 13w and Special FL)	1032	0.10	0.12	0.16	0.19	0.19	0.19	0.19	0.18	0.17	0.16	0.15	0.13
	LFL (total)		**2.37**	**2.51**	**2.81**	**3.29**	**3.41**	**3.52**	**3.63**	**3.76**	**3.90**	**4.05**	**4.18**	**4.29**
CFL	Retrofit - CFLi	523	0.04	0.08	0.16	0.28	0.33	0.40	0.48	0.57	0.65	0.72	0.77	0.80
	Non-retrofit - CFLni	633	0.05	0.07	0.10	0.14	0.15	0.16	0.18	0.19	0.21	0.22	0.22	0.22
	CFL (total)		**0.09**	**0.15**	**0.26**	**0.42**	**0.48**	**0.57**	**0.66**	**0.76**	**0.86**	**0.93**	**0.99**	**1.02**
TUNGSTEN (HL)	Single ended, mirrored (low voltage) [M16, M25 etc.]	490	0.01	0.02	0.03	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.07	0.07
	Linear (high voltage) [R7s]	3000	0.02	0.11	0.12	0.12	0.11	0.10	0.08	0.07	0.06	0.06	0.05	0.05
	LV halogen capsule [G4, GY6.35]	490	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	HV halogen capsule [G9]	420	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.02	0.02
	Mains halogen (substitute for GLS and Reflector)[E14, E27]	432	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.05	0.06	0.07
	Other mains halogen - PAR 16/20/ 25/ 30 Hard glass reflectors, GU10 etc.	420	0.00	0.00	0.01	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.05
	Tungsten-HL (total)		**0.04**	**0.16**	**0.18**	**0.21**	**0.21**	**0.21**	**0.21**	**0.22**	**0.24**	**0.25**	**0.26**	**0.28**
GLS	Reflector	513	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01
	GLS (including clear/pearl, candles, coloured & decorative)	513	0.35	0.34	0.33	0.31	0.31	0.31	0.29	0.24	0.18	0.13	0.08	0.05
	GLS (total)		**0.38**	**0.37**	**0.36**	**0.35**	**0.35**	**0.34**	**0.32**	**0.27**	**0.20**	**0.14**	**0.09**	**0.06**
HID	All mercury lamps (including mixed)	10000	0.15	0.18	0.18	0.15	0.14	0.13	0.12	0.11	0.10	0.09	0.08	0.06
	All sodium lamps	13300	0.29	0.32	0.36	0.45	0.49	0.53	0.57	0.61	0.62	0.60	0.58	0.56
	Metal halide lamps	13120	0.04	0.09	0.17	0.30	0.34	0.38	0.42	0.47	0.54	0.58	0.56	0.48
	HID (total)		**0.49**	**0.58**	**0.70**	**0.90**	**0.97**	**1.04**	**1.12**	**1.19**	**1.26**	**1.28**	**1.22**	**1.10**
LED	Directional									0.00	0.00	0.00	0.00	0.01
	Non-directional									0.00	0.00	0.00	0.00	0.01
	LED (total)		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.02**
	GLS stock	513	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Tungsten stock	504	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL		**3.37**	**3.77**	**4.32**	**5.17**	**5.42**	**5.68**	**5.94**	**6.20**	**6.46**	**6.66**	**6.75**	**6.76**

Table 7: Installed lighting capacity, EU-28 totals per lamp subtype in Tera lumen (10^{12}), years 1990, 1995, 2000, 2005 – 2013. NON-RESIDENTIAL

Lumen per household (lm/hh)	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
Number of households (mln)	**171.6**	**181.5**	**188.9**	**192.6**	**193.3**	**194.1**	**194.8**	**195.6**	**196.3**	**197.1**	**197.8**	**198.6**
LFL lumen per hh	2702	2766	2879	3163	3242	3320	3398	3470	3541	3604	3651	3676
CFL lumen per hh	544	943	1694	2713	3163	3765	4423	5123	5763	6303	6691	6944
Tungsten lumen per hh	1024	3424	3902	4393	4416	4369	4385	4583	5117	5729	6291	6660
GLS lumen per hh	8911	8233	7645	7227	7141	7047	6560	5630	4568	3632	2992	2535
LED lumen per hh	0	0	0	0	0	0	0	17	42	90	180	384
TOTAL lumen/hh	**13181**	**15366**	**16120**	**17497**	**17962**	**18500**	**18765**	**18823**	**19031**	**19358**	**19805**	**20198**
of which DLS lumen	1060	1230	1632	2099	2194	2292	2373	2444	2502	2567	2646	2718

Table 8: Installed lighting capacity per household, years 1990, 1995, 2000, 2005 – 2013 (in lumen/household).

	year 2008			year 2013		
Division of EU-28 lighting capacity over the technology types, year 2008 & 2013	All Sectors	Residential	Non-Residential	All Sectors	Residential	Non-Residential
LFL (total)	45%	18%	61%	47%	18%	63%
CFL (total)	16%	24%	11%	22%	34%	15%
Tungsten-HL (total)	11%	23%	4%	15%	33%	4%
GLS (total)	17%	35%	5%	5%	13%	1%
HID (total)	12%	0%	19%	10%	0%	16%
LED (total)	0%	0%	0%	1%	2%	0%
TOTAL	100%	100%	100%	100%	100%	100%

Table 9: Years 2008 and 2013, subdivision of EU-28 lighting capacity (lumen) over the main technology types.

2.5. EU-28 total installed lighting power

The total installed power for lighting in the EU-28 is computed by multiplying the installed number of light sources (stock, see Task 2 report) by the average powers per unit (par. 2.2). This is initially done per lamp technology subtype. Subtype values are then summed for the residential and non-residential sector, that together form the EU-28 total.

The total installed power is important for comparison with reference values from literature, such as the installed power per household or the installed power density in W/m^2 for non-residential buildings.

MELISA's total installed power for **All sectors** is reported in Figure 9, Figure **10**, Table 16 and Table 17. The values for the **Residential sector** are reported in Table 18 and Figure 11; those for the **Non-residential sector** in Table 19 and Figure 12.

The total installed lighting power in EU-28 increased from 266 GW in 1990 to 354 GW in 2007. After that year the trend is decreasing, reaching 304 GW in 2013.

In 2013, 63% of the total lighting power is installed in the residential sector (192/304 GW). The residential values imply an average of 966 Watt per household in 2013, of which 521 W for halogen, see Table 20.

Table 21 shows the subdivision of the EU-28 lighting power over the lamp technology types for the years 2008 and 2013. This table clearly indicates the shift from incandescent to halogen lamps in the residential sector, halogens accounting for 54% of the installed power in 2013. In the non-residential sector, 47% of the installed power is for LFL.

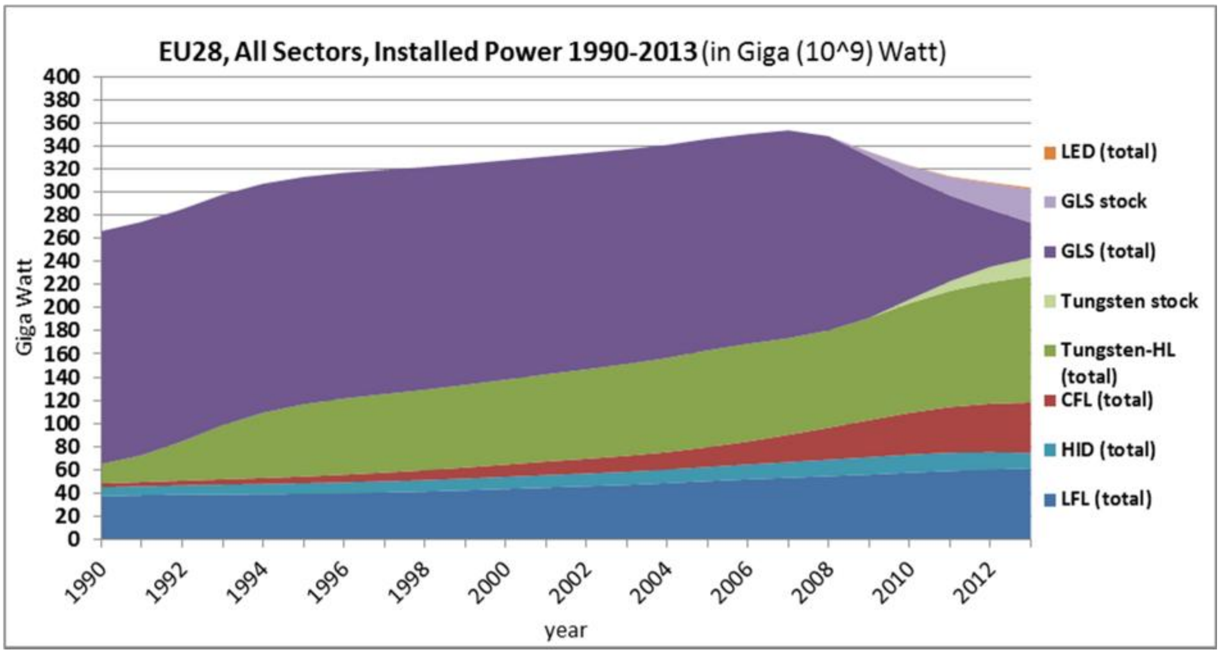


Figure 5: Installed power, EU-28 cumulative total in Giga Watt (10^9). ALL SECTORS

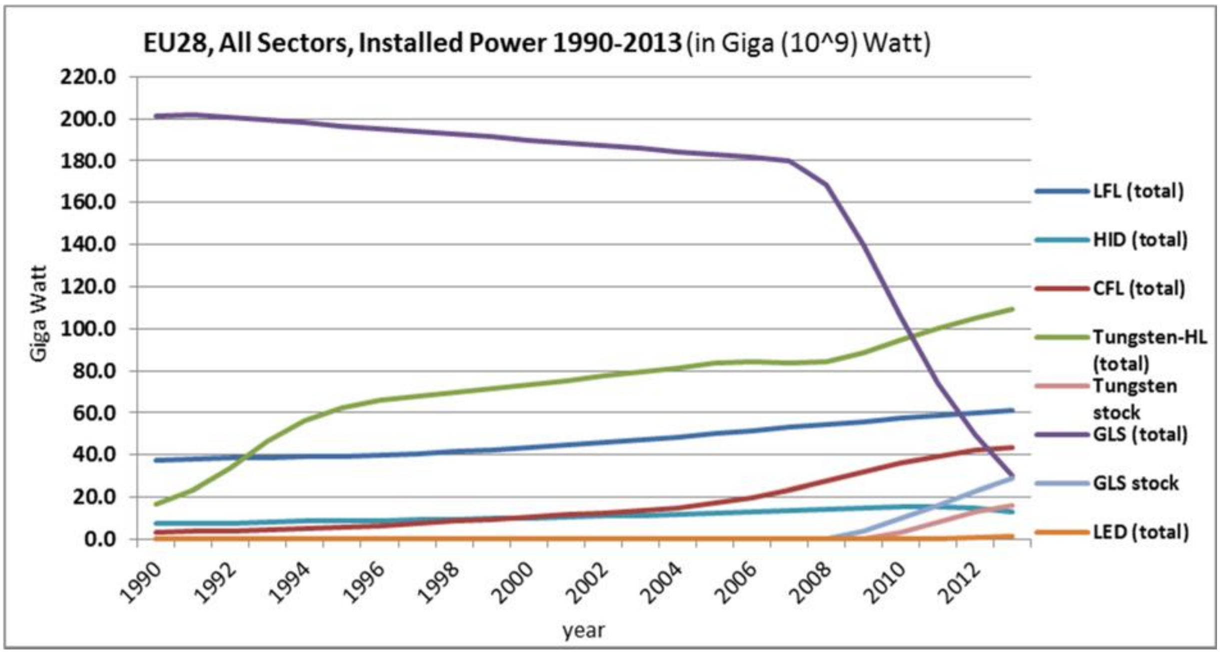


Figure 6: Installed power, EU-28 totals per lamp type in Giga Watt (10^9). ALL SECTORS

EU-28 INSTALLED POWER SUMMARY, All Sectors Giga (10^9) Watt	Average W/unit	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL (total)	29	37	39	44	50	52	53	54	56	57	59	60	61
CFL (total)	9.9	3	6	11	17	20	24	28	32	36	40	42	44
Tungsten-HL (total)	59	17	62	73	84	84	84	84	88	95	100	105	109
GLS (total)	54	201	197	190	183	182	180	168	140	105	74	49	30
HID (total)	168	7	9	10	12	13	14	14	15	16	16	15	13
LED (total)	7.8	0	0	0	0	0	0	0.0	0.1	0.3	0.5	0.8	1.4
GLS stock	54	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*4*	*10*	*16*	*23*	*29*
Tungsten stock	36	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*3*	*8*	*13*	*16*
TOTAL	**38.8**	**266**	**313**	**328**	**346**	**350**	**354**	**349**	**335**	**323**	**314**	**308**	**304**

Table 10: Installed power, EU-28 totals per main lamp type in Giga Watt (10^9), years 1990, 1995, 2000, 2005 – 2013. ALL SECTORS

EU-28 INSTALLED POWER TOTAL, All Sectors Giga (10^9) Watt		Average W/unit	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL	T12	35	11	8	5	3	3	2	2	2	1	1	1	1
LFL	T8 halophosphor	32	12	14	19	22	22	22	21	19	16	12	8	5
LFL	T8 tri-phosphor	30	13	15	18	21	22	23	25	27	30	34	38	41
LFL	T5 new (14 - 80w) including circular	25	0	0	0	1	2	3	4	6	7	9	11	13
LFL	All others (including T5 old types 4 - 13w and Special FL)	12	1	2	2	3	3	3	3	3	2	2	2	2
LFL	**LFL (total)**	**29**	**37**	**39**	**44**	**50**	**52**	**53**	**54**	**56**	**57**	**59**	**60**	**61**
CFL	Retrofit - CFLi	10	2	4	7	13	15	18	22	26	30	33	35	36
CFL	Non-retrofit - CFLni	12	1	2	3	5	5	5	6	6	7	7	7	7
CFL	**CFL (total)**	**10**	**3**	**6**	**11**	**17**	**20**	**24**	**28**	**32**	**36**	**40**	**42**	**44**
TUNGSTEN (HL)	Single ended, mirrored (low voltage) [M16, M25 etc.]	35	2	6	12	18	19	20	21	22	22	23	23	24
TUNGSTEN (HL)	Linear (high voltage) [R7s]	250	7	48	50	50	48	42	35	29	26	24	23	22
TUNGSTEN (HL)	LV halogen capsule [G4, GY6.35]	35	7	8	8	8	8	8	8	8	8	8	8	7
TUNGSTEN (HL)	HV halogen capsule [G9]	35	0	0	0	0	1	3	5	6	8	8	8	8
TUNGSTEN (HL)	Mains halogen (substitute for GLS and Reflector)[E14, E27]	36	0	0	0	0	0	1	4	9	15	19	24	29
TUNGSTEN (HL)	Other mains halogen - PAR 16/20/ 25/ 30 Hard glass reflectors, GU10 etc.	35	0	0	3	7	8	10	11	14	16	18	19	20
TUNGSTEN (HL)	**Tungsten-HL (total)**	**59**	**17**	**62**	**73**	**84**	**84**	**84**	**84**	**88**	**95**	**100**	**105**	**109**
GLS	Reflector	54	21	20	19	17	17	17	15	13	10	8	7	6
GLS	GLS (including clear/pearl, candles, coloured & decorative)	54	181	177	171	166	165	163	153	127	95	66	42	25
GLS	**GLS (total)**	**54**	**201**	**197**	**190**	**183**	**182**	**180**	**168**	**140**	**105**	**74**	**49**	**30**
HID	All mercury lamps (including mixed)	250	4	4	4	4	4	3	3	3	3	2	2	1
HID	All sodium lamps	140	3	3	4	5	5	6	6	6	7	6	6	6
HID	Metal halide lamps	160	1	1	2	4	4	5	5	6	7	7	7	6
HID	**HID (total)**	**168**	**7**	**9**	**10**	**12**	**13**	**14**	**14**	**15**	**16**	**16**	**15**	**13**
LED	Directional	7	0	0	0	0	0	0.0	0.0	0.1	0.2	0.4	0.5	0.7
LED	Non-directional	9	0	0	0	0	0	0.0	0.0	0.0	0.1	0.2	0.3	0.7
LED	**LED (total)**	**8**	**0**	**0**	**0**	**0**	**0**	**0.0**	**0.0**	**0.1**	**0.3**	**0.5**	**0.8**	**1.4**
	GLS stock	54	0	0	0	0	0	0	0	4	10	16	23	29
	Tungsten stock	36	0	0	0	0	0	0	0	0	3	8	13	16
	TOTAL	**39**	**266**	**313**	**328**	**346**	**350**	**354**	**349**	**335**	**323**	**314**	**308**	**304**

Table 11: Installed power, EU-28 totals per lamp subtype in Giga Watt (10^9), years 1990, 1995, 2000, 2005 – 2013. ALL SECTORS

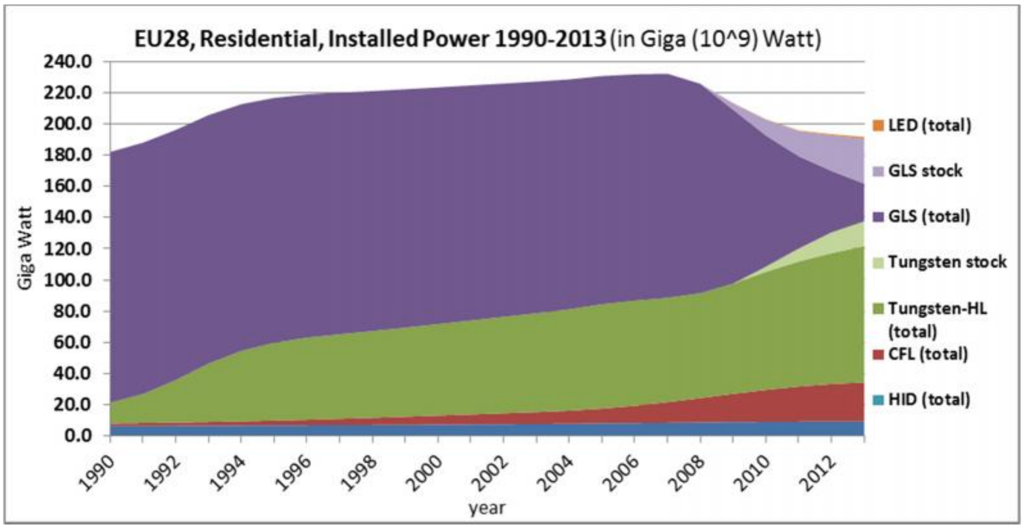


Figure 7: Installed power, EU-28 cumulative total in Giga Watt (10^9). RESIDENTIAL

EU-28 INSTALLED POWER RESIDENTIAL Giga (10^9) Watt		Average W/unit	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL	T12	35	2.1	1.8	1.3	0.8	0.7	0.6	0.6	0.5	0.4	0.4	0.3	0.3
	T8 halophosphor	32	1.9	2.3	2.8	3.5	3.6	3.7	3.7	3.6	3.5	3.2	2.9	2.6
	T8 tri-phosphor	30	2.0	2.3	2.7	3.1	3.3	3.4	3.6	3.8	4.0	4.4	4.7	5.0
	T5 new (14 - 80w) including circular	25	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
	All others (including T5 old types 4 - 13w and Special FL)	12	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	LFL (total)	**29**	**6**	**7**	**7**	**8**	**8**	**8**	**9**	**9**	**9**	**9**	**9**	**9**
CFL	Retrofit - CFLi	10	1	2	4	8	9	11	13	16	18	20	21	22
	Non-retrofit - CFLni	12	1	1	1	2	2	2	2	3	3	3	3	3
	CFL (total)	**10**	**2**	**3**	**6**	**10**	**11**	**13**	**16**	**18**	**21**	**23**	**24**	**25**
TUNGSTEN (HL)	Single ended, mirrored (low voltage) [M16, M25 etc.]	35	2	5	10	15	16	16	17	18	18	18	19	19
	Linear (high voltage) [R7s]	250	6	38	40	40	38	33	28	23	21	19	18	17
	LV halogen capsule [G4, GY6.35]	35	6	7	7	7	7	7	7	7	7	6	6	6
	HV halogen capsule [G9]	35	0	0	0	0	1	2	4	5	6	6	7	6
	Mains halogen (substitute for GLS and Reflector)[E14, E27]	36	0	0	0	0	0	1	3	7	12	15	19	23
	Other mains halogen - PAR 16/20/ 25/ 30 Hard glass reflectors, GU10 etc.	35	0	0	2	6	6	8	9	11	13	15	16	16
	Tungsten-HL (total)	**59**	**13**	**50**	**59**	**67**	**67**	**67**	**67**	**71**	**76**	**80**	**84**	**88**
GLS	Reflector	54	17	16	15	14	14	13	12	10	8	7	6	4
	GLS (including clear/pearl, candles, coloured & decorative)	54	144	141	137	133	132	131	122	102	76	53	34	20
	GLS (total)	**54**	**161**	**157**	**152**	**147**	**145**	**144**	**135**	**112**	**84**	**59**	**40**	**24**
HID	All mercury lamps (including mixed)		0	0	0	0	0	0	0	0	0	0	0	0
	All sodium lamps		0	0	0	0	0	0	0	0	0	0	0	0
	Metal halide lamps		0	0	0	0	0	0	0	0	0	0	0	0
	HID (total)		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
LED	Directional	7								0.1	0.2	0.3	0.5	0.7
	Non-directional	6								0.0	0.1	0.2	0.3	0.5
	LED (total)	**6**	**0**	**0**	**0**	**0**	**0**	**0.0**	**0.0**	**0.1**	**0.3**	**0.5**	**0.7**	**1.2**
	GLS stock	54	0	0	0	0	0	0	0	4	10	16	23	29
	Tungsten stock	36	0	0	0	0	0	0	0	0	3	8	13	16
	TOTAL	**42**	**182**	**217**	**224**	**231**	**232**	**232**	**226**	**214**	**203**	**196**	**194**	**192**

Table 12: Installed power, EU-28 totals per lamp subtype in Giga Watt (10^9), years 1990, 1995, 2000, 2005 – 2013. RESIDENTIAL

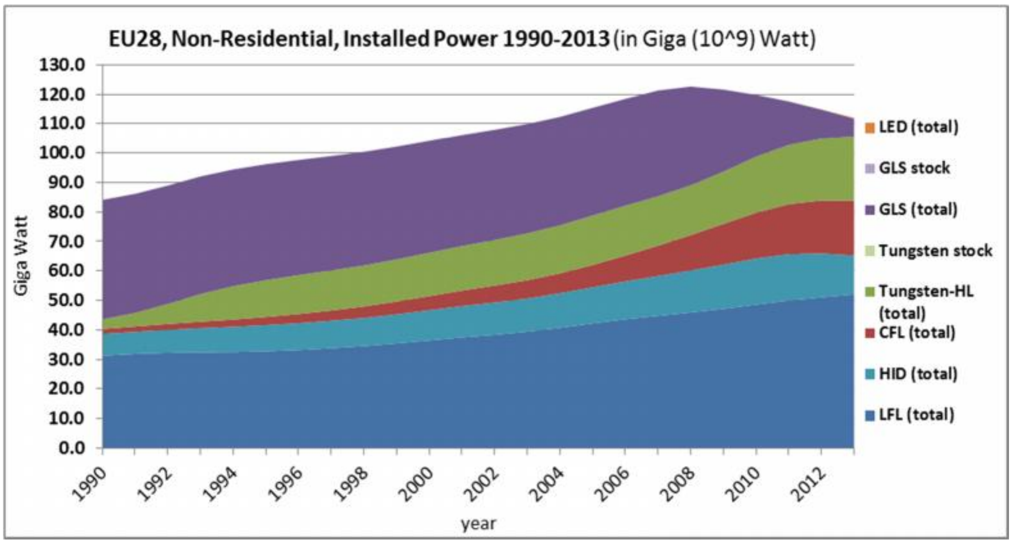


Figure 8: Operating hours, EU-28 cumulative total in Giga Watt (10^9). NON-RESIDENTIAL

	EU-28 INSTALLED POWER NON-RESIDENTIAL Giga (10^9) Watt	Average W/unit	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL	T12	35	9	7	4	2	2	2	1	1	1	1	1	0
	T8 halophosphor	32	10	12	16	19	19	18	17	15	13	9	5	2
	T8 tri-phosphor	30	11	13	15	18	19	20	21	23	26	30	33	36
	T5 new (14 - 80w) including circular	25	0	0	0	1	2	3	4	5	7	9	10	12
	All others (including T5 old types 4 - 13w and Special FL)	12	1	1	2	2	2	2	2	2	2	2	2	2
	LFL (total)	**29**	**31**	**33**	**36**	**42**	**44**	**45**	**46**	**47**	**49**	**50**	**51**	**52**
CFL	Retrofit - CFLi	10	1	1	3	5	6	7	9	10	12	13	14	15
	Non-retrofit - CFLni	12	1	1	2	3	3	3	3	3	4	4	4	4
	CFL (total)	**10**	**2**	**3**	**5**	**8**	**9**	**10**	**12**	**14**	**16**	**17**	**18**	**19**
TUNGSTEN (HL)	Single ended, mirrored (low voltage) [M16, M25 etc.]	35	0	1	2	4	4	4	4	4	4	5	5	5
	Linear (high voltage) [R7s]	250	1	10	10	10	10	8	7	6	5	5	5	4
	LV halogen capsule [G4, GY6.35]	35	1	2	2	2	2	2	2	2	2	2	2	1
	HV halogen capsule [G9]	35	0	0	0	0	0	1	1	1	2	2	2	2
	Mains halogen (substitute for GLS and Reflector)[E14, E27]	36	0	0	0	0	0	0	1	2	3	4	5	6
	Other mains halogen - PAR 16/20/ 25/ 30 Hard glass reflectors, GU10 etc.	35	0	0	1	1	2	2	2	3	3	4	4	4
	Tungsten-HL (total)	**59**	**3**	**12**	**15**	**17**	**17**	**17**	**17**	**18**	**19**	**20**	**21**	**22**
GLS	Reflector	54	4.2	4.0	3.7	3.5	3.4	3.3	3.0	2.6	2.1	1.7	1.4	1.1
	GLS (including clear/pearl, candles, coloured & decorative)	54	36	35	34	33	33	33	31	25	19	13	8	5
	GLS (total)	**54**	**41**	**39**	**38**	**37**	**36**	**36**	**34**	**28**	**21**	**15**	**10**	**6**
HID	All mercury lamps (including mixed)	250	4	4	4	4	4	3	3	3	3	2	2	1
	All sodium lamps	140	3	3	4	5	5	6	6	6	7	6	6	6
	Metal halide lamps	160	1	1	2	4	4	5	5	6	7	7	7	6
	HID (total)	**168**	**7**	**9**	**10**	**12**	**13**	**14**	**14**	**15**	**16**	**16**	**15**	**13**
LED	Directional	6								0.0	0.0	0.0	0.0	0.1
	Non-directional	15								0.0	0.0	0.0	0.0	0.2
	LED (total)	**12**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.0**	**0.0**	**0.0**	**0.1**	**0.3**
	GLS stock	54	0	0	0	0	0	0	0	0	0	0	0	0
	Tungsten stock	36	0	0	0	0	0	0	0	0	0	0	0	0
	TOTAL	**33**	**84**	**96**	**104**	**115**	**118**	**121**	**123**	**122**	**120**	**118**	**115**	**112**

Table 13: Installed power, EU-28 totals per lamp subtype in Giga Watt (10^9), years 1990, 1995, 2000, 2005 – 2013. NON-RESIDENTIAL

Power per household (W/hh)	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
Number of households (mln)	**171.6**	**181.5**	**188.9**	**192.6**	**193.3**	**194.1**	**194.8**	**195.6**	**196.3**	**197.1**	**197.8**	**198.6**
LFL power per hh	36	36	38	41	42	43	44	44	45	46	46	46
CFL power per hh	10	17	31	49	58	68	80	93	105	115	122	126
Tungsten power per hh	78	275	311	348	349	344	345	361	403	450	492	521
GLS power per hh	938	867	805	761	752	742	690	593	481	382	315	267
LED power per hh	0	0	0	0	0	0	0	1	1	3	4	6
TOTAL power in W/hh	**1062**	**1195**	**1184**	**1199**	**1200**	**1198**	**1160**	**1092**	**1035**	**995**	**979**	**966**
of which DLS power	107	116	144	177	184	191	196	199	201	202	204	201

Table 14: Installed power for lighting per household, years 1990, 1995, 2000, 2005 – 2013 (in Watt/household).

	year 2008			year 2013		
Division of EU-28 installed lighting power over the technology types, year 2008 & 2013	All Sectors	Residential	Non-Residential	All Sectors	Residential	Non-Residential
LFL (total)	16%	4%	37%	20%	5%	47%
CFL (total)	8%	7%	10%	14%	13%	17%
Tungsten-HL (total)	24%	30%	14%	41%	54%	20%
GLS (total)	48%	60%	27%	19%	28%	5%
HID (total)	4%	0%	12%	4%	0%	12%
LED (total)	0%	0%	0%	0%	1%	0%
TOTAL	100%	100%	100%	100%	100%	100%

Table 15: Years 2008 and 2013, subdivision of EU-28 installed power over the main technology types.

2.6. EU-28 total operating hours

The total lighting operating hours (full power equivalent) in the EU-28 are computed by multiplying the installed number of light sources (stock, see par. 2.7. of Task 2 report) by the average operating hours per unit (par. 2.3). This is initially done per lamp technology subtype. Subtype values are then summed for the residential and non-residential sector, that together form the EU-28 total.

The total operating hours can be conceived as the second part of the user demand for light [14] and are important during scenario analysis: in principle, different scenarios should lead to the same total operating hours (demand for light does not change between scenarios).

MELISA's total operating hours for **All sectors** are reported in Figure 9, Figure **10**, Table 16 and Table 17. The values for the **Residential sector** are reported in Table 18 and Figure 11; those for the **Non-residential sector** in Table 19 and Figure 12.

From 1990 to 2013 the total lighting operating hours in EU-28 show a continuously rising trend, from 4.7 Th in 1990 to 9.3 Th in 2013 [15].

[14] See footnote 12, the other part is the installed lighting capacity.

[15] Th = Tera hours (10^{12} hours). The 2013 value of 9.3 Th corresponds to approximately 1 billion years. The total number of light sources installed in EU-28 in 2013 is around 11000 million, so, as an average, every light sources is operated for 845 hours per year, or 2.3 hours per day.

In 2013, 34% of the total operating hours is made in the residential sector (3.20/9.31 Th). The residential values imply an average of 16130 operating hours per household per year in 2013 [16], of which 6800 h for CFL and 5700 h for halogen, see Table 20.

Table 21 shows the subdivision of the EU-28 operating hours over the lamp technology types for the years 2008 and 2013. This table clearly indicates the shift from incandescent (GLS) to CFL and halogen (HL) in the residential sector. In the non-residential sector 68% of the operating hours is for LFL.

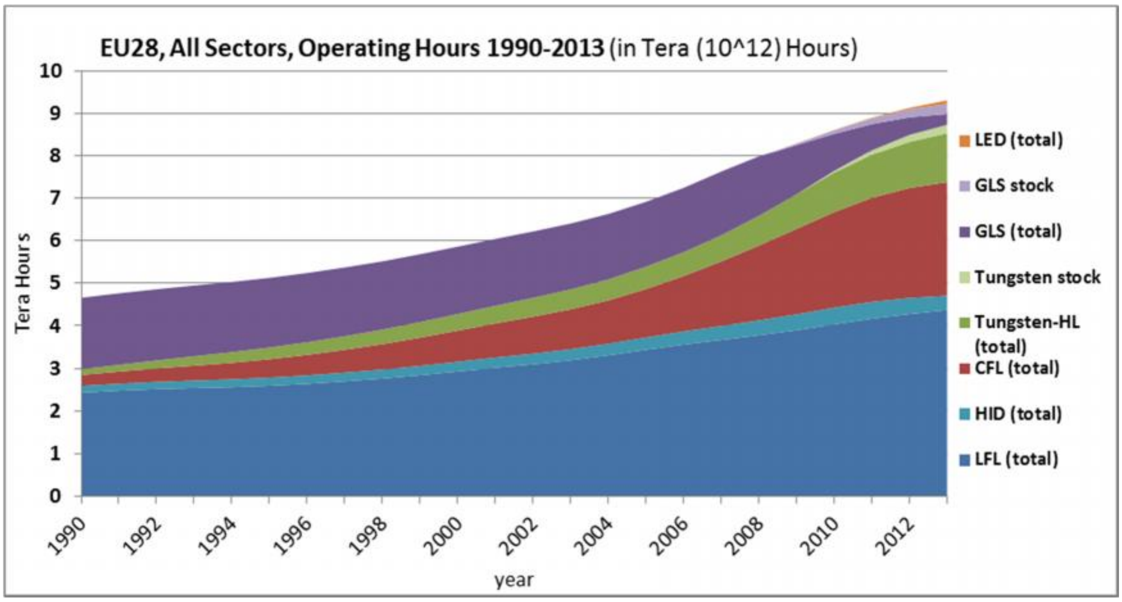


Figure 9: Operating hours, EU-28 cumulative total in Tera hours (10^{12}). ALL SECTORS

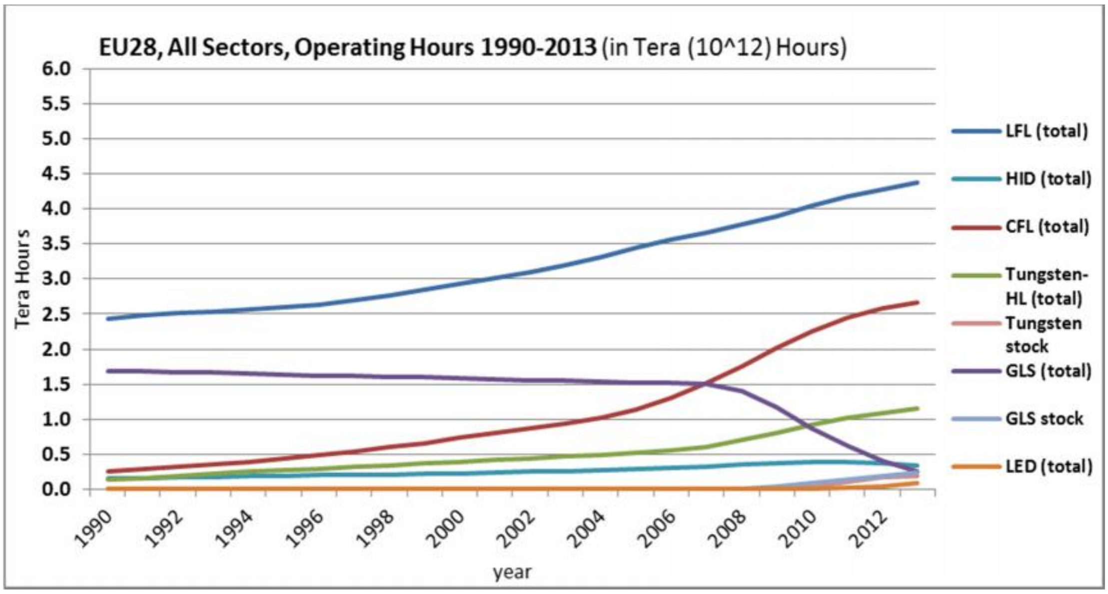


Figure 10: Operating hours, EU-28 totals per lamp type in Tera hours (10^{12}). ALL SECTORS

[16] Corresponds to approximately 44 burning hours per household per day. The average number of light sources installed per household is approximately 33, so, as an average, every household lamp is used for 1.3 hours per day.

EU-28 OPERATING HOURS SUMMARY, All Sectors Tera (10^12) hours	Average hour/unit	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL (total)	1967	2.4	2.6	2.9	3.4	3.6	3.7	3.8	3.9	4.0	4.2	4.3	4.4
CFL (total)	632	0.3	0.4	0.7	1.1	1.3	1.5	1.8	2.0	2.2	2.4	2.6	2.7
Tungsten-HL (total)	450	0.1	0.3	0.4	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.2
GLS (total)	450	1.7	1.6	1.6	1.5	1.5	1.5	1.4	1.2	0.9	0.6	0.4	0.3
HID (total)	4000	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.3
LED (total)	705	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
GLS stock	450	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*	*0.1*	*0.2*	*0.2*
Tungsten stock	450	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*	*0.2*	*0.2*
TOTAL	**843**	**4.7**	**5.1**	**5.9**	**6.9**	**7.2**	**7.6**	**8.0**	**8.3**	**8.6**	**8.9**	**9.1**	**9.3**

Table 16: Operating hours, EU-28 totals per main lamp type in Tera hours (10^{12}), years 1990, 1995, 2000, 2005 – 2013. ALL SECTORS

	EU-28 OPERATING HOURS TOTAL, All Sectors Tera (10^12) hours	Average hour/unit	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL	T12	1859	0.62	0.45	0.27	0.15	0.14	0.12	0.10	0.09	0.07	0.06	0.05	0.03
LFL	T8 halophosphor	1921	0.72	0.88	1.14	1.37	1.37	1.33	1.26	1.14	0.94	0.68	0.41	0.21
LFL	T8 tri-phosphor	1991	0.85	0.98	1.16	1.38	1.45	1.53	1.63	1.78	2.00	2.28	2.56	2.78
LFL	T5 new (14 - 80w) including circular	2097	0.00	0.00	0.00	0.11	0.18	0.26	0.36	0.48	0.62	0.77	0.92	1.05
LFL	All others (including T5 old types 4 - 13w and Special FL)	1950	0.23	0.28	0.35	0.42	0.43	0.43	0.42	0.41	0.39	0.37	0.34	0.30
LFL	**LFL (total)**		**2.43**	**2.59**	**2.93**	**3.44**	**3.56**	**3.67**	**3.78**	**3.90**	**4.04**	**4.17**	**4.28**	**4.37**
CFL	Retrofit - CFLi	500	0.10	0.19	0.39	0.66	0.79	0.96	1.16	1.36	1.55	1.72	1.83	1.91
CFL	Non-retrofit - CFLni	1204	0.16	0.24	0.35	0.48	0.52	0.56	0.60	0.65	0.69	0.73	0.75	0.76
CFL	**CFL (total)**		**0.26**	**0.43**	**0.73**	**1.14**	**1.30**	**1.52**	**1.76**	**2.01**	**2.25**	**2.45**	**2.59**	**2.67**
TUNGSTEN (HL)	Single ended, mirrored (low voltage) [M16, M25 etc.]	450	0.03	0.08	0.16	0.24	0.25	0.26	0.27	0.28	0.29	0.29	0.30	0.31
TUNGSTEN (HL)	Linear (high voltage) [R7s]	450	0.01	0.09	0.09	0.09	0.09	0.08	0.06	0.05	0.05	0.04	0.04	0.04
TUNGSTEN (HL)	LV halogen capsule [G4, GY6.35]	450	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.10	0.10	0.10	0.10
TUNGSTEN (HL)	HV halogen capsule [G9]	450	0.00	0.00	0.00	0.00	0.02	0.04	0.06	0.08	0.10	0.10	0.11	0.10
TUNGSTEN (HL)	Mains halogen (substitute for GLS and Reflector)[E14, E27]	450	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.11	0.18	0.24	0.30	0.36
TUNGSTEN (HL)	Other mains halogen - PAR 16/20/ 25/ 30 Hard glass reflectors, GU10 etc.	450	0.00	0.00	0.04	0.09	0.10	0.12	0.15	0.18	0.21	0.23	0.25	0.25
TUNGSTEN (HL)	**Tungsten-HL (total)**		**0.13**	**0.28**	**0.39**	**0.52**	**0.56**	**0.61**	**0.70**	**0.81**	**0.93**	**1.02**	**1.09**	**1.16**
GLS	Reflector	450	0.17	0.16	0.16	0.15	0.14	0.14	0.13	0.11	0.09	0.07	0.06	0.05
GLS	GLS (including clear/pearl, candles, coloured & decorative)	450	1.51	1.47	1.43	1.38	1.37	1.36	1.28	1.06	0.79	0.55	0.35	0.21
GLS	**GLS (total)**		**1.68**	**1.64**	**1.58**	**1.53**	**1.51**	**1.50**	**1.40**	**1.17**	**0.88**	**0.62**	**0.41**	**0.25**
HID	All mercury lamps (including mixed)	4000	0.06	0.07	0.07	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.03	0.02
HID	All sodium lamps	4000	0.09	0.10	0.11	0.14	0.15	0.16	0.17	0.18	0.19	0.18	0.17	0.17
HID	Metal halide lamps	4000	0.01	0.03	0.05	0.09	0.10	0.12	0.13	0.14	0.16	0.18	0.17	0.15
HID	**HID (total)**		**0.16**	**0.19**	**0.23**	**0.29**	**0.31**	**0.33**	**0.35**	**0.37**	**0.39**	**0.40**	**0.38**	**0.34**
LED	Directional	599	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04
LED	Non-directional	807	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.04
LED	**LED (total)**		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	**0.02**	**0.03**	**0.08**
	GLS stock	450	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.13	0.19	0.24
	Tungsten stock	450	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.10	0.17	0.20
	TOTAL		**4.66**	**5.13**	**5.86**	**6.92**	**7.25**	**7.63**	**7.99**	**8.30**	**8.61**	**8.90**	**9.13**	**9.31**

Table 17: Operating hours, EU-28 totals per lamp subtype in Tera hours (10^{12}), years 1990, 1995, 2000, 2005 – 2013. ALL SECTORS

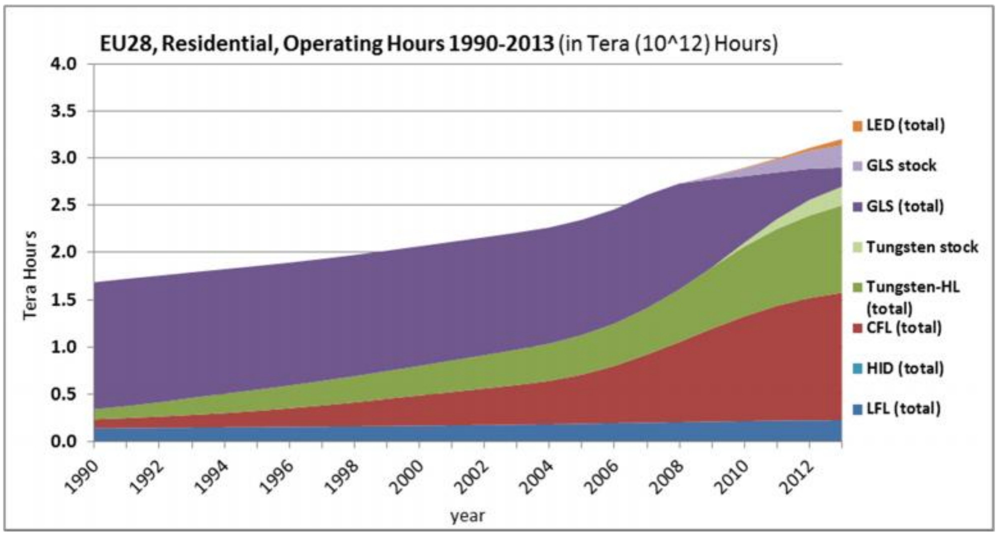


Figure 11: Operating hours, EU-28 cumulative total in Tera hours (10^{12}). RESIDENTIAL

EU-28 OPERATING HOURS RESIDENTIAL Tera (10^12) hours		Average hour/unit	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL	T12	700	0.04	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	T8 halophosphor	700	0.04	0.05	0.06	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.06	0.06
	T8 tri-phosphor	700	0.05	0.05	0.06	0.07	0.08	0.08	0.08	0.09	0.09	0.10	0.11	0.12
	T5 new (14 - 80w) including circular	700	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02
	All others (including T5 old types 4 - 13w and Special FL)	700	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	LFL (total)		**0.14**	**0.15**	**0.17**	**0.19**	**0.20**	**0.20**	**0.21**	**0.21**	**0.22**	**0.22**	**0.23**	**0.23**
CFL	Retrofit - CFLi	500	0.06	0.11	0.23	0.39	0.47	0.58	0.69	0.82	0.93	1.03	1.10	1.15
	Non-retrofit - CFLni	700	0.03	0.06	0.09	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.20
	CFL (total)		**0.09**	**0.17**	**0.32**	**0.52**	**0.60**	**0.72**	**0.84**	**0.98**	**1.11**	**1.21**	**1.29**	**1.35**
TUNGSTEN (HL)	Single ended, mirrored (low voltage) [M16, M25 etc.]	450	0.02	0.06	0.13	0.19	0.20	0.21	0.22	0.23	0.23	0.24	0.24	0.25
	Linear (high voltage) [R7s]	450	0.01	0.07	0.07	0.07	0.07	0.06	0.05	0.04	0.04	0.03	0.03	0.03
	LV halogen capsule [G4, GY6.35]	450	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	HV halogen capsule [G9]	450	0.00	0.00	0.00	0.00	0.01	0.03	0.05	0.07	0.08	0.08	0.08	0.08
	Mains halogen (substitute for GLS and Reflector)[E14, E27]	450	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.09	0.15	0.19	0.24	0.29
	Other mains halogen - PAR 16/20/ 25/ 30 Hard glass reflectors, GU10 etc.	450	0.00	0.00	0.03	0.07	0.08	0.10	0.12	0.14	0.17	0.19	0.20	0.20
	Tungsten-HL (total)		**0.11**	**0.22**	**0.31**	**0.42**	**0.45**	**0.49**	**0.56**	**0.65**	**0.74**	**0.81**	**0.87**	**0.92**
GLS	Reflector	450	0.14	0.13	0.12	0.12	0.11	0.11	0.10	0.09	0.07	0.06	0.05	0.04
	GLS (including clear/pearl, candles, coloured & decorative)	450	1.20	1.18	1.14	1.10	1.10	1.09	1.02	0.85	0.63	0.44	0.28	0.16
	GLS (total)		**1.34**	**1.31**	**1.27**	**1.22**	**1.21**	**1.20**	**1.12**	**0.93**	**0.70**	**0.49**	**0.33**	**0.20**
HID	All mercury lamps (including mixed)	700	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	All sodium lamps	700	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Metal halide lamps	700	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	HID (total)		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
LED	Directional									0.00	0.00	0.01	0.02	0.03
	Non-directional									0.00	0.00	0.00	0.01	0.03
	LED (total)		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	**0.01**	**0.03**	**0.06**
	GLS stock	450	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.13	0.19	0.24
	Tungsten stock	450	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.10	0.17	0.20
	TOTAL		**1.68**	**1.86**	**2.07**	**2.35**	**2.46**	**2.61**	**2.73**	**2.81**	**2.90**	**3.00**	**3.11**	**3.20**

Table 18: Operating hours, EU-28 totals per lamp subtype in Tera hours (10^{12}), years 1990, 1995, 2000, 2005 – 2013. RESIDENTIAL

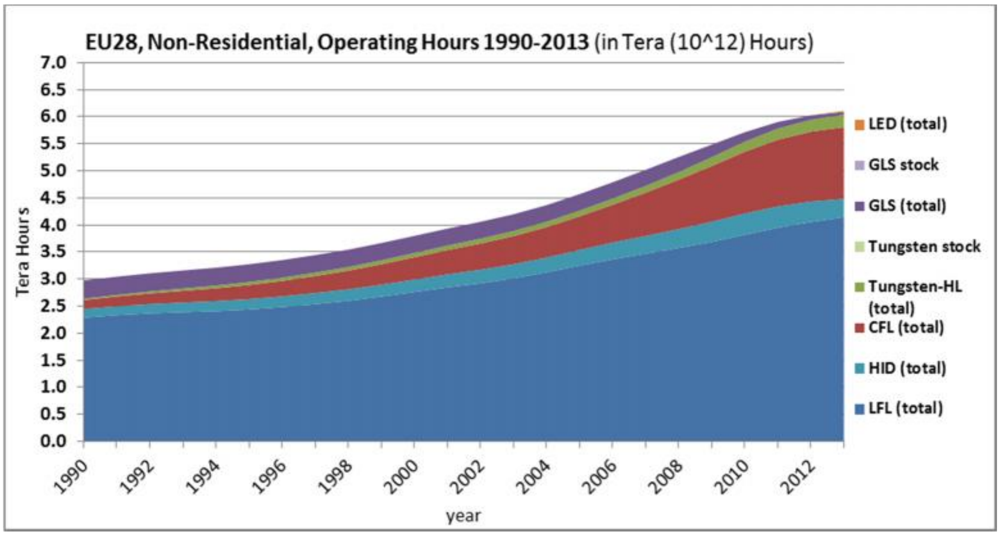


Figure 12: Operating hours, EU-28 cumulative total in Tera hours (10^{12}). NON-RESIDENTIAL

EU-28 OPERATING HOURS NON-RESIDENTIAL Tera (10^12) hours		Average hour/unit	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL	T12	2200	0.58	0.41	0.25	0.14	0.12	0.11	0.09	0.08	0.06	0.05	0.04	0.03
	T8 halophosphor	2200	0.68	0.83	1.08	1.29	1.29	1.25	1.18	1.06	0.87	0.61	0.35	0.16
	T8 tri-phosphor	2200	0.80	0.93	1.10	1.31	1.37	1.45	1.55	1.69	1.91	2.18	2.45	2.66
	T5 new (14 - 80w) including circular	2200	0.00	0.00	0.00	0.11	0.17	0.25	0.35	0.47	0.61	0.76	0.90	1.03
	All others (including T5 old types 4 - 13w and Special FL)	2200	0.22	0.26	0.33	0.40	0.41	0.40	0.40	0.39	0.37	0.34	0.31	0.28
	LFL (total)		**2.29**	**2.44**	**2.76**	**3.25**	**3.37**	**3.47**	**3.57**	**3.69**	**3.82**	**3.95**	**4.05**	**4.14**
CFL	Retrofit - CFLi	500	0.04	0.08	0.15	0.26	0.31	0.39	0.46	0.55	0.62	0.69	0.73	0.77
	Non-retrofit - CFLni	1600	0.12	0.18	0.26	0.36	0.39	0.42	0.45	0.49	0.52	0.55	0.56	0.56
	CFL (total)		**0.16**	**0.26**	**0.41**	**0.62**	**0.70**	**0.80**	**0.91**	**1.03**	**1.14**	**1.23**	**1.29**	**1.33**
TUNGSTEN (HL)	Single ended, mirrored (low voltage) [M16, M25 etc.]	450	0.01	0.02	0.03	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06
	Linear (high voltage) [R7s]	450	0.00	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
	LV halogen capsule [G4, GY6.35]	450	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	HV halogen capsule [G9]	450	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.02	0.02
	Mains halogen (substitute for GLS and Reflector)[E14, E27]	450	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.05	0.06	0.07
	Other mains halogen - PAR 16/20/ 25/ 30 Hard glass reflectors, GU10 etc.	450	0.00	0.00	0.01	0.02	0.02	0.02	0.03	0.04	0.04	0.05	0.05	0.05
	Tungsten-HL (total)		**0.03**	**0.06**	**0.08**	**0.10**	**0.11**	**0.12**	**0.14**	**0.16**	**0.19**	**0.20**	**0.22**	**0.23**
GLS	Reflector	450	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.01	0.01	0.01
	GLS (including clear/pearl, candles, coloured & decorative)	450	0.30	0.29	0.29	0.28	0.27	0.27	0.26	0.21	0.16	0.11	0.07	0.04
	GLS (total)		**0.34**	**0.33**	**0.32**	**0.31**	**0.30**	**0.30**	**0.28**	**0.23**	**0.18**	**0.12**	**0.08**	**0.05**
HID	All mercury lamps (including mixed)	4000	0.06	0.07	0.07	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.03	0.02
	All sodium lamps	4000	0.09	0.10	0.11	0.14	0.15	0.16	0.17	0.18	0.19	0.18	0.17	0.17
	Metal halide lamps	4000	0.01	0.03	0.05	0.09	0.10	0.12	0.13	0.14	0.16	0.18	0.17	0.15
	HID (total)		**0.16**	**0.19**	**0.23**	**0.29**	**0.31**	**0.33**	**0.35**	**0.37**	**0.39**	**0.40**	**0.38**	**0.34**
LED	Directional									0.00	0.00	0.00	0.00	0.01
	Non-directional									0.00	0.00	0.00	0.00	0.01
	LED (total)		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.02**
	GLS stock	450	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Tungsten stock	450	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL		**2.97**	**3.27**	**3.80**	**4.57**	**4.79**	**5.02**	**5.26**	**5.48**	**5.71**	**5.90**	**6.03**	**6.11**

Table 19: Operating hours, EU-28 totals per lamp subtype in Tera hours (10^{12}), years 1990, 1995, 2000, 2005 – 2013. NON-RESIDENTIAL

Hours per household (h/hh)	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
Number of households (mln)	**171.6**	**181.5**	**188.9**	**192.6**	**193.3**	**194.1**	**194.8**	**195.6**	**196.3**	**197.1**	**197.8**	**198.6**
LFL hours per hh	826	850	892	988	1013	1038	1063	1086	1107	1126	1140	1146
CFL hours per hh	548	946	1683	2682	3118	3700	4337	5014	5634	6158	6534	6781
Tungsten hours per hh	627	1212	1654	2175	2314	2529	2862	3320	3982	4661	5256	5655
GLS hours per hh	7816	7222	6706	6340	6264	6182	5754	4939	4007	3186	2624	2224
LED hours per hh	0	0	0	0	0	0	0	15	36	75	150	320
TOTAL hours/hh	**9818**	**10231**	**10935**	**12184**	**12710**	**13448**	**14016**	**14374**	**14766**	**15206**	**15704**	**16126**
of which DLS hours	935	1098	1490	1952	2048	2150	2242	2327	2400	2474	2553	2614

Table 20: Lighting operating hours per household, years 1990, 1995, 2000, 2005 – 2013 (in hours/household).

	year 2008			year 2013		
Division of EU-28 operating hours over the technology types, year 2008 & 2013	All Sectors	Residential	Non-Residential	All Sectors	Residential	Non-Residential
LFL (total)	47%	8%	68%	47%	7%	68%
CFL (total)	22%	31%	17%	29%	42%	22%
Tungsten-HL (total)	9%	20%	3%	15%	35%	4%
GLS (total)	18%	41%	5%	5%	14%	1%
HID (total)	4%	0%	7%	4%	0%	6%
LED (total)	0%	0%	0%	1%	2%	0%
TOTAL	100%	100%	100%	100%	100%	100%

Table 21: Years 2008 and 2013, subdivision of EU-28 operating hours over the main technology types.

2.7. EU-28 energy consumption for lighting

In MELISA the EU-28 energy consumption for a given lamp subtype, in a given sector, and in a given year is computed as the product of the corresponding annual total operating hours (par. 2.6), the average power per light source (par. 2.2), and a control gear factor.

The latter factor is the reverse of the efficiency of ballasts/drivers/control gears and increases the energy consumption. Currently the following control gear factors are being used (year 2013):

- 1.25 (efficiency 80%) for LFL T12 and T8 halophosphor)
- 1.20 (efficiency 83%) for LFL T5-old and other types and for HID
- 1.10 (efficiency 91%) for LFL T8 tri-phosphor, LFL T5-new, CFLni and LED
- 1.06 (efficiency 94%) for low voltage halogens
- 1.00 (no gear) for mains voltage halogens, legacy incandescent lamps (GLS) and CFLi

For the non-residential sector an amount of energy consumption is also shown for Special Purpose Lamps (SPL) and for Controls and Standby. As regards SPL this consumption is based on the estimate provided in Annex D of the Task 1 report, but ignoring the contribution of automotive lights, backlighting for displays, and some other SPL-types with minor impact. The value for controls and standby is a preliminary indicative estimate by the study team, to be refined also in cooperation with the Lot 37 study on lighting systems.

MELISA's electrical energy consumption for lighting in EU-28 is reported for **All sectors** in Figure 13, Figure 14, Table 22 and Table 23. The values for the **Residential sector** are reported in Table 24 and Figure 15; those for the **Non-residential sector** in Table 25 and Figure 16.

The annual electrical energy for lighting in EU-28 shows a continuously rising trend, from 276 TWh in 1990 to 397 TWh in 2007. In the period 2007 - 2011 the energy consumption is almost constant, around 400 TWh/year, while in the last two years it tends to decrease, reaching 382 TWh in 2013.

In the residential sector the peak energy consumption for lighting was reached in 2007 (near 110 TWh) and since then the trend is continuously decreasing. In 2013 the estimated consumption is 93 TWh, which accounts for 24% of the total lighting energy. The residential values imply an average of 467 kWh per household per year in 2013, of which approximately 240 kWh for halogen lamps and still 120 kWh for incandescent lamps (GLS), see Table 26.

The 2013 lighting energy consumption in the non-residential sector is estimated in 290 TWh (220 TWh when SPL, controls and standby are excluded). This corresponds to an average Lighting Energy Numeric Indicator (LENI) for non-residential buildings of 13-14 kWh/m^2/year [17].

Table 27 shows the subdivision of the EU-28 lighting energy over the lamp technology types, for the years 2008 and 2013. This table clearly indicates the reduction for incandescent (GLS). In the residential sector 51% of the energy is used for halogens, while incandescent lamps (GLS) still consume 26%. In the non-residential sector 58% of the energy is for LFL, 29% for HID.

[17] Excluding SPL, Controls and Standby, and assuming that 28% of the non-residential energy is used for outdoor lighting. This considers a total EU-28 building area of 11500 Mm^2, see Annex I.

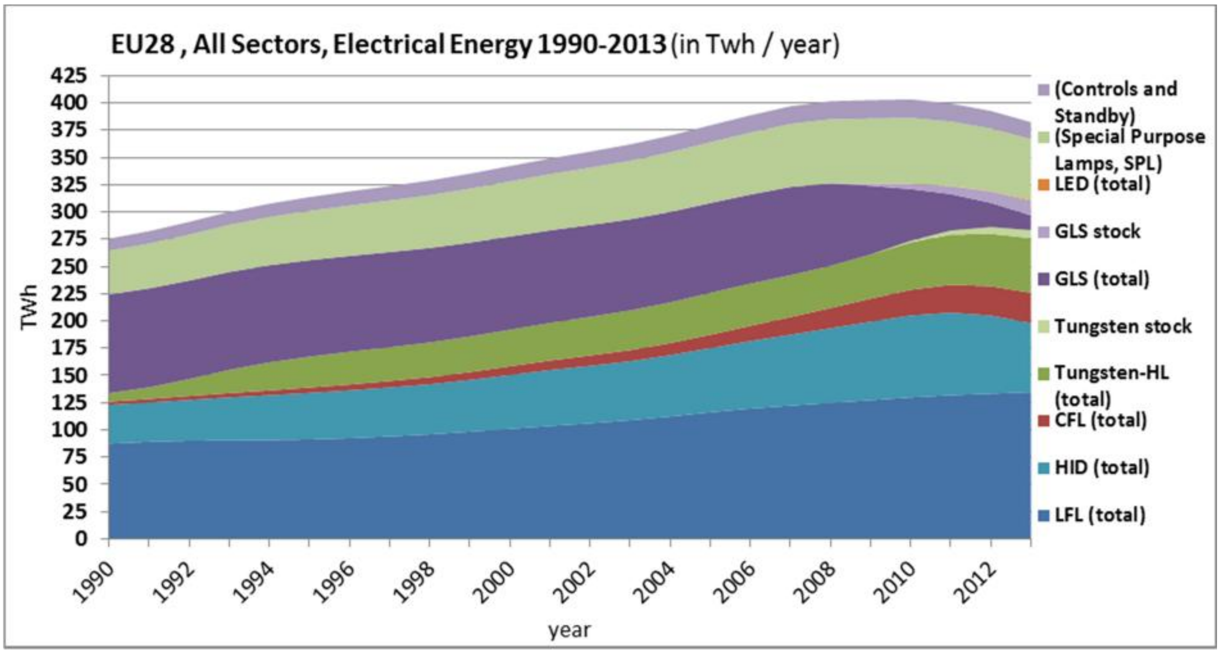


Figure 13: Electrical energy used for lighting, EU-28 cumulative total in TWh/year. ALL SECTORS

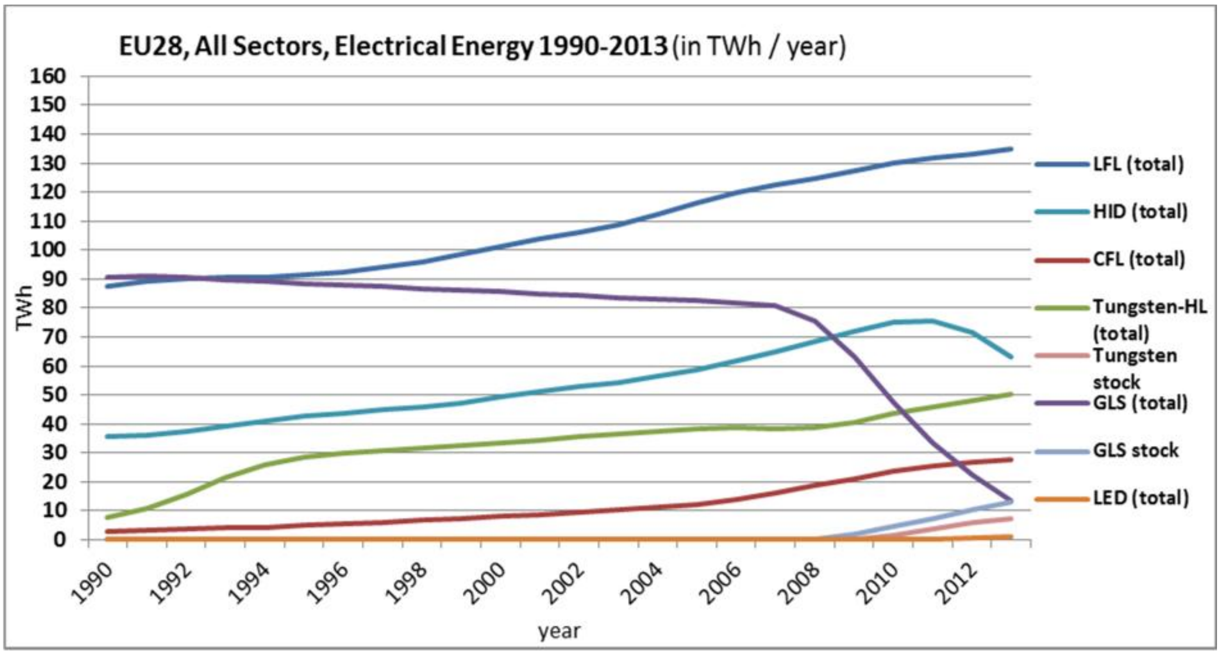


Figure 14: Electrical energy used for lighting, EU-28 totals per lamp type in TWh/year. ALL SECTORS

EU-28 LIGHTING ENERGY SUMMARY, All Sectors TWh / year	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL (total)	87.5	91.4	101.1	116.2	119.7	122.3	124.9	127.3	129.9	131.9	133.3	134.8
CFL (total)	3.0	4.9	8.0	12.3	14.0	16.2	18.6	21.2	23.6	25.5	26.9	27.8
Tungsten-HL (total)	7.7	28.4	33.6	38.4	38.7	38.4	38.6	40.6	43.5	46.0	48.1	50.1
GLS (total)	90.7	88.5	85.5	82.4	81.8	81.0	75.7	62.9	47.4	33.4	22.2	13.6
HID (total)	35.6	42.7	49.3	58.8	61.9	65.1	68.4	72.0	75.2	75.7	71.7	63.3
LED (total)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.5	1.0
Special Purpose Lamps	40.0	45.2	50.5	55.7	56.8	57.8	58.9	59.9	60.6	59.0	57.4	55.8
Controls and Standby	11.2	12.7	14.2	15.6	15.9	16.2	16.5	16.8	17.0	16.6	16.1	15.7
GLS stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	4.5	7.2	10.2	12.9
Tungsten stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	3.8	6.2	7.3
TOTAL	**275.6**	**313.7**	**342.1**	**379.6**	**388.7**	**397.0**	**401.6**	**402.6**	**403.3**	**399.5**	**392.6**	**382.3**

Table 22: Electrical energy used for lighting, EU-28 totals per main lamp type in TWh, years 1990, 1995, 2000, 2005 – 2013. ALL SECTORS

EU-28 LIGHTING ENERGY TOTAL, All Sectors TWh / year		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL	T12	27.0	19.6	12.0	6.7	6.0	5.3	4.5	3.8	3.2	2.6	2.0	1.4
	T8 halophosphor	29.0	35.3	45.6	54.9	54.9	53.3	50.5	45.6	37.8	27.4	16.6	8.5
	T8 tri-phosphor	28.1	32.5	38.4	45.5	47.7	50.4	53.9	58.8	66.2	75.4	84.4	91.6
	T5 new (14 - 80w) including circular	0.0	0.0	0.0	3.1	4.9	7.1	9.8	13.1	17.1	21.2	25.4	28.9
	All others (including T5 old types 4 - 13w and Special FL)	3.4	4.0	5.0	6.1	6.2	6.2	6.1	5.9	5.7	5.3	4.9	4.3
	LFL (total)	**87.5**	**91.4**	**101.1**	**116.2**	**119.7**	**122.3**	**124.9**	**127.3**	**129.9**	**131.9**	**133.3**	**134.8**
CFL	Retrofit - CFLi	0.9	1.8	3.7	6.3	7.5	9.2	11.0	13.0	14.8	16.3	17.4	18.2
	Non-retrofit - CFLni	2.0	3.1	4.4	6.1	6.5	7.0	7.6	8.2	8.8	9.2	9.5	9.6
	CFL (total)	**3.0**	**4.9**	**8.0**	**12.3**	**14.0**	**16.2**	**18.6**	**21.2**	**23.6**	**25.5**	**26.9**	**27.8**
TUNGSTEN (HL)	Single ended, mirrored (low voltage) [M16, M25 etc.]	1.1	3.0	5.9	8.7	9.2	9.7	10.1	10.4	10.7	10.9	11.1	11.4
	Linear (high voltage) [R7s]	3.3	21.4	22.5	22.5	21.4	18.8	15.6	13.1	11.7	10.8	10.2	9.8
	LV halogen capsule [G4, GY6.35]	3.4	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.8	3.7	3.5
	HV halogen capsule [G9]	0.0	0.0	0.0	0.2	0.5	1.3	2.1	2.9	3.4	3.6	3.7	3.6
	Mains halogen (substitute for GLS and Reflector)[E14, E27]	0.0	0.0	0.0	0.0	0.1	0.5	1.8	4.1	6.5	8.7	10.7	13.0
	Other mains halogen - PAR 16/20/ 25/ 30 Hard glass reflectors, GU10 etc.	0.0	0.1	1.3	3.1	3.6	4.3	5.2	6.2	7.3	8.2	8.7	8.8
	Tungsten-HL (total)	**7.7**	**28.4**	**33.6**	**38.4**	**38.7**	**38.4**	**38.6**	**40.6**	**43.5**	**46.0**	**48.1**	**50.1**
GLS	Reflector	9.3	8.9	8.4	7.9	7.7	7.4	6.8	5.8	4.7	3.8	3.2	2.5
	GLS (including clear/pearl, candles, coloured & decorative)	81.4	79.6	77.1	74.6	74.1	73.5	68.9	57.1	42.8	29.6	19.0	11.1
	GLS (total)	**90.7**	**88.5**	**85.5**	**82.4**	**81.8**	**81.0**	**75.7**	**62.9**	**47.4**	**33.4**	**22.2**	**13.6**
HID	All mercury lamps (including mixed)	18.3	21.4	21.4	18.3	17.2	15.9	14.6	13.3	12.1	10.9	9.1	6.7
	All sodium lamps	14.8	16.2	18.2	22.8	24.7	26.8	29.1	30.8	31.5	30.7	29.5	28.5
	Metal halide lamps	2.5	5.1	9.7	17.6	20.1	22.4	24.8	27.9	31.5	34.2	33.1	28.1
	HID (total)	**35.6**	**42.7**	**49.3**	**58.8**	**61.9**	**65.1**	**68.4**	**72.0**	**75.2**	**75.7**	**71.7**	**63.3**
LED	Directional	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4
	Non-directional	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.6
	LED (total)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**	**0.2**	**0.3**	**0.5**	**1.0**
	GLS stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	4.5	7.2	10.2	12.9
	Tungsten stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	3.8	6.2	7.3
	Special Purpose Lamps	40.0	45.2	50.5	55.7	56.8	57.8	58.9	59.9	60.6	59.0	57.4	55.8
	Controls and Standby	11.2	12.7	14.2	15.6	15.9	16.2	16.5	16.8	17.0	16.6	16.1	15.7
	TOTAL	**275.6**	**313.7**	**342.1**	**379.6**	**388.7**	**397.0**	**401.6**	**402.6**	**403.3**	**399.5**	**392.6**	**382.3**

Table 23: Electrical energy used for lighting, EU-28 totals per lamp subtype in TWh, years 1990, 1995, 2000, 2005 – 2013. ALL SECTORS

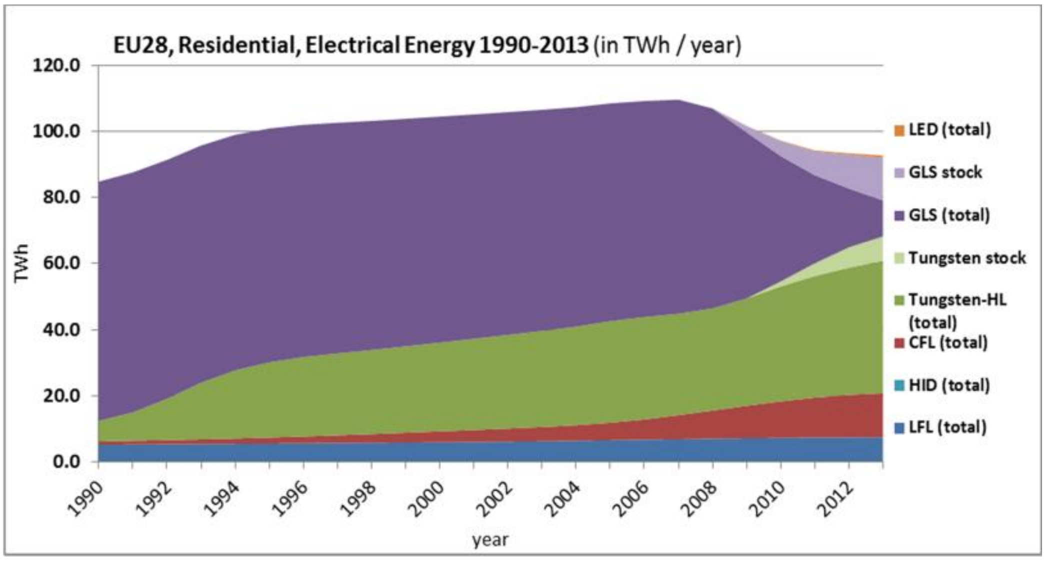


Figure 15: Electrical energy for lighting, EU-28 cumulative total in TWh. RESIDENTIAL

EU-28 LIGHTING ENERGY RESIDENTIAL TWh / year		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL	T12	1.8	1.6	1.2	0.7	0.6	0.5	0.5	0.4	0.4	0.3	0.3	0.2
	T8 halophosphor	1.7	2.0	2.5	3.1	3.2	3.2	3.2	3.2	3.1	2.8	2.6	2.3
	T8 tri-phosphor	1.5	1.8	2.1	2.4	2.5	2.6	2.7	2.9	3.1	3.4	3.6	3.9
	T5 new (14 - 80w) including circular	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.6
	All others (including T5 old types 4 - 13w and Special FL)	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.3
	LFL (total)	**5.2**	**5.5**	**5.9**	**6.6**	**6.7**	**6.9**	**7.0**	**7.2**	**7.3**	**7.3**	**7.4**	**7.4**
CFL	Retrofit - CFLi	0.6	1.1	2.2	3.8	4.5	5.5	6.6	7.8	8.9	9.8	10.5	10.9
	Non-retrofit - CFLni	0.4	0.7	1.1	1.5	1.7	1.8	1.9	2.0	2.2	2.3	2.4	2.5
	CFL (total)	**1.0**	**1.8**	**3.3**	**5.3**	**6.1**	**7.3**	**8.5**	**9.8**	**11.1**	**12.1**	**12.9**	**13.4**
TUNGSTEN (HL)	Single ended, mirrored (low voltage) [M16, M25 etc.]	0.9	2.4	4.7	7.0	7.4	7.8	8.1	8.4	8.6	8.7	8.9	9.1
	Linear (high voltage) [R7s]	2.6	17.1	18.0	18.0	17.1	15.0	12.5	10.5	9.4	8.6	8.2	7.8
	LV halogen capsule [G4, GY6.35]	2.8	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.0	2.8
	HV halogen capsule [G9]	0.0	0.0	0.0	0.1	0.4	1.0	1.7	2.3	2.7	2.9	2.9	2.9
	Mains halogen (substitute for GLS and Reflector)[E14, E27]	0.0	0.0	0.0	0.0	0.0	0.4	1.4	3.2	5.2	6.9	8.5	10.4
	Other mains halogen - PAR 16/20/ 25/ 30 Hard glass reflectors, GU10 etc.	0.0	0.1	1.0	2.5	2.9	3.4	4.1	5.0	5.8	6.5	7.0	7.0
	Tungsten-HL (total)	**6.2**	**22.7**	**26.9**	**30.7**	**31.0**	**30.7**	**30.9**	**32.5**	**34.8**	**36.8**	**38.5**	**40.1**
GLS	Reflector	7.4	7.1	6.7	6.3	6.2	5.9	5.4	4.6	3.7	3.0	2.6	2.0
	GLS (including clear/pearl, candles, coloured & decorative)	65.0	63.7	61.7	59.6	59.2	58.8	55.1	45.7	34.2	23.7	15.2	8.9
	GLS (total)	**72.4**	**70.8**	**68.4**	**65.9**	**65.4**	**64.8**	**60.5**	**50.3**	**37.9**	**26.7**	**17.8**	**10.9**
HID	All mercury lamps (including mixed)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	All sodium lamps	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Metal halide lamps	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	HID (total)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
LED	Directional								0.1	0.1	0.2	0.3	0.4
	Non-directional								0.0	0.0	0.1	0.2	0.3
	LED (total)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.6**
	GLS stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	4.5	7.2	10.2	12.9
	Tungsten stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	3.8	6.2	7.3
	TOTAL	**84.8**	**100.9**	**104.5**	**108.5**	**109.2**	**109.6**	**107.0**	**101.7**	**97.3**	**94.3**	**93.4**	**92.7**

Table 24: Electrical energy for lighting, EU-28 totals per lamp subtype in TWh, years 1990, 1995, 2000, 2005 – 2013. RESIDENTIAL

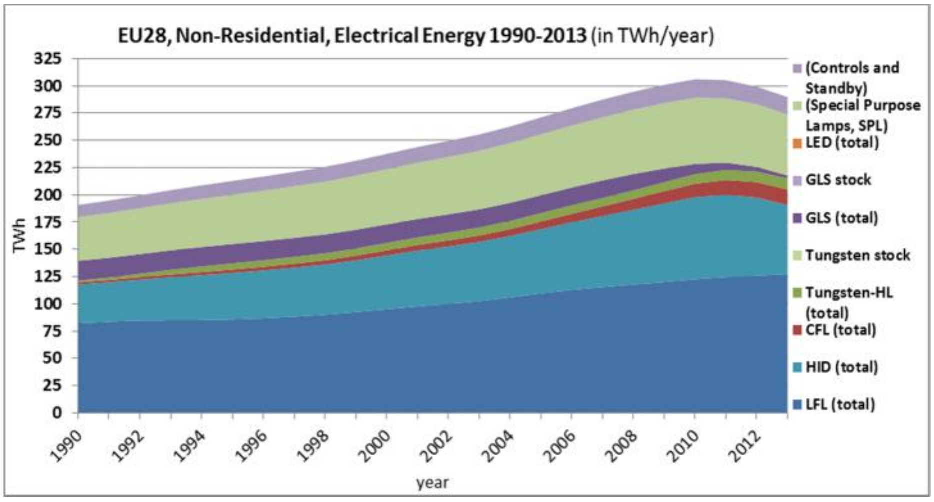


Figure 16: Electrical energy for lighting, EU-28 cumulative total in TWh. NON-RESIDENTIAL

EU-28 LIGHTING ENERGY NON-RESIDENTIAL TWh / year		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL	T12	25.2	18.0	10.8	6.0	5.4	4.7	4.1	3.4	2.8	2.3	1.7	1.2
	T8 halophosphor	27.3	33.3	43.2	51.8	51.8	50.1	47.3	42.4	34.7	24.5	14.0	6.2
	T8 tri-phosphor	26.6	30.7	36.3	43.1	45.2	47.8	51.2	55.9	63.0	72.0	80.7	87.7
	T5 new (14 - 80w) including circular	0.0	0.0	0.0	3.0	4.8	7.0	9.6	12.9	16.7	20.8	24.9	28.3
	All others (including T5 old types 4 - 13w and Special FL)	3.2	3.8	4.8	5.8	5.8	5.8	5.8	5.6	5.3	4.9	4.5	4.0
	LFL (total)	**82.3**	**85.8**	**95.1**	**109.7**	**112.9**	**115.4**	**117.9**	**120.1**	**122.6**	**124.6**	**125.9**	**127.4**
CFL	Retrofit - CFLi	0.4	0.7	1.5	2.5	3.0	3.7	4.4	5.2	5.9	6.5	7.0	7.3
	Non-retrofit - CFLni	1.6	2.3	3.3	4.5	4.9	5.3	5.7	6.1	6.6	6.9	7.1	7.1
	CFL (total)	**2.0**	**3.1**	**4.7**	**7.1**	**7.9**	**8.9**	**10.1**	**11.3**	**12.5**	**13.4**	**14.1**	**14.4**
TUNGSTEN (HL)	Single ended, mirrored (low voltage) [M16, M25 etc.]	0.2	0.6	1.2	1.7	1.8	1.9	2.0	2.1	2.1	2.2	2.2	2.3
	Linear (high voltage) [R7s]	0.7	4.3	4.5	4.5	4.3	3.8	3.1	2.6	2.3	2.2	2.0	2.0
	LV halogen capsule [G4, GY6.35]	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.7
	HV halogen capsule [G9]	0.0	0.0	0.0	0.0	0.1	0.3	0.4	0.6	0.7	0.7	0.7	0.7
	Mains halogen (substitute for GLS and Reflector)[E14, E27]	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	1.3	1.7	2.1	2.6
	Other mains halogen - PAR 16/20/ 25/ 30 Hard glass reflectors, GU10 etc.	0.0	0.0	0.3	0.6	0.7	0.9	1.0	1.2	1.5	1.6	1.7	1.8
	Tungsten-HL (total)	**1.5**	**5.7**	**6.7**	**7.7**	**7.7**	**7.7**	**7.7**	**8.1**	**8.7**	**9.2**	**9.6**	**10.0**
GLS	Reflector	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.2	0.9	0.8	0.6	0.5
	GLS (including clear/pearl, candles, coloured & decorative)	16.4	15.9	15.4	14.9	14.8	14.7	13.8	11.4	8.6	5.9	3.8	2.2
	GLS (total)	**18.2**	**17.7**	**17.1**	**16.5**	**16.4**	**16.2**	**15.1**	**12.6**	**9.5**	**6.7**	**4.4**	**2.7**
HID	All mercury lamps (including mixed)	18.3	21.4	21.4	18.3	17.2	15.9	14.6	13.3	12.1	10.9	9.1	6.7
	All sodium lamps	14.8	16.2	18.2	22.8	24.7	26.8	29.1	30.8	31.5	30.7	29.5	28.5
	Metal halide lamps	2.5	5.1	9.7	17.6	20.1	22.4	24.8	27.9	31.5	34.2	33.1	28.1
	HID (total)	**35.6**	**42.7**	**49.3**	**58.8**	**61.9**	**65.1**	**68.4**	**72.0**	**75.2**	**75.7**	**71.7**	**63.3**
LED	Directional								0.0	0.0	0.0	0.0	0.1
	Non-directional								0.0	0.0	0.0	0.1	0.3
	LED (total)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**	**0.4**
	GLS stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Tungsten stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Special Purpose Lamps	40.0	45.2	50.5	55.7	56.8	57.8	58.9	59.9	60.6	59.0	57.4	55.8
	Controls and Standby	11.2	12.7	14.2	15.6	15.9	16.2	16.5	16.8	17.0	16.6	16.1	15.7
	TOTAL	**190.8**	**212.8**	**237.6**	**271.1**	**279.5**	**287.4**	**294.6**	**300.9**	**306.0**	**305.2**	**299.3**	**289.6**

Table 25: Electrical energy for lighting, EU-28 totals per lamp subtype in TWh, years 1990, 1995, 2000, 2005 – 2013. NON-RESIDENTIAL

Energy per household (kWh/year/hh)	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
Number of households (mln)	**171.6**	**181.5**	**188.9**	**192.6**	**193.3**	**194.1**	**194.8**	**195.6**	**196.3**	**197.1**	**197.8**	**198.6**
LFL kWh/year per hh	30.1	30.6	31.4	34.0	34.7	35.4	36.1	36.6	37.0	37.3	37.4	37.2
CFL kWh/year per hh	5.8	10.0	17.4	27.5	31.7	37.4	43.6	50.2	56.3	61.4	65.1	67.6
Tungsten kWh/year per hh	36.3	125.3	142.2	159.5	160.1	158.2	158.6	166.0	184.9	206.2	225.7	238.8
GLS kWh/year per hh	422.1	390.0	362.1	342.3	338.3	333.8	310.7	266.7	216.4	172.0	141.7	120.1
LED kWh/year per hh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.8	1.4	2.1	3.2
TOTAL kWh/year/hh	**494.3**	**555.9**	**553.2**	**563.3**	**564.9**	**564.8**	**549.1**	**519.9**	**495.4**	**478.4**	**472.0**	**466.9**
of which DLS kWh/year	48.3	53.0	66.1	81.9	85.1	88.3	90.7	92.1	92.9	93.7	94.5	93.4

Table 26: Electrical energy for lighting per household, years 1990, 1995, 2000, 2005 – 2013. (in kWh/year/household)

	year 2008			year 2013		
Division of EU-28 electric energy for lighting over the technology types, year 2008 & 2013	All Sectors	Residential	Non-Residential	All Sectors	Residential	Non-Residential
LFL (total)	38%	7%	54%	43%	8%	58%
CFL (total)	6%	8%	5%	9%	14%	7%
Tungsten-HL (total)	12%	29%	4%	18%	51%	5%
GLS (total)	23%	57%	7%	9%	26%	1%
HID (total)	21%	0%	31%	20%	0%	29%
LED (total)	0%	0%	0%	0%	1%	0%
TOTAL	100%	100%	100%	100%	100%	100%

Table 27: Years 2008 and 2013, subdivision of EU-28 electrical energy for lighting over the main technology types (excluding energy for Special Purpose Lamps, Controls and Standby)

2.8. EU-28 energy cost for consumers

In MELISA the EU-28 total cost for lighting energy is computed as the product of the energy consumption (in TWh, par. 2.7) and the corresponding annual electricity price (in euros/kWh, Table 28 [18]). Costs for energy consumed by SPL, controls and standby are not included.

The energy cost is reported for **All sectors** in Figure 17, Figure 18, Table 29 and Table 30. The values for the **Residential sector** are reported in Table 31 and Figure 19; those for the **Non-residential sector** in Table 32 and Figure 20. Values are reported in billion euros, fixed euros 2010, inclusive VAT for the residential sector and exclusive VAT for non-residential.

From 1990 to 2013 the costs show fluctuations that are mainly caused by the variations in the electricity prices. In 2013 the EU-28 total lighting energy cost amounts to 43.7 billion euros. This is 0.33% of the EU-28 GDP in the same year.

In 2013, approximately 40% of the expenses is made for the residential sector (17.7/43.7 billion euros). This residential share implies an average expense for lighting energy of 89.3 euros per household per year in 2013, see Table 33.

Table 34 shows the subdivision of the EU-28 expenses for lighting energy over the lamp technology types, for the years 2008 and 2013. In 2013, 51% of the residential energy costs is for halogen lamps and 58% of the non-residential energy costs for LFL.

Considering the period 2007-2013, the **residential** electricity prices increased by 14% from 0.167 to 0.191 euros/kWh, while the total EU-28 consumer expense for lighting energy decreased by 4% from 18.3 to 17.7 billion euros. In other words, if the lighting energy consumption had remained constant, the expense in 2013 would have been 18.3*1.14 = 20.9 billion euros, while it is 17.7 billion euros: a saving of approximately 15%.

In the same period, for the **non-residential** sector, the 20% increase in electricity price from 0.099 to 0.119 euros/kWh, more or less corresponds with the 22% increase in total expense from 21.2 to 26.0 billion euros.

Residential prices of electricity (fixed euros 2010), in euros/kWh, incl. VAT									
1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
0.178	**0.188**	**0.195**	**0.188**	**0.188**	**0.181**	**0.176**	**0.173**	**0.168**	**0.163**
2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
0.162	**0.158**	**0.156**	**0.155**	**0.153**	**0.153**	**0.158**	**0.167**	**0.169**	**0.167**
2010	2011	2012	2013						
0.170	**0.177**	**0.184**	**0.191**						
Non-residential prices of electricity (fixed euros 2010), in euros/kWh, excl. VAT									
1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
0.119	**0.119**	**0.118**	**0.112**	**0.110**	**0.103**	**0.095**	**0.092**	**0.088**	**0.085**
2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
0.084	**0.083**	**0.079**	**0.083**	**0.082**	**0.087**	**0.097**	**0.099**	**0.105**	**0.107**
2010	2011	2012	2013						
0.106	**0.110**	**0.115**	**0.119**						

Table 28: Electricity prices used in MELISA, in euros/kWh, fixed euros 2010. Residential values include 20% VAT; non-residential values are exclusive VAT.

[18] For residential these prices are based on Eurostat tariff group Dc: "annual consumption of 3 500 kWh among which 1 300 kWh overnight (standard dwelling of 90m²)". For non-residential the reference was tariff group Ie: "annual consumption of 2 000 MWh, maximum demand of 500kW and annual load of 4 000 hours". These tariff group definitions are according to the old (2007) methodology.

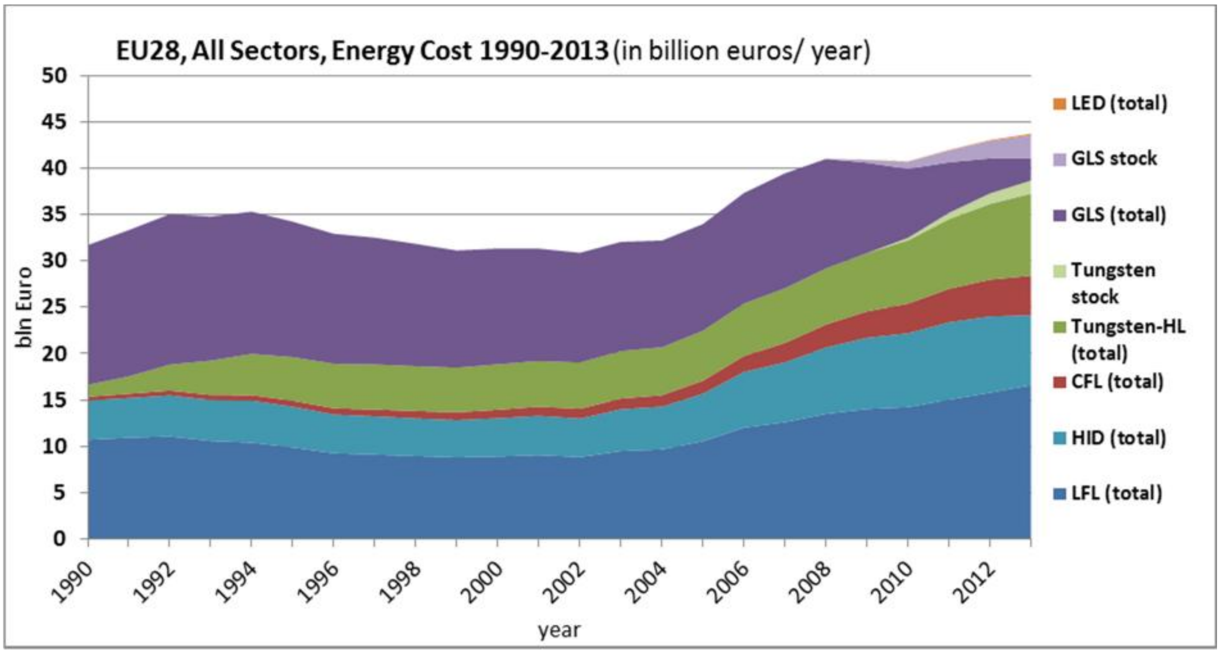


Figure 17: Consumer energy cost for lighting, EU-28 cumulative total in billion euros/year. ALL SECTORS

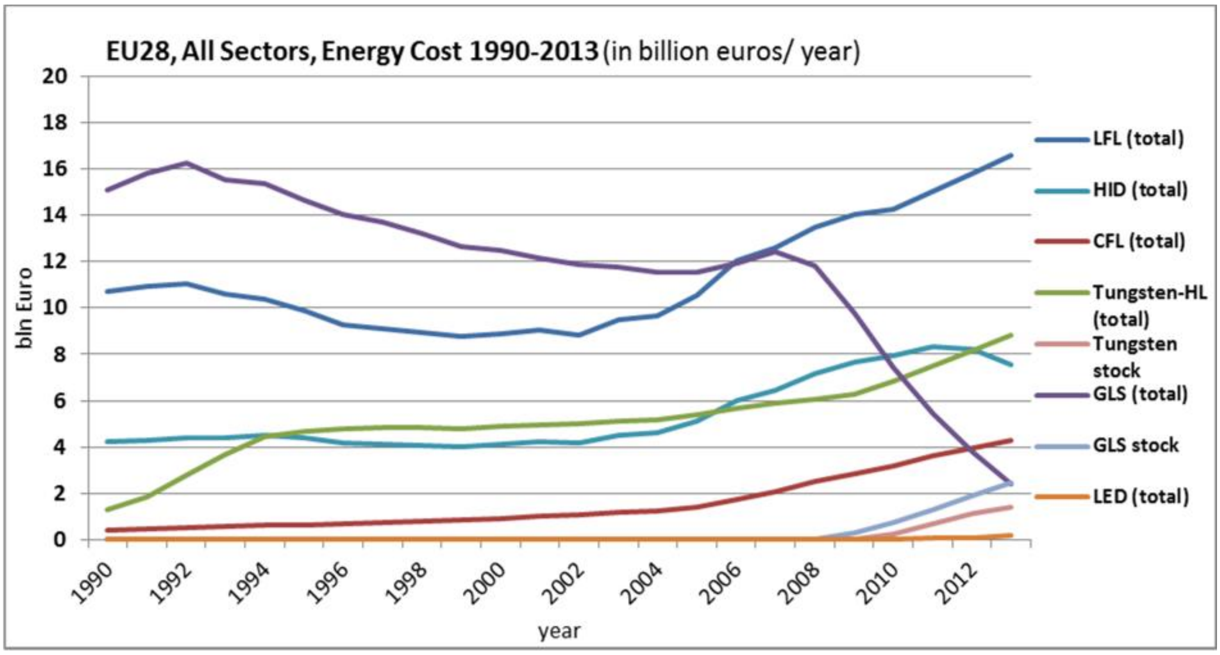


Figure 18: Consumer energy cost for lighting, EU-28 totals per lamp type in billion euros/year. ALL SECTORS

EU-28 ENERGY COST SUMMARY, All Sectors billion euros/year	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL (total)	10.7	9.9	8.9	10.5	12.0	12.6	13.5	14.0	14.2	15.0	15.8	16.6
CFL (total)	0.4	0.6	0.9	1.4	1.7	2.1	2.5	2.9	3.2	3.6	4.0	4.3
Tungsten-HL (total)	1.3	4.7	4.9	5.4	5.7	5.9	6.0	6.3	6.8	7.5	8.2	8.9
GLS (total)	15.1	14.6	12.5	11.5	11.9	12.4	11.8	9.8	7.5	5.5	3.8	2.4
HID (total)	4.2	4.4	4.1	5.1	6.0	6.5	7.2	7.7	8.0	8.3	8.2	7.5
LED (total)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2
GLS stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	1.3	1.9	2.5
Tungsten stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.1	1.4
TOTAL	**31.7**	**34.2**	**31.3**	**34.0**	**37.3**	**39.5**	**41.0**	**40.9**	**40.7**	**42.0**	**43.1**	**43.7**

Table 29: Consumer energy cost for lighting, EU-28 totals per main lamp type in billion euros, years 1990, 1995, 2000, 2005 – 2013. ALL SECTORS

EU-28 ENERGY COST TOTAL, All Sectors billion euros/year		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL	T12	3.3	2.1	1.1	0.6	0.6	0.6	0.5	0.4	0.4	0.3	0.3	0.2
	T8 halophosphor	3.5	3.8	4.0	5.0	5.5	5.5	5.5	5.1	4.2	3.2	2.1	1.2
	T8 tri-phosphor	3.4	3.5	3.4	4.1	4.8	5.2	5.8	6.5	7.2	8.5	9.9	11.2
	T5 new (14 - 80w) including circular	0.0	0.0	0.0	0.3	0.5	0.7	1.0	1.4	1.8	2.4	3.0	3.5
	All others (including T5 old types 4 - 13w and Special FL)	0.4	0.4	0.4	0.6	0.6	0.6	0.7	0.7	0.6	0.6	0.6	0.5
	LFL (total)	**10.7**	**9.9**	**8.9**	**10.5**	**12.0**	**12.6**	**13.5**	**14.0**	**14.2**	**15.0**	**15.8**	**16.6**
CFL	Retrofit - CFLi	0.1	0.3	0.5	0.8	1.0	1.3	1.6	1.9	2.1	2.4	2.7	3.0
	Non-retrofit - CFLni	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.3
	CFL (total)	**0.4**	**0.6**	**0.9**	**1.4**	**1.7**	**2.1**	**2.5**	**2.9**	**3.2**	**3.6**	**4.0**	**4.3**
TUNGSTEN (HL)	Single ended, mirrored (low voltage) [M16, M25 etc.]	0.2	0.5	0.9	1.2	1.3	1.5	1.6	1.6	1.7	1.8	1.9	2.0
	Linear (high voltage) [R7s]	0.5	3.5	3.3	3.1	3.1	2.9	2.4	2.0	1.8	1.8	1.7	1.7
	LV halogen capsule [G4, GY6.35]	0.6	0.6	0.6	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
	HV halogen capsule [G9]	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.5	0.5	0.6	0.6	0.6
	Mains halogen (substitute for GLS and Reflector)[E14, E27]	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	1.0	1.4	1.8	2.3
	Other mains halogen - PAR 16/20/ 25/ 30 Hard glass reflectors, GU10 etc.	0.0	0.0	0.2	0.4	0.5	0.7	0.8	1.0	1.1	1.3	1.5	1.6
	Tungsten-HL (total)	**1.3**	**4.7**	**4.9**	**5.4**	**5.7**	**5.9**	**6.0**	**6.3**	**6.8**	**7.5**	**8.2**	**8.9**
GLS	Reflector	1.5	1.5	1.2	1.1	1.1	1.1	1.1	0.9	0.7	0.6	0.5	0.4
	GLS (including clear/pearl, candles, coloured & decorative)	13.5	13.2	11.3	10.4	10.8	11.3	10.8	8.9	6.7	4.8	3.2	2.0
	GLS (total)	**15.1**	**14.6**	**12.5**	**11.5**	**11.9**	**12.4**	**11.8**	**9.8**	**7.5**	**5.5**	**3.8**	**2.4**
HID	All mercury lamps (including mixed)	2.2	2.2	1.8	1.6	1.7	1.6	1.5	1.4	1.3	1.2	1.0	0.8
	All sodium lamps	1.8	1.7	1.5	2.0	2.4	2.7	3.0	3.3	3.3	3.4	3.4	3.4
	Metal halide lamps	0.3	0.5	0.8	1.5	1.9	2.2	2.6	3.0	3.3	3.8	3.8	3.4
	HID (total)	**4.2**	**4.4**	**4.1**	**5.1**	**6.0**	**6.5**	**7.2**	**7.7**	**8.0**	**8.3**	**8.2**	**7.5**
LED	Directional	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	Non-directional	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	LED (total)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**	**0.1**	**0.2**
	GLS stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	1.3	1.9	2.5
	Tungsten stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.1	1.4
	TOTAL	**31.7**	**34.2**	**31.3**	**34.0**	**37.3**	**39.5**	**41.0**	**40.9**	**40.7**	**42.0**	**43.1**	**43.7**

Table 30: Consumer energy cost for lighting, EU-28 totals per lamp subtype in billion euros, years 1990, 1995, 2000, 2005 – 2013. ALL SECTORS

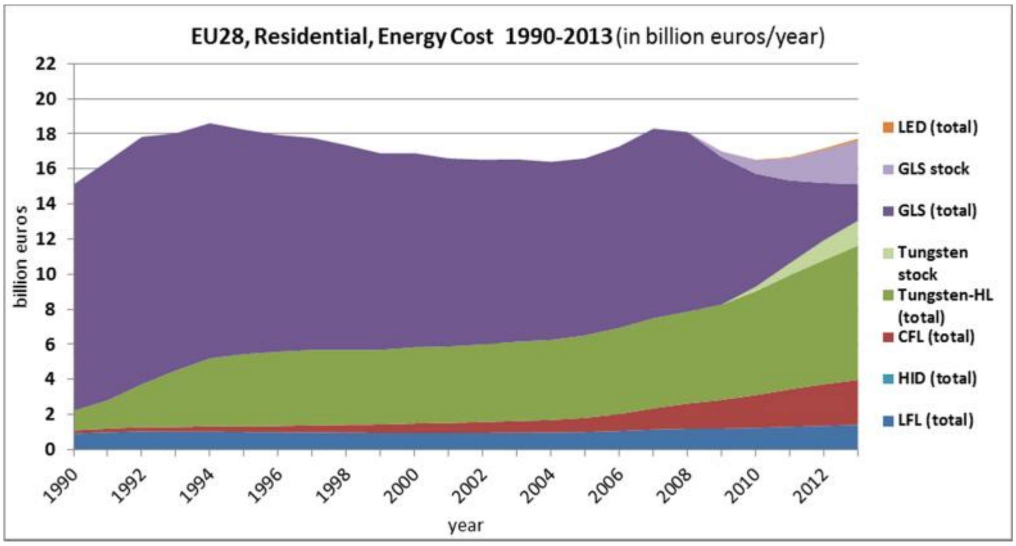


Figure 19: Consumer energy cost for lighting, EU-28 cumulative total in billion euros/year. RESIDENTIAL

EU-28 ENERGY COST RESIDENTIAL billion euros/year		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL	T12	0.3	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
	T8 halophosphor	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4
	T8 tri-phosphor	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.7	0.7
	T5 new (14 - 80w) including circular	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
	All others (including T5 old types 4 - 13w and Special FL)	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	LFL (total)	**0.9**	**1.0**	**1.0**	**1.0**	**1.1**	**1.1**	**1.2**	**1.2**	**1.2**	**1.3**	**1.4**	**1.4**
CFL	Retrofit - CFLi	0.1	0.2	0.4	0.6	0.7	0.9	1.1	1.3	1.5	1.7	1.9	2.1
	Non-retrofit - CFLni	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.5
	CFL (total)	**0.2**	**0.3**	**0.5**	**0.8**	**1.0**	**1.2**	**1.4**	**1.6**	**1.9**	**2.1**	**2.4**	**2.6**
TUNGSTEN (HL)	Single ended, mirrored (low voltage) [M16, M25 etc.]	0.2	0.4	0.8	1.1	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.7
	Linear (high voltage) [R7s]	0.5	3.1	2.9	2.8	2.7	2.5	2.1	1.7	1.6	1.5	1.5	1.5
	LV halogen capsule [G4, GY6.35]	0.5	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	HV halogen capsule [G9]	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.5	0.5	0.6
	Mains halogen (substitute for GLS and Reflector)[E14, E27]	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.9	1.2	1.6	2.0
	Other mains halogen - PAR 16/20/ 25/ 30 Hard glass reflectors, GU10 etc.	0.0	0.0	0.2	0.4	0.5	0.6	0.7	0.8	1.0	1.2	1.3	1.3
	Tungsten-HL (total)	**1.1**	**4.1**	**4.3**	**4.7**	**4.9**	**5.1**	**5.2**	**5.4**	**5.9**	**6.5**	**7.1**	**7.7**
GLS	Reflector	1.3	1.3	1.1	1.0	1.0	1.0	0.9	0.8	0.6	0.5	0.5	0.4
	GLS (including clear/pearl, candles, coloured & decorative)	11.6	11.5	10.0	9.1	9.4	9.8	9.3	7.6	5.8	4.2	2.8	1.7
	GLS (total)	**12.9**	**12.8**	**11.1**	**10.1**	**10.3**	**10.8**	**10.2**	**8.4**	**6.5**	**4.7**	**3.3**	**2.1**
HID	All mercury lamps (including mixed)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	All sodium lamps	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Metal halide lamps	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	HID (total)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
LED	Directional								0.0	0.0	0.0	0.0	0.1
	Non-directional								0.0	0.0	0.0	0.0	0.1
	LED (total)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**	**0.1**
	GLS stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	1.3	1.9	2.5
	Tungsten stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.1	1.4
	TOTAL	**15.1**	**18.2**	**16.9**	**16.6**	**17.3**	**18.3**	**18.1**	**17.0**	**16.5**	**16.7**	**17.2**	**17.7**

Table 31: Consumer energy cost for lighting, EU-28 totals per lamp subtype in billion euros, years 1990, 1995, 2000, 2005 – 2013. RESIDENTIAL

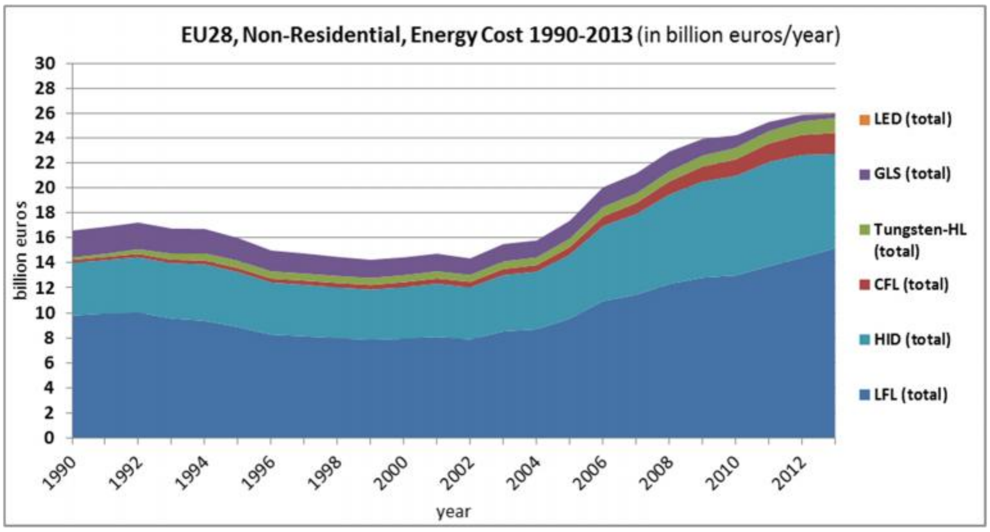


Figure 20: Consumer energy cost for lighting, EU-28 cumulative total in billion euros/year. NON-RESIDENTIAL

EU-28 ENERGY COST NON-RESIDENTIAL billion euros/year		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL	T12	3.0	1.9	0.9	0.5	0.5	0.5	0.4	0.4	0.3	0.3	0.2	0.1
	T8 halophosphor	3.2	3.4	3.6	4.5	5.0	5.0	4.9	4.5	3.7	2.7	1.6	0.7
	T8 tri-phosphor	3.2	3.2	3.0	3.7	4.4	4.7	5.3	6.0	6.7	7.9	9.3	10.5
	T5 new (14 - 80w) including circular	0.0	0.0	0.0	0.3	0.5	0.7	1.0	1.4	1.8	2.3	2.9	3.4
	All others (including T5 old types 4 - 13w and Special FL)	0.4	0.4	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5
	LFL (total)	**9.8**	**8.9**	**7.9**	**9.5**	**11.0**	**11.5**	**12.3**	**12.8**	**13.0**	**13.7**	**14.4**	**15.2**
CFL	Retrofit - CFLi	0.0	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.6	0.7	0.8	0.9
	Non-retrofit - CFLni	0.2	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.8	0.8
	CFL (total)	**0.2**	**0.3**	**0.4**	**0.6**	**0.8**	**0.9**	**1.1**	**1.2**	**1.3**	**1.5**	**1.6**	**1.7**
TUNGSTEN (HL)	Single ended, mirrored (low voltage) [M16, M25 etc.]	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3
	Linear (high voltage) [R7s]	0.1	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.2	0.2	0.2	0.2
	LV halogen capsule [G4, GY6.35]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	HV halogen capsule [G9]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
	Mains halogen (substitute for GLS and Reflector)[E14, E27]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3
	Other mains halogen - PAR 16/20/ 25/ 30 Hard glass reflectors, GU10 etc.	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
	Tungsten-HL (total)	**0.2**	**0.6**	**0.6**	**0.7**	**0.8**	**0.8**	**0.8**	**0.9**	**0.9**	**1.0**	**1.1**	**1.2**
GLS	Reflector	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	GLS (including clear/pearl, candles, coloured & decorative)	1.9	1.6	1.3	1.3	1.4	1.5	1.4	1.2	0.9	0.7	0.4	0.3
	GLS (total)	**2.2**	**1.8**	**1.4**	**1.4**	**1.6**	**1.6**	**1.6**	**1.3**	**1.0**	**0.7**	**0.5**	**0.3**
HID	All mercury lamps (including mixed)	2.2	2.2	1.8	1.6	1.7	1.6	1.5	1.4	1.3	1.2	1.0	0.8
	All sodium lamps	1.8	1.7	1.5	2.0	2.4	2.7	3.0	3.3	3.3	3.4	3.4	3.4
	Metal halide lamps	0.3	0.5	0.8	1.5	1.9	2.2	2.6	3.0	3.3	3.8	3.8	3.4
	HID (total)	**4.2**	**4.4**	**4.1**	**5.1**	**6.0**	**6.5**	**7.2**	**7.7**	**8.0**	**8.3**	**8.2**	**7.5**
LED	Directional								0.0	0.0	0.0	0.0	0.0
	Non-directional								0.0	0.0	0.0	0.0	0.0
	LED (total)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	GLS stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Tungsten stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	**16.6**	**16.0**	**14.4**	**17.4**	**20.1**	**21.2**	**22.9**	**23.9**	**24.2**	**25.3**	**25.9**	**26.0**

Table 32: Consumer energy cost for lighting, EU-28 totals per lamp subtype in billion euros, years 1990, 1995, 2000, 2005 – 2013. NON-RESIDENTIAL

Energy costs per household (euros/year/hh)	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
Number of households (mln)	**171.6**	**181.5**	**188.9**	**192.6**	**193.3**	**194.1**	**194.8**	**195.6**	**196.3**	**197.1**	**197.8**	**198.6**
LFL costs (euros) per hh	5.4	5.5	5.1	5.2	5.5	5.9	6.1	6.1	6.3	6.6	6.9	7.1
CFL costs (euros) per hh	1.0	1.8	2.8	4.2	5.0	6.2	7.4	8.4	9.6	10.9	12.0	12.9
Tungsten costs (euros) per hh	6.5	22.7	23.0	24.4	25.3	26.4	26.9	27.8	31.4	36.5	41.5	45.7
GLS costs (euros) per hh	75.3	70.5	58.6	52.4	53.5	55.7	52.6	44.6	36.8	30.4	26.1	23.0
LED costs (euros) per hh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.4	0.6
TOTAL costs (euros)/hh	**88.1**	**100.5**	**89.5**	**86.2**	**89.4**	**94.3**	**92.9**	**86.9**	**84.2**	**84.6**	**86.8**	**89.3**
of which DLS costs (euros)	8.6	9.6	10.7	12.5	13.5	14.7	15.3	15.4	15.8	16.6	17.4	17.9

Table 33: Consumer energy cost for lighting per household, years 1990, 1995, 2000, 2005 – 2013 (in euros/year/household).

	year 2008			year 2013		
Division of EU-28 energy costs for lighting over the technology types, year 2008 & 2013	All Sectors	Residential	Non-Residential	All Sectors	Residential	Non-Residential
LFL (total)	33%	7%	54%	38%	8%	58%
CFL (total)	6%	8%	5%	10%	14%	7%
Tungsten-HL (total)	15%	29%	4%	23%	51%	5%
GLS (total)	29%	57%	7%	11%	26%	1%
HID (total)	17%	0%	31%	17%	0%	29%
LED (total)	0%	0%	0%	0%	1%	0%
TOTAL	100%	100%	100%	100%	100%	100%

Table 34: Years 2008 and 2013, subdivision of EU-28 energy cost for lighting over the main technology types (excluding energy for Special Purpose Lamps, Controls and Standby)

2.9. EU-28 total consumer expense

The total consumer expense for lighting is the sum of the costs for the acquisition of new light sources (presented in par. 2.4. of the Task 2 report) and the costs for energy consumed by the installed light sources (par. 2.8). Expenses for SPL, controls and standby are not included (neither for acquisition nor for energy).

The EU-28 total consumer expense is reported for **All sectors** in Figure 21, Figure 22, Table 35 and Table 36. The values for the **Residential sector** are reported in Table 37 and Figure 23; those for the **Non-residential sector** in Table 38 and Figure 24. Values are reported in billion euros, fixed euros 2010, inclusive VAT for the residential sector and exclusive VAT for non-residential.

From 1990 to 2008 the expenses show fluctuations that are mainly caused by the variations in the electricity prices, but in general the trend is increasing. In the period 2008-2013 the total expense remains fairly constant and amounts to 54.6 billion euros in 2013. This includes 10.9 billion for acquisition costs and 43.7 billion for energy costs (Figure 25).

In 2013, approximately 43% of the total expense is made for the residential sector (23.3/54.6 billion euros). This residential share implies an average expense for lighting (acquisition plus energy use) of 117.6 euros per household per year in 2013. This is slightly less than in 2007 (119.1 billion euros), see Table 39.

Table 40 shows the subdivision of the EU-28 total expenses for lighting over the lamp technology types, for the years 2008 and 2013. In 2013, 53% of the residential costs is for halogen lamps and 57% of the non-residential costs for LFL.

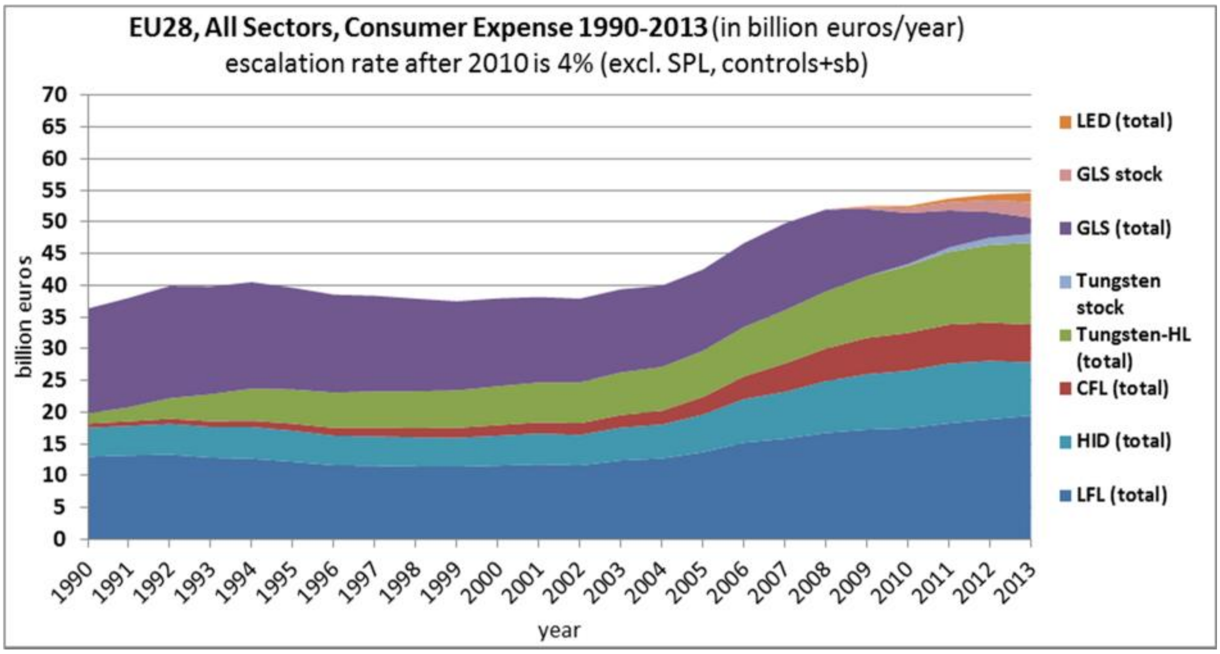


Figure 21: Total consumer expense for lighting, EU-28 cumulative total in billion euros/year. ALL SECTORS

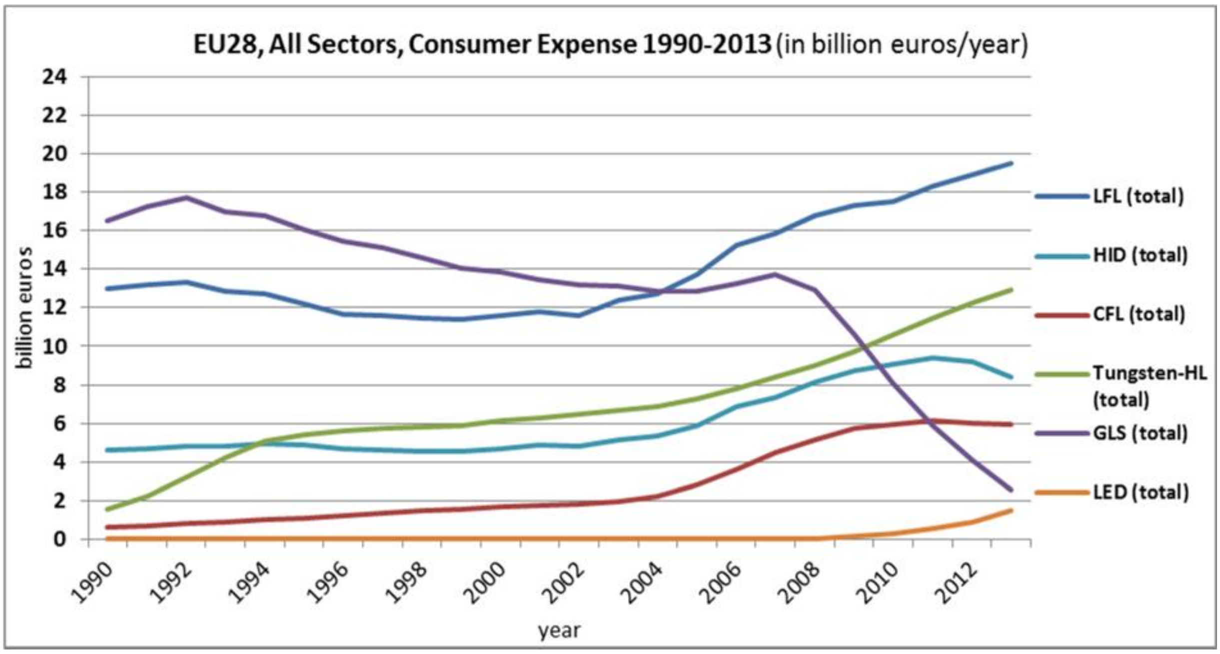


Figure 22: Total consumer expense for lighting, EU-28 totals per lamp type in billion euros/year. ALL SECTORS

EU-28 TOTAL EXPENSE SUMMARY, All Sectors	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013

billion euros/year												
LFL (total)	13.0	12.2	11.6	13.7	15.2	15.8	16.8	17.3	17.5	18.3	18.9	19.5
CFL (total)	0.7	1.1	1.7	2.8	3.6	4.5	5.2	5.7	6.0	6.1	6.0	5.9
Tungsten-HL (total)	1.6	5.4	6.1	7.3	7.8	8.4	9.0	9.7	10.6	11.5	12.3	12.9
GLS (total)	16.5	16.0	13.9	12.8	13.2	13.7	12.9	10.6	8.1	5.9	4.1	2.6
HID (total)	4.6	4.9	4.7	5.9	6.8	7.4	8.1	8.7	9.0	9.4	9.2	8.4
LED (total)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.6	0.9	1.5
GLS stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	1.3	1.9	2.5
Tungsten stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.1	1.4
TOTAL	**36.4**	**39.6**	**38.0**	**42.5**	**46.7**	**49.8**	**52.0**	**52.5**	**52.5**	**53.7**	**54.3**	**54.6**

Table 35: Total consumer expense for lighting, EU-28 totals per main lamp type in billion euros, years 1990, 1995, 2000, 2005 – 2013. ALL SECTORS

	EU-28 TOTAL EXPENSE TOTAL, All Sectors billion euros/year	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL	T12	4.0	2.5	1.3	0.8	0.7	0.7	0.6	0.5	0.4	0.4	0.3	0.2
	T8 halophosphor	4.4	4.8	5.3	6.5	6.9	6.8	6.7	6.0	4.8	3.4	2.1	1.2
	T8 tri-phosphor	4.0	4.2	4.2	5.1	5.9	6.4	7.1	7.9	9.1	10.7	12.1	13.3
	T5 new (14 - 80w) including circular	0.0	0.0	0.0	0.5	0.7	1.0	1.4	1.9	2.4	3.0	3.6	4.1
	All others (including T5 old types 4 - 13w and Special FL)	0.6	0.6	0.7	0.9	0.9	0.9	1.0	0.9	0.9	0.8	0.8	0.7
	LFL (total)	**13.0**	**12.2**	**11.6**	**13.7**	**15.2**	**15.8**	**16.8**	**17.3**	**17.5**	**18.3**	**18.9**	**19.5**
CFL	Retrofit - CFLi	0.3	0.6	1.0	1.9	2.5	3.3	3.9	4.3	4.5	4.6	4.4	4.3
	Non-retrofit - CFLni	0.4	0.5	0.7	0.9	1.0	1.2	1.3	1.4	1.5	1.6	1.6	1.7
	CFL (total)	**0.7**	**1.1**	**1.7**	**2.8**	**3.6**	**4.5**	**5.2**	**5.7**	**6.0**	**6.1**	**6.0**	**5.9**
TUNGSTEN (HL)	Single ended, mirrored (low voltage) [M16, M25 etc.]	0.3	0.7	1.2	1.7	1.8	2.0	2.1	2.2	2.2	2.3	2.5	2.6
	Linear (high voltage) [R7s]	0.6	3.8	3.6	3.4	3.4	3.1	2.6	2.2	2.0	1.9	1.9	1.8
	LV halogen capsule [G4, GY6.35]	0.7	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	HV halogen capsule [G9]	0.0	0.0	0.0	0.1	0.2	0.4	0.5	0.7	0.8	0.8	0.9	0.9
	Mains halogen (substitute for GLS and Reflector)[E14, E27]	0.0	0.0	0.0	0.0	0.0	0.1	0.5	1.0	1.5	1.9	2.4	3.1
	Other mains halogen - PAR 16/20/ 25/ 30 Hard glass reflectors, GU10 etc.	0.0	0.1	0.6	1.4	1.7	2.0	2.5	2.9	3.4	3.7	3.9	3.7
	Tungsten-HL (total)	**1.6**	**5.4**	**6.1**	**7.3**	**7.8**	**8.4**	**9.0**	**9.7**	**10.6**	**11.5**	**12.3**	**12.9**
GLS	Reflector	1.8	1.7	1.4	1.3	1.3	1.3	1.2	1.0	0.8	0.7	0.6	0.5
	GLS (including clear/pearl, candles, coloured & decorative)	14.8	14.4	12.4	11.5	11.9	12.4	11.7	9.6	7.2	5.2	3.4	2.1
	GLS (total)	**16.5**	**16.0**	**13.9**	**12.8**	**13.2**	**13.7**	**12.9**	**10.6**	**8.1**	**5.9**	**4.1**	**2.6**
HID	All mercury lamps (including mixed)	2.3	2.4	1.9	1.7	1.8	1.7	1.6	1.5	1.4	1.3	1.1	0.8
	All sodium lamps	2.0	1.9	1.8	2.3	2.7	3.0	3.5	3.7	3.8	3.8	3.8	3.8
	Metal halide lamps	0.3	0.6	1.0	1.9	2.3	2.6	3.0	3.5	3.9	4.4	4.3	3.8
	HID (total)	**4.6**	**4.9**	**4.7**	**5.9**	**6.8**	**7.4**	**8.1**	**8.7**	**9.0**	**9.4**	**9.2**	**8.4**
LED	Directional	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.5	0.6
	Non-directional	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.8
	LED (total)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.2**	**0.3**	**0.6**	**0.9**	**1.5**
	GLS stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	1.3	1.9	2.5
	Tungsten stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.1	1.4
	TOTAL	**36.4**	**39.6**	**38.0**	**42.5**	**46.7**	**49.8**	**52.0**	**52.5**	**52.5**	**53.7**	**54.3**	**54.6**

Table 36: Total consumer expense for lighting, EU-28 totals per lamp subtype in billion euros, years 1990, 1995, 2000, 2005 – 2013. ALL SECTORS

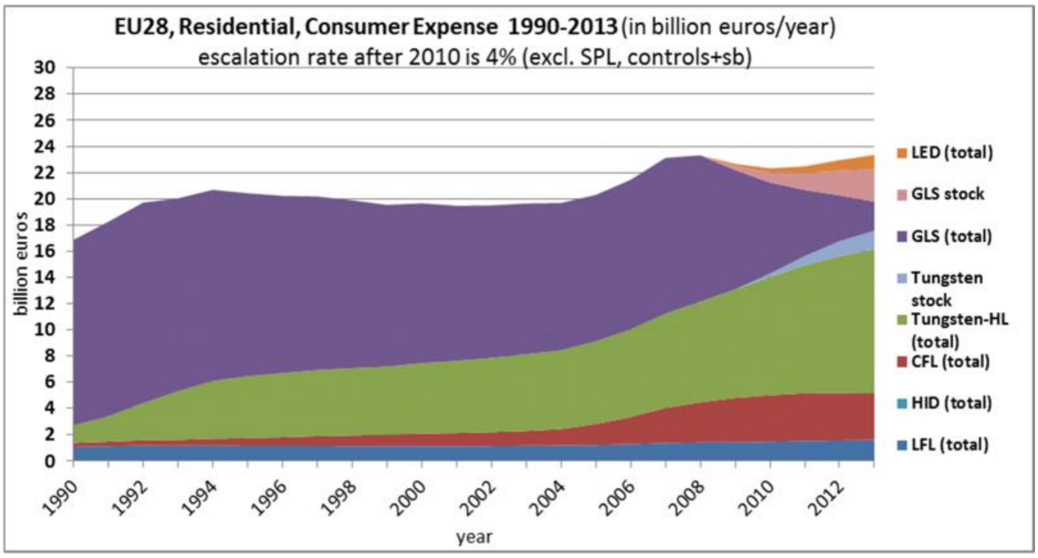


Figure 23: Total consumer expense for lighting, EU-28 cumulative total in billion euros/year. RESIDENTIAL

EU-28 TOTAL EXPENSE RESIDENTIAL billion euros/year		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL	T12	0.4	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
	T8 halophosphor	0.4	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.4
	T8 tri-phosphor	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8	0.9
	T5 new (14 - 80w) including circular	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2
	All others (including T5 old types 4 - 13w and Special FL)	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	LFL (total)	**1.1**	**1.2**	**1.2**	**1.2**	**1.3**	**1.4**	**1.4**	**1.4**	**1.5**	**1.5**	**1.6**	**1.6**
CFL	Retrofit - CFLi	0.2	0.4	0.7	1.3	1.7	2.2	2.6	2.9	3.0	3.1	3.0	2.9
	Non-retrofit - CFLni	0.1	0.2	0.2	0.3	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.6
	CFL (total)	**0.3**	**0.6**	**0.9**	**1.6**	**2.1**	**2.7**	**3.0**	**3.4**	**3.5**	**3.6**	**3.6**	**3.5**
TUNGSTEN (HL)	Single ended, mirrored (low voltage) [M16, M25 etc.]	0.2	0.6	1.0	1.5	1.6	1.7	1.8	1.8	1.9	2.0	2.1	2.2
	Linear (high voltage) [R7s]	0.5	3.3	3.1	3.0	2.9	2.7	2.2	1.9	1.7	1.6	1.6	1.6
	LV halogen capsule [G4, GY6.35]	0.6	0.7	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.6
	HV halogen capsule [G9]	0.0	0.0	0.0	0.0	0.1	0.3	0.5	0.6	0.7	0.7	0.8	0.8
	Mains halogen (substitute for GLS and Reflector)[E14, E27]	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	1.3	1.6	2.1	2.6
	Other mains halogen - PAR 16/20/ 25/ 30 Hard glass reflectors, GU10 etc.	0.0	0.1	0.5	1.2	1.4	1.7	2.1	2.5	2.8	3.1	3.3	3.1
	Tungsten-HL (total)	**1.3**	**4.7**	**5.4**	**6.3**	**6.7**	**7.2**	**7.7**	**8.3**	**9.0**	**9.8**	**10.5**	**11.0**
GLS	Reflector	1.5	1.5	1.3	1.1	1.1	1.1	1.0	0.9	0.7	0.6	0.5	0.4
	GLS (including clear/pearl, candles, coloured & decorative)	12.6	12.5	10.9	10.1	10.3	10.7	10.1	8.2	6.2	4.5	3.0	1.8
	GLS (total)	**14.1**	**14.0**	**12.2**	**11.2**	**11.4**	**11.9**	**11.2**	**9.1**	**7.0**	**5.1**	**3.5**	**2.2**
HID	All mercury lamps (including mixed)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	All sodium lamps	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Metal halide lamps	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	HID (total)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
LED	Directional								0.1	0.2	0.3	0.5	0.5
	Non-directional								0.0	0.1	0.2	0.3	0.5
	LED (total)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.2**	**0.3**	**0.5**	**0.8**	**1.1**
	GLS stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	1.3	1.9	2.5
	Tungsten stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.1	1.4
	TOTAL	**16.9**	**20.4**	**19.7**	**20.3**	**21.5**	**23.1**	**23.3**	**22.7**	**22.3**	**22.5**	**23.0**	**23.3**

Table 37: Total consumer expense for lighting, EU-28 totals per lamp subtype in billion euros, years 1990, 1995, 2000, 2005 – 2013. RESIDENTIAL

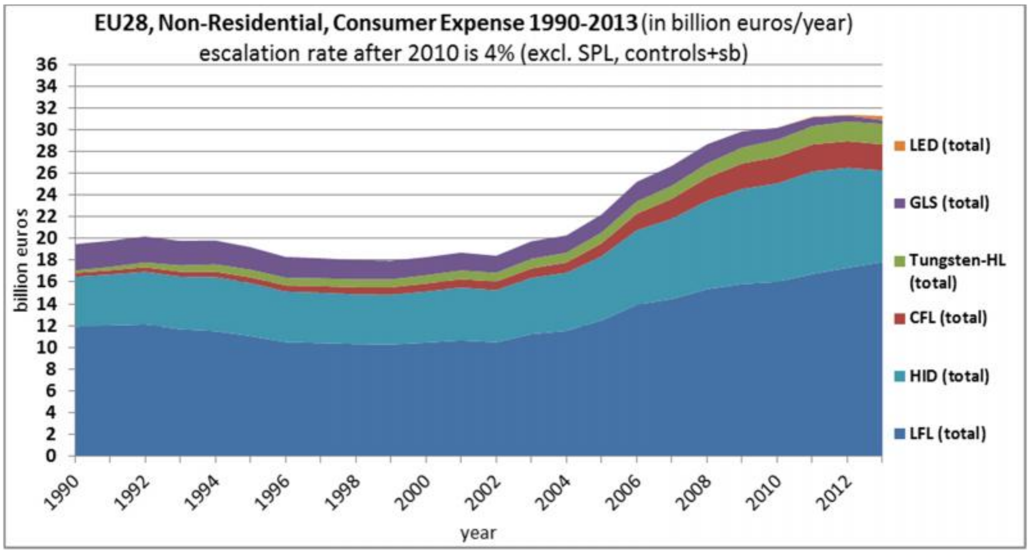


Figure 24: Total consumer expense for lighting, EU-28 cumulative total in billion euros. NON-RESIDENTIAL

EU-28 TOTAL EXPENSE NON-RESIDENTIAL billion euros/year		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
LFL	T12	3.6	2.2	1.1	0.6	0.6	0.6	0.5	0.4	0.3	0.3	0.2	0.2
	T8 halophosphor	4.0	4.4	4.8	5.9	6.3	6.2	6.1	5.4	4.2	2.9	1.6	0.8
	T8 tri-phosphor	3.7	3.8	3.8	4.7	5.4	5.9	6.5	7.3	8.4	9.9	11.3	12.4
	T5 new (14 - 80w) including circular	0.0	0.0	0.0	0.4	0.7	1.0	1.4	1.8	2.3	2.9	3.5	3.9
	All others (including T5 old types 4 - 13w and Special FL)	0.5	0.6	0.7	0.8	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.6
	LFL (total)	**11.9**	**11.0**	**10.4**	**12.5**	**13.9**	**14.4**	**15.3**	**15.8**	**16.0**	**16.7**	**17.3**	**17.8**
CFL	Retrofit - CFLi	0.1	0.2	0.3	0.6	0.8	1.1	1.3	1.4	1.5	1.5	1.4	1.3
	Non-retrofit - CFLni	0.3	0.3	0.4	0.6	0.7	0.7	0.8	0.9	1.0	1.0	1.1	1.1
	CFL (total)	**0.4**	**0.5**	**0.7**	**1.2**	**1.5**	**1.8**	**2.1**	**2.4**	**2.4**	**2.5**	**2.5**	**2.4**
TUNGSTEN (HL)	Single ended, mirrored (low voltage) [M16, M25 etc.]	0.0	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4
	Linear (high voltage) [R7s]	0.1	0.5	0.4	0.4	0.5	0.4	0.4	0.3	0.3	0.3	0.3	0.3
	LV halogen capsule [G4, GY6.35]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	HV halogen capsule [G9]	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Mains halogen (substitute for GLS and Reflector)[E14, E27]	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.4
	Other mains halogen - PAR 16/20/ 25/ 30 Hard glass reflectors, GU10 etc.	0.0	0.0	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.6
	Tungsten-HL (total)	**0.2**	**0.7**	**0.8**	**1.0**	**1.1**	**1.2**	**1.3**	**1.5**	**1.6**	**1.7**	**1.8**	**1.9**
GLS	Reflector	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
	GLS (including clear/pearl, candles, coloured & decorative)	2.2	1.9	1.5	1.5	1.6	1.6	1.6	1.3	1.0	0.7	0.5	0.3
	GLS (total)	**2.4**	**2.1**	**1.7**	**1.7**	**1.8**	**1.8**	**1.8**	**1.5**	**1.1**	**0.8**	**0.6**	**0.4**
HID	All mercury lamps (including mixed)	2.3	2.4	1.9	1.7	1.8	1.7	1.6	1.5	1.4	1.3	1.1	0.8
	All sodium lamps	2.0	1.9	1.8	2.3	2.7	3.0	3.5	3.7	3.8	3.8	3.8	3.8
	Metal halide lamps	0.3	0.6	1.0	1.9	2.3	2.6	3.0	3.5	3.9	4.4	4.3	3.8
	HID (total)	**4.6**	**4.9**	**4.7**	**5.9**	**6.8**	**7.4**	**8.1**	**8.7**	**9.0**	**9.4**	**9.2**	**8.4**
LED	Directional								0.0	0.0	0.0	0.0	0.1
	Non-directional								0.0	0.0	0.0	0.0	0.3
	LED (total)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**	**0.1**	**0.4**
	GLS stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Tungsten stock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	**19.5**	**19.2**	**18.3**	**22.2**	**25.2**	**26.7**	**28.7**	**29.9**	**30.2**	**31.2**	**31.4**	**31.3**

Table 38: Total consumer expense for lighting, EU-28 totals per lamp subtype in billion euros, years 1990, 1995, 2000, 2005 – 2013. NON-RESIDENTIAL

Expense per household (euros/year/hh)	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
Number of households (mln)	**171.6**	**181.5**	**188.9**	**192.6**	**193.3**	**194.1**	**194.8**	**195.6**	**196.3**	**197.1**	**197.8**	**198.6**
LFL costs (euros) per hh	6.4	6.5	6.2	6.5	6.8	7.2	7.4	7.4	7.6	7.8	8.1	8.2
CFL costs (euros) per hh	1.8	3.3	5.0	8.3	10.7	13.7	15.6	17.2	18.0	18.4	18.1	17.8
Tungsten costs (euros) per hh	7.8	25.8	28.3	32.6	34.4	37.1	39.4	42.3	47.3	53.0	58.6	62.5
GLS costs (euros) per hh	82.3	76.9	64.5	58.0	59.1	61.2	57.3	48.1	39.3	32.1	27.2	23.6
LED costs (euros) per hh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	1.6	2.6	4.1	5.5
TOTAL costs (euros)/hh	**98.3**	**112.6**	**104.1**	**105.4**	**111.0**	**119.1**	**119.7**	**115.9**	**113.7**	**114.0**	**116.0**	**117.6**
of which DLS costs (euros)	10.1	11.7	15.0	19.5	21.2	23.6	25.4	27.2	28.9	30.7	32.1	32.0

Table 39: Total consumer expense for lighting per household, years 1990, 1995, 2000, 2005 – 2013 (in euros/year/household).

	year 2008			year 2013		
Division of EU-28 consumer expense for lighting over the technology types, year 2008 & 2013	All Sectors	Residential	Non-Residential	All Sectors	Residential	Non-Residential
LFL (total)	32%	6%	54%	36%	7%	57%
CFL (total)	10%	13%	7%	11%	15%	8%
Tungsten-HL (total)	17%	33%	5%	26%	53%	6%
GLS (total)	25%	48%	6%	9%	20%	1%
HID (total)	16%	0%	28%	15%	0%	27%
LED (total)	0%	0%	0%	3%	5%	1%
TOTAL	100%	100%	100%	100%	100%	100%

Table 40: Years 2008 and 2013, subdivision of EU-28 total consumer expense for lighting over the main technology types (excluding energy for Special Purpose Lamps, Controls and Standby)

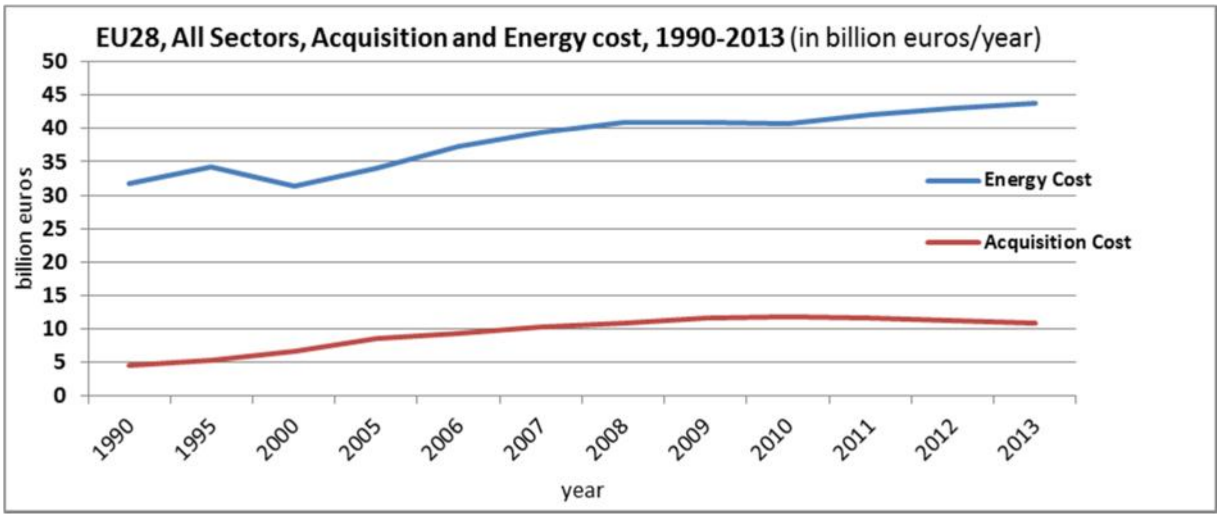


Figure 25: Acquisition cost and Energy cost for lighting, EU-28 totals in billion euros/year. ALL SECTORS

3. DATA ON LIGHTING ENERGY PARAMETERS

3.1. Introduction

This chapter presents information from various sources on the basic parameters used for the estimate of energy consumption by lighting, such as operating hours, average power, luminous flux and efficacy. The reported data form the basis for the data currently used in MELISA. The data are also used to perform an auto-critical examination of the MELISA data as compared to the most recent data sources.

In addition, this chapter presents general characteristic lighting data that can be used to verify the reasonability of the outcomes of MELISA. This includes for example:

- the installed number of light sources per household (hh),
- the average annual energy consumption for lighting per household (kWh/hh/year),
- the average annual energy consumption density per unit of building area (kWh/m^2/year),
- the installed lighting capacity density (lm/m^2).

The verification of the outcomes of MELISA against these general characteristic data is considered to be an essential aspect of the model.

3.2. Operating hours

3.2.1. Definition of operating hours for lighting

The operating hours for lighting as implemented in MELISA are full-power equivalent hours per year (h/a). This means that multiplying the installed lighting power (kW) with these hours will yield the annual electric energy consumption (kWh/a). It also implies that the effects of dimming are included in these hours. For example: a lamp that is used at full power for 250 hours/year and dimmed at half power for additional 400 hours would have 250 + 400/2 = 450 operating hours/year in the sense of MELISA.

In some occasions other definitions for operating hours are used in literature. For example the proposed standard for lighting in buildings (prEN15193 [19]) presents default operating hours per type of building (Annex I.1), but these "*values are based on the estimated time people are likely to occupy or be in the premises and will require some form of illumination*". These hours are calculated based on the hours of activity in the building (working hours), and on astronomical calculations as regards the potential availability of daylight and the subdivision in daytime hours and night-time hours [20]. During these hours the required lighting may be fully or partially provided by daylight instead of artificial light. In addition artificial lighting might be dimmed or switched off because of the observed non-occupancy of the rooms. For the determination of the real operating hours for artificial lighting to be used in energy calculations, the prEN15193 potential operating hours are significantly reduced by means of daylight dependent factors and occupancy dependent factors. Consequently the default operating hours presented in prEN15193 are not comparable to those in MELISA [21].

[19] Draft prEN 15193-1/-2 "Energy performance of buildings – Module M9 – Energy requirements for lighting – Part 1: 'Specifications' and Part 2: 'Technical report to EN 15193-1', CEN/TC 169, August 2014.

[20] prEN 15193-1:2014 annex F.7

[21] In its comments on the Task 0-3 reports, IALD states: "A methodology for determining operating hours is already established in EN15193 (LENI calculations). In view of avoiding potential situations where compliance with one regulation prevents compliance with the other, the IALD would recommend that MELISA uses the LENI calculation methodology to determine operating hours."

In other occasions literature sources report the total annual time during which at least one of the light sources in a building or room was switched on. Also these values are not comparable to those used in MELISA.

3.2.2. Standby hours

The energy consumption of lighting products such as ballasts, control gears, dimmers, sensors, etc., during the periods when the connected light sources are not producing any light, is usually computed as the product of the standby power and the standby hours. The latter are typically estimated as (8760 – operating hours) [22] . This is not correct if the operating hours are full-power equivalent hours that include hours when light was dimmed: standby hours would then be overestimated. So some care is necessary in establishing the standby hours where dimming hours are significant [23].

3.2.3. Lighting operating hours for the residential sector

The energy consumption for lighting in the residential sector has been studied in several measurement campaigns:

- United Kingdom 2012 [24] (Annex C.1)
- Sweden 2009 [25] (Annex C.2)
- REMODECE 2008 [26] (Annex C.3)
- France 2003 [27] (Annex C.4)
- EURECO 2002 [28] (Annex C.5)

Based on the information in the corresponding reports, the study team derived annual operating hours for lighting in the residential sector as presented in

Table 41.

MELISA uses 450 h/a for halogen and incandescent lamps and 500 h/a for CFLi and LED, which includes a contribution from the rebound effect (par. 3.2.5) [29]. This corresponds well to the outcome of the REMODECE project.

In the 2009 preparatory study by VITO [30], 400 h/a was used for incandescent lamps, 500 h/a for low voltage halogens, and 450 h/a for other halogens. For CFLi that study used 800 h/a, but considering that

[22] 8760 is the total number of hours in a year: 365 days times 24 hours per day. Operating hours are then intended as the period during which the light sources do produce light.

[23] In prEN15193 this does not seem to be handled correctly.

[24] Household Electricity Survey. A study of domestic electrical product usage. Intertek R66141 Final report issue 4, May 2012, chapter 12, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/208097/10043_R66141HouseholdElectricitySurveyFinalReportissue4.pdf

[25] The SWE400 project, End-use metering campaign in 400 households in Sweden, Assessment of the Potential Electricity Savings, CONTRACT 17-05-2743, 2009. http://www.energimyndigheten.se/Global/Statistik/F%C3%B6rb%C3%A4ttrad%20energistatistik/Festis/Final_report.pdf

[26] http://remodece.isr.uc.pt/downloads/REMODECE_PublishableReport_Nov2008_FINAL.pdf
http://remodece.isr.uc.pt/downloads/REMODECE_D10_Nov2008_Final.pdf
http://remodece.isr.uc.pt/downloads/REMODECE_D9_Nov2008_Final.pdf

[27] The Lighting Campaign (also referred to as Eclairage 100), as reported in http://remodece.isr.uc.pt/downloads/REMODECE_Review_monitoring%20campaign_D2.pdf.

[28] End-use metering campaign in 400 households of the European Community - Assessment of the Potential Electricity Savings – EURECO project 2002 http://www.eerg.it/resource/pages/it/Progetti_-_MICENE/finalreporteureco2002.pdf

[29] For household use of LFL and CFLni the MELISA model uses 700 h/a, but these lamp types have a minor impact in the residential sector.

[30] Preparatory Studies for Eco-design requirements of EuPs, Final Report, Lot 19: Domestic lighting, Study for the European Commission DGTREN unit D3, contact Andras Toth, by VITO in cooperation with Bio Intelligence Service, Energy Piano and Kreios, October 2009, Contract TREN/07/D3/390-2006/S07.72702, available through 'eup4light.net'. Part 1 table 2-27; part 2 table 2-15.

these lamps now mainly substitute halogen and incandescent lamps, similar operating hours (500 h/a) were assumed for the MELISA model.

In its comments on the task 0-3 reports, IALD recommends a new study on domestic lighting, beyond the DEFRA 2012 and REMODECE 2008 studies, in order to better evaluate the effects of the eco-design measures taken.

Residential Measurement campaign	Operating hours per year
United Kingdom 2012	394
Sweden 2009	515 – 567 [31]
REMODECE 2008	459 [32]
France 2003	224
EURECO 2002	425 – 576 [33]

Table 41 Residential annual operating hours for lighting (hours/year) resulting from measurement campaigns in various European countries between 2002 and 2012. These are full-power equivalent hours. Derived by the study team from information in the cited references.

3.2.4. Lighting operating hours for the non-residential sector

The energy consumption for lighting in the non-residential sector has been studied in several measurement campaigns (see references in the Annexes):

- IEE EL-Tertiary project 2008 (Annex D.1)
- France, supermarket 2001 (Annex D.2)
- France, high-school 2003 (Annex D.3)
- France, office building Strasbourg 2005 (Annex D.4)
- France, PACA region, 49 office buildings 2005 (Annex D.5)
- France, recently constructed office building 2009 (Annex D.6)

With the exception of the EL-Tertiary project, that covered 12 countries, these measurement campaigns have all been performed by Enertech in France.

Based on the information in the corresponding reports, the study team derived annual operating hours for lighting in the non-residential sector as presented in Table 42. These data are all for the tertiary sector, e.g. industry and street lighting are not covered.

Notwithstanding this collected information, as also concluded in the EL-Tertiary project, there is still a severe lack of data on lighting operating hours in the non-residential sector. The data that are available show a large spread between different building types (3984 h/a for a supermarket; 1018 h/a for a high-school) but also between buildings of the same type (1383 h/a or 2226 h/a for office buildings). Even for the same room/zone type the spread in annual hours is very large. For example the EL-Tertiary project, for circulation areas (corridors, stairs, entrance halls), found less than 180 h/a for 25% of the areas but

[31] The lower value is for houses; the higher value for apartments

[32] Covers 12 countries. See Annex C.3 for a subdivision per country. The high value for Bulgaria (932 h/a) and the low value for the Czech republic (98 h/a) do not seem reliable. Not surprisingly, the Nordic countries Denmark and Norway show operating hours above the average (637 and 752 h/a). However, for the southern countries the operating hours are not always low: Portugal 209 h/a, but Greece 420 h/a and Italy 529 h/a. Considering its geographical location, the 295 h/a for France seem on the low side, but the low operating hours are confirmed by a 2003 study (Annex C.4).

[33] Covers 4 countries. Denmark: 576 h/a, Italy: 425 h/a, Greece: 564 h/a, Portugal 653 h/a. According to the EURECO report, the Portuguese data are probably not reliable; they are also in contrast with the 209 h/a found in the later REMODECE project.

more than 1370 h/a for another 25%. The French 2005 study on 49 office buildings reports an average of 2740 h/a for corridors.

As presented in par. 2.3 and par. 2.6. of the Task 2 report, MELISA uses 2200 h/a for LFL, which is the main lamp type used in the indoor non-residential sector, and 4000 h/a for HID-lamps that are mainly used in outdoor applications (street lighting). For other lamp types see par. 2.3.
The MELISA operating hours for LFL are in line with those used in the 2007 preparatory study on office lighting [34] that used from 2000 to 2500 h/a depending on the type of control system (presence detection and dimming). The validity of the 2200 h/a value for the entire non-residential sector is uncertain, but in absence of better data it is considered to be a reasonable estimate.
The 4000 h/a for HID-lamps is related to the average period of absence of daylight in the EU-28 and should be a reasonable estimate in absence of presence detection systems for additional switching and dimming control. The same value was used in the 2007 preparatory study on street lighting [35].

Annex I.1 reports the default lighting operating hours from prEN15193, but as explained in par. 3.1, these are potential burning hours rather than real burning hours.

Non-Residential Measurement campaign	Type of building or room/zone type	Operating hours per year
EL-Tertiary project 2008	Offices (60) [36]	750 – 850 – 1080 [36]
	Conference rooms (16)	150 – 200 – 250
	Classrooms (20)	480 – 870 – 2000
	Toilets, sanitary (32)	150 – 280 - 600
	Circulation areas (80)	180 – 800 - 1370
	Service, tech, archives (42)	50 -80 -100
	Gymnasium, sports (11)	650 – 1350 - 1550
Office buildings (FR, 2005)	Single offices	1155
(average of 49 buildings)	Open offices	2513
	Floor lamps near desks	767
	Desk lamps	489
	Corridors	2740
	Stairs	1125
	Archives	1053
	Printing/copying rooms	1970
	Service rooms	1443
	Canteens/restaurants [37]	1653
	Kitchen zones [37]	538
	Conference rooms	530

[34] Preparatory Studies for Eco-design requirements of EuPs, Final Report, Lot 8: Office lighting, Study for the European Commission DGTREN unit D3, contact Andras Toth, by VITO in cooperation with Laborelec and Kreios, April 2007, Contract TREN/D1/40-2005/LOT8/S07.56452, available through 'eup4light.net', table 43

[35] Preparatory Studies for Eco-design requirements of EuPs, Final Report, Lot 9: Public Street lighting, Study for the European Commission DGTREN unit D3, contact Andras Toth, by VITO in cooperation with Laborelec and Kreios, January 2007, Contract TREN/D1/40-2005/LOT9/S07.56457, available through 'eup4light.net', paragraph 3.1.2.

[36] For the EL-Tertiary project the 25%, 50%, 75% quartile values are reported. The number of measurements is reported between brackets in the room type column. For example, for offices, 25% of the 60 rooms have operating hours less than 750, 50% less than 850, and 75% less than 1080 h/a.

[37] In the monitored office buildings

Non-Residential Measurement campaign	Type of building or room/zone type	Operating hours per year
	Sanitary, toilets	669-711
	Sanitary, washbasins	1084
	Entire building (average)	1383
Supermarket (FR, 2001)	Entire building [38]	3984
High-school (FR, 2003)	Entire building [39]	1018
Office building (FR, 2005)	Entire building [40]	2226
Office building (FR, 2009)	Entire building	Not available
IEA 2006 [41] (data 2000)	Commercial buildings	1781

Table 42 Annual operating hours for lighting (hours/year) for non-residential buildings (tertiary sector) resulting from measurement campaigns performed between 2001 and 2009. These are full-power equivalent hours. Derived by the study team from information in the cited references.

3.2.5. Rebound effect

Energy efficient light sources lead to lower costs for lighting energy consumption. In response, consumers seem to have the tendency to increase the operating times, to install a higher number of lamps, and/or to increase the average luminous flux of the lamps. This tendency is usually referred to as the direct rebound effect.

There may also be indirect rebound effects, in the lighting sector itself (new applications such as smart lamps and use of lamps for data transmission), or in other sectors (cost savings on lighting being used to buy other energy consuming products).

At least in part, this potential tendency could be balanced by an increased consumer awareness of the possibilities, and of the global environmental need to reduce energy consumption.

The 2008 REMODECE survey found that, depending on the country, from 5 to 30% of the persons declared that they operate energy efficient CFL's for longer times than the more energy consuming incandescent lamps that they substituted.

In 2012 Schleich et al. [42] performed a representative survey of more than 6000 private households in Germany with the aim to quantify the direct rebound effect as regards higher operating times and higher luminous flux. They did not consider the increase in number of lighting points. The main results of this study are:

- The average switch from incandescent or halogen to CFL or LED has a **rebound effect of 6%**, of which 60% is in increased luminosity and 40% in increased burning hours.
- Considering the main lamp in the living or dining room, the same switch has a rebound effect of 3%, of which 40% is in increased luminosity and 60% in increased burning hours.

In MELISA a rebound effect is currently implemented as regards the operating hours for CFLi and LED in the residential sector: 450 h/a is used for incandescent and halogen lamps, while 500 h/a is applied for CFLi and LED. This implies a rebound effect of more than 10% which could be excessive considering the study of Schleich.

[38] Annex D.2 provides a table with a breakdown per type of room/zone.
[39] Annex D.3 provides a table with a breakdown per type of room/zone.
[40] Annex D.4 provides a table with a breakdown per type of room/zone.
[41] LIGHT'S LABOUR'S LOST, Policies for Energy-efficient Lighting, OECD/IEA, 2006
[42] Schleich, J., et al., A brighter future? Quantifying the rebound effect in energy efficient lighting. Energy Policy (2014), http://dx.doi.org/10.1016/j.enpol.2014.04.028. Includes further references on the topic.

3.3. Lifetimes

3.3.1. Introduction and definitions

For consumers the lifetime of light sources is relevant in relation to the payback period for an investment in energy efficient lighting equipment [43] and in relation to the maintenance costs [44].

In the MELISA model the lifetimes are relevant because the installed number of light sources in a given year is computed from the sales over 'x' preceding years, where 'x' is the average lifetime in years assumed for the lamp type (see Task 2 report par. 2.7).

The lifetimes of light sources are originally expressed in burning hours. Dividing by the full-power equivalent operating hours per year (par. 3.2), the lifetime in years is obtained. The lifetimes currently used in MELISA have been reported in the Task 2 report par. 2.6.

The end-of-life of a light source can occur either as a catastrophic failure (the lamp ceases to emit light) or as a degradation of the amount of emitted light below a defined threshold. The following related definitions from the existing lighting regulations are recalled from the Task 1 report [45]:

> *'Lamp lifetime' means the period of operating time after which the fraction of the total number of lamps which continue to operate corresponds to the lamp survival factor of the lamp under defined conditions and switching frequency. For LED lamps, lamp lifetime means the operating time between the start of their use and the moment when only 50 % of the total number of lamps survive or when the average lumen maintenance of the batch falls below 70 %, whichever occurs first.*
>
> *'Lamp lumen maintenance factor' (LLMF), means the ratio of the luminous flux emitted by the lamp at a given time in its life to the initial luminous flux [46].*
>
> *'Lamp survival factor' (LSF), means the defined fraction of the total number of lamps that continue to operate at a given time under defined conditions and switching frequency.*

For the currently applicable measurement standards regarding lifetime, LLMF and LSF, see the Task 1 report and the applicable Commission communications [47]. As remarked in par 4.1.2 of the Task 1 report:

> *Currently, proving the claimed life of the lamp involves ageing a set of lamps to the claimed lifetime and checking that at least 50% of the samples have survived. Thus, this test actually proves the claimed median life of the lamp model. It could be argued that consumers expect that the claimed lamp life, as printed on the product packaging, is a minimum expected lifetime, or a mean lifetime. Consumers may be surprised to learn that a claimed lifetime of 10,000 hours means that, even under ideal laboratory conditions, only half of the lamps will survive to 10,000 hours.*
>
> *Additionally, lifetime testing of lamps is undertaken under ideal laboratory conditions of voltage and temperature, which may mean that, under real-world conditions, actual lamp lifetime is shorter.*

The actual lifetime of light sources depends on:

- Lamp type (technology, power/lumen, special designs)

---

[43] The payback period should be shorter than the lifetime of the product.

[44] Shorter lifetimes imply the need for more frequent substitution of the light sources and thus higher maintenance/installation costs.

[45] For luminaires and lighting systems, the Luminaire Maintenance Factor (LMF) and the Room Surface Maintenance Factor are also relevant, see definitions in the Task 1 report.

[46] In regulation 244/2009 it is specified that 'initial' means 100 hours, but this is not present in later definitions.

[47] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2014:022:0017:0031:EN:PDF
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2010:092:0011:0014:EN:PDF

- Operating temperature in real life conditions [48]
- Presence of shocks or vibrations
- Other environmental conditions (humidity, marine conditions, dust and dirt)
- Level and quality of the power supply (12V/110V/230V, voltage peaks)
- Switching cycles (number of switches, on/off times (3h or 12h cycle), method of starting)
- Type of ballast/control gear, if present.

For the design of light sources, a trade-off may be necessary between lifetime on the one hand, and lamp performance characteristics on the other hand, e.g. a halogen lamp can be designed to have a higher lifetime but this will reduce its efficacy [49]. Another example is that the market currently offers LFL T5 high-efficiency lamps with 112 lm/W and lifetimes up to 36,000 hours, and high-output lamps with 102 lm/W and lifetimes up to 60,000 hours (Annex E.3).

As regards **LED lighting products**, the lifetime aspects are handled in the performance standards IEC 62717 (LED modules) and IEC 62722-2-1 (Luminaires, particular requirements for LEDs). The lifetime is defined by a combination of lumen maintenance and catastrophic failure:

- The '**rated or useful life L_x**', is defined as the number of burning hours after which the luminous flux has degraded to x% of the initial flux. Typical values for x are 70, 80, 90. For example 'L_{80} – 25,000 h' means that after 25,000 burning hours the luminous flux has reduced to 80% of the initial value.
- The '**gradual failure fraction B_y**' indicates the fraction of LED modules or LED luminaires that drops below x% lumen maintenance after the time L_x. For example '$L_{80}B_{10}$ – 25,000 h' indicates that, after 25,000 burning hours, 10% of the products has a luminous flux below 80% of the initial luminous flux. The default value is y=50 (B_{50}) but for some applications B_{10} may be relevant.
- The '**abrupt failure fraction C_z**' indicates the part of the LED lighting products that have failed completely at the end of the indicated life L_0. Typical values for z are 5 or 10. For example 'L_0C_5 – 15,000 h' indicates that after 15,000 burning hours 5% of the products failed completely.
- L_xB_y and L_0C_z can be specified separately as two different lifetimes, or they can be combined in a unique indication, i.e. $L_xB_yC_z$. In the latter case z is the percentage of complete failures after the life L_x. For example '$L_{70}B_{50}C_{10}$ – 40,000 h' indicates that after 40,000 burning hours 50% of the products gives less than 70% of the initial light output while 10% of the products have failed completely.
- Tests on LED products are performed for 6,000 hours and lifetime-related data are extrapolated from these measurements.

As also remarked above, the lifetime of light sources is often defined as a median value, implying that 50% of the products is anyway expected to fail, completely or due to an excessive loss of light output, before the rated lifetime. In a lighting installation, it is usually not acceptable to keep these failed lamps in place. Up to a certain point failed lamps can be replaced on an individual basis, but at a later date group substitution of all light sources in a certain zone or building may be more cost effective. This is part of the maintenance scheme of a lighting system that might foresee such a group substitution before the rated (50% failure) lifetime is reached.

[48] In most cases the rated lifetime is specified at an ambient temperature of 25˚C.

[49] "Review study on the stage 6 requirements of Commission regulation (EC) No 244.2009 Final Report", VHK (pl) / VITO for the European Commission, Delft/Brussels 14.6.2013, SPECIFIC CONTRACT No ENER/C3/ 2012-418 LOT 2/01/SI2.645913 Implementing Framework Contract No ENER/C3/2012-418-Lot 2. http://www.eup-network.de/fileadmin/user_upload/Technical_Review_Study_by_VHK_VITO.pdf?PHPSESSID=a60a9114e01af59471374f5814656e0c , par. 2.3.

In addition, in particular for LED lighting products that have a (very) long lifetime, and in particular in fashion-sensitive sectors like retail/shops, entertainment, hotels and restaurants, it might well occur in future that luminaires, with their light sources, are being replaced before their end-of-life because they are considered to be old-fashioned or because of a general wish to renew the appearance of the rooms or buildings.

3.3.2. Lifetimes for LFL, CFLni and HID-lamps (non-residential sector)

LFL, CFLni and HID-lamps are mainly used in the non-residential sector. The average lifetimes for these lamp types in MELISA are mainly based on the LSF=0.9 values reported in a 2005 publication of ZVEI (Annex E.2). The MELISA values are presented below together with data from other sources for comparison [50]:

- **LFL T12: 8,000 hours**. Taken identical to the ZVEI value for T8 halophosphor with magnetic ballast. Less important because these lamps are being phased out.

- **LFL T8 halophosphor**: **8,000 hours**. Value taken directly from ZVEI. Less important because these lamps are being phased out.

- **LFL T8 tri-phosphor: 13,000 hours**. Derived from ZVEI values, assuming 40% electronic ballast (16,000 hours) and 60% magnetic ballast (11,000 hours). Note that this is by far the most used LFL, accounting for 62% of the installed stock in 2013. The EU GPP indoor criteria (Annex E.7) recommend at least 15,000 hours, but they take into account electronic ballast only. Regulation 245/2009, from April 2012, prescribes > 16,000 h (LSF≥0.90) for electronic ballast and > 8,000 h for magnetic ballast (Annex E.1). The LFL T8 sampled by CLASP 2014 in the UK had declared lifetimes ranging from 10,000 to 20,000 hours (Annex E.5). Currently LFL T8 lamps are on the market with declared lifetimes up to 90,000 hours (Annex E.3).

- **LFL T5 new: 20,000 hours**. Value taken directly from ZVEI. The chosen value corresponds to the EU GPP indoor criteria (Annex E.7), but for the best choice they recommend 25,000 h. IEA 4E (International Energy Agency's cooperative program on Energy Efficient End-use Equipment) uses 15,000 hours in a 2014 publication (Annex E.6). Regulation 245/2009, from April 2012, prescribes > 16,000 h (LSF≥0.90) (Annex E.1). Currently LFL T5 high-efficiency lamps with 112 lm/W and lifetimes up to 36,000 hours and high-output lamps with 102 lm/W and lifetimes up to 60,000 hours are offered on the market (Annex E.3).

- **All other LFL**: **11,000 hours**. Includes T5 old types 4-13W and special FL. The lifetime is essentially an educated guess, but the impact of this type is low.

- **CFLni: 10,000 hours**. This is an average estimated value based on the ZVEI values for the different subtypes that range from 7,000 to 16,000 hours. The chosen value corresponds to the EU GPP indoor criteria (Annex E.7). Regulation 245/2009, from April 2012, prescribes > 8,000 h (with LSF depending on the type of ballast) (Annex E.1). IEA 4E uses 6,000 hours in a 2014 publication (Annex E.6). The Impact Assessment accompanying Regulation 245/2009 reports 9,000 hours for use on magnetic ballasts and 13,000 hours on electronic ballasts.

[50] IALD comment on Task 0-3 reports: "We have identified the same confusion between lifetime and operating life exist in this section as already pointed out in Task 1. There is a divergence when quoting life of Fluorescent lamps against a discussion of 50% failure. At the stated life for fluorescent lamps 100% can be expected to be delivering less than 80% of initial Lumens though failures may be 2% to 5% of a given batch."

- **HPM: 8,000 hours**. Value taken directly from ZVEI. Less important because these lamps are being phased out.

- **HPS**: **12,000 hours**. This is the ZVEI value for the 50/70W power range. Higher power lamps have higher lifetimes but conservatively the lower value was used for all. Regulation 245/2009, from April 2009, prescribes > 12,000 h (LSF≥0.90) for HPS with power < 75 W and > 16,000 h (LSF≥0.90) for higher powers (Annex E.1). This also corresponds to the values used in the EU GPP street lighting criteria (Annex E.8).

- **MH**: **8,000 hours**. ZVEI does not provide data for this lamp type. The MELISA value essentially derives from the 2007 Lot 9 preparatory study on street lighting and corresponds to the CIE-97 value for LSF=0.9 (Annex E.9). The Impact Assessment accompanying Regulation 245/2009 (Annex E.9) and the EU GPP criteria for street lighting (Annex E.8) use 12,000 hours. The same value is required by 245/2009 starting from 2017 (Annex E.1). The MELISA value could be reconsidered.

Many of the above lifetimes for lamps of the non-residential sector correspond to LSF=0.9. Using for example LSF=0.5 would lead to higher lifetimes (see Annex E.2) and consequently to a higher installed stock and lighting capacity (lumen), and higher energy consumption. It is therefore important to verify the outcomes of the MELISA model, in particular for the non-residential sector, judging the reasonability of the installed capacity (W/m^2 or lm/m^2 per unit building area) and of the energy consumption (kWh/m^2/year). This is done in the following paragraphs.

3.3.3. Lifetimes for other lamp types (residential sector)

For GLS, HL and CFLi, which are mainly used in the residential sector, and LEDs, the MELISA lifetimes are based on various literature sources and on considerations of the study team. The MELISA values are presented below together with data from other sources for comparison:

- **Incandescent (GLS), all types: 1,000 hours**. This lifetime is used in almost all sources. The only exception is a reference to 1,600 hours for reflector lamps (Annex E.9). Less important because these lamps are being phased out.

- **Halogen, Low voltage: 2,000 hours**. The CLASP 2013 value is 3,000 hours (Annex E.4). That value is also used in the 2009 Lot 19 preparatory study (Annex E.9). Regulation 244/2009 requires ≥ 2000 h from Stage 5 (September 2013) but this is for all HL, not specific for low voltage lamps. Regulation 1194/2012 requires ≥ 4000 h from Stage 3 (September 2016) for directional lamps (Annex E.1). The same value is reported in the accompanying Impact Assessment. IEA 4E uses 1,300 hours (Annex E.6).

- **Halogen, Mains voltage, single ended: 1,500 hours**. The same lifetime was used in the 2009 Lot 19 preparatory study (Annex E.9). The CLASP 2013 value is 2,000 hours. Regulation 244/2009 requires ≥ 2000 h from Stage 5 (September 2013). Regulation 1194/2012 requires ≥ 2000 h from Stage 2 (September 2014) for directional lamps. The accompanying Impact Assessment reports 2,300 hours. IEA 4E uses 1,300 hours (Annex E.6). The EU GPP indoor criteria recommend > 2,000 hours, but >2,500 h for the best choice. This MELISA value could be increased for years after 2013.

- **Halogen, Mains voltage, double ended (R7s): 1,000 hours**. These lamps are exempted from Regulation 244/2009. The only specific reference in another source is IEA 4E with 1,300 hours (Annex E.6). For other sources the same values as for single ended MV-HL would apply.

- **CFLi: 6,000 hours**. This lifetime corresponds to that of CLASP 2013. Regulation 244/2009 requires > 6000 h with LSF increasing from 0.5 in Stage 1 (September 2009) to 0.7 in Stage 5 (September 2013). The same values apply for directional lamps in Regulation 1194/2012, but from March 2014 and September 2016 respectively. IEA 4E also uses 6000 hours (Annex E.6). The EU GPP indoor criteria also recommend > 6,000 hours, but >8,000 h for the best choice.

- **LED: 20,000 hours**. The same value is used in CLASP 2013 (Annex E.4) and in IEA 4E 2014 (Annex E.6). Regulation 1194/2012, from March 2014, for both directional and non-directional LED lamps, prescribes tests up to 6,000 hours and requires LSF≥0.9 and LLMF≥0.8. This requirement aims at guaranteeing a minimum quality for LEDs; lifetimes are expected to be much longer than these 6,000 hours.
  In many occasions manufacturers claim much higher lifetimes for LED lighting products: values from 35,000 to 50,000 hours are not an exception and even claims of 100,000 hours can be found. Full lifetime tests, i.e. not short-time tests with extrapolation of results, take many years to complete and the tested model would be outdated at test completion.
  The study team therefore preferred the more conservative value of 20,000 hours. For the residential sector (450-500 operating hours per year) this implies a lifetime of at least 40 years, with effects going well beyond the time-horizon for this study (2030). For office applications (2200 operating hours per year for LEDs replacing LFL) the lifetime would be around 9 years; for street lighting applications (4000 operating hours per year for LEDs replacing HID) the lifetime would be around 5 years. Increasing the lifetime of LEDs in MELISA would therefore have only a small effect starting from 2020 and a moderate effect in the period 2025-2030. These effects could be examined during the sensitivity analysis in a later MEErP task.

3.4. Powers

3.4.1. Introduction

The focus in this paragraph is on the average powers of light sources in the EU-28, as used in the MELISA model for energy computations. Reference values for installed power and installed power density (per m^2 building area) are also presented for the residential and non-residential sectors, and compared to MELISA results. In addition other power-related topics are addressed, such as standby power and power factor.

The requirements in the existing regulations are formulated in terms of rated powers, that can be different from the nominal powers (used to identify a product) and from the powers resulting from verification tests (due to tolerances, see par. 3.6.3). The following definitions (taken from the existing regulations) are recalled from the Task 1 Annex report:

> '*Rated value*' means the value of a quantity used for specification purposes, established for a specified set of operating conditions of a product. Unless stated otherwise, all requirements are set in rated values.
>
> '*Nominal value*' means the value of a quantity used to designate and identify a product.

3.4.2. Average powers per lamp type

The average light source powers currently used in MELISA have been reported in par. 2.2. These powers do NOT include standby powers, nor ballast/control gear powers, except where the latter are integrated in the light sources. In most cases the MELISA powers have been taken from the CLASP 2013 study [51]. In other cases the same values have been used as in the 2009 Lot 19 preparatory study [52].

In September 2014 the International Energy Agency (IEA), in the context of the cooperative program on Energy Efficient End-use Equipment (4E), published an elaboration of residential light source sales data collected by GfK in 9 European countries in the period 2007-2013. One of the interesting aspects of these data is that the sales are subdivided in 'wattage buckets' (power ranges), allowing the derivation of the average powers of the sold lamps [53].

The study team performed this derivation as described in detail in Annex F.1.

The main problem in this derivation is that reference values have to be defined for each power range. For example for the incandescent lamps, the range '40W< power ≤60W' can be assumed to have a reference power of 50W (centre value of the range) or of 59W (as suggested by IEA 4E because the most frequently sold lamp in this range is 60W). This problem of choosing a reference value is even larger for the topmost range, for example 'power >100W'.

Using different assumptions for the reference power of each range, the study team derived a minimum and a maximum estimate for the average power of the light sources sold, per type of lamp and per year.

Table 43 compares the average lamp powers for non-LED light sources from MELISA, CLASP 2013, VITO 2009, and IEA 4E (as derived by the study team). For the latter a minimum and maximum estimate are shown for the years 2007 and 2013. A 'most likely' typical power for 2013, estimated by the study team, is also presented.

Remarks and conclusions regarding the data presented in Table 43 and in Annex F.1:

- **Incandescent lamps (GLS)**: The IEA 4E average power in 2013 is clearly lower than in 2007. Most likely, this is a direct consequence of the ecodesign measures that phased out these lamps in steps, starting with the highest powers. The MELISA power of 54W seems relatively high as compared to IEA 4E data, and could be adjusted for 2007 and later years.

- **MV halogen lamps, single ended**: The IEA 4E average power in 2013 is clearly lower than in 2007. The MELISA power of 35-36W seems to be slightly on the low side and could be adapted.

- **MV halogen lamps, double ended (R7s)**: IEA 4E sales in the topmost wattage range (> 250W) are high and consequently the result is sensitive to the reference power assumed for this range. The IEA 4E average power in 2013 is lower than in 2007. The MELISA power of 250W is reasonable but could be slightly downward adjusted for recent years.

[51] "CLASP, Estimating potential additional energy savings from upcoming revisions to existing regulations under the ecodesign and energy labelling directives, feb. 2013, Appendix E and F" (http://www.eceee.org/all-news/press/2013/2013-02-19/eceee-clasp-report-estimating-potential).

[52] Preparatory Studies for Eco-design requirements of EuPs, Final Report, Lot 19: Domestic lighting, Study for the European Commission DGTREN unit D3, contact Andras Toth, by VITO in cooperation with Bio Intelligence Service, Energy Piano and Kreios, October 2009, Contract TREN/07/D3/390-2006/S07.72702, available through 'eup4light.net'

[53] The sales data have also been presented in the Task 2 report and there they have been scaled up to EU-28 level. For the current elaboration of average powers the original non-scaled sales data have been used. The resulting powers are anyway expected to be representative for the EU-28.

Average Power (W)	LFL					CFL		HL						GLS		HID		
	T12	T8 halophosphor	T8 tri-phosphor	T5 new (14 - 80w) including circular	All others (including T5 old types 4 - 13w and special FL)	Retrofit - CFLi	Non-retrofit - CFLni	Single ended, mirrored (low voltage) [M16, M25 etc.]	Linear (high voltage) [R7s]	LV halogen Capsule [G4, GY6.35]	HV Halogen capsule [G9]	Mains halogen (substitute for GLS and reflector)[E14, E27]	Other mains halogen - PAR 16/20/ 25/30 hard glass reflectors, GU10 etc.	Reflector	GLS (including clear/pearl, candles, coloured & decorative)	All mercury lamps (including mixed)	All sodium lamps	Metal halide lamps
MELISA	35	32	30	25	12	9.5	12	35	250	35	35	36	35	54	54	250	140	160
CLASP 2013	35	32	28-30	25	12	13	9.5-11.5	35	100	35	52	52	52	60	60	250	120-140	150-225
VITO 2009						13		30	300	30	40	40	40	54	54			
IEA for 2007 (1) min-max			33-46	*14-27*		12.6-13.6	*13.7-15.6*	25-36	264-347	25-36		45-50		44-52				
IEA for 2013 (1) min-max			33-45	*14-27*		13.2-14.5	*15.8-18.5*	23-35	194-243	23-35		37-43		33-41				
IEA for 2013 (2) min-max			28-41	*22-34*		13.6-14.6	*33.5-44.2*	27-37	213-271	27-37		39-45		42-50				
IEA 2013 typical			33-35			≈14		≈35	200-240	≈35		38-40		40-45				

Table 43 Average non-LED light source power (W); comparison between MELISA, CLASP 2013, VITO 2009 and values derived by the study team from IEA 4E sales data. For the latter a minimum and maximum estimate are shown, for the years 2007 and 2013. The 2007 data are shown for countries AT, BE, FR, DE, UK, IT, NL (1); the 2013 data both for countries (1) and for Spain and Poland (2). A 'most likely' typical power for 2013, estimated by the study team, is also presented.

- **LV halogen lamps (12V)**: In this case the largest part of the IEA 4E sales is in the 0-34 wattage bucket, so the average power mainly depends on the reference power assumed for this range. The MELISA power seems reasonable.

- **CFLi**: The MELISA average power of 9.5 W is clearly lower than the 13-14 W from other sources. The 9.5 W value was chosen for a CFLi that satisfies the 244/2009 efficacy requirement for non-clear lamps of $0.24\sqrt{\Phi}+0.0103\Phi$ and that replaces an average 500 lm incandescent lamp. The value was also derived from a 2009 Swedish research (Annex C.2) that leads to average 9.6W/CFLi for houses and 8.5W/CFLi for apartments [54]. The IEA 4E data correspond to a surprisingly high average of 800 lm per CFLi that would imply a very high rebound effect, not compatible with research on this topic (par. 3.2.5). During model revision the MELISA CFLi power could be reconsidered.

- **CFLni**: The CLASP value of 9.5W is for lamps compliant with Regulation 245/2009; the value of 11.5W is for non-compliant lamps. The IEA 4E derived data are for relatively low sales volumes, and show a large difference between Spain/Poland and the other countries. In addition these lamps are not typical for domestic use which was the target market of the GfK data collection.

[54] Houses: 7.6 CFL/hh, 1618 W/hh, 4.5% CFL -> 9.6 W/CFL. Apartments: 3.7 CFL/hh, 829 W/hh, 3.8% CFL -> 8.5 W/CFL

Consequently the study team preferred not to use these data. Anyway the MELISA power of 12 W seems to be on the low side.

- **LFL T5 and T8**: These are not typical household lamps, so the applicability of the IEA 4E derived data to the non-residential sector is uncertain. For T5 the data are based on low sales volumes and the study team preferred not to use them (see Annex F.1.9). For T8 the data seem more reliable. According to a CLASP 2014 study on LFL [55] the 36W T8 is the most frequently sold one in Europe. The MELISA power of 30W for T8 seems slightly on the low side.

- **HID-lamps**: The MELISA data are in line with the CLASP 2013 data. These lamps were not covered by the IEA 4E survey because they are hardly being used in the domestic sector.

LED average powers are not included in Table 43 because LEDs are treated in a special way in MELISA, see par. 2.2: in 2013 the LED power to substitute a 600 lm lamp is around 9W. CLASP 2013 used a variable average LED power from 14W in 2010 to 11W in 2030.

The average power values derived from IEA 4E data are shown in Table 44 (Retrofit LED lamps) and Table 45 (Dedicated LED lamps). See Annex F.1.10 for further details. These data indicate an average power for LED lamps in 2013 around **5.5-6.0 W for retrofit lamps** and **4.0-4.5 W for dedicated lamps**.

These tables also present the average efficacy, as reported by IEA 4E, and the corresponding lamp lumens resulting as the product of power and efficacy. From 2007 to 2013 both power and efficacy increase significantly, resulting in a high increase in capacity (lumen). The MELISA LED power of 9W for 600 lm is in line with these IEA 4E derived data.

Retrofit LED Lamps	average estimated wattage (W)		Efficacy (lm/W)	average estimated lumen	
Countries AT, BE, FR, DE, UK, IT, NL	MAX	MIN		MAX	MIN
2007	1.7	1.2	37.2	62	45
2008	1.6	1.2	40.9	67	48
2009	1.8	1.3	45.5	82	58
2010	2.2	1.7	50.9	114	85
2011	3.2	2.5	57.4	184	141
2012	5.0	3.9	64.9	324	254
2013	6.5	5.2	72.6	473	381
Countries ES, PL					
2011	3.6	2.7	57.4	206	158
2012	4.3	3.3	63.7	274	212
2013	5.8	4.6	71.7	419	333

Table 44 Retrofit LED lamps, Average Wattage, Efficacy and Lumen. Efficacies are directly reported by IEA 4E; the other data have been derived by the study team from IEA 4E/GfK data.

[55] CLASP, November 2014, "Mapping & Benchmarking of Linear Fluorescent Lighting". http://clasponline.org/en/Resources/Resources/PublicationLibrary/2014/Benchmarking-Analysis-Linear-Fluorescent-Lighting.aspx

Dedicated LED Lamps	average estimated wattage (W)		Efficacy (lm/W)	average estimated lumen	
Countries AT, BE, FR, DE, UK, IT, NL	MAX	MIN		MAX	MIN
2007	1.6	1.1	46.3	73	52
2008	1.6	1.2	51.0	83	60
2009	1.8	1.3	56.9	105	76
2010	2.4	1.8	63.2	150	112
2011	2.9	2.2	70.6	207	156
2012	4.1	3.1	79.5	327	249
2013	4.9	3.7	88.4	430	330
Countries ES, PL					
2011	3.7	2.8	71.5	262	199
2012	3.9	3.0	78.9	311	238
2013	4.8	3.7	88.0	419	322

Table 45 Dedicated LED lamps, Average Wattage, Efficacy and Lumen. Efficacies are directly reported by IEA 4E; the other data have been derived by the study team from IEA 4E/GfK data.

3.4.3. Installed lighting power in the residential sector

Table 46 shows the MELISA outcomes for the number of lamps per household, the average installed lighting power per household, and the lighting power density in W/m^2. The table also reports the data from various literature sources, for comparison.

The data regarding the number of lamps per household and the installed power per household show a large variability between the various studies and between individual countries. Considering the latter, the data from studies that cover only one country should not be confused with European averages.

In general the number of lamps per household increases with the years, and this trend could be accelerated by the availability of more energy efficient lamps.

The installed lighting power per household increased until 2007 but is on its way down now. This is also illustrated by the reported data derived from default values in prEN15193 [65]. In the standard lighting solution with an average efficacy of 15 lm/W the installed power ranges from 920 to 1380 W (15-17 W/m^2). In the suggested optimized solution with average efficacy of 60 lm/W the installed power ranges from 330 to 535 W (approximately 6 W/m^2, providing more lumens).

The MELISA 2007 data are in reasonable agreement with the 2008 REMODECE study (that covered 12 countries) and seem compatible with the reference values of prEN15193, taking into account that in 2013 the European households are in a transition phase between a standard lighting solution and an optimised solution.

Source	Number of lamps per household	Average installed lighting power per household (W)	Lighting power density for households (W/m^2)

MELISA 2013	**33**	**966**	11 [56]
MELISA 2007	**28**	**1198**	
MELISA 2000	**23**	**1184**	
MELISA 1990	**21**	**1062**	
United Kingdom 2012	34	1362	24
Sweden 2009, houses apartments	55 31	1618 829	13 11
REMODECE 2008 (12 countries)	26 [57]	1060 [58]	
IA 2009, data for 2007	19 [59]		
JRC, Bertoldi, 2006	22 [60]		
IEA, 2006 [61] (7 countries)	10 - 40		6 - 16
France 2003	28	1578	15
EURECO 2002 [62] (4 countries)	10 - 24	675 - 883	6 – 9
Delight, 1994-1997	24 [63]		
GPP Indoor [64] Residential			9 - 11
Residential communal spaces			5 - 6
prEN15193, standard (15 lm/W)		920 - 1380	15 - 17
[65] optimised (60 lm/W)		330 - 535	≈ 6

Table 46 Comparison of installed powers for lighting in residential buildings between the MELISA model and various literature sources. See par.3.2.3 and Annex C for reference information

3.4.4. Installed lighting power in the non-residential sector

According to MELISA the installed lighting power in the non-residential sector in 2013 is 112 GW (par. 2.5). In a rough estimate, all HID-lamps (13 GW) are assumed to be used in outdoor lighting, leaving approximately 100 GW for the indoor lighting of buildings.
According to the report on EU building heat demand [66], the total EU-28 non-residential building area is 11517 Mm^2. This implies **a lighting power density for non-residential buildings of 8.7 W/m^2**.

Table 46 shows the above MELISA outcome for the lighting power density in W/m^2 of non-residential buildings compared to values from some literature sources. Considering the large variety in buildings, the

[56] In 2013 the total area of residential buildings is 21218 Mm^2 VHK report Building Heat Demand, 2014)) and there are 246 million dwellings (Eurostat). This leads to 86 m^2/dwelling. 966 W / 86 m^2 = 11 W/m^2
[57] Ranging from 11 to 34 in the various countries, see details in Annex C.3
[58] Ranging from 476 to 1703 in the various countries, see details in Annex C.3
[59] See Annex C.7 for details. Prediction is 20 lamps/hh by 2013 and 22 lamps/hh by 2020. Uncertain if this also includes directional lamps; could be only for non-directional.
[60] Ranging from 6 to 40 in the various countries, see details in Annex C.8
[61] LIGHT'S LABOUR'S LOST, Policies for Energy-efficient Lighting, OECD/IEA, 2006
[62] Data for Portugal have been ignored for compiling this table, see Annex C.5
[63] Ranging from 9 to 36 in the various countries, see details in Annex C.6
[64] See details in Annex F.2
[65] See details in Annex I.2. The ranges are for different areas of the dwellings.
[66] "Average EU building heat load for HVAC equipment", final report, René Kemna (VHK) for the European Commission, August 2014, http://ec.europa.eu/energy/efficiency/studies/doc/2014_final_report_eu_building_heat_demand.pdf

large variety in types of rooms/zones in these buildings, and the various levels of efficacy of the lighting installations, it is not surprising that there is a large spread in the W/m² values. In addition there is still a lack of reliable (measured) data on lighting in the non-residential sector.
The available data do not allow a real judgement of the MELISA value of 8.7 W/m², but it seems to be on the low side. It should be remembered however that it has been obtained by dividing the total installed power by the entire estimated building area, which may have led to an excessively low density value. See also the comparison of the lm/m² (par. 3.5.4) and kWh/m²/year values (par. 3.7.2).

Source	Room/zone type	Lighting power density for non-residential buildings (W/m²)
MELISA 2013	**Average of all buildings**	**8.7**
EL-Tertiary project 2008	Offices (82)	6 – 13 – 21 [67]
	Conference rooms (20)	12 – 14 – 18
	Classrooms (40)	5 – 8 – 12
	Toilets, sanitary (40)	7 – 12 – 18
	Circulation areas (108)	4 – 7 – 13
	Service, tech, archives (42)	6 – 8 – 12
	Gymnasium, sports (14)	6 – 7 – 12
Office buildings (FR, 2005) (average of 49 buildings)	Entire building, original	19
	After proposed improvements	10
Office building (FR,2005) (1 large building) [68]	Corridors	15
	Offices (ceiling lamps)	13
	Entrance hall	7
	Conference rooms	32
	Offices (desk lamps)	5
IEA, 2006 [69]	commercial buildings	15-16
GPP Indoor (Annex F.2)	Various building types	7 - 14
prEN15193-2 [70]	Circulation areas	29 (existing) 8 (standard)
	Personal offices	35-43 (existing) 16-18 (standard) 12-14 (efficient)
	Conference room	12 (efficient)
	Open floor office	27 (existing) 11 (efficient)
	Kitchen in non-residential building	33 (existing) 12 (efficient)
	Manufacturing hall	34 (existing) 7-13 (efficient)

Table 47 Comparison of installed lighting power densities (W/m²) in non-residential buildings, between the MELISA model and various literature sources. See par.3.2.4 and Annex D for reference information.

[67] For the EL-Tertiary project the 25%, 50%, 75% quartile values are reported. The number of measurements is reported between brackets in the room type column. For example, for offices, 25% of the 82 rooms have an installed power less than 6 W/m², 50% less than 13 W/m², and 75% less than 21 W/m².
[68] See Annex D.4 for data on other rooms/zones with minor energy consumption
[69] LIGHT'S LABOUR'S LOST, Policies for Energy-efficient Lighting, OECD/IEA, 2006
[70] Draft prEN 15193-2 "Energy performance of buildings – Module M9 – Energy requirements for lighting –Part 2: 'Technical report to EN 15193-1', CEN/TC 169, August 2014, in particular table 9. Values are indicated for a typical existing solution and for a standard or efficient solution. For further details, see the source.

3.4.5. Standby power and No-load power

The following definitions (taken from the Regulation 1194/2012) are recalled from the Task 1 Annex report:

> '*No-load mode*' means the condition of a lamp control gear where it is connected to the supply voltage and where its output is disconnected in normal operation from all the primary loads by the switch intended for this purpose (a faulty or missing lamp, or a disconnection of the load by a safety switch is not normal operation).
>
> '*No-load power*' means the power consumed by the lamp control gear in no-load mode.
>
> '*Standby mode*' means a mode of lamp control gear where the lamps are switched off with the help of a control signal under normal operating conditions. It applies to lamp control gear with a built-in switching function and permanently connected to the supply voltage when in normal use.
>
> '*Standby power*' means the power consumed by the lamp control gear in standby mode.

According to Regulation 245/2009 the 'standby power' [71] of fluorescent lamp ballast shall be less than 1W in Stage 1 (April 2010) and less than 0.5W in Stage 2 (April 2012). There are no requirements for the standby power of HID lamp ballast. In addition the 'standby' power of luminaires (for both fluorescent lamps without integrated ballast and high-intensity discharge lamps) shall not be greater than that of the incorporated ballasts.

In Regulation 1194/2012 [72], as from Stage 2 (September 2014) the no-load power of a lamp control gear intended for use between the mains and the switch for turning the lamp load on/off shall not exceed 1W. As from Stage 3 (September 2016), the limit shall be 0.5W [73].

As from Stage 3 (September 2016), the standby power of a lamp control gear shall not exceed 0.5 W.

In the current regulations, the requirements regarding no-load and standby power are related to the control gears and the luminaires. This may have to change in future regulations in order to cover network connected '**smart lamps**' (see Task 1 report par. 4.1.2). The functional philosophy of these lamps is that they are 'always on' or at least in 'network standby' and consequently there is a potential for significant additional energy consumption that undermines the attempts for energy saving.

An illustration of this potential barrier to energy reduction is given by a November 2014 article from Australia [74]. The authors tested the performance, including measuring standby power consumption, of two wireless operation LED lamp products available in the Australian market. One of these lamps (Lamp A) had a standby power of about half a Watt while the second (Lamp B) consumed about 3 Watts in standby mode. The article presents the power consumption, including standby mode, for the two lamps tested when they are turned ON for one hour every day throughout the year. Taking into account standby power use (for the other 23 hours per day), in this scenario Lamp B actually uses more power than an equivalent inefficient tungsten filament incandescent lamp (now phased out) would use when turned ON

[71] The term standby power is not used in the regulation. The actual wording is: "The power consumption of ballasts used with fluorescent lamps without integrated ballast shall not exceed 0.5 / 1 W when operated lamps do not emit any light in normal operating conditions. This requirement shall apply to ballasts when other possible connected components (network connections, sensors etc.) are disconnected. If they cannot be disconnected, their power shall be measured and deducted from the result."

[72] This does NOT apply to ballasts and luminaires for fluorescent and HID lamps.

[73] For lamp control gear with output power (P) over 250 W, the no-load power limits shall be multiplied by P/250 W.

[74] "Smart lighting maybe not so smart", Laura di Pauli, 25 November 2014 http://www.energyrating.gov.au/blog/2014/11/25/smart-lighting-maybe-not-so-smart/

for the one hour each day. Including standby power, **both** wireless models consumed far more energy than the LED efficacy levels recommended by the International Energy Agency (IEA) 4E Solid State Lighting (SSL) Annex and used more energy during the standby period than during the hour of operation.

So even standby powers of 0.5W, intuitively low, can more than double the energy consumption of a LED lamp, but some manufacturers advertise this as a low standby power [75]. According to a contribution on ledjournal.com much lower standby powers are feasible, down to 10mW. In that case a context-aware lighting system for a conference room that uses 20 motion sensors and 20 adjustable light sources could consume less than 0.5W in standby if the sensors can run in a zero-load mode [76].

In its comments to the report, the Danish Energy Agency states that the best network-connected smart lamps operate with 0.17 – 0.25 W standby power consumption while other smart lamps have up to ten times higher standby consumption. DEA recommends maximum standby power consumption 0.3 W per smart lamp.

Note that in addition to the smart lamps themselves, other network-related products like bridges and routers may be necessary, which have their own efficiency and standby power.

These topics will be treated in further detail in the Lot 37 lighting systems study.

3.5. Luminous flux

3.5.1. Introduction

The following definitions, taken from Regulation 1194/2012, are recalled from the Task 1 Annex report:

> '*Luminous flux*' (Φ) means the quantity derived from radiant flux (radiant power) by evaluating the radiation in accordance with the spectral sensitivity of the human eye. Without further specification it refers to the initial luminous flux [77] (unit: lumen, lm).
>
> '*Initial luminous flux*' means the luminous flux of a lamp after a short operating period.
>
> '*Useful luminous flux*' (Φ_{use}) means:
> - the entire luminous flux (in all directions) for non-directional lamps,
> - the part of the luminous flux of a lamp falling within a cone of 120° ($\Phi_{120°}$) for directional lamps with a beam angle ≥ 90° other than filament lamps,
> - the part of the luminous flux of a lamp falling within a cone of 90° ($\Phi_{90°}$) for other directional lamps [78].
>
> '*Beam angle*' means the angle between two imaginary lines in a plane through the optical beam axis, such that these lines pass through the centre of the front face of the lamp and through points at which the luminous intensity is 50 % of the centre beam intensity, where the centre beam intensity is the value of luminous intensity measured on the optical beam axis.
>
> '*Luminous intensity*' means the quotient of the luminous flux leaving the source and propagated in the element of solid angle containing the given direction, by the element of solid angle (unit: candela, cd = lm/sr).
>
> '*Luminance*' means the amount of light, per unit of apparent surface, that is emitted by or reflected by a particular area within a given solid angle (unit: cd/m^2).

[75] http://www.marvell.com/led-lighting/drivers/88EM8189/
[76] http://www.ledjournal.com/main/blogs/smart-lighting-removing-the-power-burden/
[77] Regulations 244/2009 and 245/2009 are more specific: "*measured after 100 hours of lamp running time*"
[78] For directional lamps see also regulation 1194/2012 Annex III and point 3.1.2(j).

In addition the illuminance is relevant in the current study:

> '*Illuminance*' means the luminous flux incident on a unit surface area (unit: lux=lm/m^2). Indoor lighting requirements are usually expressed in lux.

The luminous flux is not the real radiant power output of the light source. As also indicated in the definition, the sensitivity of the human eye to electromagnetic radiation depends on the wavelength of this radiation. The real power output is therefore weighted by a wavelength-dependent function (the CIE standard or modified photopic observer) to define the luminous flux. The photopic observer is valid in daylight conditions. For night-time or mixed conditions (particularly relevant for outdoor lighting) the sensitivity of the human eye is different and the scotopic or mesopic weighting functions can be more adequate [79].

See the applicable Commission communications for the measurement procedures related to luminous flux, luminance and lumen maintenance [80].

See the Lot 37 exploratory study [81] for a discussion on the related measurement units (cd, lm, lux) and on the description of the spatial light distribution [82].

The luminous flux is the 'modern way' to compare the light output of lamps. In the past, consumers were used to judge the 'force' of incandescent lamps by means of their power, i.e. 25, 40, 60, 75, 100W lamps. With the appearance on the market of other lamp technologies that provide the same amount of light using less input power, this is no longer adequate. Therefore the luminous flux is nowadays used as the main parameter to compare the light output of lamps. However, consumers are still used to the old method and consequently many lamp vendors still indicate the 'equivalent incandescent lamp power ' [83]. Most reference information for lighting from the past is expressed in terms of power, e.g. installed lighting power per household, or specific power density in W/m^2 (see previous paragraph).

In the same way as for power, also for the luminous flux a difference has to be made between nominal value (used to identify a product), rated value (measured in specific conditions), and values resulting from verification tests (see par. 3.6.3 on tolerances).

3.5.2. Average luminous flux per lamp type

In MELISA, for non-LED light sources, the average power and the average efficacy are basic values while average lumens are derived as the product of these two. For the period up to 2013 these values are constants, not variable with the years. As regards the (non-)distinction between the efficacy and flux of directional and non-directional lamps, see remarks in par. 2.2.

For LED light sources the approach is different. The basic assumption is that the average luminous flux should match that of the lamps that are being substituted. The average efficacy of LEDs is assumed to vary

[79] For background information on the topic, see for example:
LIGHT'S LABOUR'S LOST, Policies for Energy-efficient Lighting, OECD/IEA, 2006, page 67 and following,
Preparatory Studies for Eco-design requirements of EuPs, Final Report, Lot 9: Public Street lighting, Study for the European Commission DGTREN unit D3, contact Andras Toth, by VITO in cooperation with Laborelec and Kreios, January 2007, Contract TREN/D1/40-2005/LOT9/S07.56457, available through 'eup4light.net', par.3.1

[80] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2014:022:0017:0031:EN:PDF
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2010:092:0011:0014:EN:PDF

[81] "Exploratory study on lighting systems, including lighting schemes, luminaires and lighting controls for intelligent systems, for Ecodesign, Energy Labelling, and/or Energy Performance of Building requirements ('Lot 37') Final Report", VITO reference 2014/ETE/R/036, March 2014, prepared for the European Commission DG-ENER-C3, SPECIFIC CONTRACT No ENER/C3/2012-418 LOT1/05/SI2.660099 Implementing Framework Contract No ENER/C3/2012-418-Lot 1. Restricted Distribution.

[82] CEN flux code, polar intensity curve, Cartesian light distribution diagram, illuminance cone diagram, peak intensity.

[83] Claimed equivalence with incandescent power shall be that specified in Regulation 244/2009 table 6 (non-directional lamps) or Regulation 1194/2012 table 6 (directional lamps).

with the years (par. 2.2) and the power is derived as flux divided by efficacy. Efficacy and flux are different for directional and non-directional lamps, depending on the mix of lamps that they substitute.

Table 48 compares the average luminous flux for non-LED light sources from MELISA, CLASP 2013 [84], VITO 2009 [85], and IEA 4E 2014 (as derived by the study team, see Annex F.1 and G.1). For the latter a minimum and maximum estimate are shown for the years 2007 and 2013.

The MELISA luminous flux for **LFL, CFLni and HID-lamps** is identical to the values used in the CLASP report. The average LFL flux is low as compared to values derived from IEA 4E data, but considering that IEA 4E focused on sales of domestic light sources, it is uncertain that their LFL-values are representative for the non-residential sector as well.

As regards **CFLi**, the average 523 lm from MELISA are low compared to those from the other sources. This is a direct consequence of the low assumed average power, see remarks in par. 3.4.2.

Average Flux (lm)	**LFL**					**CFL**		**HL**						**GLS**		**HID**		
	T12	T8 halophosphor	T8 tri-phosphor	T5 new (14 - 80w) including circular	All others (including T5 old types 4 - 13w and special FL)	Retrofit - CFLi	Non-retrofit - CFLni	Single ended, mirrored (low voltage) [M16, M25 etc.]	Linear (high voltage) [R7s]	LV halogen Capsule [G4, GY6.35]	HV Halogen capsule [G9]	Mains halogen (substitute for GLS and reflector)[E14, E27]	Other mains halogen - PAR 16/20/ 25/30 hard glass	Reflector	GLS (including clear/pearl, candles, coloured & decorative)	All mercury lamps (including mixed)	All sodium lamps	Metal halide lamps
MELISA	2450	2400	2400	2275	1032	523	633	490	3000	490	420	432	420	513	513	10000	13300	13120
CLASP 2013	2450	2400	2352-2400	2275	1032		617-632									10000	13300	13500-14625
VITO 2009						559		392[86]	5177	435[86]	480 (R:315 [87])			258 [87]	572-594			
IEA for 2007 (1) min-max			2600-3610			720-780		430-630	5050-6630	430-630	650-730			500-600				
IEA for 2013 (1) min-max			2600-3610			790-860		410-630	3640-4570	410-630	530-600			350-440				
IEA for 2013 (2) min-max			2160-3150			810-870		480-670	4040-5150	480-670	550-640			480-570				

Table 48 Average luminous flux (lm) for non-LED light sources; comparison between MELISA, CLASP 2013, VITO 2009 and values derived by the study team from IEA 4E sales data. For the latter a minimum and maximum estimate are shown, for the years 2007 and 2013. The 2007 data are shown for countries AT, BE, FR, DE, UK, IT, NL (1); the 2013 data both for countries (1) and for Spain and Poland (2).

The MELISA luminous flux for **low voltage halogen lamps** is in reasonable agreement with the IEA 4E derived values, while the flux for **mains voltage halogen lamps** is on the low side, both for single ended and for double ended lamps. As this is a direct consequence of the assumed powers and efficacies, see remarks in the corresponding paragraphs.

[84] "CLASP, Estimating potential additional energy savings from upcoming revisions to existing regulations under the ecodesign and energy labelling directives, Feb. 2013, appendix F, table 2.3". http://www.eceee.org/all-news/press/2013/2013-02-19/eceee-clasp-report-estimating-potential

[85] Preparatory Studies for Eco-design requirements of EuPs, Final Report, Lot 19: Domestic lighting, Study for the European Commission DGTREN unit D3, contact Andras Toth, by VITO in cooperation with Bio Intelligence Service, Energy Piano and Kreios, October 2009, Contract TREN/07/D3/390-2006/S07.72702, available through 'eup4light.net'

[86] Average functional lumen output within opening angle of 90˚ : 392 lm for directional lamps; 435 lm for non-directional

[87] Average functional lumen output within opening angle of 90˚.

For **incandescent lamps**, the luminous flux from MELISA is in line with the values derived from IEA 4E data, but for the year 2013 it seems on the high side [88].

As regards **LED lamps** (not shown in Table 48), the MELISA 2013 value for 'lumen to fit' is 600 lm for the residential sector [89]. This value is higher than the 320-470 lm estimates derived from the IEA 4E data (see Table 44 and Table 45). Although the IEA 4E data indicate a clear trend towards higher lumens, it seems that on average the 600 lm have not been reached in the sales yet [90].

3.5.3. Installed lighting capacity (lumen) in the residential sector

According to MELISA, a total of 4.01 Tlm lighting capacity is installed in the EU-28 domestic sector in 2013 (par. 2.4). In the same year there are 198.6 million households (Eurostat), which implies **20200 lm per household**. Compared to this, the default guiding values derived from prEN15193 (Annex I.2) seem somewhat low, ranging from 12600 to 21300 lm for the optimised lighting solution (60 lm/W) and from 8250 to 12750 lm for the standard solution (15 lm/W).

Dividing the total capacity by the total residential building area of 21218 Mm^2 estimated in the EU Building heat load report [91], an average of nearly **190 lm/m²** is obtained. From the residential data presented in prEn15193 (Annex I.2) an average of 226-233 lm/m^2 can be derived for the optimised lighting solution (60 lm/W) and 137-153 lm/m^2 for the standard lighting solution (15 lm/W). Consequently the values are in reasonable agreement.

3.5.4. Installed lighting capacity (lumen) in the non-residential sector

According to MELISA, a total of 6.76 Tlm lighting capacity is installed in the EU-28 non-residential sector in 2013 (par. 2.4). In a rough estimate, all HID-lamps (1.1 Tlm) are assumed to be used in outdoor lighting, leaving approximately 5.7 Tlm for the indoor lighting of non-residential buildings.

According to the estimate in the EU Building heat load report [91], the total EU-28 non-residential building area is 11517 Mm^2. This implies **a lighting capacity density for non-residential buildings of approximately 500 lm/m²**. Note that this is at light source level and that the value cannot be compared directly to the illumination requirements in lux (=lm/m^2) that are specified at task level.

No reference values have been found that enable to judge this MELISA outcome. For this reason an attempt will be made in future (in the context of the Lot 37 study on lighting systems) to derive the same value using a non-residential area breakdown, required illuminances at task level, and assuming a 'typical' luminaire efficiency and room surface reflection, calculating backwards from task level to light source level.

[88] IEA 4E data show a recent trend towards lower powers and consequently lower lumens.

[89] Both for directional and non-directional lamps. The value reflects the luminous flux of the lamps that are expected to be substituted by LEDs, including some LFL replacements.

[90] For the IEA 4E / GfK data it is not known what part of the LEDs was directional. For directional lamps the flux is measured in a 90˚ or 120˚ cone and is therefore lower than for a non-directional lamp of the same power. The Dutch "Consumentengids, November 2014" reports test results for 20 LED spot lights with beam angles between 28˚ and 44˚ and powers from 2.5 to 7.5 W. The measured flux ranges from 121 to 382 lm with an average of 238 lm. If this is indicative for the average of directional LEDs in 2014, the average for non-directional LEDs could be significantly higher than the overall average of 320-470 lm.

[91] "Average EU building heat load for HVAC equipment", final report, René Kemna (VHK) for the European Commission, August 2014, http://ec.europa.eu/energy/efficiency/studies/doc/2014_final_report_eu_building_heat_demand.pdf

3.6. Luminous efficacy

3.6.1. Introduction

The following efficacy [92] definitions have been taken Regulations 244/2009 and 245/2009:

> '*Lamp efficacy*' (η_{lamp}), which is the quotient of the luminous flux emitted (Φ) by the power consumed by the lamp (P_{lamp}): $\eta_{lamp} = \Phi / P_{lamp}$ (unit: lm/W). The power dissipated by non-integrated auxiliary equipment, such as ballasts, transformers or power supplies, is not included in the power consumed by the lamp (244/2009).
>
> '*Luminous efficacy of a source*', '*light source efficacy*' or '*lamp efficacy*' (η_{source}), which means the quotient of the luminous flux emitted (Φ) by the power consumed by the source (P_{source}). $\eta_{source} = \Phi / P_{source}$ (unit: lm/W). The power dissipated by auxiliary equipment such as ballasts is not included in the power consumed by the source.

In Regulations 1194/2012 and 874/2012 the luminous efficacy is not defined. In these regulations the 'efficacy concept' is replaced by the Energy Efficiency Index (EEI, details in Annex H.1).

Annex H.1 reports graphs of the minimum efficacy required by the current lighting regulations, in function of the luminous flux, respectively for non-directional lamps (244/2009), linear fluorescent lamps (245/2009) and directional lamps (1194/2012). The same Annex also provides graphs clarifying the relationship between the EEI limits of the energy labelling classes of Regulation 874/2012 and the corresponding lamp efficacies and powers.

3.6.2. Average efficacy per lamp type

The average light source efficacies currently used in MELISA have been reported in par. 2.2. These efficacies do NOT include the efficiencies of ballast/control gear, except where the latter are integrated in the light sources. For LFL, CFLni and HID the MELISA efficacies have been taken from the CLASP 2013 study [93]. For most halogen lamps the same values have been used as in the 2009 Lot 19 preparatory study [94].

In September 2014 the International Energy Agency (IEA), in the context of the cooperative program on Energy Efficient End-use Equipment (4E), published an elaboration of residential light source sales data collected by GfK in 9 European countries in the period 2007-2013. This publication also includes information on the efficacy of light sources in function of their power, and a trend in the development of efficacies over the recent years (Annex H.2).

Table 49 compares the average lamp efficacy for non-LED light sources from MELISA, CLASP 2013, VITO 2009, and IEA 4E. For the latter, data are shown for the years 2007 and 2013.

For **LFL T8 tri-phosphor**, the MELISA efficacy is in good agreement with the IEA 4E values. For other LFL-types the IEA 4E efficacies are less reliable because their study targeted residential lamps only.

[92] The term 'efficiency' is usually intended as the ratio between an energy input and an energy output. For light sources the output is measured as an amount of light in lumen (luminous flux, see par. 3.5) which is not directly an amount of energy, even though related to it. Therefore for light sources the term 'efficacy' is more appropriate.

[93] "CLASP, Estimating potential additional energy savings from upcoming revisions to existing regulations under the ecodesign and energy labelling directives, feb. 2013, Appendix E and F" (http://www.eceee.org/all-news/press/2013/2013-02-19/eceee-clasp-report-estimating-potential).

[94] Preparatory Studies for Eco-design requirements of EuPs, Final Report, Lot 19: Domestic lighting, Study for the European Commission DGTREN unit D3, contact Andras Toth, by VITO in cooperation with Bio Intelligence Service, Energy Piano and Kreios, October 2009, Contract TREN/07/D3/390-2006/S07.72702, available through 'eup4light.net'

For **CFLni**, the MELISA average efficacy of 55 lm/W seems low when compared to the 70 lm/W found by IEA 4E, but as said, that study targeted residential lamps only and the value may not be generally valid for the non-residential sector as well.

For **incandescent, halogen and CFLi lamps**, the MELISA average efficacies are generally low with respect to the values reported by IEA 4E. This can be taken into account during the model revision.

As regards **LED light sources** (not shown in Table 49), MELISA uses an average efficacy of 80 lm/W for products sold in 2013 (par. 2.2). This corresponds well to the values reported by IEA 4E of 73 lm/W for retrofit LED lamps and 88 lm/W for dedicated LED lamps (Table 44, Table 45).

Average Efficacy (lm/W)	LFL					CFL		HL						GLS		HID		
	T12	T8 halophosphor	T8 tri-phosphor	T5 new (14 - 80w) including circular	All others (including T5 old types 4 - 13w and special FL)	Retrofit - CFLi	Non-retrofit - CFLni	Single ended, mirrored (low voltage) [M16, M25 etc.]	Linear (high voltage) [R7s]	LV halogen Capsule [G4, GY6.35]	HV Halogen capsule [G9]	Mains halogen (substitute for GLS and reflector)[E14, E27]	Other mains halogen - PAR 16/20/ 2 5/30 hard glass reflectors, GU10 etc.	Reflector	GLS (including clear/pearl, candles, coloured & decorative)	All mercury lamps (including mixed)	All sodium lamps	Metal halide lamps
MELISA	70	75	80	91	86	55	55	14	12	14	12	12	12	9.5	9.5	40	95	82
CLASP 2013	70	75	80-84	91	86		55-65									40	95-110	65-90
VITO 2009						43		10	17 [95]	14		12 [96]		5	11			
IEA for 2007 (1) min-max			79	*87*		57	*66*	17.5	19.1	17.5		14.5		11.5				
IEA for 2013 (1) min-max			80	*89*		60	*70*	17.7	18.8	17.7		14.1		10.7				
IEA for 2013 (2) min-max			77	*91*		60	*76*	17.9	19.0	17.9		14.3		11.5				

Table 49 Average efficacy (lm/W) for non-LED light sources; comparison between MELISA, CLASP 2013, VITO 2009 and values derived by the study team from IEA 4E sales data. For the latter a minimum and maximum estimate are shown, for the years 2007 and 2013. The 2007 data are shown for countries AT, BE, FR, DE, UK, IT, NL (1); the 2013 data both for countries (1) and for Spain and Poland (2).

3.6.3. Tolerances and differences between rated efficiencies and test results

The European Commission is currently working on a horizontal approach regarding verification tolerances. Contractors are well aware of that and do not want to pre-empt in any way possible outcomes of such an approach. This paragraph, which is part of the contract, is thus limited to a general description of the problem, supplemented by some quantitative data.

As part of the assignment this study shall also fulfil the legal review requirements of Commission Delegated Regulation (EU) No 874/2012. As remarked in par.2.4 of the Task 0 report, this review shall in particular assess the verification tolerances set out in Annex V of the regulation.

[95] Efficacy 10.5 lm/W for directional lamps
[96] Efficacy 6.3 lm/W for directional lamps

These tolerances regard the verification procedure for market surveillance purposes. Annex V states that: '*The model shall be considered to comply with the requirements (….) if the model's energy efficiency index corresponds to its declared energy efficiency class and if the average results of the batch do not vary from the limit, threshold or declared values (including the energy efficiency index) by more than 10 %.*' [97]

This paragraph is intended as a first recognition of the problem for discussion purposes. Although the presentation focuses on Regulation 874/2012, the same issue also applies to other lamp regulations, because all regulations tend to express lamp efficacy limits in terms of rated values.

As explained in par. 3.6.1 and Annex H.1, Regulation 874/2012 establishes an energy efficiency index (EEI) for lamps, that depends on the rated lamp power and on the rated luminous flux.

Due to the fact that EEI relies on the rated values, both luminous flux and power are allowed to differ from the actual (tested) values, which is common practice embodied in IEC/EN lamp performance standards. This is reportedly to allow for manufacturing variability - if a lamp (or group of lamps) is randomly selected and tested, then it is possible that these lamp(s) are from an 'underperforming' production run and this needs to be catered for.

For example, the IEC performance standard for general purpose halogen lamps, IEC 60357, allows maximum power to be 108% of rated, and luminous flux to be 85% of rated [98]. When expressed as lamp efficacy, these combine as 85% ÷ 108% to allow an actual efficacy which is 78.7% of the 'rated' efficacy [99]. In other words, the actual efficacy can be 21.3% lower than one would expect from the flux and power values printed on the lamp packaging.

This issue is also raised in the Task 1 report par. 4.1.2 which discusses the issue of employing IEC 'type test' standards for regulation purposes.

Figure 26 shows independent Australian Government test results (power versus luminous flux; rated and tested values) for a small number of mains voltage, non-directional halogen lamps sampled randomly from the Australian market in 2013 (7 models x 10 samples) [100]. Figure 27 is for the same lamps but shows efficacy versus luminous flux; rated and tested values.

The figures show that the lamps tested generally had higher power and lower luminous flux than rated values would suggest. It is also interesting that lamp samples are relatively tightly grouped, suggesting low manufacturing variability within each batch. However, the test results are consistently grouped on the 'poor' side of rated. This suggests that the allowable tolerance is being applied asymmetrically. Only one of the tested models included any samples that met their 'rated' efficacy.

[97] LE-comment on same phrase in Task 0 report: "To note that tolerance are relevant to limits and shall not be considered as including the measurement uncertainties of MS Authorities labs. Any test carried out by MS Authorities shall be done according to future EN 13032-4 and it means that a specific budget of uncertainties shall be calculated before producing the test results"

[98] These values may not be up-to-date with the last version of the standard, but they are good for example-purposes.

[99] Noting that rated efficacy is not a value that actually appears on the lamp packaging, but is easily calculated from packaging values for luminous flux and power.

[100] The rated values in this figure are derived from lamp packaging (not from the Australian MEPS registration system). Australian regulations allow a tolerance between rated and tested values, however Australian lamp MEPS regulations are always expressed in terms of tested values.

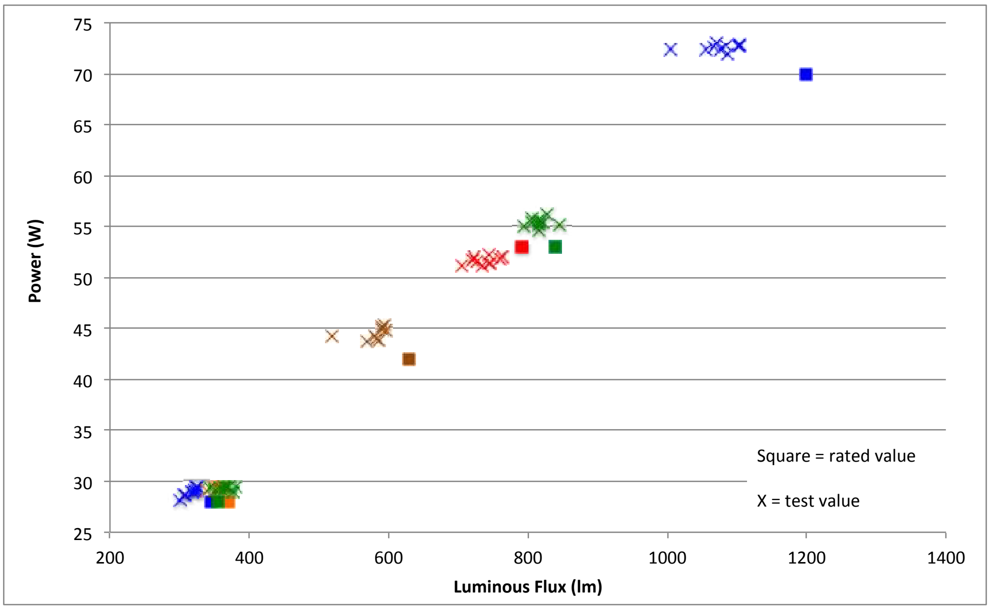


Figure 26 Independent Australian Government test results on power and luminous flux, for a small number of mains voltage, non-directional halogen lamps sampled randomly from the Australian market in 2013 (7 models x 10 samples). Rated values (squares) are derived from lamp packaging (not from the Australian MEPS registration system)

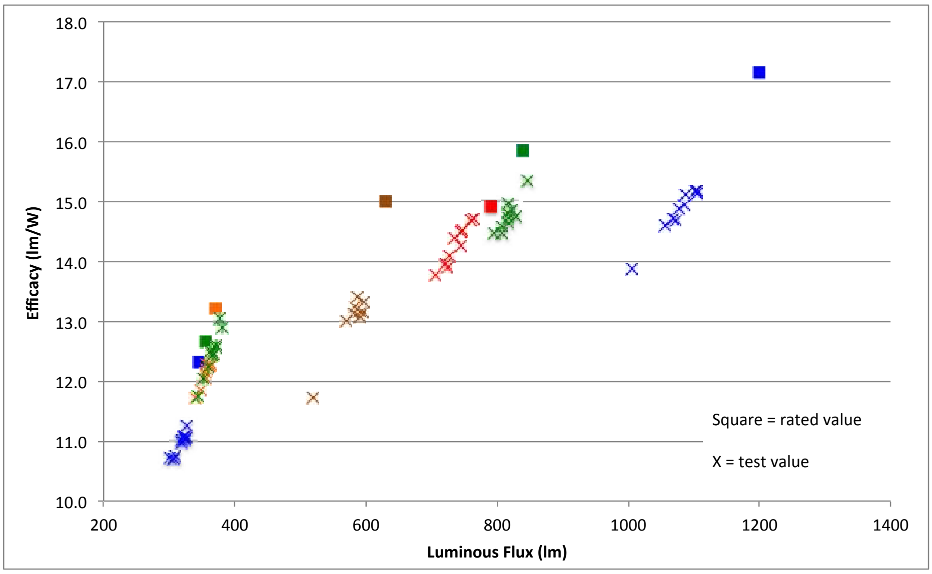
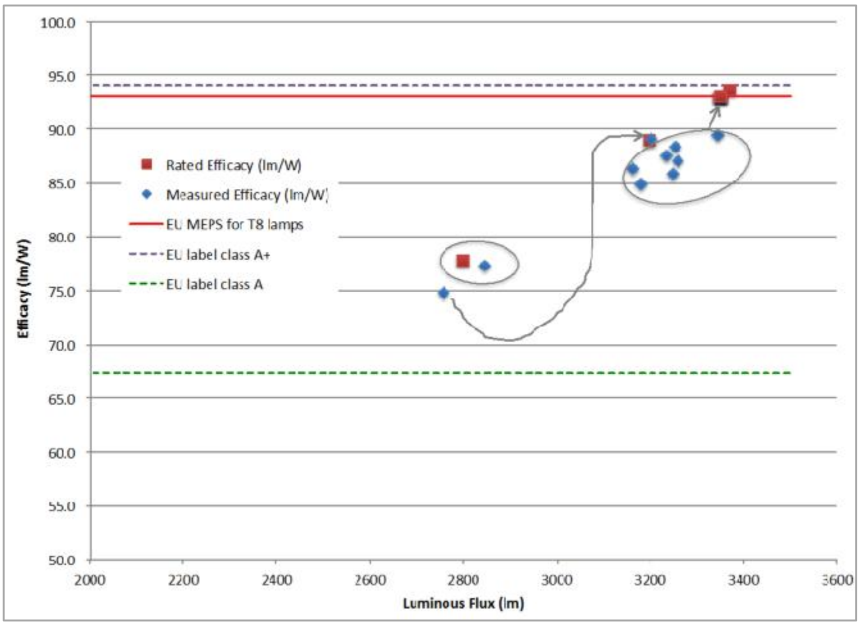


Figure 27 For the same lamps as the previous figure, but showing efficacy versus luminous flux.

Other examples of rated against tested efficacy values are reported in a recent CLASP study on LFL T8 lamps [101] and presented below.

[101] CLASP, November 2014, “Mapping & Benchmarking of Linear Fluorescent Lighting”. http://clasponline.org/en/Resources/Resources/PublicationLibrary/2014/Benchmarking-Analysis-Linear-Fluorescent-Lighting.aspx

As observed in the CLASP report, most of the tested European lamps (top part of Figure 28) claim efficacies that would meet MEPS [102] while tested values are below this limit. Citing CLASP: "*The appropriate IEC lamp performance standard (IEC 60081) allows an 8% difference between the rated and measured luminous flux, and a 5% difference between rated and measured lamp power. Allowing for an 8% reduction in luminous flux has the effect of lowering the effective efficacy requirement (i.e. when assessed from the viewpoint of actual measured performance) from 93 to 85.6 lm/W. Many of the tested lamp models passed this effective limit, although two lamp models failed significantly (efficacies of 75-77 lm/W). Two models very slightly failed this effective limit.*"



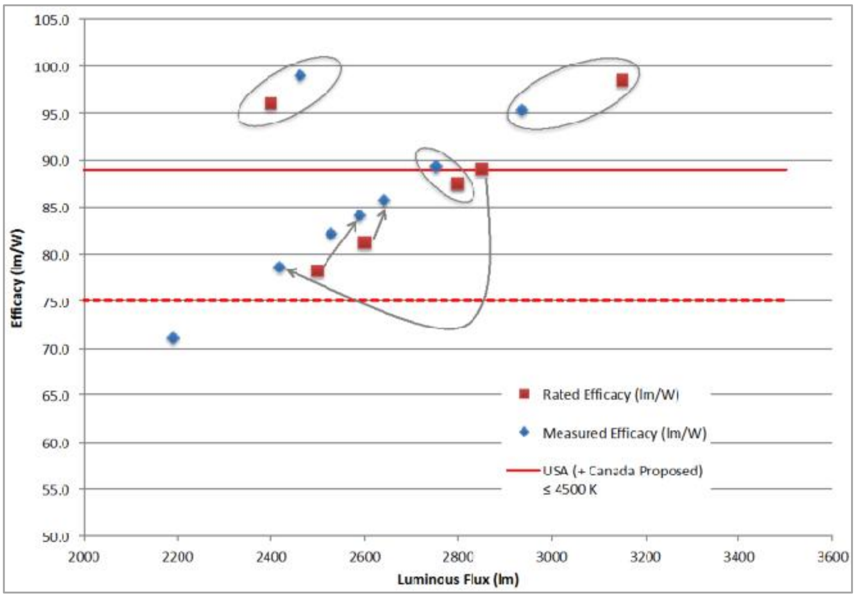


Figure 28 Rated and tested efficacy for T8 LFL lamps. Top: European lamps, 36W. Bottom: US lamps, 25 and 32W. Related rated and measured values are grouped by grey lines and ovals (Source: CLASP 2014)

[102] 93 lm/W for 36W T8 lamps according to Regulation 245/2009. Note that the upper two data points (squares) represent 7 lamps with the same or similar claimed efficacies.

In addition to tolerances for manufacturing variability, there is an issue of measurement uncertainty. From perusal of recent laboratory test reports for lamp efficacy testing [103], these are likely to be in the order of 0.6% for power, 1.6% for luminous flux and 1.7% for efficacy.

3.7. Specific energy consumption comparison

3.7.1. Specific energy consumption in the residential sector

According to MELISA, in 2013 the total EU-28 consumption of electric energy for lighting in the residential sector is 93 TWh (par.2.7). In the same year there are 198.6 million households (Eurostat), which implies **467 kWh/year/household**.

Dividing the total energy consumption by the total residential building area of 21218 Mm^2 (Annex L), an average of **4.3 kWh/m²/year** is obtained.

Table 50 compares the MELISA values for the specific energy consumption by lighting in households with information from other sources. The MELISA value of 467 kWh/year/household is reasonable considering the available reference information, and considering that in 2013 the European households are already in a transition phase towards more energy efficient lighting.

Source	Annual energy consumption for lighting per household (kWh/hh/year)	Lighting energy density for households (kWh/m^2)	reference
MELISA 2013	**467**	**4.3**	par.2.7
MELISA 2007	**565**		
MELISA 2000	**553**		
MELISA 1990	**494**		
United Kingdom 2012	537	10	Annex C.1
The Netherlands 2011	464		note [104]
Sweden 2009, houses apartments	646-937 240-691	6.7	Annex C.2
REMODECE 2008 (12 countries)	487		Annex C.3
JRC, Bertoldi, 2006 (EU-28)	498		Annex C.8
IEA, 2006 (7 countries)	375-775	3.3-9.3	note [105]
France 2003	354	3.7	Annex C.4
EURECO 2002 [106] (4 countries)	375-426	3.3-4.0	Annex C.5
France 2000, CIEL	500		note [107]
Delight, 1994-1997 (19 countries)	569	3.4-12.1	Annex C.6

Table 50 Comparison of energy consumption for lighting in residential buildings between the MELISA model and various literature sources.

[103] IEA 4E Solid State Lighting Annex: 2013 Interlaboratory Comparison, final report 10 September 2014, available through: http://www.iea-4e.org/publications

[104] "Energie trends 2012", published by ECN, Energie-Nederland and Netbeheer Nederland. The average annual electricity consumption for households in The Netherlands in 2011 is reported as 3312 kWh, of which 14% for lighting, i.e. 464 kWh/year.

[105] LIGHT'S LABOUR'S LOST, Policies for Energy-efficient Lighting, OECD/IEA, 2006

[106] Data for Portugal have been ignored for compiling this table, see Annex C.5

[107] France, project CIEL, 2000. Measured lighting in 114 apartments. http://www.enertech.fr/modules/catalogue/pdf/42/economie%20electricite%20logement%20social_2000.pdf

3.7.2. *Specific energy consumption in the non-residential sector*

According to MELISA, the 2013 lighting energy consumption in the non-residential sector is estimated in 290 TWh. Excluding SPL, controls and standby this reduces to 220 TWh. In a rough estimate, all HID-lamps (63 TWh) are assumed to be used in outdoor lighting, leaving approximately 160 TWh for the indoor lighting of non-residential buildings.

According to the estimate in the EU Building heat load report [91], the total EU-28 non-residential building area is 11517 Mm^2. This implies **a lighting energy density (LENI [108]) for non-residential buildings of approximately 13.4 kWh/m^2/year**.

Table 51 shows the above MELISA outcome for the lighting energy density in kWh/m^2/year of non-residential buildings, compared to values from some literature sources. Considering the large variety in buildings, the large variety in types of rooms/zones in these buildings, the various levels of efficacy of the lighting installations, and the use of various types of areas [109], it is not surprising that there is a large spread in the LENI values. In addition there is still a lack of reliable (measured) data on the energy consumption by lighting in the non-residential sector.
The available data do not allow a real judgement of the MELISA value of 13.4 kWh/m^2/year, but it could be reasonable. See also the comparison of the lm/m^2 (par. 3.5.4) and W/m^2 values (par. 3.4.4).
Two French studies (Annex D.4, D.6) seem to indicate that 6 kWh/m^2/year could be a target value for a modern office building with optimized lighting design and management.

Source	Room/zone type	Lighting energy density for non-residential buildings (kWh/m^2/year)
MELISA 2013	**Average of all buildings**	**13.4**
EL-Tertiary project 2008 (Annex D.1)	Office buildings (10)	21 (median) 25 (average)
	School buildings (11)	5 (median) 10 (average)
	Hotel buildings (4)	28.2
	Offices (82)	7 – 20 – 30 [110]
	Conference rooms (20)	3 – 6 – 9
	Classrooms (40)	0 – 4 – 12
	Toilets, sanitary (40)	1 – 5 – 25
	Circulation areas (108)	4 – 13 – 22
	Service, tech, archives (42)	1 – 2 – 7
	Gymnasium, sports (14)	1 – 5 – 15
Office buildings (FR, 2005) (Annex D.5)	Offices	*14.6 -> 9.5* [111]
	Circulation areas	*7.1 -> 4.8*
	Common rooms	*4.1 -> 2.7*
	Sanitary	*1.2 -> 0.6*
	Average of 49 office buildings	26.7 -> 17.6

[108] LENI = Lighting Energy Numeric Indicator as defined in prEN 15193 (see Annex I).

[109] Some sources use the gross building area, others the net or useful building area. For rooms/zones in buildings some sources relate the energy consumption to the area of that room/zone, but others relate it to the area of the entire building.

[110] For the EL-Tertiary project, for room types, the 25%, 50%, 75% quartile values are reported. The number of measurements is reported between brackets in the room type column. For example, for offices, 25% of the 82 rooms have a lighting energy less than 7, 50% less than 20, and 75% less than 30 kWh/m^2/year. Rooms can be in different building types. For example of the 82 offices, 54 were in office buildings, 25 in schools and 3 in other buildings.

[111] For this reference, all values are per m^2 total building area, e.g. NOT per m^2 office area or sanitary area. Values are shown for the existing situation and for the projected situation after implementation of savings measures (existing -> after savings).

Source	Room/zone type	Lighting energy density for non-residential buildings (kWh/m²/year)
Office building (FR,2005)	Entire building (1)	28.1 -> 6 [112]
IEA, 2006 [113]	commercial buildings	27.7
Recent office building (FR,2009)	Entire building (1)	6.2 -> 3.9 [114]
IWU (Germany 2014) (Annex D.7) [115]	93 non-residential buildings	15 (median) 23 (average)
	10 public buildings	13 (average) 7 – 24 (range)
	140 offices (single & open)	19
	50 class rooms	15
	13 hotel rooms	12
	128 circulation areas	11
prEN15193-2 [116]	Circulation areas	26 (existing) 4.3-6.8 (standard)
	Personal offices	31-39 (existing) 15-16 (standard) 6-13 (efficient)
	Conference room	10-15 (efficient)
	Open floor office	58 (existing) 19-23 (efficient)
	Kitchen in non-residential building	68 (existing) 19-24 (efficient)
	Manufacturing hall, with roof lights	8.5 (existing) 1.8-3.3 (efficient)
	Manufacturing hall, without roof lights	132 (existing) 27-51 (efficient)

Table 51 Comparison of lighting energy densities (kWh/m²/year) in non-residential buildings, between the MELISA model and various literature sources.

3.8. Conclusions

The sources for the lighting energy parameters currently used in MELISA have been clarified. An auto-critical examination of these parameters has also been performed, comparing them with the most recent data available from a 2014 IEA 4E study [117].

This comparison provided indications on which MELISA parameters could be adjusted before the final use of the model in the scenario analysis of MEErP Task 7.

The MELISA outcome for the 2013 domestic energy consumption for lighting of 467 kWh/household/year is reasonable considering the available reference information

[112] See Annex D.4 for details. Values are shown for the existing situation and for a projected situation after implementation of savings measures (existing -> after savings).

[113] LIGHT'S LABOUR'S LOST, Policies for Energy-efficient Lighting, OECD/IEA, 2006

[114] See Annex D.6 for details. Values are shown for existing situation and for the projected situation after implementation of savings measures (existing -> after savings).

[115] Approximate values, derived by study team from data reported in the reference.

[116] Benchmark values. See further details in Annex I.3. Values are indicated for a typical existing solution and for a standard or efficient solution.

[117] "4E Mapping Document, European Union, Domestic Lighting". Available through: http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5 together with other supporting material.

For non-residential lighting, the MELISA outcomes for installed lighting power density (W/m^2) and lighting energy density (kWh/m^2/year, LENI) are difficult to judge because the available reference information shows a large variability in values. The study team intends to further examine this point:

- Considering the building area data per sector and per type of room/zone that can be derived from the EU building heat load report [91], the lighting requirements set by standards like EN 12464-1 (indoor workplaces), EN 12193 (sports buildings), and EN 1838 (emergency escape lighting), and average efficiencies for luminaires and room surface reflections, the intention is to derive the corresponding total required installed lighting capacity (and power). This could then be compared with the MELISA outcomes.
- Considering the default operating hours for non-residential buildings from prEN-15193, the occupancy factors presented in the same standard, and an assumption for average daylight factors, compute the real operating hours for lighting per type of building/room/zone. The result can be compared with the current assumptions in MELISA regarding operating hours.
- From the combination of these two points it should be possible to derive an estimate for the LENI of non-residential buildings that can be compared with the MELISA outcome.

These computations will be performed in the context of the parallel Lot 37 study on lighting systems.

4. LIGHT SOURCES AS ENERGY-RELATED PRODUCT

Light sources, even energy efficient light sources, emit heat as a by-product and this makes them energy-related products for heating, ventilating, and air conditioning (HVAC) equipment. In other words: the heat produced by light sources has to be taken into account when optimally dimensioning space heating equipment and air-conditioning equipment.

As defined in a recent report on EU building heat load [118], the "*Internal gain is the space heating contribution of people, pets and energy-using products in the household*". Due to efficiency improvements, the contribution of lighting and appliances to the internal heat gain will diminish, resulting in an increase of the heating load for space heating systems, and potentially in a decrease of the cooling load for air-conditioning systems.

Citing from the same report:

> "*Lighting makes up around 500 kWh per year per household. It is considered a very effective contributor to space heating, because it is generated at the place and the time that people actually need space heat. The theoretical efficiency of lighting, i.e. the efficiency at which all electricity is used to generate light and there is no waste heat, is defined at 628 lm/W. Given the composition of the light sources in a 2010 EU household with still a majority share of incandescent and halogen bulbs (10-15 lm/W), 4 or 5 CFLs (30-60 lm/W) and 2 LFLs (60-80 lm/W), the average luminous efficacy is no more than 20 lm/W. This comes down to an efficiency of 3.2%, meaning that 96.8% (around 480 kWh) is lighting waste heat that can contribute to space heating. With new light sources (LED) this number is expected to drop, but even at 100 lm/W average, and no growth in lumen output, the space heating contribution of lighting will still be around 85% of the input*."

Considering also the contributions of other appliances and of the body heats of persons:

> "*The sum of the internal gain contributions gives around 2500 kWh during the heating season for the average EU dwelling in 2010. At an average dwelling surface of 90 m² and a heating season of 5000 h this results in 5.5 W/m², i.e. some 10% more than was assumed in most building standards. However, with increased efficiency of the devices, especially the electronics, 5 W/m² seems quite robust as a long term average.*" (Figure 29)

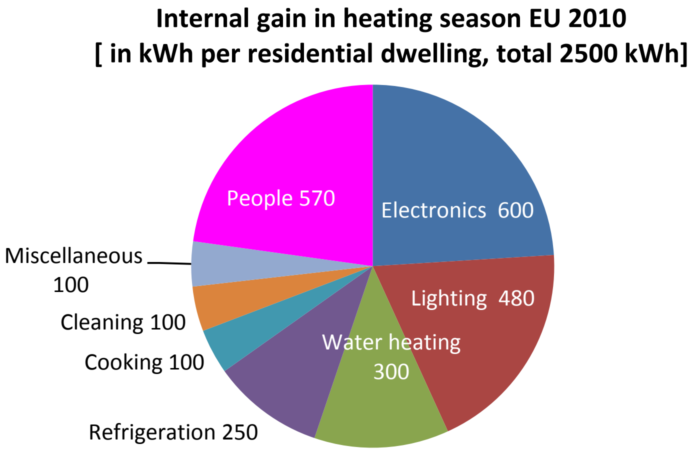


Figure 29 Internal gain in heating season EU 2010, in kWh per residential dwelling, total 2500 kWh. (source: VHK report on EU building heat load [118])

[118] "Average EU building heat load for HVAC equipment", final report, René Kemna (VHK) for the European Commission, August 2014, http://ec.europa.eu/energy/efficiency/studies/doc/2014_final_report_eu_building_heat_demand.pdf

As reported in the EU building heat demand report, the total internal heat gain in 2010 is believed to contribute 2.3 °C to the target temperature of the household spaces to be heated. If, as projected, there is a 16% decrease in energy for lighting and appliances by 2020 (compared to 2010), this contribution will decrease to 1.9 °C. This is a 0.4 °C deficit that has to be filled in by space heaters.

Note that the contribution of lighting products to these figures is less than 20% (Figure 29): this gives a good estimate of the order of magnitude of the heating effects related to lighting in households.

The discussion in the cited report is for households, but similar effects occur in non-residential buildings.

In addition to the above, it should be noted that sooner or later also the useful (visible) light may become heat that is relevant for the space heating or cooling balance. The light will fall on surfaces in the room and have a local heating effect. A part may be reflected on these surfaces and reach other surfaces where it creates some heat. At the end, only the light that escapes from the room, for example through windows, will not have a space heating effect.

In some cases light sources might be cooled by a ventilation system and the corresponding heated air might be exported from the room/building. In an optimised situation such a system would be managed differently during the heating season (maintain the heat in the building) and the cooling season (export the heat).

Different types of lamps emit heat in different manners. For incandescent lamps, a large part of the heat (infrared) is radiated from the lamp together with the visible light. For halogen lamps the same principle applies, but the amount of infrared radiation may depend on the presence of the infrared coating that reflects the heat back to the filament for increased efficacy. In the case of LED lamps, a large part of the heat is generated directly in the basic semi-conductor material and exported from there mainly by means of a dedicated heat dissipater (or directly by means of the lamp housing and cap), using conduction and convection. Theoretically, whether by radiation, convection or conduction, all heat contributes to the heat balance of the room containing the light sources. However, the more radiating filament lamps might distribute the heat in a more useful way then LED lamps, that tend to mainly provide local heating near ceilings or walls (near the light sources).

5. OTHER ENVIRONMENTAL IMPACTS OF LIGHT SOURCES

5.1. Health aspects

5.1.1. Introduction

In the Stage 6 review report [119] the following health aspects related to lighting are presented and discussed:

- Effects of ultraviolet radiation (UVR) of artificial lighting to the skin and retina of healthy people.
- Influence of blue light and ultraviolet radiation on photosensitive patients.
- Effects of flicker of lamps on diseases as epilepsy and migraine.
- Effects of artificial lighting on the light-sensitive symptoms in some patients with such diseases as chronic actinic dermatitis and solar urticarial.
- Effects of artificial (blue) light on the day-night rhythm.
- Differences in effects of various types of lighting, especially concerning the different light spectrum.
- Health concerns related to mercury exposure from accidental breaking of CFLs.

The statements made in that report and in the cited SCENIHR and SCHER reports [120] are still valid, and the reader is referred to those publications [121].

5.1.2. IEA 4E health aspects of LEDs

As an integration to that information, in September 2014 the IEA 4E published a report on the health aspects of Solid State Lighting (SSL, i.e. LEDs) [122]. The study mainly regards glare, photobiological effects, flickering, and non-visual effects of light, for example on the circadian rhythm and on the biological clock. The main conclusions of the report are summarized below:

- **Electrical safety** of SSL products is appropriately addressed by existing safety standards.

- Human exposure to **electromagnetic fields** emitted by SSL products is not a critical issue.

- **Glare** can be a critical issue for SSL products. It can cause discomfort, temporary visual disability, and, indirectly, cause accidents and injuries. According to the reference, the Unified Glare Rating (UGR) method is not applicable to visible LED point sources. It is recommended to report the maximum luminance for finished SSL products [123].

---

[119] "Review study on the stage 6 requirements of Commission regulation (EC) No 244.2009 Final Report", VHK (pl) / VITO for the European Commission, Delft/Brussels 14.6.2013, SPECIFIC CONTRACT No ENER/C3/ 2012-418 LOT 2/01/SI2.645913 Implementing Framework Contract No ENER/C3/2012-418-Lot 2. http://www.eup-network.de/fileadmin/user_upload/Technical_Review_Study_by_VHK_VITO.pdf?PHPSESSID=a60a9114e01af59471374f5814656e0c

[120] http://ec.europa.eu/health/archive/ph_risk/committees/04_scenihr/docs/scenihr_o_019.pdf
http://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_035.pdf
http://ec.europa.eu/health/scientific_committees/environmental_risks/docs/scher_o_124.pdf
http://ec.europa.eu/health/scientific_committees/environmental_risks/docs/scher_o_159.pdf

[121] IALD comment: "We would support further research on this area, to fully address the health effects of flicker and strobing published since last SCENHIR."

[122] IEA 4E Solid-State Lighting Annex, Potential Health Issues of Solid State Lighting, Final Report, 24 September 2014, http://ssl.iea-4e.org/task-1-quality-assurance/health-aspects-report

[123] IALD comment: "The reference to glare in SSL products mentions that it is recommended to report the maximum luminance for finished SSL products. We would to get some further clarification on what exactly should be reported."

- IEA 4E recommends to perform a **photobiological safety** assessment for all SSL devices according to the existing standards. Manufacturers should report the risk group for their product. The reference states that the general public is not aware of potential risks for the eye and recommends warning labels in certain cases. Additional work on standard IEC 62471 to take into account the sensitivity of certain specific population groups is also mentioned. Particular attention is asked for white LEDs based on violet and UV chips, that have a potential for blue light hazard and UV hazard that should be assessed.

- **Flicker** can lead to headache, migraine, dizziness and impaired visual performance. Some LED lamps are free of flicker while others reach the maximum percent flicker value of 100%. The reference states that it is unacceptable that there are currently no clear requirements to limit light flickering.

- Compared to other lighting technologies, SSL products are not expected to have more direct negative impacts on human health with respect to **non-visual effects**. However, the LED technology might lead to more lighting points being installed and consequently to an increase in exposure to artificial light [124].

As regards **mercury in lighting products**, see also the remarks in the Task 1 report par. 3.2 (resources use), par. 5.1.9 (EU Ecolabel, 2011/331/EU), par. 5.1.14 (RoHS2 and Minamata convention), par. 5.1.16 (WEEE).

As regards the relationship between **lighting and human performance**, information can be found, for example, in two publications of the “licht.wissen” series [125], indicating that correct lighting can increase the work output, decrease errors, and reduce health complaints of employees in the work environment.

5.1.3. LightingEurope guide on photobiological safety

In February 2013 LightingEurope published a guide on photobiological safety of lighting products [126]. This document clarifies that

- The legal context for photobiological safety of lighting products is given by **directive 2006/25/EC** (as amended) [127], that provides optical radiation limit values in relation to exposure times [128].

[124] the EIA 4E reference further explains this: “The low cost of LEDs combined with their form factor and their low energy consumption may cause more lighting points to be installed at home, at work or in the streets, thereby increasing the overall exposure to artificial light and the potential risks linked to non-visual effects such as the perturbation of the biological circadian clock. The experts recommend preserving a dark nocturnal environment while maintaining a suitable exposure level during daytime through a combination of daylight and artificial lighting.“

[125] Licht.wissen 04, Office lighting: motivating and efficient.
http://en.licht.de/fileadmin/shop-downloads/120828_lichtwissen04_Office_Lighting_Motivating_and_Efficient.pdf
Licht.wissen 05, Industry and Trade.
http://en.licht.de/fileadmin/shop-downloads/lichtwissen05_industry_trade.pdf

[126] “LightingEurope Guide on Photobiological Safety in general lighting products for use in working places”, Edition February 2013, http://www.lightingeurope.org/uploads/files/LE_Photobiological_Safety_Feb2013.pdf

[127] DIRECTIVE 2006/25/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 April 2006 on the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (artificial optical radiation) (19th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) (OJ L 114, 27.4.2006, p.38), consolidated version with amendments up to December 2013, http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02006L0025-20140101

[128] As noted by LightingEurope, on lighting products, unless the work or the task requires to stare at the light source, the viewing of the source is random and normally happens accidentally turning the eyes towards it.

- **Standard IEC 62471** [129] gives guidance for evaluating the photobiological safety of lamps and lamp systems including luminaires. It specifies the exposure limits, reference measurement technique, and classification scheme (risk groups, RG) for the evaluation and control of photobiological hazards from all electrically powered incoherent broadband sources of optical radiation. It considers UV-radiation, IR-radiation, and the 'blue light hazard' [130].
- The technical report **IEC/TR 62778** defines the limits and criteria for the application of IEC 62471, regarding the evaluation of blue light hazard [131]. Amongst others, the report identifies combinations of illuminance (lux) and colour temperature that lead to the limit of risk group 1 (i.e. no further evaluation necessary). For example, for a warm white light source with CCT=2700 K an illuminance of 1850 lux would still be RG 1, while for a cold white lamp with CCT=7000 K this level would be only 500 lux.

- The **luminaire standard IEC 60598-1** [132] takes into account the possibility of having light sources that emit a level of UV greater than 2 mW/klm. In this case, the lamps are identified by a symbol indicating that the lamp cannot be used in open luminaires without any glass protection. The protective glass shall be designed so that the UV emission will not be excessive and the assessment is made by the standard being based on RG 0 of IEC 62471.

- Many **technical standards for specific lamp types** (see detailed list in [126]) already include statements on the photobiological hazards, implying that luminaires using lamps that comply with these standards will not require further assessment for photobiological safety.

- The LightingEurope guide concludes with a table showing that for most lamp types there are no UV-, IR- or blue light- hazards. The exceptions, where **additional investigation would be necessary**, are:
  - Halogen lamps for special application (IEC 60432-3) in case of luminaires using narrow beam focusing optics (projection, photographic, stage lighting),
  - Clear metal-halide lamps (IEC 62035), as regards blue light hazard,
  - LED Modules (IEC 62031), as regards blue light hazard.

5.1.4. Philips position paper on test methods for flicker and stroboscopic effects

As part of their comments on the original issue of this document, LightingEurope supplied a Philips position paper regarding test methods for Temporal Light Artefacts (TLA) [133].

TLA are undesired changes in visual perception of an observer in a certain environment, induced by a light stimulus whose luminance or spectral distribution fluctuates with time. This includes flicker [134] and

[129] CIE S 009 E:2002 / IEC 62471:2006, EN 62471:2008 ; FprEN 62471-5:2014 'Photobiological safety of lamps and lamp systems', see Task 1 report, annex H.2.

[130] 'Blue-light hazard is defined as the potential for a photochemical induced retinal injury resulting from electromagnetic radiation exposure at wavelengths primarily between 400–500 nm.' http://en.wikipedia.org/wiki/High-energy_visible_light#Blue-light_hazard

[131] IEC/TR 62778: 2012 'Application of IEC/EN 62471 for the assessment of blue light hazard to light sources and luminaires (Technical report)', see Task 1 report, Annex H.14.

[132] EN 60598-1:2008/A11:2009 ; FprEN 60598-1:2014 'Luminaires - Part 1: General requirements and tests', see Task 1 report, annex H.6

[133] EMC-14-JAW-009, External TLA position paper SHAPE version.1, 2014-11-27.pdf, Philips sector lighting. This document will be made available through: http://ecodesign-lightsources.eu/

[134] Perception of visual unsteadiness induced by a light stimulus whose luminance or spectral distribution fluctuates with time, for a static observer in a static environment. The typical frequency range is: few Hz up to 80 Hz.

stroboscopic effects [135]. Both can be caused by lighting product characteristics or by system properties (e.g. interaction with an internal dimmer in the lamp or an external dimmer, see also par. 7.2). Flicker can also be caused by mains voltage fluctuations in the power supply.

As observed in the paper, scientific committees like SCENIHR [136] have associated these TLA with potential health-, performance- and safety-related effects. As a consequence the European Commission has issued mandate M/519/EN [137], that also regards standards for flicker and stroboscopic effects. The appropriate CIE and IEC standardization committees have concluded that the current TLA performance standardization is hampered by lack of adequate TLA assessment methods [138] and have therefore started projects on the development of appropriate methods.

The position paper introduces the proper TLA assessment methods (see reference for details):

- The recommended method to evaluate **flicker**, either due to mains voltage fluctuations or to product/system characteristics, is based on the existing IEC short-term flicker metric P_{st}, as standardized in IEC TR 61547-1.

- The recommended method to evaluate **stroboscopic effects** is the Stroboscopic Visibility Measure (SVM) metric, whose measurement setup will be standardized in a CIE TR, which is currently (November 2014) being defined in CIE TC1.83.

- The test setups make reference to the NEMA SSL7A [139] standard dimmer.

The Philips (and LightingEurope) position is that:

"*In view of anticipated future European TLA standardization and regulation, Philips recommends to wait for the CIE and IEC publications of the proper TLA assessment methods and to avoid the adaptation of improper metrics, such as Modulation Depth (also called Flicker Percentage) and Flicker Index*."

See also IALD comments on this topic [140].

135 Change in motion perception induced by a light stimulus whose luminance or spectral distribution fluctuates with time, for a static observer in a non-static environment. The typical frequency range is: 80 Hz up to 2000 Hz.

136 Scientific Committee on Emerging and Newly Identified Health Risks, http://ec.europa.eu/health/scientific_committees/emerging/index_en.htm , see also note 120.

137 See Task 1 report, annex H.20.1.

138 The position paper clarifies that "*the currently applied metrics Modulation Depth (also called Flicker Percentage) and Flicker Index do not quantify TLA correctly because none of these metrics account for the root cause, the effect of the frequency nor wave shape of the light stimulus. Consequently, these incorrect metrics and the associated pass/fail criteria may wrongly include or exclude certain LED topologies.* "

139 NEMA SSL 7A-2013 Phase Cut Dimming for Solid State Lighting: Basic Compatibility.

140 IALD comment on Task 0-3 reports: "We believe this is an urgent problem that should be addressed. Work has been done and published by Professor Arnold Wilkins and others from Surrey University with methodologies for testing flicker and with recommendations for acceptable limits (Lehman, B. and Wilkins A.J. (2014). Designing to mitigate the effects of flicker in LED lighting. IEEE Power Electronics Magazine, Vol. 1, No. 3, September. http://www.energy.ca.gov/appliances/2014-AAER-01/prerulemaking/documents/2014-09-). These should be studied and used as is or with documented variations until such time as broader standards are developed; the introduction of new methodologies in future regulations should be addressed with care. Flicker is a specific and particular problem with LED given the generalised use of switch mode power supplies and PWM dimming from digital signals."

5.1.5. GLA white paper on optical and photobiological safety of light sources

As part of their comments on the original issue of this document, LightingEurope supplied a 2012 GLA white paper on the optical and photobiological safety of light sources [141].

The paper discusses a wide range of lighting-related safety aspects, both for 'normal' people and for persons with a particular sensitivity for UV- and blue-light. In the annexes the paper provides reference data for the spectral emissions and blue light energies for different lamp types, and other background information.

The GLA position regarding the safety of light sources can be summarized as follows:

- Based on accepted and widely adopted safety standards for lamps, all general lighting sources, including LED and CFL sources (either lamps or systems) and luminaires can be safely used by the consumer when used as intended.

- The portion of blue light produced by an LED is not significantly different from the portion of blue produced by lamps using other technologies at the same colour temperature. A comparison of LED and CFL retrofit products to the traditional products they are intended to replace reveals that the risk levels are very similar and well within the accepted range.

- Individuals with an enhanced sensitivity to UV may want to consider using LED based lighting for their high efficiency lighting needs if there are any concerns about even the small levels of UV that are produced by CFLs. (Another option for such UV sensitive individuals is to use a covered CFL or ensure the CFL is in a covered luminaire.)

- Blue and cool white light sources can be used to create lighting conditions such that people will receive their daily portion of blue light to keep their physiology in tune with the natural day-night rhythm. Both LED and fluorescent lamps can be tailored to fulfil this purpose.

5.1.6. Ökopol report on health aspects of LED light sources

As part of their comments on the original issue of this document, the Federal Environment Agency of Germany (Umwelt BundesAmbt, UBA) supplied an Ökopol paper regarding, amongst others, the safety aspects of LED light sources [142].

Based on a description of the composition of the lamps and LEDs and the used substances and materials, the study investigates possible risks related to the used substances, the optical properties, the availability of relevant raw materials, possible recycling scenarios as well as the energy efficiency (development) and further usage characteristics, among them the service life. The study focuses on LED retrofit lamps.

As regards health-related aspects the study draws the following conclusions:

- The substances contained in LEDs have only limited toxic or eco-toxic impacts according to the available data. A release of these substances from the semiconductor or carrier material is very unlikely under normal conditions of use. A "worst case" estimate (complete release and uptake

[141] GLA = Global Lighting Association, http://www.globallightingassociation.org/mint/pepper/tillkruess/downloads/tracker.php?url=http%3A//www.globallightingassociation.org/documents/gla_papers/20120226_Optical_Safety_of_LEDs_-_Long_Paper.pdf

[142] EXPERTISE LEUCHTDIODEN, UMWELT-, GESUNDHEITS- UND VERBRAUCHERRELEVANTE ASPEKTE VON LEUCHTMITTELN AUF BASIS VON LED, August 2013, Ökopol – Institut für Ökologie und Politik, (in German, with English summary) http://www.oekopol.de/archiv/material/551_1_Oekopol_LED_Endbericht_Aug%202013.pdf.

of substances contained in LED) of possible maximum release levels shows that the resulting exposition for humans and the environment clearly lies below known effect thresholds [143].

- The electromagnetic fields created by LED lamps are rather low and approximately in the range of those of incandescent lamps considering the known frequency dependent impacts on the human body.

- Regarding the share of blue light, a comparison of spectra shows that LEDs do not have a fundamentally different spectral quality compared to fluorescent lamps. The risk of acute blue-light damages caused by white LEDs therefore lies within the range of risks of fluorescent lamps of comparable colour temperatures and can, for the technology currently applied for general lighting, be even lower for children because of the lack of UV components. Increased long-term risks through LED and fluorescent lamps in comparison to incandescent and halogen lamps seem to be in principle possible though due to the higher relative share of blue light.

- Disposal: It can be assumed that there is no acute risk for humans and the environment when LED lamps get into the currently available disposal paths.

5.2. Obtrusive light

Obtrusive light, related to the concept of 'sky glow', is part of the more general 'light pollution'. The following definitions, taken from Regulation 245/2009, are recalled from the Task 1 Annex report:

> '*Light pollution*' means the sum of all adverse impacts of artificial light on the environment, including the impact of obtrusive light.
>
> '*Obtrusive light*' means the part of the light from a lighting installation that does not serve the purpose for which the installation was designed. It includes:
> - light improperly falling outside the area to be lit,
> - diffused light in the neighbourhood of the lighting installation,
> - sky glow, which is the brightening of the night sky that results from the direct and indirect reflection of radiation (visible and non-visible), scattered from the constituents of the atmosphere (gas molecules, aerosols and particulate matter) in the direction of observation.

Obtrusive light is relevant in particular for outdoor lighting and sometimes for indoor lighting in 'open' spaces like greenhouses. Readers are invited, the next time they take an airplane at night, to look downwards and observe the differences between street lighting systems. Some roads will appear illuminated while the light sources themselves cannot be distinguished. For many other roads the street lights themselves are clearly visible from above, meaning that a large part of the light is emitted in the wrong direction. This is not only a pollution, it is also a waste of energy.

As obtrusive light depends mainly on the design of the luminaires and of the lighting systems, this topic will be addressed in the parallel Lot 37 study on lighting systems. In the meantime, reference is made to

[143] However, the study notes that for some types of material no safety threshold values are available, so that no judgement could be formulated.

the 2009 Lot 9 preparatory study on street lighting [144], to the CIE-publications 001-1980, 126-1997 and 150-2003, and to the standard EN 12464-2 on the lighting of outdoor workplaces (see Task 1 report).

5.3. Outdoor lighting and insects

Outdoor artificial lighting attracts insects and this can be considered as an undesired effect of lighting on the environment [145]. This topic will not be handled in detail here, but it is interesting to note that recent studies indicate that LED-lighting, in particular warm-white LED-lighting, attracts far less insects than HID-lamps (Figure 30). This is confirmed in two separate studies in Germany and Austria [146].

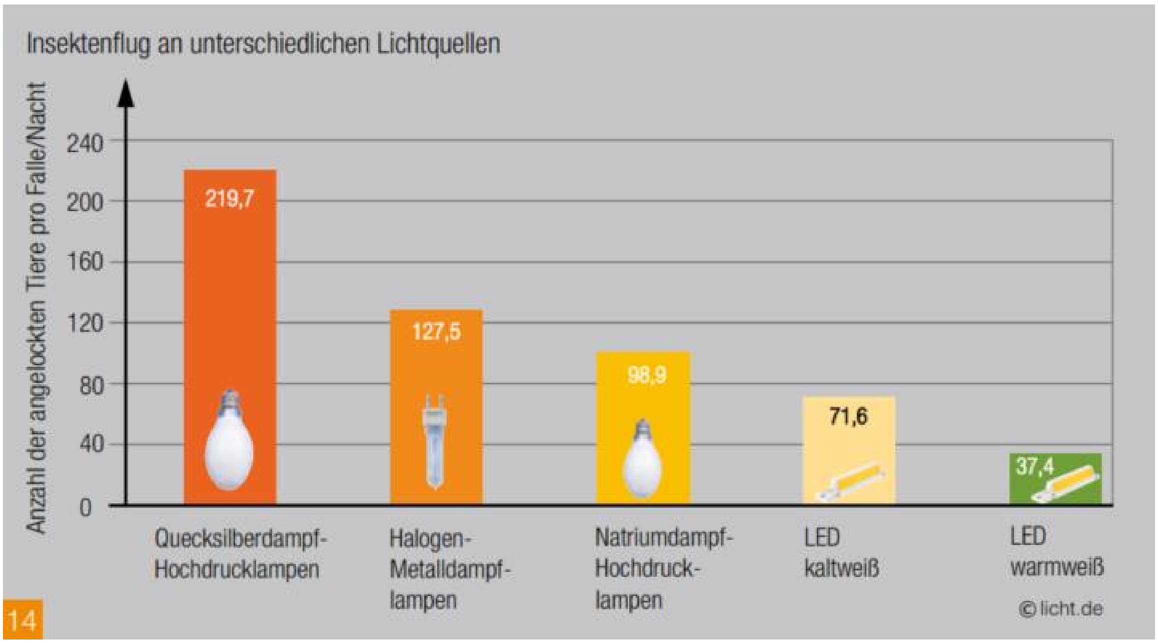


Figure 30 Number of insects attracted by outdoor artificial lighting (in trapped insects per night), depending on the type of lighting installed. From left to right: high pressure mercury, metal-halide, high pressure sodium, cold-white LED and warm-white LED (source: [147]).

[144] Preparatory Studies for Eco-design requirements of EuPs, Final Report, Lot 9: Public Street lighting, Study for the European Commission DGTREN unit D3, contact Andras Toth, by VITO in cooperation with Laborelec and Kreios, January 2007, Contract TREN/D1/40-2005/LOT9/S07.56457, available through 'eup4light.net'

[145] This topic has many other aspects, i.e. lighting can also have influence on birds, bats and other animals, and also the colour of lighting may play an important role. This has not been further investigated here.

[146] http://www.nabu.de/stadtbeleuchtung/cd-rom/Inhalte/PDF/H3-7.pdf
https://www.wien.gv.at/verkehr/licht/beleuchtung/studie-insekten.html
https://www.wien.gv.at/verkehr/licht/pdf/studie-insekten.pdf

[147] Licht.wissen 03, Strassen, Wege und Plätze.
http://www.licht.de/fileadmin/Publikationen_Downloads/1403_lw03_Strassen_Wege_web.pdf

6. END-OF-LIFE ASPECTS

6.1. Introduction

Lamps and luminaires are in part covered by the Waste Electrical and Electronic Equipment (WEEE) Directive 2012/19/EU (Task 1 report, par. 5.1.16). Annex I of the directive distinguishes 'lighting equipment' as an EEE category (5) to which the directive applies, also in the transitional period (2012-2018). Annex II gives examples of EEE falling into this category: *LFL, CFL, HID (HPS, MH), LPS, "luminaires for fluorescent lamps with the exception of luminaires in households", "other lighting or equipment for the purpose of spreading or controlling light with the exception of filament bulbs*".

Note that filament lamps (incandescent and halogen lamps) and household luminaires are excluded from the directive. They form part of the general waste stream, ending up in landfills or incinerators, although not completely excluding a recycling fraction or heat recovery [148].

LED-lamps are covered by the WEEE-directive and consequently have to be collected separately.

The main concern in the collection and processing of lamps at end-of-life is to avoid that the small amounts of mercury contained in fluorescent and HID-lamps are released to the environment. These lamps are processed in specialized facilities, more or less as follows [149]:

- Lamps are crushed in specialized machines that are sealed and work in sub-pressure to avoid that any mercury is released to the environment.
- The phosphor powder is separated in different steps from the glass and metal by-products by means of a sophisticated air transportation and handling system.
- Clean glass and aluminium end-caps are separated and stored for re-use.
- The powder is collected below the cyclone and then retorted to drive out the mercury.
- At the end of the process the glass, metal end-caps, powder, and mercury can all be re-used.
- A recycling certificate is issued.

More detailed descriptions and alternative processes can be found in a 2008 ZVEI publication [150] or in the CORDIS-Relight project [151].

The WEEE-directive puts the responsibility for handling of WEEE on the producers of such equipment. They shall finance the collection and treatment of their WEEE in a harmonised way that avoids false competition. Producers will shift payments to the consumers under the principle that the 'polluter pays', avoiding costs for the general tax payer.

According to a Philips publication [152]:

> *Within the overall WEEE scope, lamps have some very specific dynamics.*

[148] Methodology Study Ecodesign of Energy-related Products, MEErP Methodology Report, in particular part 2, par. 2.5 on Waste, December 2011, VHK BV, Netherlands and COWI, Belgium, for the European Commission, specific contract SI2.581529 under framework contract , TREN/R1/350-2008 Lot 3: "Technical Assistance for the update of the Methodology for the Ecodesign of Energy-using Products (MEEuP)" http://www.meerp.eu/

[149] http://www.aircycle.com/recycling/recycling-process

[150] "Collection and Recyclong of Discharge Lamps", ZVEI 2008. http://www.osram.com/media/resource/HIRES/338017/1127407/collection-and-recycling-of-discharge-lamps.pdf

[151] The key objective of this project is to test and develop novel technologies in the niche application of compact fluorescent lamp (CFL) recycling, to determine a cost effective means of recovering high value materials from the waste. http://cordis.europa.eu/result/rcn/144590_en.html

[152] http://www.lighting.philips.com/main/lightcommunity/assets/sustainability/Waste-Electorical-Electronic-Equipment-WEEE.pdf

The cost of collection and recycling of lamps is 25-100% of the cost price of a lamp (incandescent and halogen lamps excluded). All other product categories within the scope of the WEEE Directive have either costs of only a few per cent of the cost price or even a positive value.

In 2003, European lamp manufacturers decided to found CRSOs, not-for-profit Collection & Recycling Service Organizations dedicated to lamps and in some cases lighting fixtures. There are now lamp/lighting CRSOs in 22 EU member-states. These CRSOs have a market share of 75-95%; the other part of the market is occupied by other collective schemes.

With yearly sales of over 200 million WEEE lamps in the EU, and an average collection and recycling fee of €0.14, Philips' liability in Europe is an estimated € 30 million per year.

A list of CRSO's can be found in the Philips publication or on the website of other manufacturers [153]. Some CRSO's handle luminaires as well. They are also involved in information campaigns to increase the awareness among consumers that fluorescent lamps have to be collected separately from other waste.

As regards standards related to the end-of-life of lamps, see the Task 1 report, par. 3.2.

For general background information, see also the MEErP part 2, par 2.5 [148]

6.2. Eurostat WEEE statistics for lighting products

The 'Eurostat Environmental Data Centre on Waste' collects data on WEEE collection and recycling from the Member States and publishes them on the Eurostat web site [154]. As regards lighting products, data are reported for:

- Category 5, lighting equipment (all except discharge lamps)
- Category 5a, discharge lamps

The study team downloaded the data on the years 2008-2012 (state of 11 December 2014). The elaborated data are presented below. For a better understanding, the following definitions from Directive 2008/98/EC [155] (as referenced in the WEEE directive) are recalled:

'*collection*' means the gathering of waste, including the preliminary sorting and preliminary storage of waste for the purposes of transport to a waste treatment facility.

'*re-use*' means any operation by which products or components that are not waste are used again for the same purpose for which they were conceived.

'*treatment*' means recovery or disposal operations, including preparation prior to recovery or disposal.

'*recovery*' means any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy. Annex II sets out a non-exhaustive list of recovery operations.

'*recycling*' means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of

[153] For example: http://www.osram.com/osram_com/sustainability/environmental/eco-efficiency/key-performance-indicators/mercury/recycling-mercury/index.jsp

[154] http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/key_waste_streams/waste_electrical_electronic_equipment_weee, table [env_waselee]

[155] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:0030:en:PDF

organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations.

In addition the minimum recovery targets for lighting products from the WEEE-directive Annex V are recalled:

- From 13/8/2012 to 14/8/2015 : 70% recovered ; 50% recycled
  80% recycled for gas discharge lamps
- From 15/8/2015 to 14/8/2018 : 75% recovered ; 55% prepared for re-use and recycled
  80% recycled for gas discharge lamps
- After 15/8/2018 : 80% recycled for all lamps.

As specified in article 11.2 of the WEEE, these percentages are calculated "*by dividing the weight of the WEEE that enters the recovery or recycling/preparing for re-use facility, after proper treatment in accordance with Article 8(2) with regard to recovery or recycling, by the weight of all separately collected WEEE for each category*". So the percentages are **with respect to the collected WEEE**, and NOT with respect to the total amount of WEEE generated.

Table 52 shows the products put on the market, the waste collected, the amount treated, re-used or recovered, and the total recycled or re-used. All quantities are expressed in kt (kilotonnes). Data are presented separately for 'discharge lamps' (bottom part of table) and all other 'lighting equipment' (top of table).

The data from Eurostat present gaps and some anomalous values. Some of these gaps have been filled in and some values have been 'corrected' by the study team, by assuming that data were the same as in adjacent years. As a consequence, the **data should be used with caution**. The quantity 'put on the market' is the value from Eurostat: it may not be compatible with the quantities from the MELISA model.

The study team also computed the percentages shown in the last two columns of the table. As regards discharge lamps, the fraction recycled or re-used is close to the target of 80%, and there does not seem to be a significant change from 2008 to 2012. The fraction collected is around 30% for all years. So the main problem in waste management of discharge lamps seems to be the collection phase.

EU-28 Totals, Lighting equipment except discharge lamps, quantities in kt (kilotonnes)												
year	Products put on the market	Waste collected	Waste collected from households	Waste collected from other sources	Treated in the Member State	Treated in another Member State of the EU	Treated outside the EU	Reuse	Recovery	Total recycling and reuse	% collected / put-on-market	% recycled or re-used / collected
2008	609	32	24	9	17	3	0	0	13	12	5%	38%
2009	423	16	11	6	11	1	0	0	11	10	4%	62%
2010	396	19	12	7	16	1	0	0	14	12	5%	63%
2011	429	18	13	5	17	1	0	0	15	14	4%	77%
2012	411	20	14	6	18	1	0	0	16	15	5%	75%

EU-28 Totals, Discharge lamps, quantities in kt (kilotonnes)												
year	Products put on the market	Waste collected	Waste collected from households	Waste collected from other sources	Treated in the Member State	Treated in another Member State of the	Treated outside the EU	Reuse	Recovery	Total recycling and reuse	% collected / put-on-market	% recycled or re-used / collected
2008	137	38	28	10	26	3	0	0	0	29	28%	75%
2009	107	35	26	9	31	3	0	0	0	31	33%	89%
2010	120	34	25	10	31	3	0	0	0	27	29%	79%
2011	120	34	27	8	29	3	0	0	0	26	28%	76%
2012	111	34	27	8	30	3	0	0	0	27	31%	77%

Table 52 WEEE statistics from Eurostat regarding ‘discharge lamps’ (bottom) and all other ‘lighting equipment’. Quantities in kilotonnes. Source: Eurostat; elaboration by the study team.

7. LOCAL INFRASTRUCTURE

This chapter is used to address some topics regarding the interaction of light sources, that are the main subject of this Lot 8/9/19 preparatory study, with their surrounding environment. It includes the interaction between light sources and luminaires (lock-in effect), the interaction between light sources and lighting controls (with a focus on dimmer compatibility), and some aspects related to the electricity grid.

Many of these topics will be further addressed in the Task 4 report and (later) in the parallel Lot 37 study on lighting systems.

7.1. Interaction between light sources and luminaires

As regards the interaction between light sources and luminaires, the main question is if new energy-efficient light sources will fit in and perform well in existing luminaires. This is usually referred to as the '**lock-in effect**', and particularly relevant for LED retrofit lamps. The lock-in effect has the following aspects that will be briefly described below:

- Fixture compatibility.
- Geometric compatibility.
- Weight compatibility.
- Power supply compatibility.
- Thermal compatibility.
- Photometric compatibility.

<u>Fixture compatibility</u>: the caps of the new light sources have to match the sockets of the existing luminaires. Potentially this means that LED retrofit lamps have to be developed for all socket types appearing in existing luminaires. As regards lock-in for G9 and R7s sockets see the Stage 6 review report par 2.2 [156].

<u>Geometric compatibility</u>: the dimensions of the new efficient light sources shall be similar to those of the lamps they replace to ensure that they fit in the available space in the existing luminaires. LED retrofit lamps tend(ed) to be larger than the lamps they aim to replace, due to built-in electronics (in particular in the case of dimmable lamps, power factor correction, anti-flicker circuits) and due to the presence of a thermal dissipater (in particular for higher lumen lamps).

<u>Weight compatibility</u>: for luminaires with movable parts that are kept in equilibrium by springs, counterweights, friction hinges or similar, the (potentially higher) weight of new efficient light sources shall anyway allow the lamp to be used in most of the equilibrium positions that could be reached with the old light sources.

<u>Power supply compatibility</u>: luminaires for LFL, CFLni and HID lamps may have integrated ballast/control gear. Luminaires for LV halogen lamps may have built-in voltage transformers. Most LED retrofit lamps need a current source [157] and usually they cannot directly be connected to a voltage source, neither in low

[156] "Review study on the stage 6 requirements of Commission regulation (EC) No 244.2009 Final Report", VHK (pl) / VITO for the European Commission, Delft/Brussels 14.6.2013, SPECIFIC CONTRACT No ENER/C3/ 2012-418 LOT 2/01/SI2.645913 Implementing Framework Contract No ENER/C3/2012-418-Lot 2. http://www.eup-network.de/fileadmin/user_upload/Technical_Review_Study_by_VHK_VITO.pdf?PHPSESSID=a60a9114e01af59471374f5814656e0c

[157] In some cases a voltage source can be used with LED loads being mounted in parallel, see http://www.lighting.philips.com/main/connect/lighting_university/faq.wpd

(12 V) nor in high voltage circuit (230 V) without some form of electronic circuit. This may require a re-wiring in the luminaire to bypass the existing control gear, with implications for the safety responsibility.

Thermal compatibility: existing luminaires are thermally designed to handle incandescent, halogen, fluorescent, or high-intensity discharge lamps up to a certain power. This is related to their safety certification. LED retrofit lamps have a lower input power than the lamps they replace [158] and therefore in total generate less heat. However, LED lamps have different characteristics as regards the way in which the heat is released, i.e. less heat is radiated away (infrared) with the visible light and more heat is produced locally in the semi-conductor material, to be exported by conduction and convection. This completely changes the thermal situation in the luminaire. A luminaire thermally designed for 'old' lamp types is therefore not always compatible with LED retrofit lamps, even if the input power for the new lamp is lower.

This potential thermal problem is also related to the burning position of the lamps, e.g. horizontal, vertical facing upwards, vertical facing downwards. Thermal problems can be anticipated especially in closed luminaires (no ventilation possibilities) and for luminaires where the base of the socket faces upwards (down lighting).

The thermal aspect is in addition relevant for the lifetime and the efficiency of the LED lamps, that will both decrease as the operating temperature in the luminaire rises. Changes in temperatures will also lead to a shift in the colour of the emitted light.

In extreme cases there may be safety aspects related to overheating and there have been cases with LED lamps being recalled from the market for this reason [159]. Quality LED lamps have protections against overheating and they will shut off the current if the temperature crosses a certain threshold. Overheating will then manifest itself as flickering or as lamps shutting off completely, which seems to be a real and frequent problem [160]. Even conscious consumers that respect the maximum power rating for their existing luminaire may run into problems on this aspect.

In their comments on this document, the Federal Environment Agency of Germany (UBA) [161] presents data on the thermal behaviour of LED lamps in some existing luminaires. Their findings can be summarized as follows:

- If a LED lamp is applied in a luminaire which hinders heat dissipation of the lamp, particularly in small closed luminaires, junction temperatures may occur which are too high thus leading to a significant shorter lifetime of the lamp.
- In order to prevent such a setback, unsuitable combinations of LED lamps and luminaires must be avoided.
- A globalised assessment of luminaires as suitable or not suitable for LED lamps would be the wrong way.
- An assessment of each individual combination of lamps and luminaires as suitable or not suitable would be the wrong way.
- UBA Proposal:
  (1) Lamp manufacturers define a standard maximum value for air temperature in immediate proximity to LED lamps. This maximum value is to be set in such a way that under steady

[158] And this input power will further decrease considering the trend of increasing efficiency of LED retrofit lamps
[159] http://www.cpsc.gov/en/Recalls/2013/LED-Light-Bulbs-Recalled-by-Lighting-Science-Group/
[160] http://lighttalk.via-verlag.com/2011/09/led-and-overheating/
http://www.dailykos.com/story/2014/01/14/1269678/-Something-to-watch-with-LED-lighting
http://www.edn.com/electronics-blogs/led-insights/4423570/That-60W-equivalent-LED--What-you-don-t-know--and-what-no-one-will-tell-you-?cid=nl_edn&elq=b2acc9672ad54b8e8948c93cd16a02e1&elqCampaignId=3287
http://www.ledsmagazine.com/articles/2005/05/fact-or-fiction-leds-don-t-produce-heat.html
[161] See Annex A of the UBA comments, published on the website http://ecodesign-lightsources.eu/documents

state conditions, inside the LED lamp a junction temperature exists at which the declared values of lifetime etc. can be obtained.

(2) Luminaire manufacturers determine for each of their products the maximum power (W) a lamp may have without exceeding under steady state condition the temperature defined in step (1).

(3) Based on a product information requirement, luminaire manufacturers declare the maximum power value, determined in step (2), on their products and in product documents, e.g. in the following format: "LED: 60 °C → max. 20 W" (where 60 °C is to be replaced by the actual agreed temperature). For examples of such a labelling see the reference.

Photometric compatibility: single LEDs provide directional light by nature. LED retrofit lamps typically include several LEDs that are oriented differently inside the lamp to create a non-directional lighting effect. Other related photometric issues are the position of the luminous centre of the lamp, the colour rendering characteristics, the colour consistency, glare characteristics, the brilliance and general visual appearance of the lamp, and in some cases the spectrum of the light emitted.

The question if suitable LED retrofit lamps exist for all lamps/luminaires currently on the market, taking into account all the aspects described above, will be addressed in the Task 4 report. For additional information see also the Stage 6 review report [156] and the 2014 Danish study on the availability of LED retrofit lamps for non-directional household lamps [162].

Regulation 244/2009 does not contain any requirements on luminaires.

Regulation 245/2009 addresses some energy aspects of luminaires, and the compatibility with certain types of ballasts, but as regards lamps, it only states that "*if the ballast or the lamp are not placed on the market together with the luminaire, references used in manufacturers' catalogues must be provided on the types of lamps or ballasts compatible with the luminaire (e.g. ILCOS code for the lamps)*", and "*all luminaires for high intensity discharge lamps shall indicate that they are designed for either clear and/or coated lamps*".

In Annex III point 2.3, Regulation 1194/2012 states that:" *When a luminaire is placed on the market and intended to be marketed to the end-users, and lamps that the end-user can replace are included with the luminaire, these lamps shall be of one of the two highest energy classes, according to Commission Delegated Regulation (EU) No 874/2012, with which the luminaire is labelled to be compatible.*"

Regulation 874/2012 prescribes energy labels for luminaires, that indicate the EEI classes of the lamps with which the luminaire is compatible, if the luminaire is suitable for LED lamps, and if these lamps can be substituted by the consumer. The regulation does not seem to resolve all lock-in problems however, and of course it does not apply to existing luminaires.

7.2. Interaction with Dimmers and Controls

7.2.1. Introduction

Lighting energy savings are expected in the nearby future from a shift to energy efficient LED lamps and from an increased use of lighting control systems, that shut off the lights or regulate the level of artificial lighting (dimming), in function of the availability of daylight, in function of the occupancy of the lighted

[162] "Availability of non-directional LED replacement lamps", Casper Kofod, Energy piano, Peder Øbro, ÅF Lighting, 2014-02-27 Study done for the Danish Energy Agency, http://www.ens.dk/sites/ens.dk/files/forbrug-besparelser/apparater-produkter/energikrav-produkter/belysning/lyskilder/led_replacement_lamps_for_incandescent_lamps_27-02-2014_final.pdf

spaces, or in function of the degradation of the luminaires and light sources with the years. As regards LEDs, dimming does not only save additional energy, but it also lowers their average temperature, which potentially means a longer lifetime. Although lighting control systems will mainly be addressed in the parallel Lot 37 preparatory study, the compatibility between light sources (in particular LEDs) and lighting controls (existing and new) is an important aspect for this Lot 8/9/19 preparatory study.

Currently there are problems related to the dimming of LED lighting products. These problems have the potential to disturb and slow down the market introduction of LEDs and the use of LEDs in controlled lighting systems, which could lead to missing a part of the possible energy savings.

In this moment the main problem is the compatibility of LED retrofit lamps and integrated LED luminaires with existing control components, such as dimmers, that are already installed in households and non-residential buildings, and that were designed to operate on other types of lamps (incandescent, halogen, fluorescent, HID) with electrical characteristics that are completely different from those of LEDs. In this case, the characteristics of the existing dimmers are a given fact, and dimmable LED control gears have to be designed accordingly to guarantee compatibility (as far as possible).

For the future the main issue is what can be done to guarantee that any new LED lighting product and any new control device will operate satisfactorily together. Activities are ongoing to develop new standards on this topic. In this case, requirements can be prescribed both for the LED control gears and for the dimmers (or other control components).

From the consumer point of view, compatibility and performance are closely related. For many LED-dimmer combinations the issue is not that they do not work at all, but rather that they do not (always) work properly, or that the behaviour of the combination is not as expected by the consumer. The following problems can be encountered:

- Flicker (on/off of lamps, at a frequency that is perceived by the consumer [163]).
- Shimmer (variations in light intensity, at a frequency that is perceived by the consumer).
- Stroboscopic effects (when objects are moving fast with respect to the light source).
- Dead travel (changes in dimmer position do not lead to perceived changes in light intensity).
- Pop-on (raising the dimmer from the off-position, the light suddenly pops on at an unexpected high intensity level).
- Drop-out (lowering the dimmer, the light suddenly shuts off while the consumer expected a further intensity decrease).
- Colour change when dimming (this may be desirable or undesirable).
- Non-linear dimming curve (the (perceived) light intensity does not vary linearly with the dimmer position; this may be desirable or undesirable).
- Impossibility to reach low dimming levels (related to drop-out).
- Reduced light intensity at maximum dimmer setting (the consumer does not want to dim, but the emitted light is (far) less than the rated maximum output of the light source).
- Noise, buzzing (from the dimmer, the control gear or the lamp itself)
- Ghosting (the lamp continues to glow in the off-position)
- Reduced lifetime or abrupt failure of one of the system components (dimmer, control gear or LED-module).
- Higher energy consumption than expected (low efficiency when lights are on, and/or high standby consumption).

[163] In its comments on the task 0-3 reports, IALD signals work done and published by Professor Arnold Wilkins and others from Surrey University with methodologies for testing flicker and with recommendations for acceptable limits (Lehman, B. and Wilkins A.J. (2014). Designing to mitigate the effects of flicker in LED lighting. IEEE Power Electronics Magazine, Vol. 1, No. 3, September. http://www.energy.ca.gov/appliances/2014-AAER-01/prerulemaking/documents/2014-09-). Their conclusion is that under worst case conditions, flicker can be seen by most observers at frequencies of 2kHz.

Essentially, dimming of LEDs is a real, technical problem, but there are also some commercial interests involved in the discussion, and some stakeholders may highlight certain aspects of the problem, to defend these interests.

As regards dimming-related problems, the study team had meetings with LightingEurope (LE), representing the European manufacturers of light sources and luminaires, and with CECAPI [164], representing the European manufacturers of lighting controls. In particular CECAPI supplied very detailed data on the issue. In addition, a lot of information on the topic was found on the internet [165].

Consumers are used to the dimming behaviour of filament lamps, that can be regulated smoothly down to nearly 0% (when the filament will emit a weak orange glow) and that will change to a warmer colour when dimmed. In general they will expect the same behaviour from LED-lamps, and in principle this is possible: in the correct circumstances LED lamps can be dimmed to below 1% and dimming to warmer colours can be implemented. For comparison: CFL dim down to 10-30% (measured) of maximum light output and HID-lamps to 30-60% [166].

7.2.2. Techniques for dimming of LEDs at control gear level

An LED dimming system typically consists of:

- Dimmer
- LED control gear (LED driver)
- LED board

Essentially, **if a LED lamp is dimmable at all, depends on its control gear**: some gears are designed to apply dimming (in combination with certain types of dimmers) while others do not foresee any type of dimming.

If the control gear allows dimming, the dimming behaviour of the dimmer->gear->board combination depends both on the information (signals, current, voltage) that the dimmer passes to the control gear, and on the information (essentially current) that the control gear supplies to the LED board. Both types of information are referred to as dimming, but the techniques and terminology involved are completely different. As the literature often confuses the two, some explanation is necessary here. This paragraph will deal with the information from the control gear to the LED board; the next paragraph will describe the information from the dimmer to the control gear.

An LED is an electronic component based on semi-conductor material that provides light when an electric current is passed through it. LEDs light up only if this current is in the correct direction; in the opposite direction the current does not pass. Therefore they essentially require a direct current source. Unlike filament lamps, that have a thermal inertia and will continue to emit light even if the current is missing for a short time, LEDs will react instantly to the presence or absence of current, stopping to emit light as

[164] Comité Européen des Constructeurs d'Appareillage Electrique d'Installation (European Committee of Electrical Installation Equipment Manufacturers). http://www.cecapi.org/

[165] The following publications have been particularly useful and are recommended to all readers.
http://www.lutron.com/technicaldocumentlibrary/367-2035_led_white_paper.pdf
http://www.themhcompanies.com/downloads/Dimming_101.pdf
http://www.lutron.com/TechnicalDocumentLibrary/048360a_PWM_vs_CCR_LED_App_Note.pdf
http://www.lutron.com/TechnicalDocumentLibrary/3683586_Challenges_of_Dimming_Whitepaper.pdf
http://www.archlighting.com/leds/leds-a-deep-dive-in-dimming_o.aspx

[166] http://www.archlighting.com/leds/leds-a-deep-dive-in-dimming_o.aspx

soon as the current stops, even for a very short time. This characteristic enables PWM-dimming (see below) and also explains why LEDs are prone to flicker when not properly controlled.

In general (there are some exceptions) the main function of the LED control gear is to transform the mains voltage to the low-voltage required by the LED board and to rectify the alternate current (AC) to direct current (DC). In reaction to information received from the dimmer, the control gear uses one of two techniques to dim the light emitted by the LED board: Pulse Width Modulation (PWM) or Constant Current Reduction (CCR).

In the case of **Pulse Width Modulation**, the control gear will maintain the current at the rated level for the LEDs (the one that gives the maximum light output), but turn it on and off at a high frequency. As LEDs will promptly react to this presence/absence of current, the ratio between on-time and off-time will determine the brightness of the lamp, i.e. the percentage dimming (Figure 31).

In the case of **Constant Current Reduction**, the control gear will leave the current constantly on, but reduce its level to the one corresponding to the dimming instructions received (Figure 32).

PWM and CCR will both do the dimming job, but with different characteristics [167].

The **PWM technique** requires high frequencies (e.g. above 200 Hz) to avoid that consumers experience the on/off as flickering, especially when in peripheral vision, and to avoid stroboscopic effects in fast moving environments. Implementation of higher frequencies typically implies higher costs, in particular if low light levels have to be enabled.

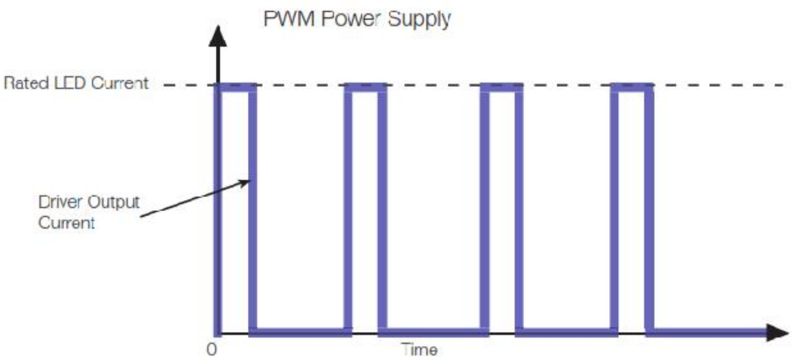


Figure 31 LED dimming by means of Pulse Width Modulation: the rated LED current corresponding to maximum light output is maintained, but the current is switched on and off at high frequency (source: Lutron)

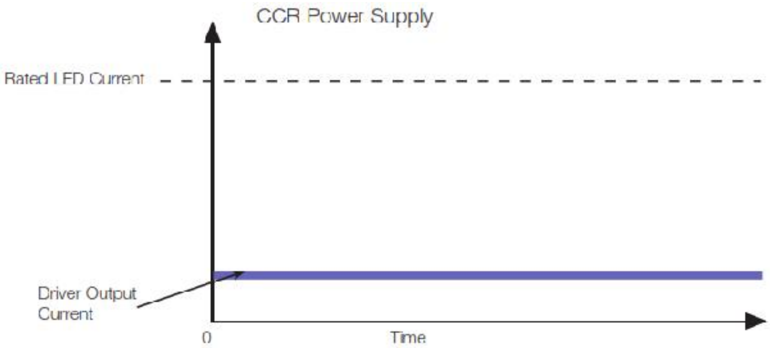


Figure 32 LED dimming by means of Constant Current Reduction: the current level is reduced but it remains continuously on. (source: Lutron)

167 http://www.lutron.com/TechnicalDocumentLibrary/048360a_PWM_vs_CCR_LED_App_Note.pdf
http://www.lighting.philips.com/main/connect/lighting_university/faq.wpd
http://www.archlighting.com/leds/leds-a-deep-dive-in-dimming_o.aspx

LED characteristics as colour temperature depend on the level of the forward current. PWM leaves this level unchanged and consequently maintains the colour when dimming (this can be desirable or undesirable).

In general, PWM enables a more precise light output control and to lower levels (1%) than CCR (10%). This can be of particular importance in applications where colours have to be mixed in correct proportions.

PWM is characterised by fast rising and falling currents. This can induce electro-magnetic interference (EMI) that may not be allowable in some applications. In addition it might give less good results in the case of long wires (when the control gear is far from the LEDs).

The **CCR technique** is suitable in the presence of long wires, in cases where there are strict EMI requirements, and in the presence of fast moving objects. In addition CCR could be the preferred solution for outdoor or damp locations. CCR can give problems when trying to dim LED-lamps below 10% of their maximum light output [168].

PWM is more widely used (at least in the USA), but CCR is stated (by some) to be more efficient [169].

As observed by IALD in its comments on the report, there are also mixed mode control gears that use a combination of PWM and CCR. These gears are stated to be highly effective for digital control.

LED control gears can be constant current or constant voltage. The type of control gear depends on the type of LED load, and the two types are not interchangeable.

Constant voltage drivers (10 V, 12 V, 24 V) are used where LED modules are connected in parallel and where the number of loads is variable. They are used for example in coves (LED-strips), under-cabinet lighting and signage applications. These LED control gears are similar or identical to the low voltage power supplies of halogen lights (strips or MR16). They can use only the PWM technique for dimming. See also par. 7.2.4.

Constant current drivers (350 mA, 700 mA, 1050 mA) are used for single LED lamps or where a number of lamps or luminaires is connected in series. Typical applications are down-lighters, sconces or other LED luminaires with one LED module per control gear. These drivers can use either PWM or CCR for dimming.

Essentially, **it is the control gear that determines the dimming capabilities** of a LED retrofit lamp or of an integrated LED luminaire. This includes the dimming curve, the dimming range, and the lowest reachable dimming level. As regards the latter, control gear specifications may indicate that they are able to dim down to 20, 10, 5 or 1% of the maximum rated light output. These are measured light output levels. The perceived output levels by consumers are different, because at lower light levels pupils will dilate so that more light can be captured by the human eye. The perceived light intensity fraction is the square root of the measured light intensity fraction [170]. This implies that:

- 20% measured light corresponds to 45% perceived light
- 10% measured light corresponds to 32% perceived light
- 5% measured light corresponds to 22% perceived light
- 1% measured light corresponds to 10% perceived light

Different LED control gears may have different dimming characteristics, even if the declared lowest dimming level is identical. This can lead to dimming differences when substituting an LED lamp or luminaire by another or when using different lamps or luminaires on the same dimmer.

[168] http://www.archlighting.com/leds/leds-a-deep-dive-in-dimming_o.aspx
[169] As regards efficiency, some contrasting information has been found
[170] http://www.lutron.com/technicaldocumentlibrary/367-2035_led_white_paper.pdf

Although the control gear is the first responsible for dimming possibilities, **even a good control gear may not work well if used in conjunction with an incompatible dimmer**.

7.2.3. Techniques for dimming of LEDs at dimmer level

This paragraph concerns the interface between the dimmer and the control gear.

For lamps without control gear, such as incandescent and halogen lamps, it is really the dimmer itself that regulates the light intensity by varying the power supplied to the lamp. For lamps with control gear, including LEDs, the situation is a more complex interaction: the dimmer could be conceived as the component issuing the light intensity commands, while the actual dimming is performed by the control gear (by PWM or CCR in the case of LEDs, see previous paragraph) [171].

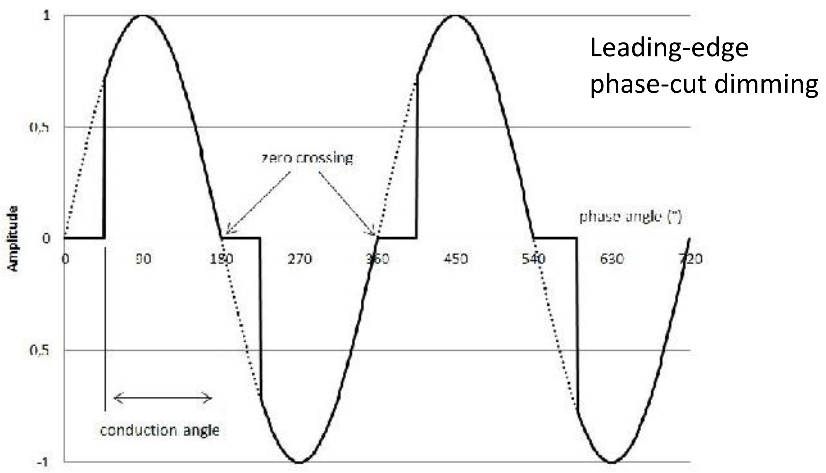
There are various ways in which the dimmer can 'communicate commands' to the control gear:

- leading-edge phase-cut dimming
- trailing-edge phase-cut dimming
- universal phase-cut dimming
- 3-wire phase-cut dimming
  0-10 V control dimming
- digital control dimming
- wireless control dimming

These techniques will be briefly discussed below, with a focus on phase-cut dimming and dimming of LED lamps.

Phase-cut dimming, general

The AC mains power supply of 230 V 50 Hz is characterised by a sine wave variation in time of the voltage. Phase-cut dimmers cut away, i.e. do not transmit to the lamp or control gear, a portion of each voltage half-wave, thus lowering the average transmitted voltage. The cut-away portion can be at the leading-edge (LE), directly after a zero-crossing of the sine wave (Figure 33), or at the trailing-edge (TE), directly before a zero-crossing of the sine wave. The average voltage transmitted (dimming level) can be varied by changing the conduction angle, i.e. the portion of the sine half wave that is transmitted.



[171] This is probably not electrically correct, but it is useful to conceive the situation like this.

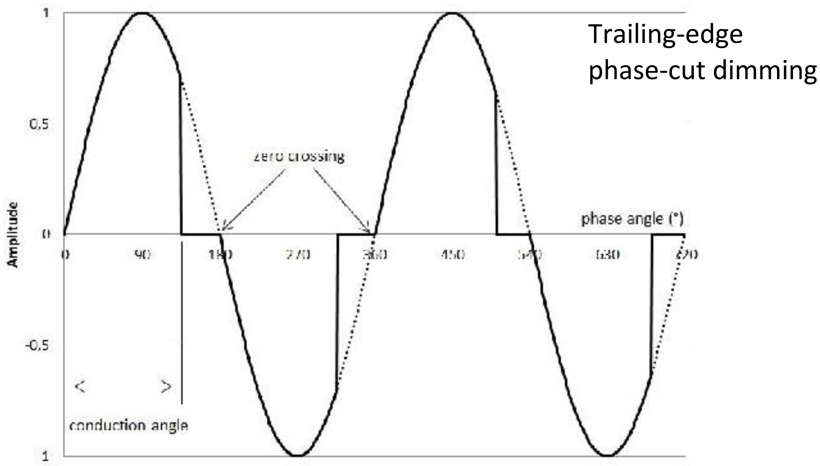


Figure 33 Phase-cut dimming: the dimmer does not transmit a part of the voltage sine wave directly after each zero crossing (leading-edge dimming) or directly before each zero crossing (trailing-edge dimming), thus lowering the average voltage transmitted (source: CECAPI)

Leading-edge phase-cut dimming

Alternative names: Forward phase dimming, TRIAC dimming, SCR dimming, Incandescent dimming

Leading-edge phase-cut dimmers were first developed for use with mains voltage filament lamps. These lamps do not have a control gear and are electrically resistive so that the lower average voltage due to the phase-cut leads to a lower average current, a lower filament temperature, and hence lower light emission. The change in filament temperature also leads to the light getting warmer (more orange) while dimming. The thermal inertia of the filaments helps to avoid flicker. Dimming is normally smooth and continuous and can reach low levels [172]. This dimming behaviour is the reference for consumers.

Later, leading-edge phase-cut dimmers were also developed for use with low-voltage filament lamps that use magnetic transformers (MLV) to convert the mains voltage to the required low voltage, see par. 7.2.4.

These dimmers are the least expensive ones and form the largest part (60%) of the installed phase-cut dimmer base in Europe (they are even more widespread in the USA). Consequently it is essential for the success of LED retrofit lamps that they perform well on these dimmers. Although there are LED control gears that have been specifically designed for compatibility with leading-edge phase-cut dimmers (incandescent compatible LED drivers/lamps), trying to eliminate potential problems like flicker, ghosting, pop on, drop out, etc., the **compatibility is often a matter of 'hit and miss'**.

The existing dimmers may also require a certain minimum number of LED lamps to be installed on the same dimmer, to satisfy the minimum power requirements of the dimmer.

Recent leading-edge phase-cut dimmers may have been specifically designed to operate LED lamps. In that case the dimmer manufacturer should specify a list of compatible LED loads for which the dimmer has been tested.

[172] In http://www.themhcompanies.com/downloads/Dimming_101.pdf a minimum of 10% depending on dimmer limitations is stated, but this is probably intended in combination with LED lamps. Incandescent lamps would be expected to dim to lower levels.

Trailing-edge phase-cut dimming

Alternative names: Reverse phase dimming, ELV dimming

Trailing-edge phase-cut dimmers were first developed for use with low-voltage filament lamps (12 V MR16 type fixtures) that use electronic transformers (ELV) to convert the mains voltage to the required low voltage, see also par. 7.2.4.

Compared to the leading-edge phase-cut dimmers, the trailing-edge phase-cut dimmers are more expensive, but they offer a better control, to lower dimming levels, and they tend to have a longer lifetime and a more silent operation.

The major part of the LED control gears use ELV transformers, which are electrically capacitive loads, that are better controlled with trailing-edge dimmers, and in many cases leading-edge dimmers will not work with these LED drivers. A large number of test results is available for trailing-edge phase-cut dimmers for control of LED lamps/luminaires that use ELV transformers.

The installed base of trailing-edge dimmers in Europe is smaller than that for leading-edge dimmers, except in Germany and Nordic countries (par. 7.2.8). This is a potential complication for the introduction of dimmable LED retrofit lamps.

Universal phase-cut dimming

Universal phase-cut dimmers offer both the leading-edge phase-cut technology and the trailing-edge phase-cut technology. The technology to be used can be selected manually or be detected automatically by the dimmer, depending on the type of load, i.e. resistive-inductive or capacitive.

3-wire phase-cut dimming

This technology was originally developed by ballast/driver/control manufacturer Lutron to enable dimming down to 1% for fluorescent and compact fluorescent lamps. The control gear receives the neutral, and two power wires connect the control gear to the dimmer (Figure 34), a Line or Switched-Line, and a Dimmed-Line. The latter carries the phase-cut dimming signal separate from the power wires [173].

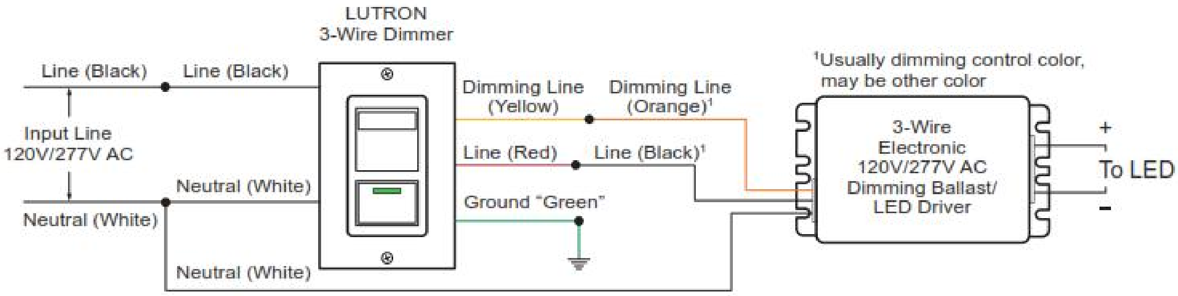


Figure 34 Lutron Hi-Lume 3-wire solution for dimming of fluorescent lamps and LEDs down to 1% of the maximum output level (source: Liton [174])

This 3-wire configuration is claimed to dim down to 1%, to be more precise and less susceptible to electrical noise. It is more expensive than the standard (2-wire) solutions and needs additional wiring to

[173] In this case the 3-wire indication refers to Neutral, Dimmed-Line and Switched-Line that arrive at the control gear. This is not be confused with the 3-wire indication discussed in par.7.2.5, that refers to the number of wires on the dimmer.

[174] http://www.liton.com/webcatalog/brochures/wp_dimmingfacts.pdf

be installed. The same 3-wire dimmer that controlled fluorescent dimming ballasts could be used to adequately control LED drivers designed with a 3-wire control input [175] [176].

0-10 V analogue control dimming

This is not a phase-cut technology. Instead, the dimmer sends low-voltage signals to the control gear, varying from 0 V (off), 1 V (minimum light) to 10 V (maximum light) that have to be translated by the control gear in an associated dimming level. This implies a total of 4 wires arriving at the control gear: the (switched) line power and neutral wires, and two low-voltage control wires, not counting the grounding wire.

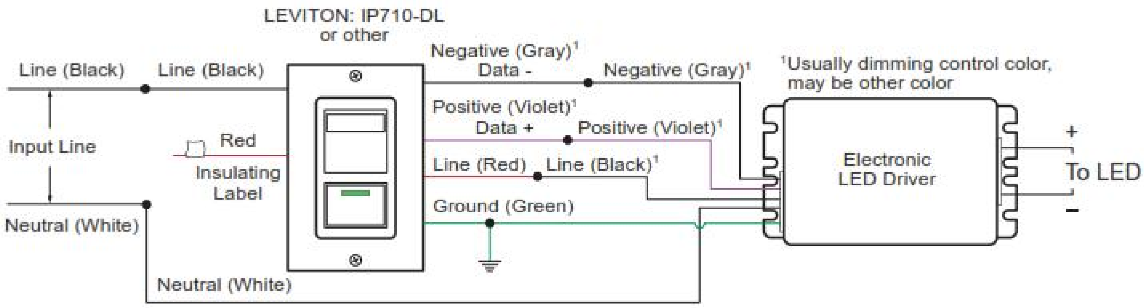


Figure 35 0-10 V (4-wire) control solution for dimming of fluorescent lamps and LEDs (source: Liton [174])

The use of this solution is widespread especially in non-residential applications, originally used for fluorescent lighting in combination with daylight and occupancy sensors. It is now becoming popular for LED products as well, and most existing 0-10 V systems should work with LED retrofit lamps that have drivers able to interpret these signals. This type of dimming control is defined in IEC standard 60929 Annex E [177], but some sources report that not all manufacturers strictly follow this standard, in some cases leading to unexpected incompatibilities between dimmers and control gears [175].

The solution is stated to enable dimming down to 5% of the maximum rated light output. The control signal is a small analogue voltage whose level may drop if wires from the dimmer to the control gear are long. Different wire lengths may also cause differences in dimming behaviour between luminaires attached to the same system.

4-wire digital control dimming

This is similar to the 0-10 V dimming control explained above, but instead of analogue 0-10 V signals, the dimmer and the control gear exchange digital signals over the low-voltage wiring. The digital technology considerably enhances the control possibilities. Amongst others, all luminaires, sensors, switches, time-clocks, etc. of a system can be addressed individually, and these components can also provide feedback on their status to the lighting control system, enabling a higher flexibility. In addition to light intensity variation, additional functionality can be implemented such as colour control and movable fixtures. Digital control dimming may require specific, expensive, equipment and specific installer and user knowledge. It is therefore used mainly in non-residential applications.

---

[175] http://www.lutron.com/technicaldocumentlibrary/367-2035_led_white_paper.pdf

[176] As observed by IALD in its comments to this report: "We would like to point out that in the diagrams taken from Lutron USA products, 3-wire fluorescent dimming has not been available in EU market for more than five years. The ballasts referenced would not meet current EU energy efficiency standards."

[177] This standard only defines the electrical interface of the protocol. It does not ensure compatibility or define the aesthetic performance of the dimming, such as a smooth, flicker-free dimming curve, or the low-end light level.

The digital signals are send according to agreed communication protocols, the most important being DMX and DALI.

DMX was originally developed for the specific needs of theatres and concerts. It is now also increasingly used for architectural lighting applications, in particular to implement spectacular colour changing effects.

DALI (Digital Addressable Lighting Interface) is an International Standard (IEC 62386) for the control of electronic control gears, voltage transformers, LED drivers, emergency lights and exit signs. It originated in Europe but is now also spreading in non-residential buildings in the USA. The DALI standard is more robust than the 0-10 V standard, and less susceptible to disturbances and line lengths, but using DALI dimming controls and DALI control gears from different manufacturers does anyway not ensure compatibility or a good dimming performance [175]. In addition not all consumer-desired functionality is defined in DALI so that manufacturer-specific extensions exist on the market, that may also lead to incompatibility problems.

wireless control dimming

Wireless Radio Frequency (RF) technology is increasingly used for the control of LED lighting products. The LED lamps themselves can have built-in RF receivers/transmitters (smart lamps). Alternatively these RF transceivers can be implemented in separate interface devices, using one of the other technologies described above, such as phase-cut dimming, analogue 0-10 V signals, or digital signals, to control the dimming of LED lamps.

There are several RF communication protocols, and products using different protocols usually are not compatible with each other, requiring special interfaces, bridges or gateways to function together. The RF used for lighting control may interfere with other RF applications in the same space that use the same or similar frequencies (e.g. WiFi, Bluetooth). While this is 'just' annoying for some applications as mobile phones, the reliability of lighting control can be essential, considering that light can be a life safety system.

7.2.4. Dimming of LEDs operating on existing low-voltage transformers

This paragraph is based for a large part on a Lutron publication [178], that explains very well the problems associated with dimming of low-voltage LEDs. It is technical, but understandable also for electronic non-experts, and therefore recommended reading. A brief summary of the main points is presented below.

There is a large installed base of low-voltage halogen MR16 lamps that are increasingly being substituted by LED retrofit lamps. In addition low-voltage LED-strips are increasingly being sold for use in coves, under-cabinet or under-counter lighting, sometimes replacing low-voltage halogen festoon type lighting.

These LED lamps will be expected to work on the existing voltage transformers (230 V -> 12 or 24 V) and in combination with existing or new dimmer controls. In this case, for a good dimming performance, not three but four components have to work seamlessly together:

- Dimmer
- Voltage transformer
- LED electronics ('driver')
- LED lamps

In this case the dimmer will typically be of the phase-cut type, either leading-edge cut or trailing-edge cut. The (existing) voltage transformer can be a magnetic low-voltage transformer (MLV) or an electronic low-

[178] http://www.lutron.com/TechnicalDocumentLibrary/3683586_Challenges_of_Dimming_Whitepaper.pdf

voltage transformer (ELV). The LED electronics could be relatively simple, but normally it should include at least a rectifier to convert the AC output of the transformer into the DC required by the LED lamps.

MLV transformers are electrically inductive and need a leading-edge phase-cut dimmer. Using the trailing-edge method, the sudden decrease in voltage would create voltage spikes in the MLV that can also damage the dimmer or the LED lamp. MLV transformers also require a good symmetry between the positive and negative halves of the sine wave. The dimmer should be adequately designed for this, but also the LED-part should draw a symmetric current from the transformer. Even small imbalances between the two sine half waves can cause significant heating in the transformer, leading to an unsafe condition or transformer failure. In less severe cases these imbalances can cause perceivable shimmer (variations in LED brightness).

Existing MLV transformers have a minimum and maximum load requirement that is designed for the power of the halogen lamps with which they were intended to be used. LED lamps have a lower power and it may be necessary to connect several LED lamps [179] to the transformer to meet the minimum power requirement. If the transformer is made to work below or near its lower power limit, this may cause voltage spikes called 'ring-up voltages'. These spikes can be higher than the maximum voltage ratings for some of the components in the system, damaging them.

ELV transformers are electrically capacitive and need a trailing-edge phase-cut dimmer. Using the leading-edge method, the sudden increase in voltage would create 'repetitive peak currents' that lead to acoustic noise and stress the transformer and the dimmer, leading to premature failure. Existing ELV transformers designed for halogen lamps have similar minimum power requirements as described above for the MLV transformers. If the attached LED lamps do not meet these requirements, the system may not work or be unstable. In recent years many manufacturers have introduced 'LED compatible' or 'Low Wattage' transformers which have small, or even zero, minimum load requirements. These transformers are expected to provide stable output regardless of loading.

As ELV transformers are highly capacitive, they may 'hold-up' the line-voltage output of the dimmer when it tries to cut the phase. This disturbs the speed of decay of the voltage and may make it difficult for the dimmer to identify the zero-crossing points that it needs for the phase-cutting. Most ELV dimmers require a neutral wire (par. 7.2.5) for proper operation which helps the dimmer switch on and off properly, regardless of load characteristics. Using a dimmer with adjustable low-end trim can help to minimize areas of the dimming curve with poor performance.

Further details are provided in the reference document, that also provides criteria for a good design, and concludes that, notwithstanding all difficulties involved, it is possible to design dedicated TE-dimmers, ELV-transformers and LED-loads that work properly together. But regarding the use of existing components the reference states: "*However,(…), it is nearly impossible to predict if these (criteria) are met by either a particular LED product or an existing transformer in a retrofit application. The only way to ensure the dimming will be smooth and continuous, especially at low end, is to test all the devices together as a complete system*."

An illustration of the difficult situation regarding the compatibility of low-voltage LED-lamps with existing equipment is given, for example, by a Philips dimmable LED spot [180]. This lamp is marketed accompanied by a recommended transformer compatibility list [181] that specifies the test results for 40 ELV transformer types. As regards MLV transformers, the document notes that "*magnetic transformers are in general compatible, however some can give unwanted performance*", or "*lamp will work but Philips cannot guarantee electromagnetic compatibility will be according norms*". In addition there is a disclaimer stating that "*Although Philips has attempted to provide the most accurate information and test results from lab*

[179] The number of LED retrofit lamps may need to be higher than the number of halogen lamps that is being substituted.
[180] http://download.p4c.philips.com/files/8/8718291653776/8718291653776_pss_enggb.pdf
[181] http://download.p4c.philips.com/files/8/8718291653776/8718291653776_tfc_enggb.pdf

experiments the results may differ under your application conditions. Philips will not accept claims for any damage caused by implementing the recommendations in this document." In addition there is a recommended dimmer list [182] with more than 100 dimmers tested in combination with 10 different LED-lamps, with the same disclaimer, but the list seems to regard only mains-voltage LED lamps. Obviously, it would be impractical to test all the possible combinations of all low-voltage transformers with all dimmers for the indicated lamp….

Figure 36 Philips dimmable LED spot, 12 V, 6.5 W, 330 lumen, GU5.3 cap, warm white

7.2.5. Power supply for dimmers and consequences for LED control gears

Control devices such as dimmers, switches, time-clocks and sensors, can be connected to the mains power supply in a 2-wire configuration or in a 3-wire configuration (Figure 37). Essentially the difference is if the neutral wire is present at dimmer level. **In most European houses** (and in some non-residential buildings) **the neutral wire is not normally distributed to the controls**. The absence of the neutral wire implies that the dimmer has to receive its power supply through the load (lamp/control gear) and also that it has to sense the phase through this load (i.e. to detect the zero crossings in the sine wave, required for correct phase-cutting).

For some dimmer – control gear combinations the presence of the neutral wire is required at dimmer level for an acceptable dimming performance. This seems to be the case in particular for some trailing-edge phase-cut dimmers [183]. In most houses this would require pulling an additional wire.

Dimmers that work in the 2-wire configuration, without neutral, have to receive their power supply through the load, also during the short periods where the phase is cut and the control gear (or lamp alone) is not powered, and also when the control gear/lamp is switched off for longer periods, but the dimmer has to remain in standby.

For resistive loads as incandescent and halogen lamps, this does not present particular problems, because at the current levels needed for the dimmer (less than 50 mA) these lamps will not emit any light. LED lamps however operate at much lower currents, and the current drawn by the dimmer might charge the capacitor of the LED lamp, making it light up even when it is supposed to be switched off. This is called 'ghosting' and illustrated in Figure 38.

In addition, differently from filament lamps, the small current required by the dimmer will normally not pass through the LED lamps and control gears, unless special 'bleeder circuits' are implemented. Standardisation work is ongoing to define this aspect of the compatibility between dimmers and control gears (par. 7.2.11).

182 http://download.p4c.philips.com/files/8/8718291653776/8718291653776_dmc_enggb.pdf
183 http://www.themhcompanies.com/downloads/Dimming_101.pdf
http://www.lutron.com/technicaldocumentlibrary/367-2035_led_white_paper.pdf

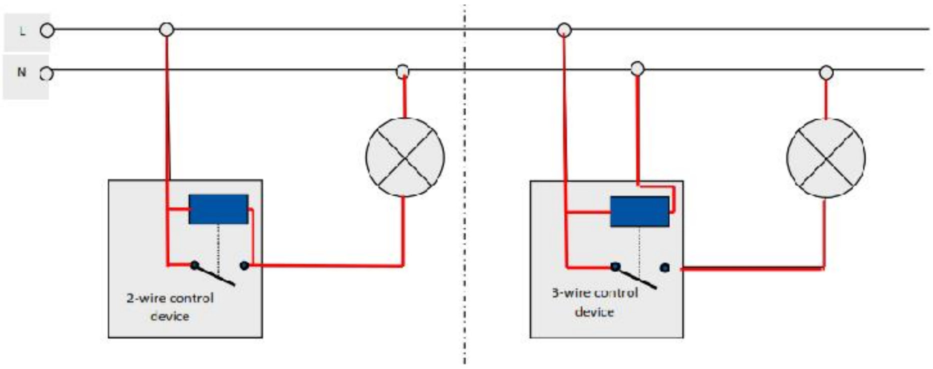


Figure 37 2-wire and 3-wire connection for a control device (such as a dimmer). In the 2-wire case, the control device has to receive its power through the load (lamp or lamp & control gear) (source: CECAPI)

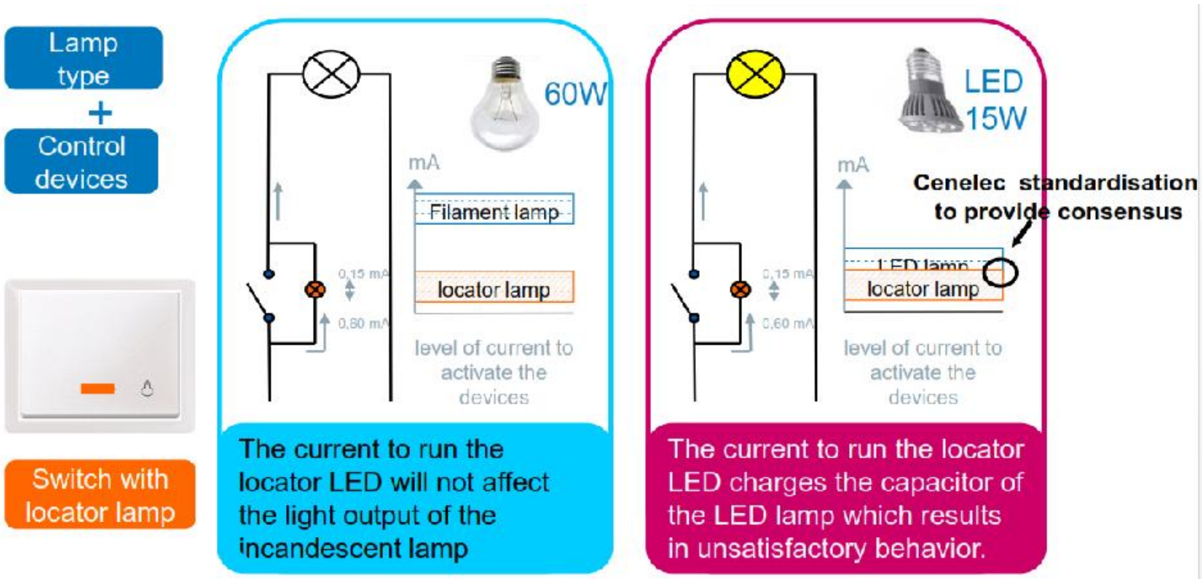


Figure 38 Switch with locator lamp in a 2-wire configuration, drawing its power supply through the main lamp. An incandescent lamp will not give problems, but an LED lamp with control gear might light up (ghosting). The same may happen with other control devices such as dimmers (source: CECAPI)

7.2.6. Dimming curve and minimum and maximum dimming levels

Figure 39 provides some examples of dimming curves for dimmable lamps with integrated control gear. The figure gives the measured light output in function of the conduction angle of the phase-cut dimmer. It is not important here exactly which lamps have been tested and with which dimmer, the only purpose of the figure is to show the variety in dimming curves.

Some curves show a nearly linear relationship between conduction angle and light output, while others are clearly non-linear. There are also curves exhibiting 'dead travel', where the light output does not change while the conduction angle is varied, i.e. in these zones the lamps do not react to changes in the dimmer setting. At the lower end there are some curves that do not reach zero output, or that completely disappear near conduction angles of 40-50˚, indicating 'drop-out', i.e. they switch off completely at low dimming levels.

Seeing these curves in 2012, CECAPI raised the question what lamps can still be called 'dimmable'. They feel the need for a definition, i.e. for a minimum set of requirements that a lamp should meet to be declared 'dimmable' and associated test methods. In the existing situation consumers could remain disappointed from the dimming behaviour and this could negatively affect the market for dimmers. The definition of 'dimmable' is one of the subjects in the currently ongoing standardisation activities (par. 7.2.11).

Considering the high side of the curves in Figure 39, it must be observed that the curves go to 100% light output. This must be interpreted as the highest light output of the lamp when mounted in the dimmer circuit. The maximum rated output of the lamp (outside of the dimmer circuit) will normally be higher, because the dimmer induces losses.

As stated by CECAPI, also considering the low bleeder currents (par. 7.2.5) that are currently being proposed in the standardisation work, conduction angles higher than 130˚ may be difficult to reach by future dimmers. The question is which percentage of the maximum rated light output the lamps should at least emit at this conduction angle. Discussed values currently vary from 75 to 90%.

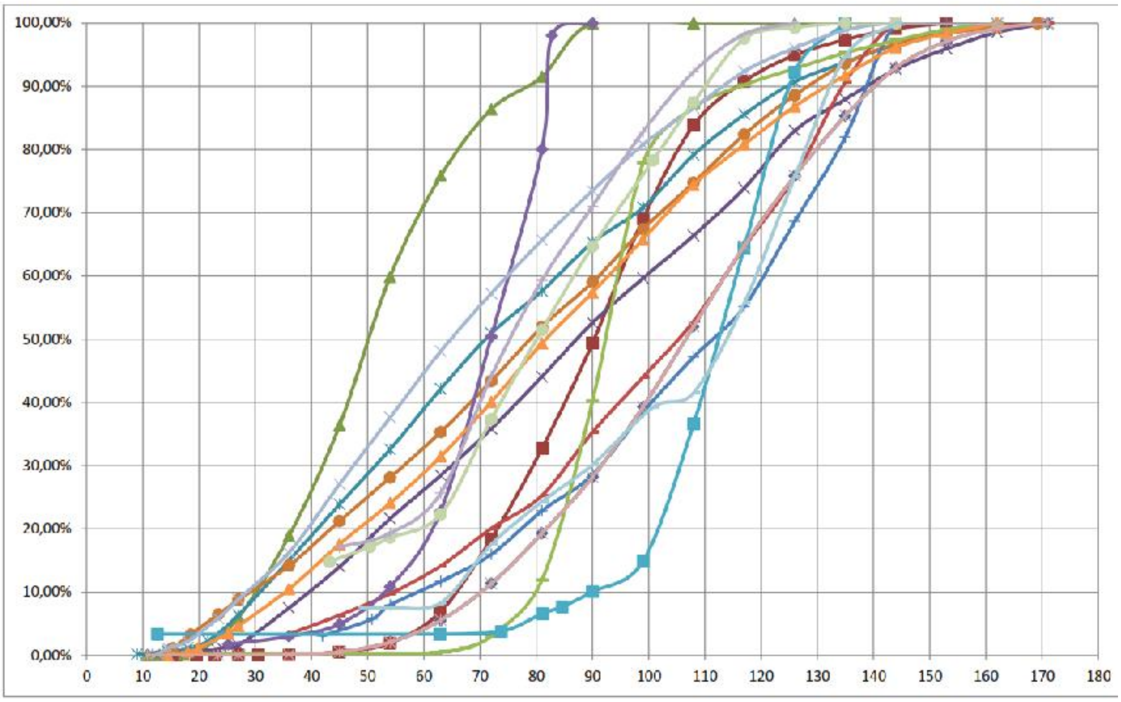


Figure 39 Example of dimming curves. The horizontal axis gives the conduction angle, i.e. the part of the 180˚ sine half wave that is NOT cut away. The vertical axis gives the corresponding measured light output as percentage of the maximum output that can be reached when attached to a dimmer (source: CECAPI)

Considering the low side of the curves in Figure 39, the dimmers usually have a minimum setting that could be a conduction angle of 60˚ for CFLi or 45˚ for LEDi. On some dimmers this minimum may be settable by the user, but anyway it would not be expected to go below 35˚. Here the discussion is on the highest light output that the lamps are allowed to have at this minimum conduction angle. The discussed values are around 20-30% of the maximum rated output.

Another aspect that is currently being discussed between lamp manufacturers and dimmer manufacturers is the allowable shape of the curve between the maximum and the minimum zone. No consensus has been reached yet.

7.2.7. Number of (LED) lamps per dimmer

For existing dimmers, the sum of the powers of the connected lamps should be below a specified maximum and above a specified minimum. These limit powers typically took into account filament lamps, that have a relatively high power and that stress the dimmer in a certain (acceptable) way due to their resistive nature.

LED lamps have lower powers, but their capacitive nature has the tendency to stress the dimmers more than filament lamps did, due to the possible occurrence of voltage and/or current spikes (see also remarks in par.7.2.4). The implication of this is that a dimmer designed for 600 W incandescent lamps can normally not be connected to 40 LED lamps of 15 W each (40x15W=600W). More likely, the maximum LED lamp power should be around 150 W. This can be quite confusing for consumers. Recent dimmers will most likely have two load ratings, one for resistive filament lamps, and a lower one for capacitive LED lamps, but this indication will be missing on older installed dimmers.

The above also implies that LED lamps on existing dimmers may work relatively close to the minimum power of the dimmer. As regards the possible consequences of this, see remarks in par.7.2.4.

7.2.8. Number and types of dimmers installed

According to CECAPI, the following can be stated regarding the sales of phase-cut dimmers in Europe:

- In 2010 5.2 million phase-cut dimmers were sold in Europe [184], corresponding to 148 million euros in revenue.
- In 2013 5.8 million phase-cut dimmers are expected to be sold, corresponding to 180 million euros in revenue.
- In 2010 around 61% of the sold phase-cut dimmers was leading-edge, around 27% trailing-edge and 12% universal.
- In terms of revenues the percentages are different because leading-edge dimmers have a lower cost. In 2010 34% of the revenues from phase-cut dimmers was leading-edge, around 30% trailing-edge and 36% universal.
- Trailing-edge dimmers are popular (50% of unit sales or more) in the Nordic countries and in Germany.
- From 2010 to 2013 the growth will be stronger for trailing-edge dimmers than for leading-edge dimmers because the former are thought to be more suitable for CFL and LED lamps.
- In 2010 approximately 75% of the phase-cut dimmers is sold in the residential sector, and 25% in the non-residential sector, with only slight variations of this percentage per type.

In addition CECAPI estimates that:

- The installed base of phase-cut dimmers for Europe is between 110 and 120 million units in 2010, of which 75% installed in the residential sector.
- Approximately 3% are 3-wire installations; the bulk are 2-wire installations and thus face the discussed problem of power supply through the load. The existing or new electrical installations in UK, Germany, Poland, France, Spain and Italy do not have a neutral connection at switch level in residential buildings. The number of houses in these countries is close to 160 million.
- It can be forecasted that 80% of the installed base of dimmers will face issues when loaded with new energy saving lamps (minimum load of the installed dimmer, repetitive peak current, repetitive ring up voltage,…).

[184] Actually the countries covered by the study are France, Germany, Italy, UK, Denmark, Finland, Norway, Sweden, both residential and non-residential sectors.

7.2.9. Smart lamps compared to use of separate dimmers

CECAPI presented to the study team a comparison of the power losses for two dimming solutions:

- App controlled: from 0 to 12 LED lamps of 6.3 W with integrated dimmer and RF functional block (smart lamp), with dimming controllable from a mobile phone using a Gateway and WiFi/Zigbee.

- Traditionally controlled (electronic switching): from 0 to 12 dimmable LED lamps of 6.3 W, wired to one electronic switching dimmer.

For the App controlled solution they found:

- The Gateway consumes 2.1 W, independent of the number of attached lamps
- The RF functional block in the lamp consumes 0.42 W (for each of the lamps)
- Total losses range from 2.10 W for no connected lamps to 7.14 W for 12 connected lamps

For the Traditionally controlled solution they found:

- The dimmer operation consumes 0.49 W, independent from the number of attached lamps
- The dimmer switching losses are 0.029 W for each lamp (depends on current, increases with number of attached lamps)
- Total losses range from 0.49 W for no connected lamps to 0.83 W for 12 connected lamps

The CECAPI conclusion is that a traditional solution with one central dimmer wired to several lamps has less losses than separate dimmers incorporated in each of a number of smart lamps and commanded remotely through a gateway.

Following a discussion in the 1st stakeholder meeting of 5 February 2015, where doubts were raised if people will still use the traditional dimming technology in future, considering the existence of smart lamps and their remote control possibilities, CECAPI forwarded the following opinion:

Phase-cut dimmers are very popular as it is a simple, affordable, sustainable and energy efficient way to dim lights. CECAPI does not foresee that users will shift towards smart lamps controlled by smartphones completely, but instead will remain using traditional dimmers where smartphone control will be an added feature.

The reasons are:

- *People do not want to rely on smartphones/tablets only. Functionalities need to be executed independently from the availability of networks and battery capacities.*
- *The use of traditional dimmers to control light sources is faster (e.g. always available, no entry code, no app start-up).*
- *The interface to control the light output is known to the consumer and uniform for all lamps, independent of brands. The interface is also identical in form and design with the other control devices in the building.*
- *Phase-cut dimmers are an integrated part of building management systems which controls light, temperature, blinds, ventilation, etc. with complete software packages.*

7.2.10. Step dimming

In addition to the technologies described in the preceding paragraphs, step-dimming lamps exist on the market (also referred to as DorS-dimming or Free Dimming). These lamps have integrated dimmers and can be controlled, for example, to 100%, 60% or 20% light output by operating an ordinary on/off switch. This solution can avoid dimmer-lamp compatibility problems in several applications.

The 3-step dimming technology offers three different light levels for the consumer to choose from, while the 4-step variant offers four different levels, typically including a 0.5 or 1% output level, that can be used as night-light. At switch-on, some lamps start at the maximum light level, while others start at the minimum light level.

Dimming is obtained by operating an ordinary on/off switch, without the need for a dimmer. At each off-switch followed by an on-switch within a few seconds, the lamp will pass to the following dimming level, for example 100%→60%→20%→100%.

The step-dimming technology is patented by O_2micro; for further information see the references [185].

7.2.11. Standardisation activities

In the context of Commission mandate 519 (see Task 1 report) the IEC has created a standardization Joint Adhoc Group (JAHG), that brings together experts on light sources/control gears (TC34) and experts on dimmers (SC23B). The purpose of this group is to prepare technical reports on the "*requirements and tests for dimmable LEDs to be used with phase-cut dimmers*" and on the "*requirements and tests for phase-cut dimmers to be used with dimmable LEDs*". In a next phase these technical reports have to be implemented in new or existing standards.

The study team had the possibility to examine the current draft text, which deals with Power Supply and Synchronization, i.e. it addresses the problem signalled in par.7.2.5 of power supply to the dimmers through the load in case of 2-wire systems, and synchronization topics regarding the phase-cutting.

Other topics are still under study. They include:

- Minimum performance and reliability related to the interface
- Basic ON/OFF
- Maximum light level in OFF condition (ghosting)
- Light level stability
- Minimum number of operations
- Life time
- Minimum dimming range
- Audible noise
- Smooth transition, including basic definition of dimming curve
- Marking
- Systems and products within the scope

The technical reports are planned to be ready by June 2015 and the implementation into standards is foreseen for 2017/2018.

In the USA, on 22 April 2013, NEMA published the standard SSL 7A-2013 "Phase Cut Dimming for Solid State Lighting: Basic Compatibility" [186]. This standard deals only with compatibility issues, not with performance issues for dimming. In addition it is limited to leading-edge phase-cut dimming because that

[185] http://www.o2micro.com/news/pr_120716.html;
http://globenewswire.com/news-release/2013/04/15/538238/10028377/en/O2Micro-Extends-Free-Dimming-TM-Technology-for-the-Global-LED-Retrofit-Lighting-Market-With-Two-Step-Nightlight-Driver.html
http://www.designingwithleds.com/on-off-switch-dimming/
http://www.megamanlighting.com/en/technology/controlling-an-led
http://electricalconnection.com.au/article/10022407/megaman-release-three-new-products

[186] http://www.nema.org/news/Pages/NEMA-Publishes-NEMA-SSL-7A-2013-Phase-Cut-Dimming-for-Solid-State-Lighting-Basic-Compatibility.aspx (launch announcement)
For some explanations and comments: http://www.lutron.com/en-US/Education-Training/Documents/LCE/LightSources/LED/LFI%202013%20Are%20We%20There%20Yet-V1.01%20FINAL.pdf

is by far the most widespread technology in the USA. It defines the dimming range only from 50% to 80% of the maximum light output. CECAPI stated to the study team that this American standard would be insufficient for the European situation.

Meanwhile, IEC SC 77a, WG 1, TF8 has issued a new document (77A_847e_DC) in which is clearly written down that, due to high electromagnetic disturbances induced by integrated electronic control gear when dimmed in phase cut, manufacturers shall not produce LED dimmers of maximum load above 100W if dimming is operated in leading-edge, while in trailing-edge 200W are allowed due to lesser perturbations.

7.2.12. Conclusions

A good dimming behaviour of LED retrofit lamps and integrated LED luminaires is important for the introduction of the LED lighting technology in the market, and for the realization of the energy savings that are expected from daylight-dependent and occupancy-dependent dimming by lighting control systems.

In the current situation there are significant problems with the dimming of LEDs, in particular as regards the dimming of LEDi retrofit lamps on phase-cut dimmers already installed in the households. These problems include:

- Flicker (on/off of lamps, at a frequency that is perceived by the consumer).
- Shimmer (variations in light intensity, at a frequency that is perceived by the consumer).
- Stroboscopic effects (when objects are moving fast with respect to the light source).
- Dead travel (changes in dimmer position do not lead to perceived changes in light intensity).
- Pop-on (raising the dimmer from the off-position, the light suddenly pops on at an unexpected high intensity level).
- Drop-out (lowering the dimmer, the light suddenly shuts off while the consumer expected a further intensity decrease).
- Impossibility to reach low dimming levels (related to drop-out).
- Noise, buzzing (from the dimmer, the control gear or the lamp itself)
- Ghosting (the lamp continues to glow in the off-position)
- Reduced lifetime or abrupt failure of one of the system components (dimmer, control gear or LED-module).

The background and some possible reasons for these problems have been identified and are explained in this report, even if not exhaustive.

LightingEurope, representing the European manufacturers of light sources and luminaires, and CECAPI, representing the European manufacturers of lighting controls (including dimmers), acknowledge that these problems exist. They also agree that it is impossible to develop lamps that are compatible with all types of dimmers now installed in Europe. The installed base of dimmers is to disparate and often characteristics are not well known.

LED lamp manufacturers and dimmer manufacturers are now publishing lists of dimmers or LED lamps that have been tested to be compatible with their products. Although valuable, these lists are usually accompanied by disclaimers and by warnings that laboratory tests may not correspond to the real situation of the consumer. In addition these lists are not available for many older dimmers already installed. In many literature sources it is recommended to test each specific combination dimmer – control gear – LED board; currently it is often a matter of 'hit and miss'.

A major problem is also that the majority of the phase-cut dimmers works in a 2-wire configuration, because in most European houses, and in some non-residential buildings, the neutral wire is not distributed to the lighting control points. The implication is that many lighting controls, including dimmers and sensors, have to receive their power supply through the lamps/control gears. This did not give particular problems for filament lamps, but it is a considerable problem for LED lamps.

Standardization activities are ongoing to resolve compatibility problems between phase-cut dimmers and LED lamps in the future, and to define minimum performance standards for dimming, thus implicitly defining what 'dimmable' exactly means. The implementation of these standards is expected for 2017/2018. Theoretically, after the introduction of this standard, any new dimmer would be compatible with any new LED lamp. However, as also stated above, it will be impossible to make these new lamps backwards compatible with all old dimmers. Consequently there continues to be a risk that consumers will have to substitute their old dimmers by new ones.

In 2010 there were more than 110-120 million phase-cut dimmers installed in the EU-28, of which 60% leading-edge phase-cut dimmers and 40% trailing-edge or universal phase-cut dimmers. 75% of the dimmers was installed in households and 25% in the non-residential sector. The share of trailing-edge dimmers is increasing in recent years because this technology is deemed more suitable for LED lamps.

7.3. Power factor

The definition (from the existing regulations) is recalled from the Task 1 Annex report:

> '*Power factor*', means the ratio of the absolute value of the active power to the apparent power under periodic conditions.

A more extensive description of the power factor and its impacts, as related to Regulation 244/2009, is provided in Annex F.3.

As also noted in the Task 1 par. 3.1. report, in the most recent IEC lighting standards, the treatment of power factor has been made more sophisticated. Power factor, or to avoid confusion 'true power factor' is defined as [real power] divided by [rms voltage x rms current] [187]. However, true power factor for electronic equipment (including CFLs and LEDs) is actually comprised of two components:

- Displacement factor ($K_{displacement}$) is the fundamental frequency (50 or 60Hz) component of power factor, which is the degree to which the current waveform drawn by the device is out of phase with the voltage waveform.
- Distortion factor ($K_{distortion}$) is due to the device drawing harmonic currents, which are currents at higher frequencies than the fundamental frequency – multiples of the fundamental frequency.

These two factors mathematically combine to calculate true power factor as follows:

True power factor = $K_{displacement} \cdot K_{distortion}$

The most recent IEC lighting product standards deal with both of these components of power factor, requiring each of them to be measured using sophisticated power measurement/analysis equipment.

A low power factor for lighting products potentially leads to additional energy losses in the electricity distribution, but these losses are uncertain and difficult to quantify because they mix with, and can be partially or completely compensated by, the effects of other electricity consumers attached to the same distribution network (Annex F.3). For this reason **these effects are not accounted for in MELISA**.

[187] For a detailed explanation, see Annex F.3

Considering this uncertainty on additional energy losses, the existing regulations anyway set rules for the power factor (PF) of lighting products: in general PF>0.5 for lamps with power < 25W and PF>0.9 for lamps with power > 25 W (details in Annex F.3) [188].

In a LightingEurope position paper on power factor [189] it is recommended to use $K_{displacement}$ and $K_{distortion}$ for regulation purposes, and not the (true) power factor, because it is a composite metric. The paper also provides reference values that should avoid negative effects from light sources on the public power supply systems.

7.4. Other grid-related aspects

7.4.1. Line voltage fluctuations from the grid on light sources:

Sources of voltage fluctuations [190]:

The primary cause of voltage fluctuations in the medium and high voltage grid (>1000 VAC) is the time variability of the reactive power component of fluctuating loads; in the low voltage grid (e.g. 230/400VAC) it is the fluctuating load of active and reactive power. Other causes are capacitor switching and on-load transformer tap changers, which can change the inductive component of the source impedance. Variations in generation capacity of, for example, wind turbines can also have an effect. In some cases, voltage fluctuations can be caused by low frequency voltage inter-harmonics.

In Europe CENELEC has harmonized the line voltage at 230 VAC +/- 10% for products but local grid codes can require tighter tolerances (e.g. +10/-6%).

Direct impact on light output and lamp efficacy:

Light sources with control gear and appropriate control circuits are little sensitive to line voltage fluctuations. The problem is mainly related to incandescent lamps that are directly operated on the mains. These halogen lamps have a direct relationship [191] between lamp efficacy versus life time, lamp voltage, wattage and color temperature. Specifications for mains voltage halogen lamps are in standard conditions 230 VAC and do not take these voltage fluctuations into account despite having significant impact. For example the permissible supply voltage variation (+/- 10 %) causes a halogen lamp to deliver as little as 70% or as much as 140% of its nominal luminous flux respectively. Fast changing line voltage variations can cause flicker. EN 50160 sets limits to non-lighting equipment(e.g. washing machines) to avoid flicker in halogen lamps. It can be concluded that the sensitivity of mainly incandescent lamps (e.g. HL-MV) caused external cost in other appliances to avoid flicker (EN 61000-3-3, EN 61000-3-11).

Conclusions with regard to impact of line voltage in this study:

- It is proposed to calculate with the nominal and average values in Tasks 4-6, because they reflect the usual condition for residential users and in tertiary lighting halogen lamps are not used when the concept of maintained illuminance is applied [192].
- It is proposed to not take into account the external costs from halogen mains voltages that resulted from EN 61000-3-3&11 in other non-lighting equipment, because these aspects are regulated within the respective standardisation committees and the cost figures are unknown.

[188] In its comments to the report, the Danish Energy Agency recommends to keep the PF > 0.5 requirement as this is fulfilled by products of quality and there is no reason to impose extra costs on LED for adding electronics which will be the consequence of requiring PF>0.7.
[189] http://www.lightingeurope.org/uploads/files/Position_Paper_Power_Factor_Sept_2014.pdf
[190] Leonardo(2012): 'Power Quality Application Guide: Voltage Disturbances 5.1.4'
[191] Lighting Handbook, 8th Edition, Illumination Engineering Society of North America (p. 186), ISBN 0-87995-102-8.
[192] See lot 8&9 preparatory studies on street and office lighting (www.eup4light.net)

- For policy options with respect to information requirements, minimum performance, labelling and equivalence claims in Task 7 it makes sense to consider the worst case voltage conditions (+/-10%) instead of nominal conditions.

7.4.2. Harmonic line currents from light sources on the power grid

Sources:

Today, nearly every piece of electrical equipment generates harmonic currents and voltages [193]. Harmonic frequencies are integral multiples of the fundamental supply frequency (50 Hz), e.g. a third harmonic is 150 Hz. Harmonic load currents are generated by all non-linear loads such as Switched mode power supplies.

Direct impact on the grid:

Harmonic currents and voltages cause many problems in electrical installations, including overheating of equipment and cabling, reduced energy efficiency, and reduced functionality due to loss of electromagnetic compatibility. Harmonic currents from installations flow back into the network and propagate as voltage harmonics, distorting the supply waveform, increasing network losses, and reducing the reliability of equipment. A comprehensive field test study was carried out by 'The Community of the Austrian Electricity Suppliers', including laboratory measurements and field measurements. The Austrian measurements showed that extensive use of CFLi's did not lead to negative effects on the voltage quality [194].

Halogen lamps are linear loads and do not emit harmonic currents to the grid in normal operation. Only when halogen lamps are connected to dimmers harmonic currents are injected in the grid due to non-linear deformation of the sine wave with phase-cut dimmers. All other lamp types need control gear and the emission of harmonic currents depends on the design of the control gear (see Task 4).

Harmonic current emission is regulated with standard EN 61000-3-2 on "Limits for harmonic current emissions". Lighting forms a separate class of equipment (class C) and has severe requirements [195], especially above 25 Watt because they form a significant load on the grid installed mainly in tertiary lighting.

Conclusions with regard to impact of line voltage in this study:

- it is proposed to not take harmonic currents into account because they are already regulated with EN 61000-3-2 within CENELEC.

7.4.3. Line voltage transients, surges and temporary overvoltages

Sources [196]:

A transient overvoltage or surge is a short duration increase in voltage between two or more conductors from microseconds to a few milliseconds that can vary from a few volts to thousands of volts. 'Transient overvoltage', is technically and descriptively the best terminology. However, transients are also referred to as surges, spikes and glitches. Transient overvoltages are generally caused by lightning and/or electrical switching events.

[193] ECI (2011): APPLICATION NOTE HARMONICS: CAUSES AND EFFECTS, David Chapman, November 2011.

[194] Brauner G, Wimmer K., "Netzruckwirkungen durch kompaktleuchtsofflampen in Niederspannungsnetzen", Verband der Elektrizitätswerke Osterreich, 1995.

[195] http://www.epsma.org/pdf/PFC%20Guide_November%202010.pdf

[196] BEAM(2014): BEAMA Guide to Surge Protection Devices (SPDs): selection, application and theory

Direct impact of transient voltages on light sources life time:

Transients occurring on the AC power supply can affect electronic equipment [197] such as lighting control gear. They can cause either an upset or permanent damage to components in several different ways, depending on the characteristic of the surge and the design of the equipment.

Protection against overvoltages.

EMC performance requirements are now increasingly standardized and should provide adequate immunity if implemented at the equipment level and/or installation level [198]. Light sources transient voltage immunity at the equipment level is regulated by EN standard EN 61547 also referring EN 61000-4-2,4,5 and 11. As explained in Task 4 transient voltage protection can have impact on the design and cost of electronic control gear. For LED lighting, EN 61547 requires for example surge 0.5kV L to N. Compared to the line voltage this is not impressive and complementary protection at installation level might be needed. Some light control gear manufacturers announce in the product documentation improved immunity levels, for example 'EN61547, light industry level (surge 4kV)'.

Conclusions with regard to impact of transient voltages in this study:

- It is proposed to not take into account the impact of voltage transients in Task 4-6 because these aspects are regulated in EN standards.

[197] ECI (2012) APPLICATION NOTE TRANSIENTS & OVERVOLTAGES: SYSTEM INTERACTIONS AND EFFECTS ON EQUIPMENT, UIE, January 2012

[198] BEAM(2014): BEAMA Guide to Surge Protection Devices (SPDs): selection, application and theory

7.5. Replacement costs of non-residential light sources

In non-residential lighting it is common practice to compare solutions based on the system costs [199] [200], taking into account the capital cost related to the initial installation, the estimated energy cost, and the maintenance cost. Of course, this does not exclude that many installations are inefficient and not properly maintained.

Lighting installations are typically designed to comply with standards (e.g. EN 12464, EN 13201), taking into account maintenance factors. The following partial maintenance factors are defined in CIE 97 (Indoor lighting) and CIE 154 (Outdoor lighting) (see Task 1):

- LLMF: Lamp Lumen Maintenance Factor
- LSF: Lamp Survival Factor
- LMF: Luminaire Maintenance Factor
- RMF: Room Maintenance Factor (indoor)
- SMF: Surface Maintenance Factor (outdoor)

The overall maintenance factor MF of the lighting installation is the product of the individual maintenance factors. Table 53 contains an extract of the LLMF- and LSF-data used in the 2007 lot 8 study on office lighting [201].

Operating hours		10000 h	15000 h	20000 h
LFL tri-phosphor on magnetic ballast	LLMF	0.9	0.9	
	LSF	0.98	0.5	
LFL tri-phosphor on electronic ballast (preheat)	LLMF	0.9	0.9	0.9
	LSF	0.98	0.94	0.5
LFL halo-phosphate on magnetic ballast	LLMF	0.79	0.75	
	LSF	0.82	0.5	
CFLni on magnetic ballast	LLMF	0.85		
	LSF	0.5		
CFLni on electronic ballast (preheat)	LLMF	0.9	0.85	
	LSF	0.95	0.5	

Table 53: LLMF and LSF data for selected lamps (Source: data supplied by ELC (2006 and 2007) & adapted CIE 97 (2006) as reported in the 2007 VITO study on office lighting [201])

Installation and maintenance costs will be based on estimated labor times for the associated activities and the average hourly labor cost representative for the EU-28. As regards the latter, the direct labor cost in 2014 has been taken from Eurostat [202] as 24.60 euros/hour. Overhead costs of 50% have been assumed, leading to a total of 36.90 euros/hour, rounded to 37 euros/hour.

[199] licht.wissen 01 'Lighting with Artificial Light' available from licht.de

[200] ZVEI(2013): 'Guide to Reliable Planning with LED Lighting Terminology, Definitions and Measurement Methods: Bases for Comparison'.

[201] Preparatory Studies for Eco-design requirements of EuPs, Final Report, Lot 8: Office lighting, Study for the European Commission DGTREN unit D3, contact Andras Toth, by VITO in cooperation with Laborelec and Kreios, April 2007, Contract TREN/D1/40-2005/LOT8/S07.56452, available through 'eup4light.net'

[202] http://ec.europa.eu/eurostat/statistics-explained/index.php/Hourly_labour_costs

Estimates for the required installation and maintenance times as used in previous lighting studies are shown in Table 54.

Installation or maintenance activity	Time (minutes)	
	Indoor (office)	Outdoor (street)
Time required for installing one luminaire	20	20
Time required for group lamp replacement (per lamp)	3	10
Time required for spot lamp replacement	20	20
Time required for luminaire cleaning (in addition to time for group lamp replacement)	1.5	
Time required for maintenance including ballast replacement		30

Table 54: Estimation of maintenance and installation cost related parameters used for LCC calculations in this study (Source: [201] [203])

[203] Preparatory Studies for Eco-design requirements of EuPs, Final Report, Lot 9: Public Street lighting, Study for the European Commission DGTREN unit D3, contact Andras Toth, by VITO in cooperation with Laborelec and Kreios, January 2007, Contract TREN/D1/40-2005/LOT9/S07.56457, available through 'eup4light.net'

8. CONSUMER REACTION TO ENERGY LABELLING FOR LAMPS

It is not the intention of this chapter to provide an extensive review of the consumer reaction to the energy labelling of lamps. Recently several studies have examined this topic [204], even if not specifically targeted at lighting products, and their findings are not repeated here.

Instead, the results of two recent studies in the United States of America will be briefly presented below. These studies addressed the question how the consumer choice between incandescent lamps and CFLs is influenced by the information provided on the label.

The first study [205] claims to have demonstrated that promoting the environment by means of the supply of information on the product label (in this case carbon emission reduction) can negatively affect adoption of energy efficient lamps in the United States because of the political polarization surrounding environmental issues. The first part of the study found that politically conservative consumers were less in favour of investments in energy-efficient lamps than politically liberal consumers, because the former give less psychological value to reducing carbon emissions. The second part of the study showed that this has a direct real-life effect on the lamp acquisition behaviour of politically conservative consumers: notwithstanding the cost advantages, they were less likely to purchase a more expensive energy-efficient light bulb when it was labelled with an environmental message than when it was unlabelled.

In comments on this research it is remarked that, although the political aspect is relevant, it cannot entirely explain why people are buying less CFLs than would be expected based on the long-time cost advantages. An additional reason could be that "*There is a lingering misconception about green products that they don't work and that they are overpriced because they are gouging people based on their sentiments about saving the planet*." In addition it is observed that the consumer dislike of CFLs probably has other grounds than only price and messaging, because for example LED sales are growing rapidly and these lamps have even higher acquisition costs than CFLs. The research did not include LED lighting however. More in general, there can be a considerable difference between US consumer behaviour and EU consumer behaviour and thus the value of these types for the EU-situation is limited.

The second study [206] is an attempt to determine Implicit Discount Rates (IDRs) [207] that can express the consumer behaviour during the choice between incandescent lamps and CFLs. The study analysed the

---

[204] For example (not exhaustive):
"Research on EU product label options, Final report", Study delivered by Ipsos MORI, London Economics and AEA for the European Commission, October 2012, http://ec.europa.eu/energy/efficiency/studies/doc/2012-12-research-eu-product-label-options.pdf
Ecofys, Evaluation of the Energy Labelling Directive and specific aspects of the Ecodesign Directive ENER/C3/2012-523, Final technical report, June 2014, http://www.energylabelevaluation.eu/tmce/Final_technical_report-Evaluation_ELD_ED_June_2014.pdf
"Study on the impact of the energy label – and potential changes to it – on consumer understanding and on purchase decisions", ENER/C3/2013-428 DRAFT FINAL REPORT, IPSOS/LE, August 2014

[205] "Political ideology affects energy-efficiency attitudes and choices", Dena M. Grommet, Howard Kunreuther, Richard P.Larrick, Proceedings of the National Academy of Sciences of the United States of America, vol. 110 no.23, June 2013, http://www.pnas.org/content/110/23/9314 as summarised and discussed in:
"Pro-Environment Light Bulb Labeling Turns Off Conservatives, Study Finds", Brian Handwerk for National Geographics New, April 30, 2013, http://news.nationalgeographic.com/news/energy/2013/04/130430-light-bulb-labeling/

[206] "Labeling energy cost on light bulbs lowers implicit discount rates", Jihoon Min, Inês L. Azevedo, Jeremy Michalek, Wändi Bruine de Bruin, Ecological Economics 97 (2014) http://www.sciencedirect.com/science/article/pii/S092180091300325X

[207] As explained in the article: "The IDR, or hurdle rate, is the value of the discount rate for a hypothetical net-present-value-maximizing consumer that best matches observed choice behaviour. When viewed from the framing of classical economic discounting, consumers appear to behave as though they are using the implicit discount rate to value current vs. future costs

choices of 183 consumers when provided with varying sets of information on three types of lamps, for example:

If these were your only options for light bulbs for your floor lamp, which would you buy?

(1) CFL, $4.49, 27 W ($3.60 annual electricity cost), life 8000 h, 1800 lumens, daylight
(2) Incandescent, $0.49, 75 W ($10 annual electricity cost), life 1000 h, 1200 lumens, soft white
(3) CFL, $2.49, 9 W ($1.20 annual electricity cost), life 12000 h, 500 lumens, bright white

Parameters were changed from choice to choice. Operating cost information was withheld from 83 participants while it was shown to the other 85. A selection of the main conclusions of the research follows (see the reference for further details):

- A majority of the consumers prefers CFL technology and high brightness.
- There is no clear preference regarding colour temperature and power.
- Providing operation cost information increases the preference for low power and long life.
- Consumers are willing to pay $2.63 more for CFL bulbs than for incandescent bulbs [208].
- For every 1000 h of lifetime increase, consumers are willing to pay $0.52 more per lamp when annual cost information is NOT provided, and $0.66 more when such information IS given.
- For every 10 W decrease, consumers are willing to pay $0.46 more per lamp when the annual cost information is shown.
- Providing annual operating cost information induces consumers to pay more attention to the savings effects of long lifetime and low power. This might be one of the reasons that CFL sales were lower than expected before the introduction of packaging showing such information. Providing operating cost information does not significantly change the preferences for colour temperature, brightness, type, and price.
- Politically liberal consumers have a stronger preference than non-liberals for low power lamps and for CFLs [209].
- Consumers with a high income have a higher preference for long-life lamps than those with a low income.
- Participants that correctly answered that CFLs contain toxic materials and that consider this toxicity as 'very dangerous' have a higher preference for incandescent lamps.
- The average IDR is 100% for the group that was provided with operating cost information, and more than five times higher for the group that did not receive such information (indicating that the latter group is more reluctant to buying energy efficient lamps).
- The IDR is lower for groups with higher income. This means that the high initial acquisition cost and the delayed energy cost saving is a barrier in particular for the lower income groups.
- The IDR=100% found for lighting is higher than the IDR currently used in energy economy modelling for other products. This seems to imply that consumers are not aware of the savings potential or that they feel that they will not realize these savings. The fact that savings from a single energy efficient lamp are smaller than those of larger appliances, e.g. washing machines or fridges, might contribute to this feeling. Consequently lighting might face higher barriers for introduction of energy efficiency than other product groups, and operating cost information on the labels will contribute significantly but may not be sufficient by itself.

(with some error). The IDRs are used as inputs in many energy-economy models to explain how the share of end-use energy technologies evolves over time".

[208] But there was a high variability, and some participants were willing to pay more for incandescent lamps…..

[209] This confirms the outcome of the first study described above, i.e. that the political orientation influences the choice of the lamp type.

The studies are for the situation in the U.S. while the European context is probably different. In addition the research compared incandescent lamps with CFLs, and it is uncertain if the same conclusions would be found for LED lamps. Anyway it is worthwhile to take the findings of the studies into account.

REFERENCES

See footnotes in text

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

4E	Energy Efficient End-use Equipment (cooperative program of IEA)
a	Annum, year
ANSI	American National Standards Institute
ASP	Average Selling Price (for McKinsey data)
AT	Austria
BAT	Best Available Technology
BAU	Business As Usual
BE	Belgium
BEF	Ballast Efficacy Rating
BGF	Ballast Gain Factor (due to dimming)
BLE	Ballast Luminous Efficiency
BMF	Ballast Maintenance Factor
bn / bln	Billion (10^9)
BNAT	Best Non-Available Technology
BOM	Bill Of Materials
CCFL	Cold-Cathode Fluorescent Lamp
CCR	Constant Current Reduction (LED dimming method)
CCT	Correlated Colour Temperature
cd	candela
CDR	Commission Delegated Regulation
CECAPI	European Committee of Electrical Installation Equipment Manufacturers
CEN	European Committee for Standardisation
CENELEC	European Committee for Electrotechnical Standardisation
CIE	International Commission on Illumination
CFL	Compact fluorescent lamps
CFLi	CFL with integrated ballast
CFLni	CFL without integrated ballast
CISPR	Comité International Spécial des Perturbations Radioélectriques
CN / CN8	Combined Nomenclature (coding)
cor	corrected
CRI	Colour Rendering Index
DALI	Digital Addressable Lighting Interface
DE	Germany

DLS	Directional light sources
DEFRA	UK Department for Environment, Food and Rural Affairs
E14, E27	Screw-type lamp caps for general purpose lamp
EC	European Commission
ECEEE	European Council for an Energy Efficient Economy
ECG	Electronic Control Gear
ECO	Scenario considering ecodesign or energy labelling measures
ED	Ecodesign / Ecodesign Directive
EEI	Energy Efficiency Index
ELC	European association of lighting manufacturers, now part of LightingEurope
ELD	Energy Labelling Directive
ELV	Extra Low Voltage
ELV	Electronic Low Voltage transformer
EMC	Electro-Magnetic Compatibility
EoL	End of Life
ErP	Energy related Product
ESL	Electron Stimulated Luminescence
ESO	European Standardisation Organisation
EU	European Union
FIPEL	Field-Induced Polymer Electroluminescent Lighting
FR	France
FU	Functional Unit
G4, GY6.35	Low voltage halogen lamp types, 2-pin cap, single ended
G9	Mains voltage halogen lamp, 2-pin cap, single ended
GDP	Gross Domestic Product
GLS	General Lighting Service (a.k.a. incandescent lamp)
h	Hour
HF	High Frequency
Hg	Mercury
hh	Household
HID	High-Intensity Discharge
HL	Halogen
HPM	High-Pressure Mercury
HPS	High-Pressure Sodium
HS	Harmonised System (coding)
HVAC	Heating, Ventilating, and Air Conditioning
HW	High Wattage
Hz	Hertz
IDR	Implicit Discount Rate
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IES / IESNA	Illuminating Engineering Society (of North America)
ILCOS	International Lamp Coding System
ILV	International Lighting Vocabulary
IR, IRC	Infrared, Infrared coating
IR	Incandescent Reflector Lamp

IRP	Industry Revenue Part (of end-user sales price)
ISA	International Solid State Lighting Alliance
ISO	International Organization for Standardisation
IT	Italy
LBS	Lampen-Bezeichnungs-System
LCC	Life Cycle Cost
LE	LightingEurope (lighting manufacturers association)
LE	Leading-edge phase-cut dimming
LED	Light Emitting Diode
LENI	Lighting Energy Numerical Indicator
LER	Luminaire Efficacy Rating
LFL	Linear Fluorescent Lamp
LLCC	Least Life Cycle Cost
LLE	LED Light Engine
LLMF	Lamp Lumen Maintenance Factor
lm, Φ	Lumen, unit of luminous flux Φ
LMF	Luminaire Maintenance Factor
LOR	Light Output Ratio
LPD	Lighting Power Density [W/(m².lx)] (Pr EN 13201-5)
LV	Low Voltage (typical 12V)
LW	Low Wattage
max	maximum
MEErP	Methodology for Ecodesign of Energy-related Products
MELISA	Model for European Light Sources Analysis
MEPS	Minimum Efficacy Performance Standard
MH	Metal Halide
min	minimum
MLV	Magnetic Low Voltage transformer
mn / mln	Million (10^6)
MOCVD	Metal Oxide Chemical Vapour Deposition
Mt	Mega tonnes (10^9 kg)
MV	Mains Voltage (typical 230V)
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne (coding)
NDLS	Non-directional light sources
nec	Not elsewhere classified
NEMA	National Electrical Manufacturers Association
NL	the Netherlands
OJ	Official Journal of the European Union
OLED	Organic Light Emitting Diode
P	Rated power
par	paragraph
PF	Power factor
ProdCom	PRODuction COMmunautaire (coding)
PWM	Pulse Width Modulation (LED dimming method)
-R	Reflector
R	Electrical Resistance

R7s	Mains-voltage linear halogen lamp, double ended
Ra	Colour rendering index, unit
ref	reference
RF	Radio frequency
RGB	Red Green Blue
rms	Root mean square
s	Second (as unit for time)
SCHER	Scientific Committee on Health and Environmental Risks
SCENHIR	Scientific Committee on Emerging and Newly Identified Health Risks
SPL	Special Purpose Lamp
SPP	Special Purpose Product
sr	steradian
SSL	Solid State Lighting
TBC	To Be Confirmed
TBW	To Be Written / To Be Worked
TC	Technical Committee
TE	Trailing-edge phase-cut dimming
TPF	True power factor
TWh	Tera Watt hour (10^12)
UF	Utilisation Factor
UGR	Unified Glare Rating
UK	United Kingdom
ULOR	Upward Light Output Ratio
US(A)	United States of America
UV	Ultraviolet (subtypes UVA, UVB, UVC)
UVA	near UV-Black Light, 315-400 nm
UVB	middle UV-Erythemal, 280-315 nm
UVC	far UV-Germicidal, 100-280 nm
V	Volt
VHK	Van Holsteijn en Kemna
VITO	Vlaamse Instelling voor Technologisch Onderzoek
W	Watt
WEEE	Waste Electrical and Electronic Equipment
yr	year

Annex A. STATEMENT OF CONTRACTOR ON RIGHT TO DELIVERED RESULT

I, Dirk Fransaer, representing the “Consortium of VITO NV, VHK BV, Viegand & MaagØe ApS, Wuppertal Institute for Climate, Environment and Energy GmbH, and ARMINES”, party to the contract ‘Preparatory Study on Lighting Systems for Ecodesign and/or Energy Labelling Requirements (‘Lot 8/9/19’), specific contract No. ENER/C3/2012-418 LOT1/07/SI2.668526 implementing framework contract No. ENER/C3/2012-418-Lot 1’, warrant that the Contractor holds full right to the delivered Task 3 report of the ‘Preparatory Study on Lighting Systems for Ecodesign and/or Energy Labelling Requirements (‘Lot 8/9/19’)’, which is free of any claims, including claim of the creators who transferred all their rights and will be paid as agreed within 30 days from the receipt of confirmation of acceptance of work.

Mol, Belgium,

Date:

Signature:

Dirk Fransaer

Managing Director VITO NV

Annex B. DESCRIPTION OF MEERP TASK 3

The MEErP [210] prescribes the following topics to be addressed in Task 3, Users:

System aspects Use phase, for ErP with Direct energy consumption

Identify, retrieve and analyse data, report on the environmental & resources impacts during the use phase for ErP with a direct energy consumption effect, with impact levels subdivided in

3.1.1 a strict product/ component scope (e.g. steady state efficiency and emissions at nominal load, as in traditional standards)

3.1.2 an extended product approach: considering that the ErP will be subject to various loads/user demands; the product scope could extend to controllability (flexibility and efficiency to react to different load situations, e.g. modulating burner, variable speed drive, "inverter"), the quality of possible controls (sensors, actuators, central processing unit) and/or the quality of auxiliary devices that may or may not be part of the ErP as placed on the market (e.g. separate heat recovery devices such as PFHRD)

Examples of possibly important factors to consider, depending on the nature of the ErP, are:

- Load efficiency (real load vs. nominal capacity);
- Temperature- and/or timer settings;
- Dosage, quality and consumption of auxiliary inputs (detergents, paper- and toner use, etc.);
- Frequency and characteristic of use (e.g. hours in on, standby or off mode);
- Identification of use of second hand auxiliary inputs during product life (e.g. toner, recycled paper);
- Power management enabling-rate and other user settings;
- Best Practice in sustainable product use, amongst others regarding the items above.

3.1.3 a technical systems approach: considering that the ErP is part of a larger product system and –through certain features of the ErP—can influence the functional performance and/or the resources use and emissions of that of that larger product system. E.g. central heating boiler regulation influencing indoor temperature fluctuation (discomfort), thus increasing heat demand. Other example: combination and possible synergy from combining strict ErP with other ErP (consumer electronics TV/ PC/ phone/camera; combi-boiler with both space and hot water heating; hybrid boiler combining gas boiler with heat pump, etc.). Note that this still considers solutions of which the ErP is a physical part.

3.1.4 a functional systems approach: considering that often there are several ways to realize the basic function. E.g. water-based (hydronic) heating systems versus air-based heating systems, various modes of food preparation, etc.. This analysis will often not directly affect a single Ecodesign legislation, but it is of strategic interest to guarantee coherence and consistency between the various ErP being regulated.

System aspects Use phase, for ErP with Indirect energy consumption

Identify, retrieve and analyse data, report on the indirect environmental & resources impacts during the use phase for ErP with an indirect energy consumption effect (e.g. windows, insulation material, shower head, water taps), specifically

3.2.1 describe the affected energy system(s), i.e. the systems/products whose energy consumption in the use phase of the ErP is influenced by features of the ErP

3.2.2 repeat Tasks 1.2, 1.3 (relevant standards, legislation) and Task 2 (economic and market analysis) for the affected energy system, but only related to technical parameters that relevant for the aforementioned interaction with the ErP and only in as much as they are not already taken into account in Task 1 and 2 for the ErP.

3.2.3 information retrieval and analysis of the use phase energy consumption of the affected energy system (repeat 3.1 but only for the use phase of the affected energy system).

3.2.4 assess the interaction between the ErP and the affected energy system: describe the basic physical/chemical or other parameters and mechanisms behind the interaction, possible backed-up by statistical data or field trial or laboratory data.

3.2.5 quantify the energy use and the energy-related resources & environmental impacts during the use phase of the affected energy system(s) that is influenced by the ErP, following the outcomes of the relevant parts of Tasks 4 to 7 for the affected energy system.

End-of-Life behaviour

Identify, retrieve and analyse data, report on consumer behaviour (avg. EU) regarding end-of-life aspects. This includes:

3.3.1 Product use & stock life (=time between purchase and disposal);

3.3.2 Repair- and maintenance practice (frequency, spare parts, transportation and other impact parameters);

[210] MEErP 2011, Methodology for Ecodesign of Energy-related Products, part 1: Methods and part 2: Environmental policies and data, René Kemna (VHK) November 28th 2011

3.3.3 Collection rates, by fraction (consumer perspective);
3.3.4 Estimated second hand use, fraction of total and estimated second product life (in practice);
3.3.5 Best Practice in sustainable product use, amongst others regarding the items above.

Local Infra-structure

Identify, retrieve and analyse data, report on barriers and opportunities relating to the local infra-structure regarding
3.4.1 Energy: reliability, availability and nature
3.4.2 Water (e.g. use of rain water, possibilities for “hot fill” dishwashers);
3.4.3 Telecom (e.g. hot spots, WLAN, etc.);
3.4.4 Installation, e.g. availability and level of know-how/training of installers;
3.4.5 Physical environment, e.g. fraction of shared products, possibilities for shared laundry rooms, etc.

Recommendations

Make recommendations on
3.5.1 refined product scope from the perspective of consumer behaviour and infrastructure
3.5.2 barriers and opportunities for Ecodesign from the perspective of consumer behaviour and infrastructure

Annex C. LIGHTING ENERGY PARAMETERS FOR HOUSEHOLDS

C.1 United Kingdom 2012, lighting measurements in households

The reference [211] presents the results of a survey of 251 households in England that was undertaken to monitor the electrical power demand and energy consumption over the period May 2010 to July 2011. Of the 251 households surveyed, 26 were monitored for a period of one year and the rest were monitored for periods of one month at intervals throughout the year. Different types of houses (terraced, flat, stand-alone) with different types of households (pensioners, workers, with or without children) were involved. Lighting energy consumption was part of the measurements.

A seasonality lighting curve was calculated using the 26 households that were monitored for one year [212]. This curve was used to calculate the annual consumption for the lights monitored for one month.

The average **number of light sources per household**, all types taken together, was **33.6**. As reported in the reference, this value is between the numbers for the ECL100 project in France (28.3) and the SWE400 project in Sweden (42.0). Subdivision over the lamp types:

Lamp type	Number per household	Share of lamps
Incandescent	12.9	38%
halogen MV	5.1	15%
halogen LV	5.4	16%
CFL	7.9	24%
LFL	2.0	6%
LED	0.2	1%
Total	**33.6**	100%

Table 55 Number of lamps per household, United Kingdom, 2012

The average is **0.61 bulbs per m² per household**. As reported in the reference, for France, during the ECL100 campaign, the average was 0.26 bulbs per m² and in Sweden 0.43 bulbs per m².

On average, the **total installed wattage, taking all light sources together, was 1.362 kW**. As reported in the reference, this value is smaller than that in the SWE400 project in Sweden (1.618 kW) and the ECL100 project in France (1.578 kW). Subdivision over the lamp types:

Lamp type	Installed power (W)	Share of lamp power
Incandescent	678	50%
halogen MV	370	27%
halogen LV	153	11%
CFL	91	7%
LFL	68	5%
LED	2	0%
Total	**1362**	100%

Table 56 Installed lighting power per household, United Kingdom, 2012

[211] Household Electricity Survey. A study of domestic electrical product usage. Intertek R66141 Final report issue 4, May 2012, chapter 12, http://savethebulb.org/wordpress/wp-content/uploads/2012/07/10043_R66141HouseholdElectricitySurveyFinalReportissue41.pdf

[212] figure 465 in the reference

The **average installed wattage density** is **24.1 W/m²**. As remarked in the reference, compared with the values found in the ECL100 project in France (15 W/m²) and the SWE400 project in Sweden (13 W/m²), the high UK-value suggests that the houses measured in England were smaller than the ones in the other two countries.

The **annual electric energy consumption for lighting ranged from 413 kWh to 581 kWh** with an **average of 537 kWh**. For comparison: the annual consumption in the ECL100 project in France was 354 kWh while the SWE400 project in Sweden found from 646 kWh to 937 kWh (see also Annex C.2).

The households with the highest lighting consumption are not the ones with the highest installed lighting wattage. The higher the percentage of CFLs there was in the household, the lower was the annual consumption, but the highest consumptions were not in the households with the lowest percentage of CFL but in those having between 20% and 50% CFL.

Study team computation: the average annual consumption of 537 kWh and the average installed power of 1.362 kW imply **394 average operating hours per year**.

The **annual consumption per person** is a function of the number of people in the household. The values per person should be treated with some care because the family structure has to be taken into account as well. Annual consumption equals 560 kWh/person for 1 person, between 220 kWh/person and 250 kWh/person for households with 2 or 3 people, and then decreases to around 100 kWh/person for households with more than 3 people.

The **average annual consumption density** over all the households is **10.0 kWh/m²**. This is 2.7 times greater than that found in the ECL100 project in France (3.7 kWh/m²) and 1.5 times the resulting from the SWE400 project in Sweden (**6.7 kWh/m²**).

Average hourly lighting. Lighting consumption during the night occurred in all types of household. As stated in the reference, it is unlikely that this consumption could be entirely due to night time uses such as getting up to use the bathroom. It was not possible in this case to identify the lights that were responsible for the night consumption. The **main peak was always between 21:00 and 23:00 and ranged from 0.13 to 0.2 kW**.

C.2 Sweden 2009, lighting measurements in households

The reference [213] reports the results of the measurement campaigns that took place in Sweden in cooperation between the Swedish Energy Agency, Enertech (France) and YIT Sverige AB. The campaign went from August 2005 to December 2008. A total of 40 households were measured for one year. Additional 360 households were monitored for one month. The lodgings were approximately 50% apartments and 50% houses. On average, houses had a useful area of 127 m^2 and apartments 76 m^2. The households had a differing number of persons.

The **average total number of light sources [214] per household**, all types taken together, is **42.** For houses this value is 55.2 and for apartments 31.2.

[213] The SWE400 project, End-use metering campaign in 400 households in Sweden, Assessment of the Potential Electricity Savings, CONTRACT 17-05-2743, 2009. http://www.energimyndigheten.se/Global/Statistik/F%C3%B6rb%C3%A4ttrad%20energistatistik/Festis/Final_report.pdf

[214] A light source is any bulb, fluorescent strip lighting, low energy light bulb, or halogen spotlight. If a light fitting should comprise several sources (bulbs), each one of them is taken into account separately.

Lamp type	Number per household	Share of lamps
incandescent	25.4	60%
halogen MV	0.7	2%
halogen LV	6.1	15%
CFL	5.5	13%
LFL	4.3	10%
LED	0	0%
Total	42	100%

Table 57 Number of lamps per household, Sweden, 2009 [215].

The **average number of bulbs per m²** is 0.43 for houses and 0.34 for apartments.

The average **total installed wattage**, taking all light sources together, is **1618 W for houses and 829 W for apartments**.

Lamp type	Installed power (W)	Share of lamp power
incandescent	1140	70%
halogen MV	73	5%
halogen LV	178	11%
CFL	73	5%
LFL	154	9%
LED	0	0%
Total	1618	100%

Table 58 Installed lighting power per household, Sweden, 2009 [215].

The **average installed wattage density** is **13.0 W/m²** for houses and **11.1 W/m²** for apartments.

The **annual electric energy consumption** is **646-937 kWh/year** for houses and **240-691 kWh/year** for apartments.

The **annual consumption per person** is a function of the number of persons in the household. The values per persons should be treated with some care, since the family structure has to be taken into account as well. This consumption is equal to 340 kWh/person/year for 1 or 2 persons, 285 kWh/person/year for household with 3 or 4 persons and then decreases to 200 kWh/person for 6 persons.

The **annual energy consumption density** is **6.7 kWh/m²/year** for houses and **6.3 kWh/m²/year** for apartments. As remarked in the reference, these values are close to each other and consequently it is mainly the difference in size between houses and apartments that explains the difference in consumption between the two.

Elaboration by the study team: given the available data, in this case the **average operating hours** are more conveniently derived from the average data per m^2 for energy consumption and installed wattage. For houses: 6.7 kWh/m^2/year / 0.013 kW/m^2 = **515 hours/year**. For apartments: 6.3 kWh/m^2/year / 0.0111 kW/m^2 = **567 hours/year**.

[215] The shares are similar for houses and apartments, even if total number of 'bulbs' is different

The following table is an attempt by the study team to derive average operating hours per type of room. To be used as indicative values only [216].

Room type in **Houses**	Average installed power (W)	Average annual consumption (kWh)	Average operating hours (h/a)
Kitchen	207	179	865
Living room	262	150	572
Outdoor/garage	117	110	940
Circulation	102	72	706
Bathroom	103	65	631
Office	108	50	463
Bedroom	130	50	385
Other rooms	81	39	481
Cellar/store	67	16	234

Room type in **Apartments**	Average installed power (W)	Average annual consumption (kWh)	Average operating hours (h/a)
Kitchen	162	118	723
Living room	221	136	615
Outdoor/garage	56	57	1018
Circulation	101	100	990
Bathroom	71	61	859
Office	127	61	430
Bedroom	124	50	403
Other rooms	67	27	403
Cellar/store	56	8	143

Table 59 Average installed power (W), annual energy consumption (kWh) and annual operating hours (h/a) for different types of rooms in houses (top) and apartments (bottom). Elaboration by study team based on data in the reference [213].

Lighting consumption during the night exist in any type of household. According to the reference, it is less than probable that this consumption could be entirely due to night users. Here is a potential energy saving that is sometimes significant.

The main **peak** of lighting power demand is always between 20:00 and 22:00 and goes from **135 to 300 Watt for houses and 90 to 200 Watt for apartments**. The maximum power demand for the two types of households is always obtained for families.

[216] As remarked in the reference, the values per room are averaged over all the rooms of the same type. The addition of all these different wattages (and energies) has therefore no physical meaning at all, and will always be different from the household average installed wattages (and energies). For the study team elaboration the values for average annual consumption have been read from a graph and consequently are approximate.

C.3 REMODECE 2008, lighting survey and measurements in households

REMODECE is an abbreviation for "Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe". This project of Intelligent Energy Europe was performed in the years 2006-2008. The project also considered energy use for lighting. The information presented below derives from different reports [217].

Data were gathered in the REMODECE project by means of a combination of measurements and of survey's (questionnaires), in the following countries: Belgium, Bulgaria, Czech Republic, Denmark, France, Germany, Greece (Hellas), Hungary, Italy, Norway, Portugal and Romania.

The measurement campaigns were performed in at least 100 households per country, using equipment capable to monitor the energy demand every 1 or 10 minutes. The measurement period has been approximately two weeks per household.

On average, the electric energy consumption for **lighting** was found to be **18% of the total household consumption of electricity** (excluding electric space heating and electric water heating.

The **average number of lamps per household was 26** [218]. As shown in Table 60, this number varied considerably from country to country, from 11 in Romania to 34 in Norway. On average there were 4 compact fluorescent lamps per household. The largest share was incandescent lighting, representing about 50% of the total number of lights installed. Low wattage halogen lamps were the second most used lamps. This is explained in the references by the fact that this type of lighting is used in false ceilings with a high number of light points. Fluorescent and compact fluorescent lamps had small percentages (only in Belgium these two combined were more than 30% of the total lighting lamps). Figure 40 and Figure 41 show the subdivision of lamp types per country and per room-type.

total of lamps by type	Pt	Be	Dk	Gr	Bu	It	No	Ro	Fr	Cz	De	Hu	Average
Incandescent	13	9	14	10	9	15	14	8	14	12	13	8	13
Low wattage Halogen	4	10	9	3	4	7	11	1	4	5	7	2	6
Halogen 230V	1	1	2	1	0	2	0,5	0	1	0	1	0	1
Fluorescent	3	3	3	1	1	3	4,2	1	2	2	2	0	2
Compact Fluorescent (CFL)	4	7	6	4	2	6	4,5	1	4	6	3	3	4
Total	26	31	33	20	16	33	34	11	24	25	25	14	26

Table 60 Number of lamps per household in various European countries (REMODECE project, 2006-2008)

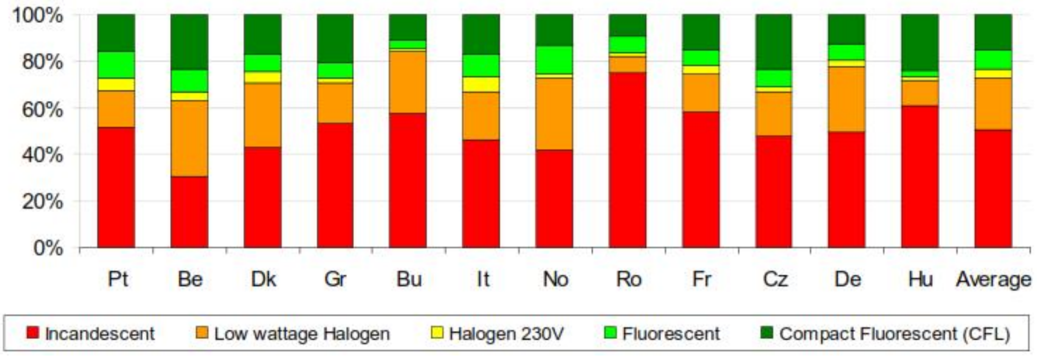


Figure 40 Types of lamps installed in various European countries (REMODECE project, 2006-2008)

[217] http://remodece.isr.uc.pt/downloads/REMODECE_PublishableReport_Nov2008_FINAL.pdf
http://remodece.isr.uc.pt/downloads/REMODECE_D10_Nov2008_Final.pdf
http://remodece.isr.uc.pt/downloads/REMODECE_D9_Nov2008_Final.pdf

[218] Some of the reports state 26, others 27.

Figure 41 Types of lamps installed in different residential rooms (REMODECE project, 2006-2008)

Table 61 reports the average installed lighting power per household (**1060 W**) and the average annual electric energy consumption for lighting per household (**487 kWh/a**). These data have been taken directly from the REMODECE reports. The table also presents the average annual operating hours (**459 h/a**). The latter have been derived by the study team, dividing the energy consumption by the installed power.

As regards the resulting operating hours, the high value for Bulgaria (932 h/a) and the low value for the Czech republic (98 h/a) seem suspicious. Not surprisingly, the Nordic countries Denmark and Norway show operating hours above the average (637 and 752 h/a). However, for the southern countries the operating hours are not always low: Portugal 209 h/a, but Greece 420 h/a and Italy 529 h/a. Considering its geographical location, the 295 h/a for France seem on the low side, but low operating hours there are confirmed by a 2003 study (Annex C.4).

Figure 42 clarifies that a high installed lighting power does not always imply a high energy consumption for lighting.

Country	Average installed power (W)	Average annual consumption (kWh)	Average operating hours (h/a)
BE	1144	524	458
BG	832	776	932
CZ	692	68	98
DE	793	352	444
DK	1425	908	637
FR	1530	452	295
GR	1094	459	420
HU	569	221	388
IT	1703	901	529
NO	1346	1013	752
PT	1116	233	209
RO	476	143	300
average	**1060**	**487**	**459**

Table 61 Average installed power (W), average annual energy consumption (kWh) and average annual operating hours, per household, for different European countries. (REMODECE project, 2006-2008; operating hours computed by the study team)

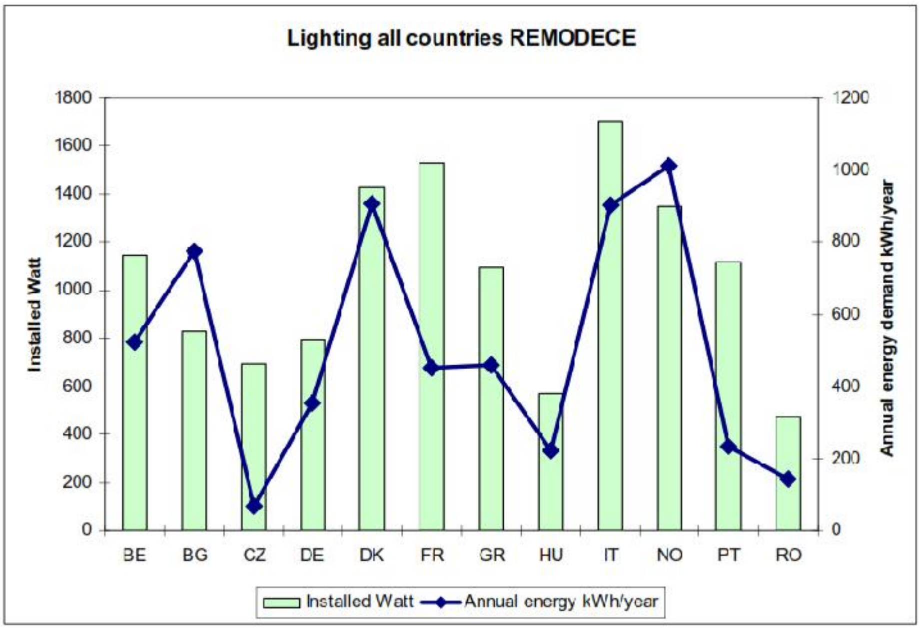


Figure 42 Energy demand and installed power for lighting (REMODECE project, 2006-2008)

The REMODECE project found a **peak power demand** for lighting in the evening hours (just like other studies) of **160 W**. For more information on the distribution of the energy use for lighting during a typical day in a typical household, see the references.

The figure below shows the distribution of the lighting energy consumption over the year for France. Seasonality curves like this are used in most studies to scale values measured over limited periods to annual consumptions.

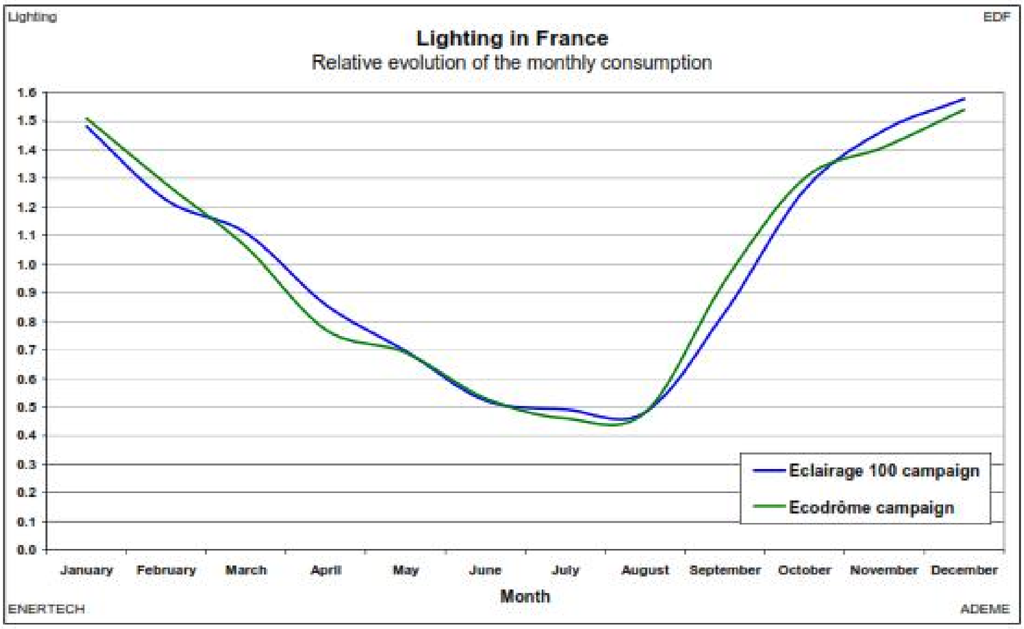


Figure 43 Seasonality curve for lighting energy (REMODECE project, 2006-2008)

As regards the rebound effect, the REMODECE survey found that, depending on the country, from 5 to 30% of the persons declared that they operate energy efficient CFL's for longer times than the more energy consuming incandescent lamps.

C.4 France 2003, lighting measurements in households

In this campaign [219] the lighting consumption of 100 households has been monitored during one year. As stated in the reference, in each household, every light source and the mains have been monitored which allows to have a very precise representation of electricity that is consumed for lighting.

The households were equally located in Strasbourg (north-east), Angers (north-west), Nice (south-east) and Toulouse (south-west). The purpose of the choice of these regions was to investigate different latitudes and longitudes.

The **average number of light bulbs was 28.3 per household** [220] . The repartition between the different light sources is given Figure 44. Note that this research was performed in 2003, which explains the high share of incandescent lamps.

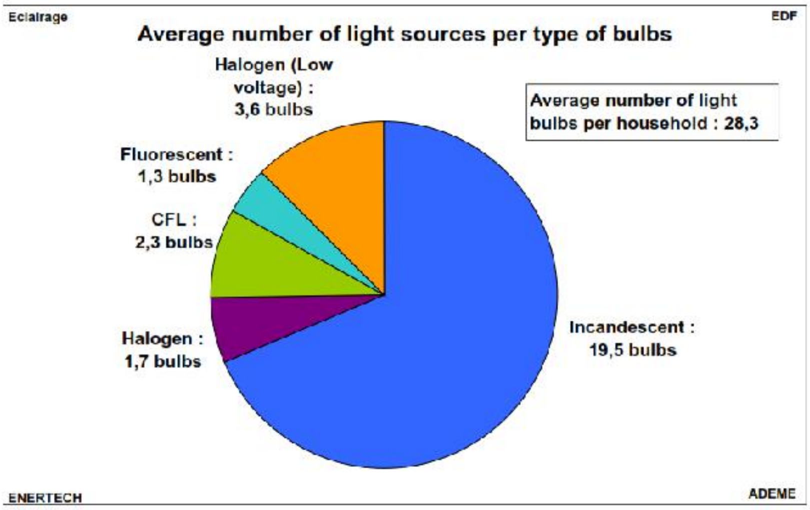


Figure 44 Repartition of the 28.3 lamps per household over the technology types (Eclairage 100 project, France 2003, as reported in the REMODECE reference)

[219] The Lighting Campaign (also referred to as Eclairage 100), as reported in http://remodece.isr.uc.pt/downloads/REMODECE_Review_monitoring%20campaign_D2.pdf.
No full final report has been found for this project. Some results are also reported in the UK research (Annex C.1).

[220] This number is 24 in the 2006-2008 REMODECE study, Annex C.3

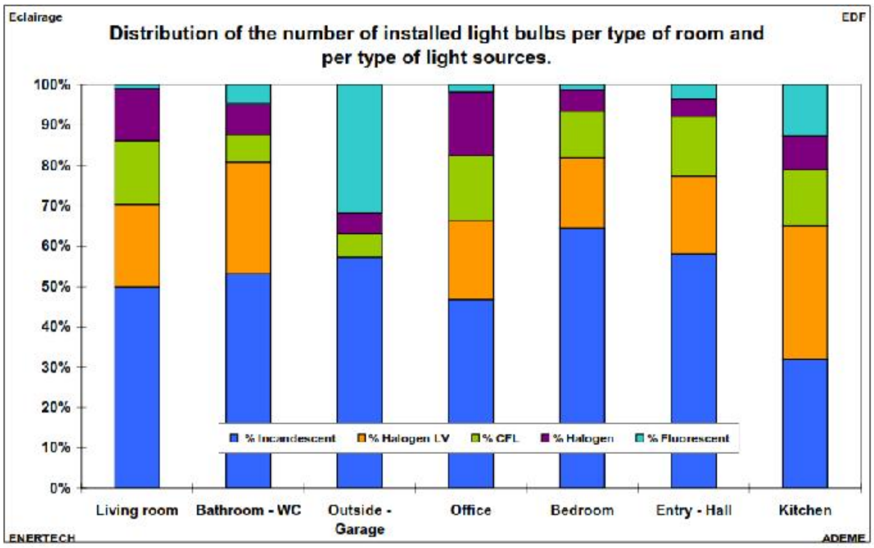


Figure 45 Shares of the lamp types in the various household rooms (Eclairage 100 project, France 2003, as reported in the REMODECE reference)

The **average installed power per household was 1578W** [221] which was shared by the various rooms as shown in Figure 46.

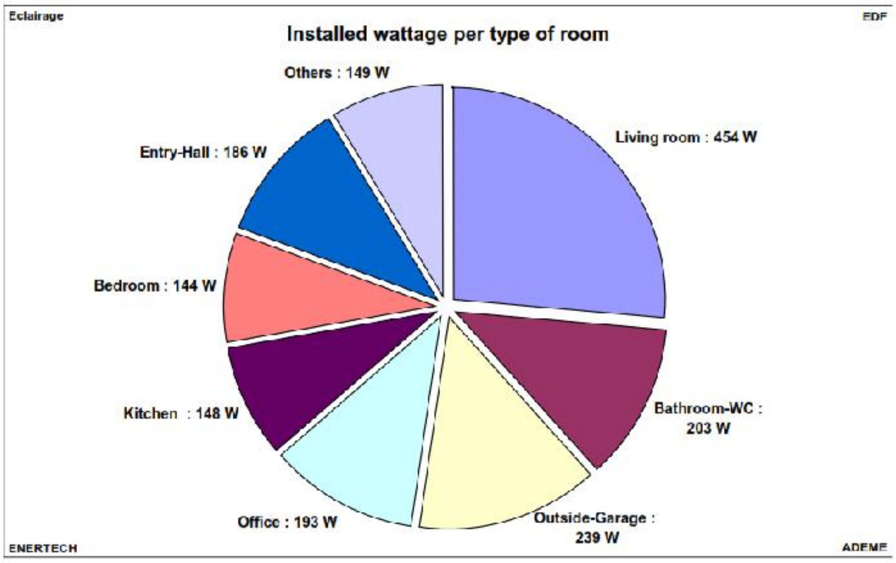


Figure 46 Shares of installed lighting power in the various household rooms (Eclairage 100 project, France 2003, as reported in the REMODECE reference)

The **average yearly consumption was 354 kWh per household** [222].

Elaboration by study team: 354 kWh/year / 1.578 kW -> **224 hours/year average operating hours** [223].

[221] This number is 1530 in the 2006-2008 REMODECE study, Annex C.3
[222] This number is 452 in the 2006-2008 REMODECE study, Annex C.3
[223] This number is 295 in the 2006-2008 REMODECE study, Annex C.3

C.5 EURECO 2002, lighting measurements in households

EURECO was a European project financed under the SAVE programme [224]. Five countries were involved: Denmark, Greece, Italy, Portugal, and France. The measurement campaigns took place in the first four countries. France (Enertech) was in charge of the data analysis, because of its experience in this field.

In each country, 100 households were monitored during one month. The campaign took more than one year, allowing the determination of the influence of seasonality. Amongst others, all the sources of light were monitored (one lamp-meter per control point). Except in Denmark where 90 % of the monitored households were villas, most of the panel in the other countries consisted of apartments (between 75 and 85 %). The over-representation of apartments is due to the fact that most of the measurement campaigns were conducted in towns [225].

The **average total number of light sources per household**, all types taken together, is **23.7** (33) in Denmark, **10.4** (20) in Greece, **14.0** (33) in Italy, and **6.9** (26) in Portugal [226]. Values between brackets are from the later REMODECE project, see Annex C.3, and show the large increase in number of lamps per household between 2002 and 2008. As shown in Table 62 there is a large variation per household.

The part of incandescent light sources varies from 57 % (Denmark) to 82 % (Italy).

Country	Denmark	Greece	Italy	Portugal	*Ecodrome* (reminder)
Total number of light sources	23·7	10·4	14·0	6·9	18·5
Average number of light sources per m^2	0·18	0·10	0·14	0·06	0·23
Average number of m^2 per source of light	5·6	10·0	7·1	16·7	4·4
Maximum value of the number of light sources per m^2	0·31	0·28	0·29	0·28	--
Minimum value of the number of light sources per m^2	0·04	0·02	0·008	0·01	--
Maximum/minimum ratio	1 : 7·8	1 : 14	1 : 37	1 : 28	--

Table 62 Number of light sources per household in four European countries (EURECO project 2002)

On average, the **total installed wattage**, taking all light sources together, is **740 W** (1425) in Denmark, **675 W** (1094) in Greece, **883 W** (1703) in Italy, and **274 W** (1116) in Portugal. Values between brackets are from the later REMODECE project, see Annex C.3. Table 63 shows that the **installed lighting power densities** vary from 2.5 W/m^2 in Portugal to 8.6 W/m^2 in Italy, with a considerable variation between households.

[224] End-use metering campaign in 400 households of the European Community - Assessment of the Potential Electricity Savings – EURECO project 2002 http://www.eerg.it/resource/pages/it/Progetti_-_MICENE/finalreporteureco2002.pdf

[225] As stated in the reference: "*We did not try to get the most representative sample of the population, but to get the maximum number of monitored appliances and the most complete database per appliance type. Practically, this choice lead to the monitoring of non-representative households on a national scale (see details in § 3.4)*."

[226] The reference states that it is uncertain that all light sources in Portugal were actually monitored.

Country	Denmark	Greece	Italy	Portugal	*Ecodrome* (reminder)
Average value of the installed wattage per m² (in W/m²)	5·7	6·6	8·6	2·5 (?)	16·1
Maximum value of the installed wattage per m² (in W/m²)	10·9	19·8	20·9	11·2	-
Minimum value of the installed wattage per m² (in W/m²)	1·2	1·3	3·2	0·3	-
Maximum/minimum ratio	1 : 9·1	1 : 15·2	1 : 6·5	1 : 37·3	-

Table 63 Installed lighting power density per household in four European countries (EURECO project 2002)

The **average annual energy consumption per household** for lighting is **426** kWh/year (908) for the Danish sample, **381** kWh/year (459) for the Greek one, **375** kWh/year (901) for the Italian one, and **179** kWh/year (233) in Portugal [227]. Again: values between brackets are from the later REMODECE project, see Annex C.3. Table 64 shows that the **average energy densities** vary from 1.6 kWh/m^2/year in Portugal to 4.0 kWh/m^2/year in Italy.

Country	Denmark	Greece	Italy	Portugal	*Ecodrome* (reminder)
Average value of the annualized lighting consumption per m² (kWh/year/m²)	3·3	3·7	4·0	1·6 (?)	5·7

N.B. : for ***Ecodrome*** *the values are measured over a whole year* **in kWh/year/m²**

Table 64 Energy consumption density per household in four European countries (EURECO project 2002)

Elaboration by study team: dividing the annual consumption per household by the installed wattage, the following **operating hours** result:

Denmark: **576** h/a, Italy: **425** h/a, Greece: **564** h/a, Portugal: **653** hours/year

[227] As stated in the reference: "*these last results should be considered with caution, as only an averaged 4•5 control points were monitored*".

C.6 DELight, 1998

The data in this paragraph have been taken from the Impact Assessment accompanying Regulation 1194/2012 [228]. They have been derived from the 1994-1997 DELight study [229].

DELight study

Table. EU Domestic Lighting, 1994-1997 country profiles

Country	kWh (per hh pa)	kWh/ m2	Bulbs (per hh)
Austria	345 [1995]	4.0	No data
Belgium	291 [1994]	3.4	31
Bulgaria	350 [1994]	*No data*	11.8
Czech Rep.	250 [1997]	*No data*	*No data*
Denmark	585 [1997]	5.5	26
Finland	920 [1993]	12.1	*No data*
France	500 [1994]	6.2	18.5
Germany	775 [1997]	9.3	30
Greece	310 [1988]	3.9	4.7
Ireland	438 [1996]	4.8	25
Italy	296 [1995]	*No data*	20
Lithuania	240 [1997]	4.1	*No data*
Netherlands	528 [1996]	5.0	36
Poland	600 [1997]	9.4	16
Portugal	425 [1995]	4.8	*No data*
Romania	*No data*	*No data*	9
Spain	500 [1995]	5.8	29.5
Sweden	760 [1997]	6.9	40
UK *	720 [1996]	8.6	20
EU Average	569 kWh/hh	-	24

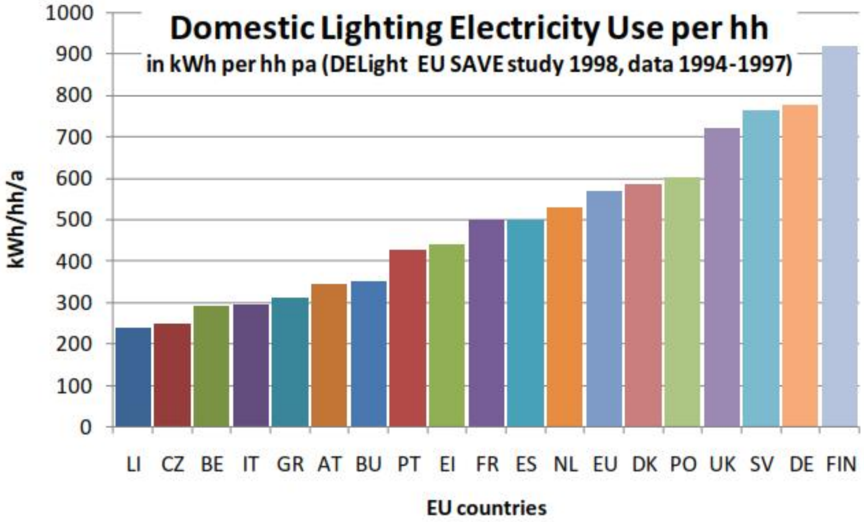
Palmer, J. and Boardman, B., *DELight, Domestic Efficient Lighting*, EU SAVE study, ECU/EM/ESH, Oxford, 1998

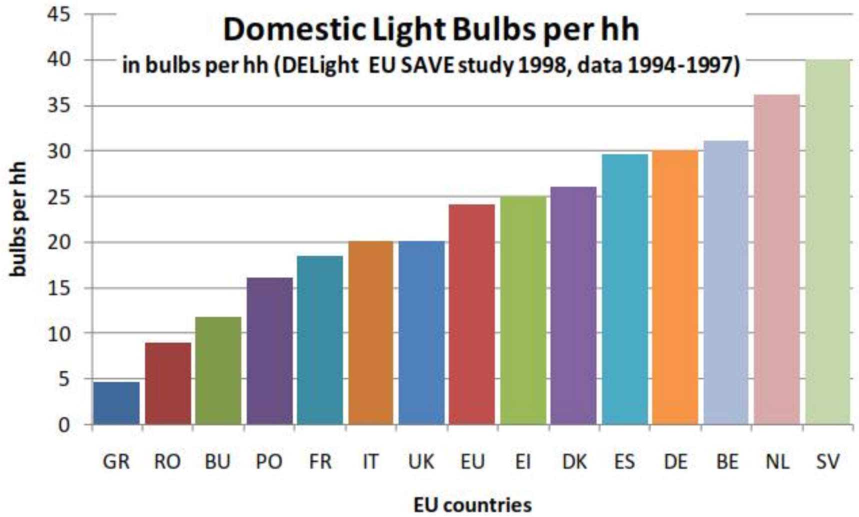
* = UK high wattage per bulb; Sweden low wattage per bulb

Table 65 DELight study, 1994-1997, energy consumption and number of lamps in households in various European countries.

[228] Commission Staff Working Document, accompanying document to the Commission Regulation implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for directional lamps, light emitting diode lamps and related equipment, Impact Assessment, Brussels, 2012, available as http://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2012/swd_2012_0418_en.pdf

[229] Palmer, J. and Boardman, B., DELight, Domestic Efficient Lighting, EU SAVE study, ECU/EM/ESH, Oxford, 1998





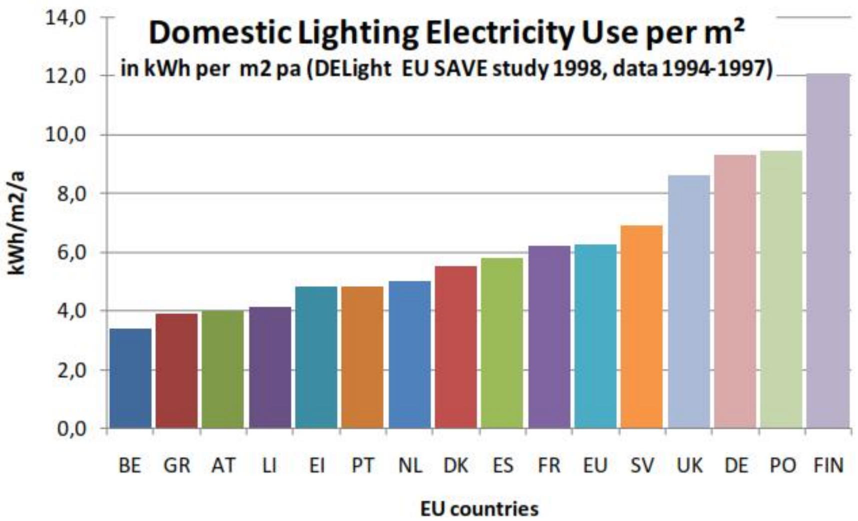


Figure 47 DELight study, 1994-1997, energy consumption and number of lamps in households in various European countries.

C.7 Impact Assessment NDLS, 2009

The data in this paragraph have been taken from Annex II of the Impact Assessment accompanying Regulation 244/2009 [230].

	GLS-F	GLS-C	HL-MV-LW	HL-MV-HW	HL-LV	CFLi	TOTAL
	Nb/hh	Nb/hh	Nb/hh	Nb/hh	Nb/hh	Nb/hh	Nb/hh
2007	7.89	2.42	0.60	0.53	2.24	4.81	**18.48**
2008	6.89	2.22	0.86	0.67	2.30	5.85	**18.80**
2009	6.08	2.03	1.12	0.82	2.37	6.70	**19.13**
2010	5.43	1.84	1.39	0.96	2.43	7.40	**19.45**
2011	4.87	1.65	1.65	1.10	2.50	8.00	**19.77**
2012	4.47	1.64	1.76	1.13	2.55	8.47	**20.00**
2013	4.26	1.62	1.86	1.16	2.59	8.75	**20.24**
2014	4.07	1.61	1.97	1.19	2.64	9.00	**20.47**
2015	3.95	1.59	2.07	1.22	2.68	9.19	**20.71**
2016	3.83	1.58	2.18	1.25	2.73	9.38	**20.94**
2017	3.73	1.56	2.28	1.28	2.77	9.55	**21.18**
2018	3.64	1.55	2.39	1.31	2.82	9.70	**21.41**
2019	3.56	1.54	2.49	1.34	2.86	9.85	**21.65**
2020	3.48	1.52	2.60	1.37	2.91	10.00	**21.88**

GLS-F: frosted incandescent, GLS-C: clear incandescent, HL-MV-LW: halogen mains voltage low power, HL-MV-HW: halogen mains voltage high power, HL-LV: halogen low voltage, CFLi: self-ballasted compact fluorescent lamp.

Table 66 Forecast of the number of lamps per household from the 2009 Impact Assessment accompanying Regulation 244/2009.

[230] Commission Staff Working Document, accompanying document to the Commission Regulation implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for non-directional household lamps, Full Impact Assessment, Brussels, 18.3.2009, SEC(2009) 327, available as http://ec.europa.eu/energy/efficiency/ecodesign/doc/legislation/sec_2009_327_impact_assesment_en.pdf

C.8 JRC, Bertoldi, 2006

The source [231] reports the following table, that seems to be based on questionnaires filled in by national experts.

The reported lighting energy consumption for EU-28 is 498 kWh/household/year

The average number of lamps per household for EU-28 is not reported but has been computed by the study team from the reported data as 4261 million lamps / 193.2 million households = 22 lamps per household.

Table 1: national lighting consumption and CFL penetration data (data supplied by national experts)

	No. of Households (HH) [milion]	Residential electricity cons. TWh	Lighting consumption TWh	Lighting consumption as share of total residential electricity consumption [%]	Average cons lighting/HH kWh	Number of HH with CFLs [%]	CFL's/HH [including HH without CFLs]	Lighting points/HH
AT	3,08	16	1,1	6,875	357,14	70	4	26
BE	3,90	18,20	2,23	12,23	343,22	70,50	2,50	26,00
DK	2,31	9,71	1,36	14,00	589,00	65,00	4,90	25,40
FIN	2,30	12,20	1,7	13,93	739	50	1	23,5
FR	22,20	141,06	9,07	6,43	409	52	2,26	18,9
GR	3,66	18,89	3,4	18	1012	50	1	7
DE	39,10	140,00	11,38	8,13	310	70	6,5	32
EI	1,44	7,33	1,32	18	1000	38	1,5	18
IT	22,50	66,67	8	12	370	60	0,8	18
LU	0,20	0,75	0,098	13	487,5	70	2	20
NL	6,73	23,75	3,8	16	524	60	4	40
PT	4,20	11,40	1,6	14,04	427	54	1,7	11,4
ES	17,20	56,11	10,1	18	684	15	2	25
SE	3,90	43,50	4,6	16	1143	55	2,2	22
UK	22,80	111,88	17,9	16	785	50	2	20
CZ	3,83	14,53	1,74	12	455,37	70	2,9	10
CY	0,32	1,32	0,33	25	1040,7	79	2	16
EE	0,60	1,62	0,45	28	753,81	20	0,25	6
HU	3,75	11,10	2,775	25	740,48	60	0,27	18
LV	0,97	1,47	0,41	28	424,16	18,8	0,42	20
LT	1,29	2,07	0,62	30	479,72	20	0,25	6
MT	0,13	0,60	0,15	25	1172,15	50	1	15
PL	11,95	22,80	6,38	28	534,4	50	0,2	20
SK	1,67	4,82	0,4	8,3	240,05	60	1,5	15
SI	0,68	3,01	0,43	14,3	628,9	50	1	19
BG	2,9	8,77	0,9	10	420	50	0,2	10
RO	8,13	8,04	2,911	35,18	356,75	40	0,2	10
HR	1,42	6,07	1,1	18,11	773,76	39	1	14

Table 2: EU summary

	No. of HHs [milion]	Residential electricity cons. TWh	Lighting consumption TWh	Lighting consumption as share of total residential electricity consumption [%]	Average cons lighting/HH kWh	Number of HH with CFLs [%]	CFL's/HH [including HH without CFLs]
EU-15	154,86	663,26	77,65	11,71	501,45	54,62	3,14
New EU-10	25,18	63,32	13,69	21,61	543,54	52,10	0,77
EU-25	180,03	726,58	91,34	12,57	507,34	54,27	2,81
EU AC	11,03	16,81	3,81	22,67	345,54	42,63	0,20
EU-28	191,06	743,39	95,15	12,80	498,00	53,60	2,66

Table 67 Household lighting data from JRC, Bertoldi, 2006

[231] Residential Lighting Consumption and Saving Potential in the Enlarged EU, Paolo Bertoldi and Bogdan Atanasiu, European Commission – DG Joint Research Centre, Institute for Environment and Sustainability, 2006 http://iet.jrc.ec.europa.eu/energyefficiency/sites/energyefficiency/files/id150_bertoldi_final.pdf

Annex D. LIGHTING ENERGY PARAMETERS FOR NON-RESIDENTIAL

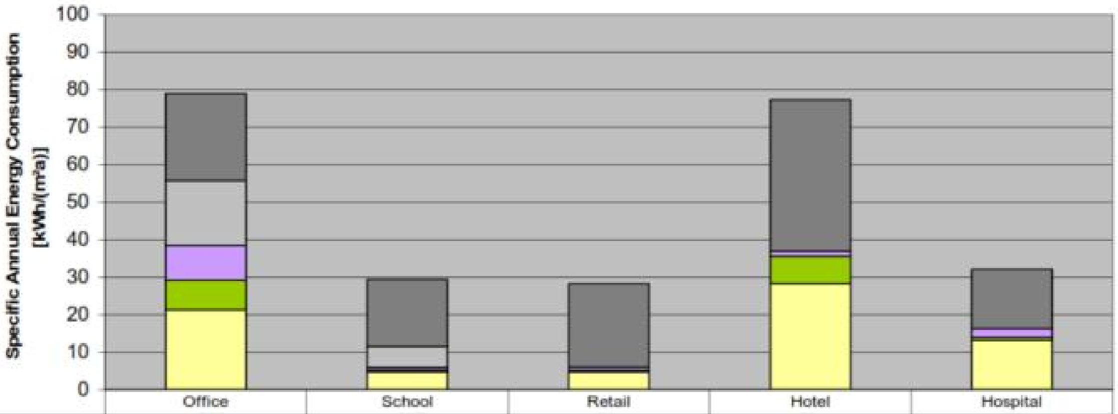
D.1 IEE EL-Tertiary project (2008)

In the period 2006-2008, in the context of the Intelligent Energy Europe (IEE) programme, the project EL-Tertiary was performed [232]. As part of this project, energy data were measured, calculated or collected in 123 tertiary buildings in 12 European countries. The references state that lighting was considered in 80% of the cases, but the published data on lighting seem to be based on a much lower number of buildings (Figure 48). No measurements were performed for lighting [233].

The project signalled a severe lack of existing data on electric energy consumption in buildings. The data gathered during the project highlight large differences between countries and between individual buildings, even those of the same type.

Selected data as extracted from the references follow below.

Specific annual energy consumption for lighting in kWh/m2/year



	Office	School	Retail	Hotel	Hospital
Number of Buildings	14	12	2	4	2
Other	23,2	17,9	22,3	40,4	15,7
Central IT	17,3	5,6	0,0	0,0	0,0
Office equipment	9,3	0,8	0,8	1,3	2,5
Ventilation	7,9	0,3	0,4	7,4	0,8
Lighting	21,3	4,8	4,8	28,2	13,1

Figure 48 Median composition of energy consumption in buildings in kWh/m²/year. See bottom line of table and lower part of histogram for lighting data. (source: EL-tertiary project)

For the 14 individual office buildings with median 21.3 kWh/m²/year (Figure 48), the following lighting energy densities are reported: 1, 6, 14, 14, 18, 25, 25, 26, 42, 76 (plus other four buildings without data for lighting). The average is 24.7 kWh/m²/year; discarding the extreme values (1,76) the average is 21.3 kWh/m²/year.

---

232 http://ec.europa.eu/energy/intelligent/projects/en/projects/el-tertiary
http://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/el-tertiary_el_tertiary_final_report_en.pdf
http://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/el-tertiary_el_tertiary_summary_slides_en.pdf
http://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2009/Panel_4/4.184/presentation

233 Most measurements concerned the total electric energy consumption of the building; the subdivision over the various applications was made using audits, surveys, etc.

For the 12 individual schools with median 4.8 kWh/m²/year (Figure 48), the following lighting energy densities are reported: 2, 2, 3, 4, 4, 5, 6, 12, 22, 24, 26 (plus one school without data for lighting). The average is 10 kWh/m²/year.

Figure 49 shows the specific annual energy consumption for lighting per room type. Note also here the large variety in consumption for a given room type.

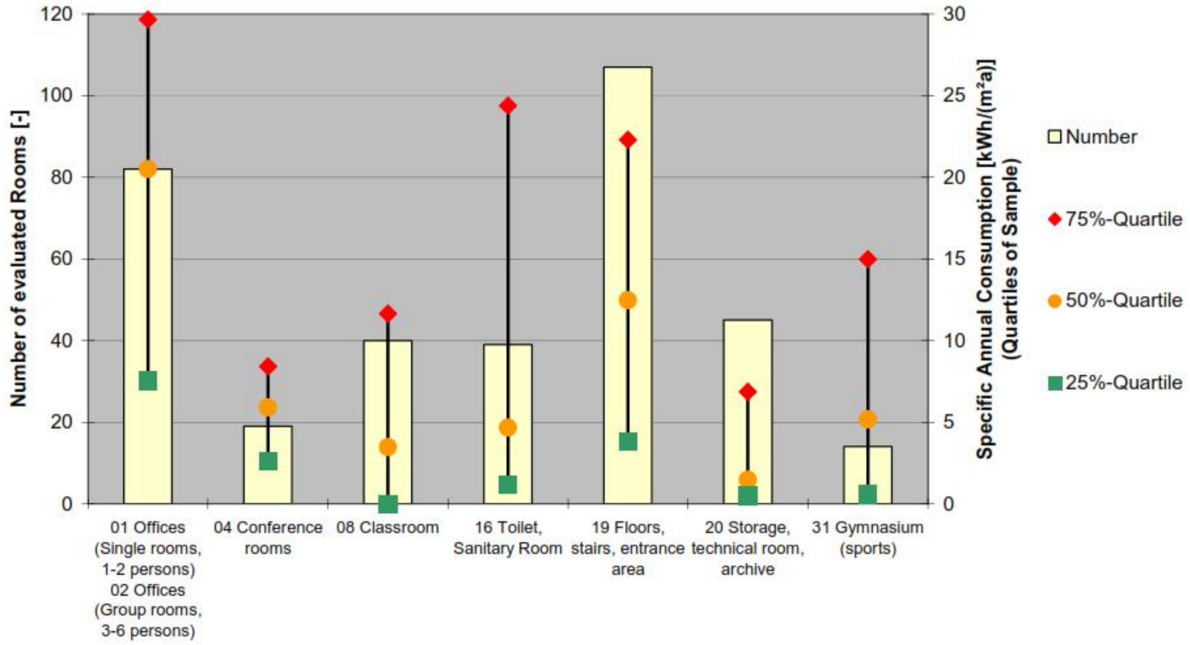


Figure 49 Specific annual electric energy consumption for lighting in different tertiary building room types, in kWh/m²/year. (source: EL-tertiary project)

<u>Installed lighting power density in W/m²</u>

Figure 50 shows the installed lighting power density in 43 offices in office buildings: the data vary from 4 to 26 W/m² with a median around 18 W/m².

Figure 51 shows the installed lighting power density in 75 class rooms: the data vary from 1 to over 40 W/m² with a median around 8 W/m².

Figure 52 shows the same parameter for different room types in tertiary buildings.

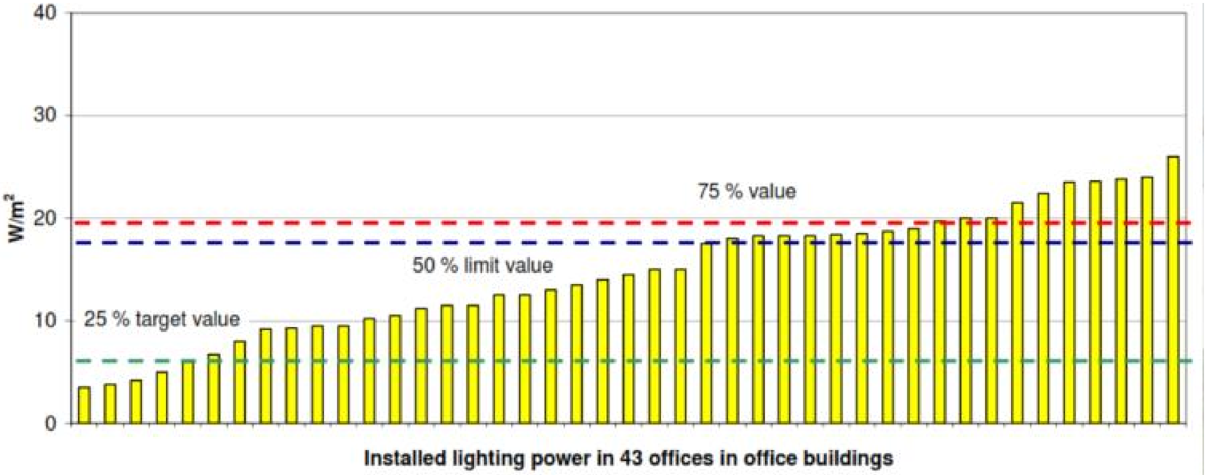


Figure 50 Installed lighting power density in offices of office buildings, in W/m². (source: EL-tertiary project)

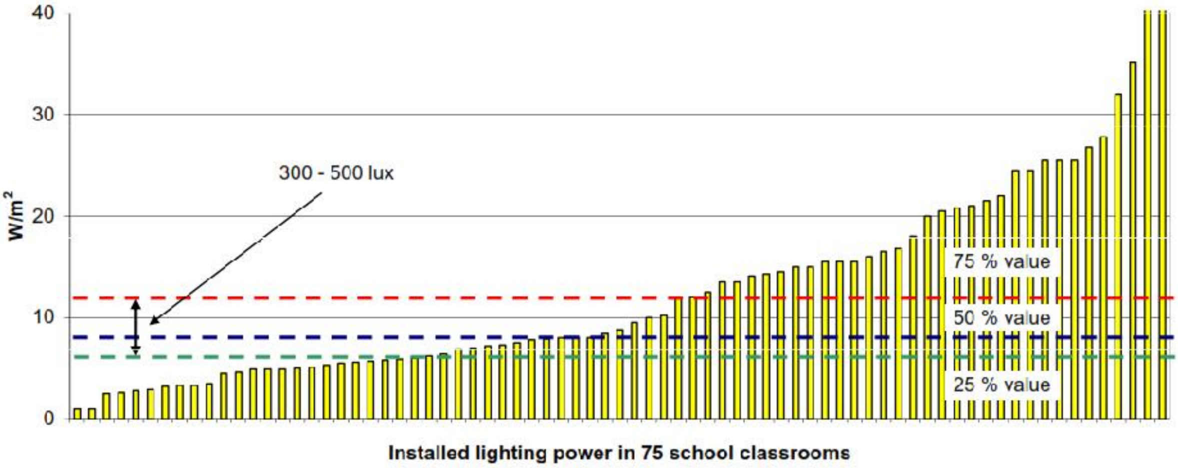


Figure 51 Installed lighting power density in class rooms, in W/m². (source: EL-tertiary project)

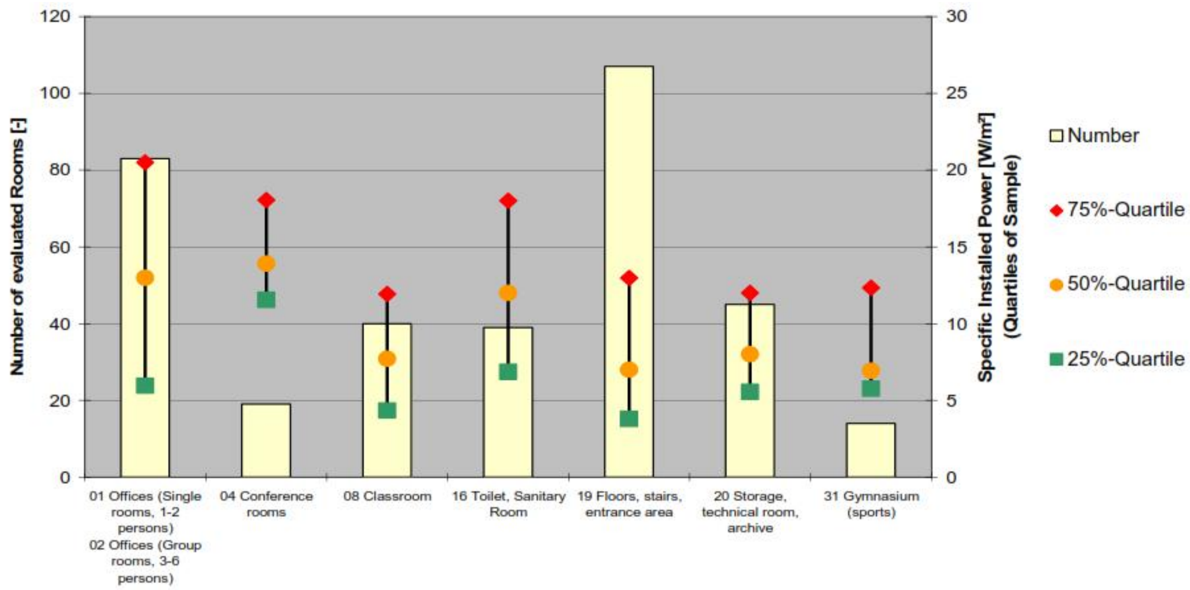


Figure 52 Installed lighting power density in tertiary building room types, in W/m². (source: EL-tertiary project)

Annual operating hours

Figure 53 shows the annual lighting operating hours in tertiary buildings per room type. In offices, class rooms and circulation areas (floors, stairs, entrances) the median value is around 850 – 900 hours per year.

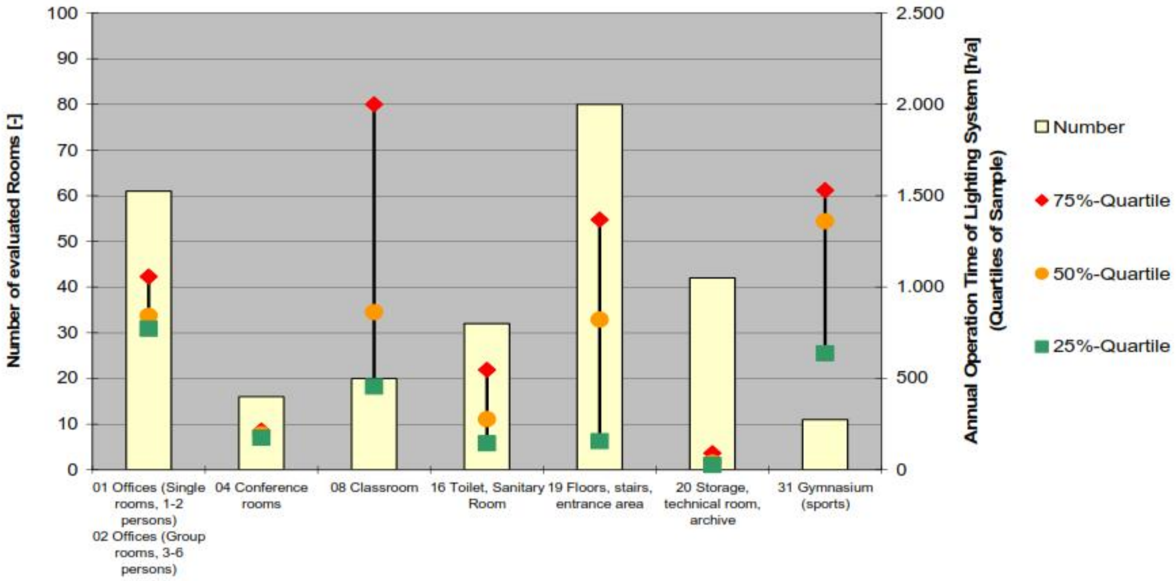


Figure 53 Annual lighting operating hours in tertiary building room types, in h/a. (source: EL-tertiary project)

D.2 France, supermarket (2001)

In the years 2000-2001 Enertech undertook a measurement campaign to study the lighting energy consumption in a supermarket in France [234]. The study team extracted the data from various sources and reorganised them in Table 68.

The **average annual operating hours** for all reported zones, calculated as total annual energy consumption by total installed power, are **3984 h/a**.

Activity /room	Installed lighting power (W)	Annual energy consumption (kWh/a)	Operating hours per year (h/a)
Strip lighting ('Rampes d'éclairage')	23500	97002	4127
Meat and cheese	5300	19854	3746
Dairy	4590	17824	3883
Fruit and vegetables	984	3353	3407
Emergency lighting ('Éclairage réserve')	441	2430	5510
Butcher's work room	294	1098	3735
Bread	260	844	3246
Office 3	102	570	5589
Butcher's cool room	147	566	3850
Office 5	102	290	2844
Cash register zone		289	
Office 1	102	261	2559
Office 4	102	147	1441
Office 2	102	101	990
Corridor near offices	15	94	6267
Corridor changing room	120	76	633
Women's clothing	60	35	584
Men's clothing	60	2.6	44
TOTAL / average	**36281**	**144548**	**3984**

Table 68 Installed lighting power, annual energy consumption and operating hours for a supermarket in France. (Source for basic data: Enertech 2001; presentation and some elaboration by study team)

---

234 http://www.enertech.fr/modules/catalogue/pdf/61/caracteristiques%20fonctionnement%20equipements%20electriques%20supermarche%202.pdf

http://www.enertech.fr/modules/catalogue/pdf/61/consommation%20energie%20supermarche_resume.pdf

http://www.enertech.fr/modules/catalogue/pdf/61/caracteristiques%20fonctionnement%20equipements%20electriques%20supermarche%203.pdf

http://www.enertech.fr/modules/catalogue/pdf/61/caracteristiques%20fonctionnement%20equipements%20electriques%20supermarche%205.pdf

http://www.enertech.fr/modules/catalogue/pdf/61/caracteristiques%20fonctionnement%20equipements%20electriques%20supermarche%201.pdf

D.3 France, high-school (2003)

In the year 2003 Enertech undertook a measurement campaign to study the lighting energy consumption in a high-school in France [235]. The study team extracted the data from various sources and reorganised them in Table 69.

The **average annual operating hours** for all reported zones, calculated as total annual energy consumption by total installed power, are **1018 h/a**.

Activity /room	Installed lighting power (W)	Annual energy consumption (kWh/a)	Operating hours per year (h/a)
Classroom (wall)	43457	33294	766 [236]
Classroom (window)	22292	17137	769 [236]
Corridors (permanent)	5260	16084	3058
Other rooms	4041	6182	1530
Sanitary	921	3115	3382
Classroom (blackboard)	1453	1397	961
Corridors (time switch)	280	1082	3864
School-yards (play area)	169	699	4136
Corridors (other)	255	404	1584
Staircases	181	338	1867
TOTAL / average	**78309**	**79732**	**1018**

Table 69 Installed lighting power, annual energy consumption and operating hours for a high-school in France. (Source for basic data: Enertech 2003; presentation and some elaboration by study team)

235 http://www.enertech.fr/modules/catalogue/pdf/62/caracteristiques%20fonctionnement%20equipements%20electriques%20lycee%202.pdf

http://www.enertech.fr/modules/catalogue/pdf/69/Diagnostic%20instrumente%20CG67_resume.pdf

http://www.enertech.fr/modules/catalogue/pdf/62/caracteristiques%20fonctionnement%20equipements%20electriques%20lycee%203.pdf

http://www.enertech.fr/modules/catalogue/pdf/62/consommation%20energie%20lycee_resume.pdf

236 These computed hours (energy divided by power) do not correspond with values found in the text of one of the references of 479 h/a near the window and 496 h/a near the wall. This difference remained unexplained. The reference further observes that the illumination level is 600 lux, which is very high compared to the 300 lux requested by French regulations.

D.4 France, Strasbourg, office building (2005)

In the years 2004-2005 Enertech undertook a measurement campaign to study the lighting energy consumption in an office building in France [237]. The building concerned is the "Hôtel du Département du Bas Rhin" in Strasbourg, which was built in 1989, has an area of 35,310 m² (of which 11,886 m² parking) and in 2003 occupied 737 workers. The building is equipped with an energy management system (GTC).

The lighting energy consumption was measured in detail (582 points) for half a year and the results could be extrapolated to cover an entire year. The total annual electric energy consumption was 158 kWh/m^2/year of which 17.8% was used for **lighting** -> **28.12 kWh/m^2/year.**

Figure 54 shows the subdivision of the annual energy consumption over the room types / zones in the building. It is noteworthy that only 24% of the lighting energy is used in the offices ('bureaux'). The main consumption is for corridors ('couloirs',29%) and other rooms ('autres locaux', 25%), while the parkings account for 16%.

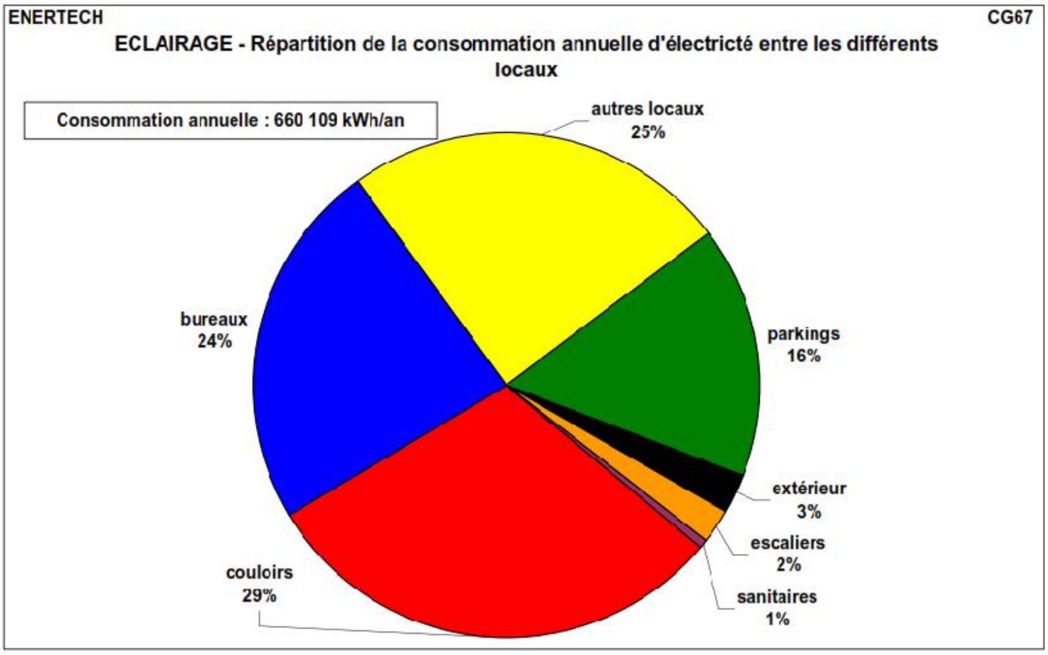


Figure 54 Subdivision of the lighting energy consumption in an office building over the various zones. (source: Enertech 2005)

The study team extracted the data from the references and reorganised them in Table 70. In this case the references also report **possible energy savings**: according to the study around 63% of the lighting energy could be saved, **reducing the original 28.12 kWh/m^2/year to around 6 kWh/m^2/year**. The proposed savings mainly consist in:

- Substitution of LFL T8 with magnetic ballast by T5 with electronic ballast.
- Substitution of standard luminaires by high-efficiency luminaires.
- Substitution of the ceiling lighting equivalent to 500 lux by one equivalent to 200 lux, integrating the task area illumination by means of local desk lamps.

[237] http://www.enertech.fr/modules/catalogue/pdf/38/electricite-et-batiments-a-energie-positive.pdf
http://www.enertech.fr/pdf/69/Diagnostic%20instrumente%20CG67.pdf

The **average annual operating hours** for all reported zones, calculated as total annual energy consumption divided by total installed power, are **2226 h/a**.

Activity /room	Installed lighting power (W)	Annual energy consumption (kWh/a)	Operating hours per year (h/a)	Estimated possible savings (kWh/a)
Corridors (main)	≈60000 (14.6 W/m²)	187279	3121 (2915-3820)	162000
Offices (modular) (ceiling lamps)	111000 (13 W/m2)	138557 (10.7 kWh/m²/a)	1247	85000
Parking souterrain		87800	3350-4180	77700
Entrance hall	12000 (6.6 W/m²)	67327	5610	9540
Parking outside, covered	5200	19000	3100-4200	16826
Security rooms	2100	18466	8760	2650
Conference rooms	12600 (32 W/m²)	18249	1448	16564
Offices (modular) (desk lamps)	40000 (4.6 W/m2)	17334	469	11959
Cafetaria (réfectoire)	9200 (23.1 W/m²)	16822	1828	2120
Outdoor lighting	5650	16734	2962	
Staircases	3500	13362	3818	10022
Printing room	5400 (8.8 W/m²)	13329	2468	4272
Board room	16800 (33 W/m²)	11186	666	2557
Photocopiers room	2500	9051	3620	6969
Cafetaria	3800 (22.8 W/m²)	8783	2311	8119
Corridor and hall	1674	5862	3502	1228
Corridor (ground floor)	1014	3996	3940	432
Sanitary	3000 (5.9 W/m²)	4556	1519	
TOTAL / average	**295400**	**657700**	**2226**	

Table 70 Installed lighting power, annual energy consumption, operating hours and estimated possible energy savings for an office building in France. (Source for basic data: Enertech 2005; presentation and some elaboration by study team)

D.5 France, PACA region, office buildings (2005)

In the years 2003-2005 Enertech undertook a measurement campaign to study, amongst other, the lighting energy consumption in 49 office buildings of the French PACA region [238]. More than 1000 light switching points, controlling more than 3000 light sources, were measured for half a year and results were then extrapolated to an entire year.

Offices

In the monitored offices, 89% of the luminaires were equipped with linear fluorescent tubes, of which 41% of the type 4x18 W. The desk lamps contained 11 W CFL's in 40% of the cases, 50 W halogens in another 40% and incandescent lamps for the remaining 20%. The registered **operating hours** were as follows:

- Single offices 1155 h/a
- Open offices 2513 h/a
- Floor standing lamps near desks 767 h/a
- Desk lamps (counting all lamps) 489 h/a
  Desk lamps (not counting those with zero hours) 527 h/a

Annual lighting energy consumption for the offices: 14.6 kWh/m²/year [239] (369 kWh/person/year). Of this consumption, 81% was due to the LFL illumination.

Circulation areas

In the circulation areas 54% of the luminaires was equipped with LFL and 16% with halogen or incandescent bulbs [240]. The registered **operating hours** were as follows:

- Corridors 2740 h/a
- Stairs 1125 h/a

Annual lighting energy consumption for the circulation areas: 7.1 kWh/m²/year (176 kWh/person/year). Of this consumption, 66% was due to the LFL illumination and more than 25% to halogens and incandescent lamps. The consumption tends to be higher in larger buildings.

Common rooms

These are all the spaces of an office building that are not office, circulation area or sanitary. In these areas 79% of the luminaires was equipped with LFL (4x18 W or 2x36 W). The registered **operating hours** were as follows:

- Archives 1053 h/a
- Printing/copying rooms 1970 h/a
- Service rooms 1443 h/a
- Canteens/restaurants 1653 h/a
- Kitchen zones 538 h/a
- Conference rooms 530 h/a

Annual lighting energy consumption for the common rooms: 4.1 kWh/m²/year (108 kWh/person/year).

[238] PACA = Provence Alpes Côte d'Azur
http://www.enertech.fr/modules/catalogue/pdf/60/consommation%20eclairage%20bureautique%20bureaux_resume.pdf
http://www.enertech.fr/pdf/60/consommation%20eclairage%20bureautique%20bureaux.pdf

[239] The interpretation of the study team is that this is per m² building area, not per m² room/zone area ! The same applies to the values presented for the other zones.

[240] This seems to imply that 40% is CFL, but that is not specified.

Sanitary

In the toilets and other sanitary facilities, 50% of the luminaires contains incandescent lamps, while 25% is CFL or LFL. Ten percent of the lights was equipped with a time switch and 4% by a presence detector.

The registered **operating hours** were as follows:

- Sanitary (general) 1183 h/a [241]
- Toilet cabin 669 h/a
- Washbasin 1084 h/a
- Integrated toilet and washbasin 711 h/a

Annual lighting energy consumption for the sanitary: 1.2 kWh/m²/year (32 kWh/person/year).

The above data are summarized in Table 71. The **average total energy consumption for lighting in the monitored office buildings is 26.7 kWh/m²/year** [242] (674 kWh/person/year). The subdivision over the room types is shown in Figure 55.

	Bureaux				Circulations		Locaux communs	Sanitaires		
	Indivi-duel	Paysa-ger	Lampa-daire	Lampe de bureau	Couloir	Escalier		Bloc	Lavabo	Cabine
h/an	1155	2513	767	489	2740	1125	530 1970	711	1084	669
kWh/m².an	14,6				7.1		4,1	1,2		
kWh/personne. an	369				176		108	32		

Table 71 Main results of lighting energy measurements in 49 offices in the French PACA region. (Source: Enertech 2005)

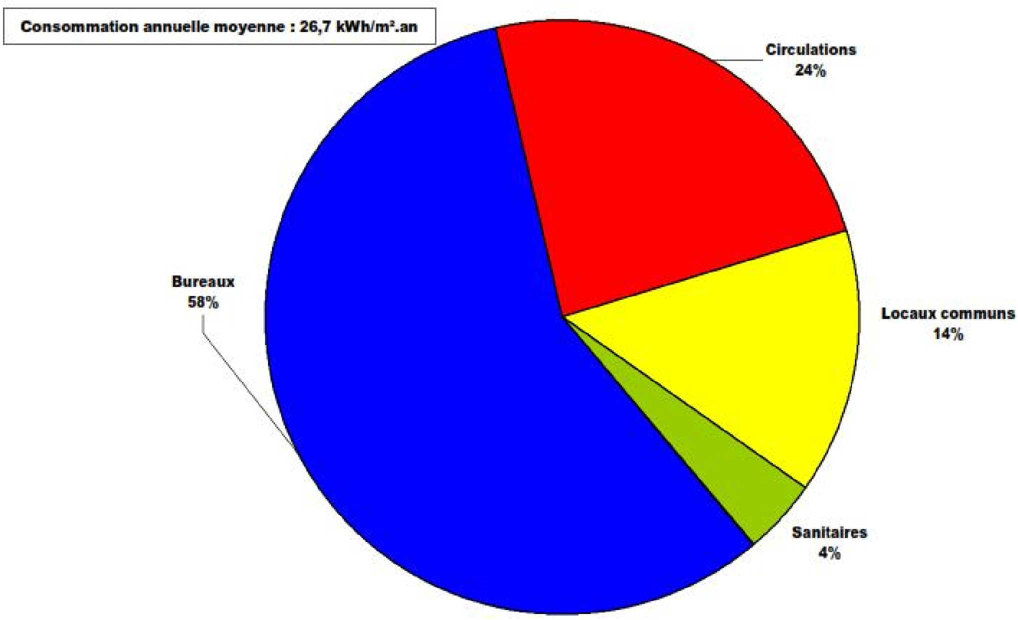


Figure 55 Subdivision of the total energy consumption for office buildings over the room types. (source: Enertech 2005)

[241] This is stated to be the time during which at least one of the luminaires in the monitored sanitary blocks is emitting light. It does not seem to be the average operating time for all lamps in the sanitary rooms.

[242] Note that this is the sum of the four subtotals reported above. This implies that all kWh/m²/year are per m² building area and not room/zone area !

The **average installed power (at regional level) in the existing situation is 19.3 W/m^2**. As one of the savings options, it is proposed to reduce this to 10 W/m^2 by reducing the general office illumination to 200 lux and integrating with desk lamps to reach 400-500 lux in the task areas.

Elaboration by study team: dividing the energy consumption of 26.7 kWh/m^2/year by the installed power of 19.3 W/m^2, the **average operating hours per year for the office buildings are 1383 h/a**.

Considering all the proposed measures for lighting energy reduction, the savings and target energy consumption of

Room / zone in office building	Percent savings with respect to existing situation using the proposed measures	Predicted lighting energy consumption after savings in kWh/m^2 building/year
Offices	-35%	9.5
Circulation areas	-33%	4.8
Common rooms	-34%	2.7
Sanitary	-52%	0.6
TOTAL		17.6

Table 72 Possible energy savings and predicted final lighting energy consumption for 49 offices in the French PACA region. (Source: Enertech 2005; elaboration by study team)

D.6 France, recent office building (2009)

In the year 2009 Enertech undertook a measurement campaign to study, amongst other, the lighting energy consumption in a recently constructed office building, the INEED in Alixan (Drôme, Gare TGV Valence) [243].

The available data for this study are less detailed, but the example is interesting as a benchmark for the level of lighting energy consumption that could be reached in an optimised building.

The 2009 electric energy consumption for lighting is reported to be **6.2 kWh/year/useful m^2**, and it is argued that this **could be further optimised to reach 3.9 kWh/year/useful m^2**.

For comparison: the "Hotel du Departement du Bas Rhin" (Annex D.4) had a specific energy consumption for lighting of 28 kWh/year/useful m^2, later improved to 23.5 kWh/year/useful m^2.

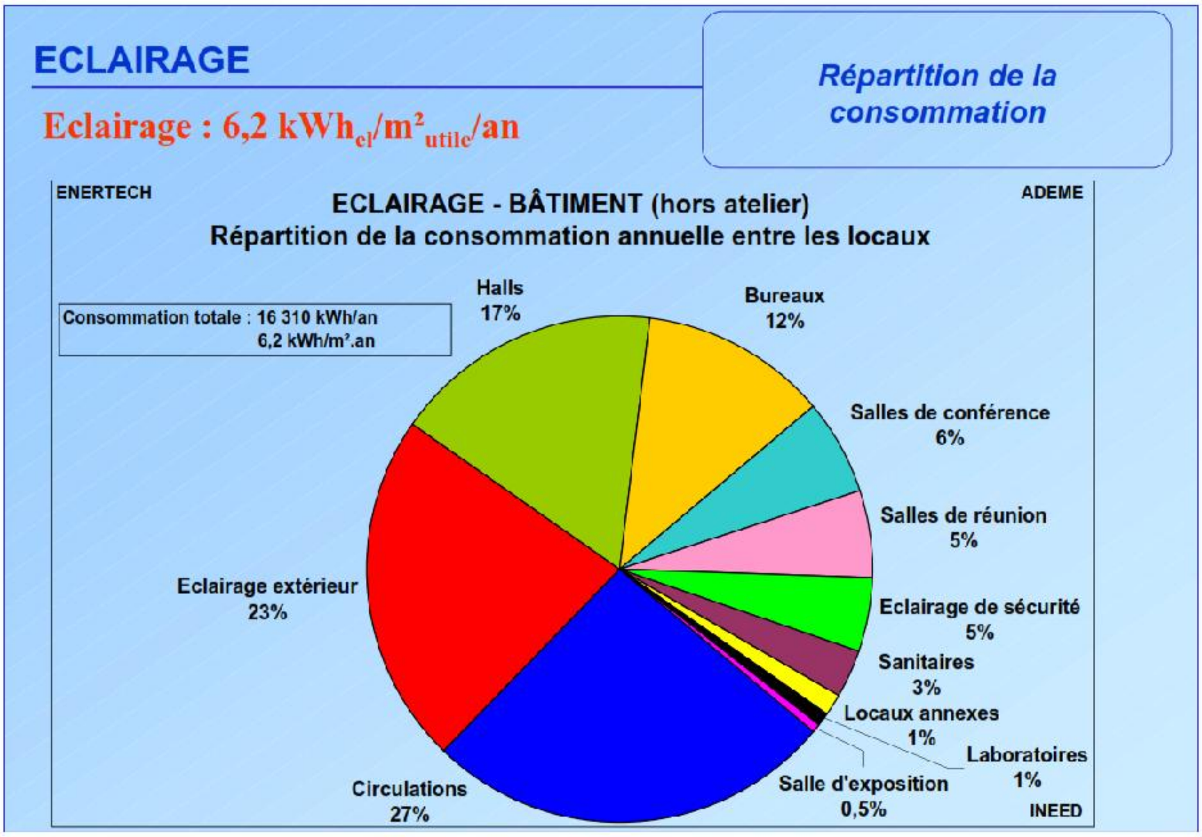


Figure 56 Subdivision of the lighting energy consumption for the INEED building in Alixan, France. (Source: Enertech 2009)

243 http://www.enertech.fr/modules/catalogue/pdf/38/le-role-de-l-electricite-dans-les-batiments-sobres-en-energie.pdf
http://www.enertech.fr/modules/catalogue/pdf/38/bilan-mesures-ineed.pdf

D.7 Germany, non-residential buildings (2014)

In 2014 the German 'Institut Wohnen und Umwelt' (IWU) published a report [244] containing an analysis of the energy-related data for non-residential buildings based on the TEK database.

The data seem to be based on a combination of measures, surveys and modelling/calculations, and regard a total of 93 non-residential buildings in Germany. A quality control on the data was performed for 82 of these buildings. The buildings included 23 office buildings, 11 retail/trade buildings, 19 high-schools, 8 hotels, 15 elementary schools and nurseries, 16 public buildings and 1 sports hall. In general the buildings are not of recent construction and not particularly optimised from the energetic point of view.

Although most data in the report regard the building energy consumption in general, there are some specific data on lighting energy that are reported below.

Bild 3-5 Häufigkeitsverteilung gebäudebezogener Teilenergiekennwerte für den elektrischen End-energiebedarf in allen 93 Gebäuden

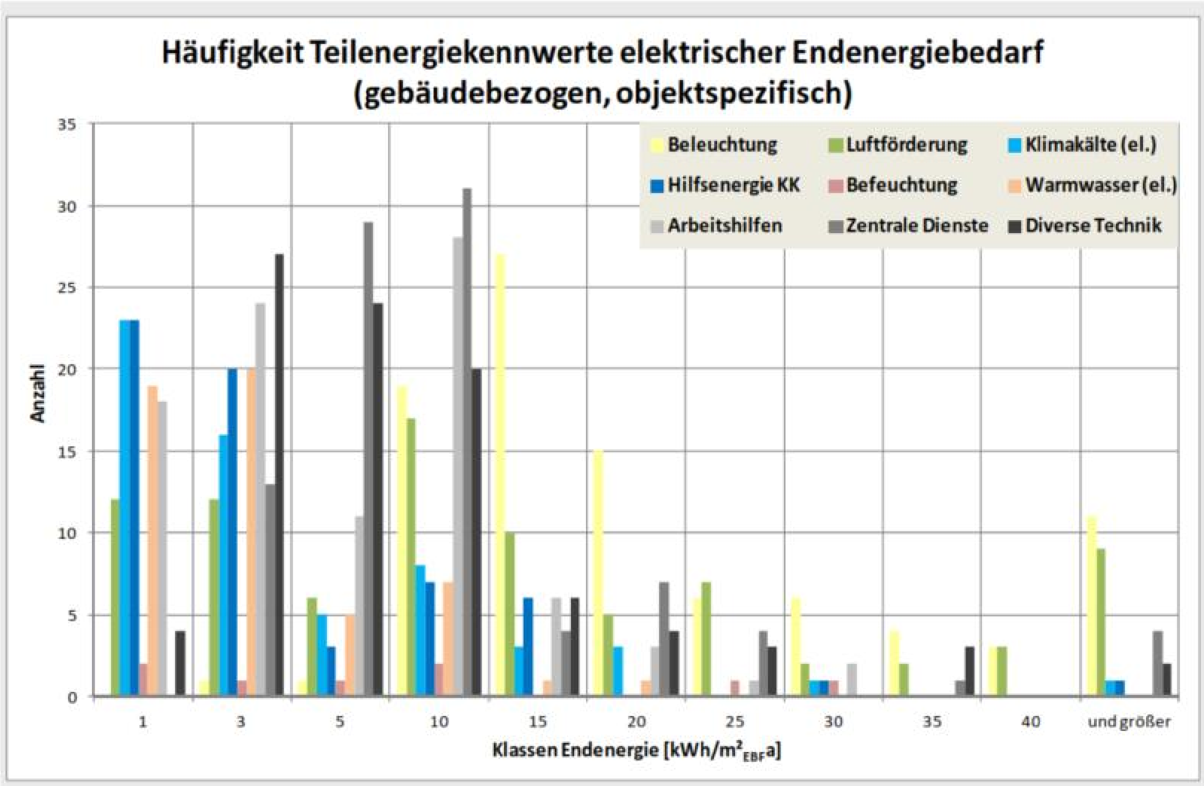


Figure 57 Number of buildings with specific annual electrical energy consumption (kWh/m²/year) in the indicated interval. The yellow bars are for lighting energy. (source: IWU 2014)

It can be derived from Figure 57 that the median value for lighting energy is around 15 kWh/m²/year while the average can be estimated around 23 kWh/m²/year.

[244] "Teilenergiekennwerte von Nichtwohngebäuden (TEK), Querschnittsanalyse der Ergebnisse der Feldphase, IWU 10.06.2014, gefördert vom Bundesministerium für Wirtschaft und Energie im Forschungsschwerpunkt Energieoptimiertes Bauen (ENOB), Förderkennzeichen: 0327431J, http://www.enob.info/fileadmin/media/Publikationen/EnOB/Projektberichte/TEK_von_Nichtwohngebaeuden_-_Querschnittsanalyse.pdf

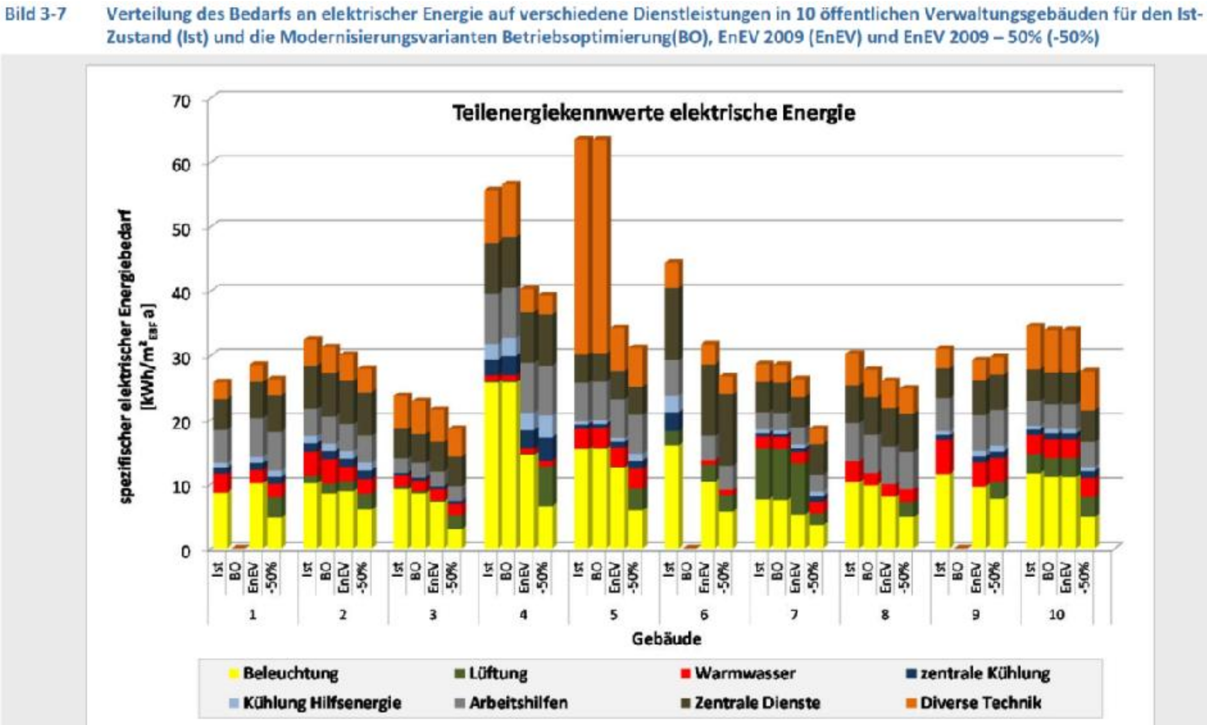


Figure 58 Specific annual electrical energy need (kWh/m²/year) for 10 public buildings. The yellow bars are for lighting energy. The left-most bar ('Ist') is for the current situation; the other bars are for optimisation variants (source: IWU 2014)

Figure 64 shows that the specific annual energy need for lighting in 10 public buildings, in the current situation, varies from approximately 7 to 24 kWh/m^2/year, with an average estimated in 13 kWh/m^2/year.

From Figure 59 to Figure 62 the following approximate lighting energy needs can be estimated:

- Offices (single and open): 19 kWh/m^2/year
- Class rooms: 15 kWh/m^2/year
- Hotel rooms: 12 kWh/m^2/year
- Circulation areas: 11 kWh/m^2/year

Figure 63 shows the annual lighting energy need and installed power density for a single office building, subdivided per zone. The current situation is compared to a low target reference. Annual burning hours are also shown.

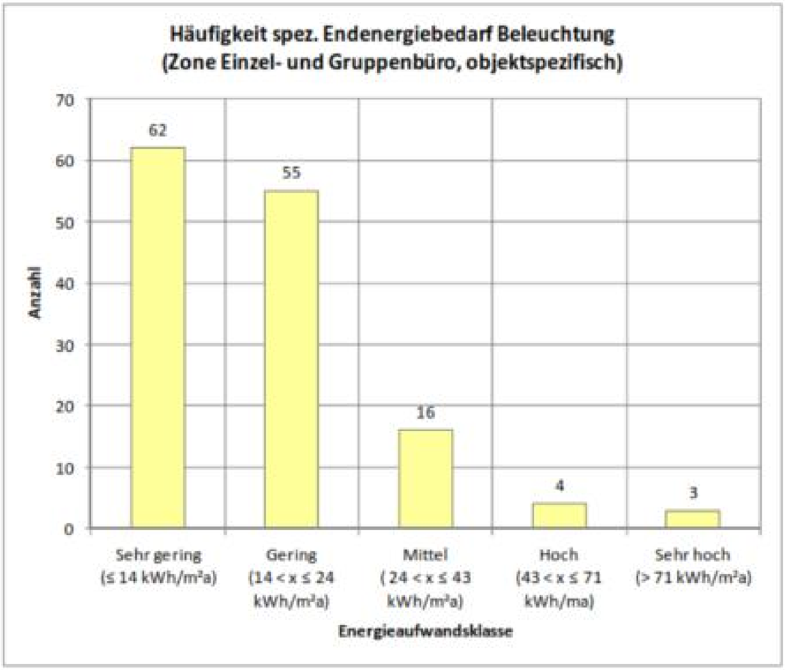


Figure 59 Specific annual electrical lighting energy need (kWh/m²/year) for offices (single and open). Number of offices with specific energy in a given interval. (source: IWU 2014)

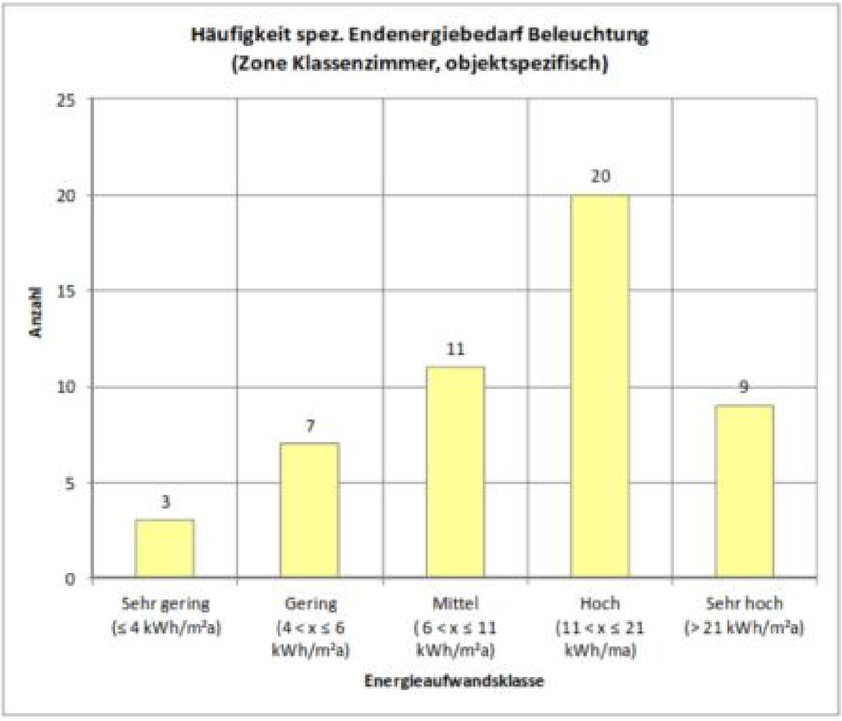


Figure 60 Specific annual electrical lighting energy need (kWh/m²/year) for class rooms. Number of offices with specific energy in a given interval. (source: IWU 2014)

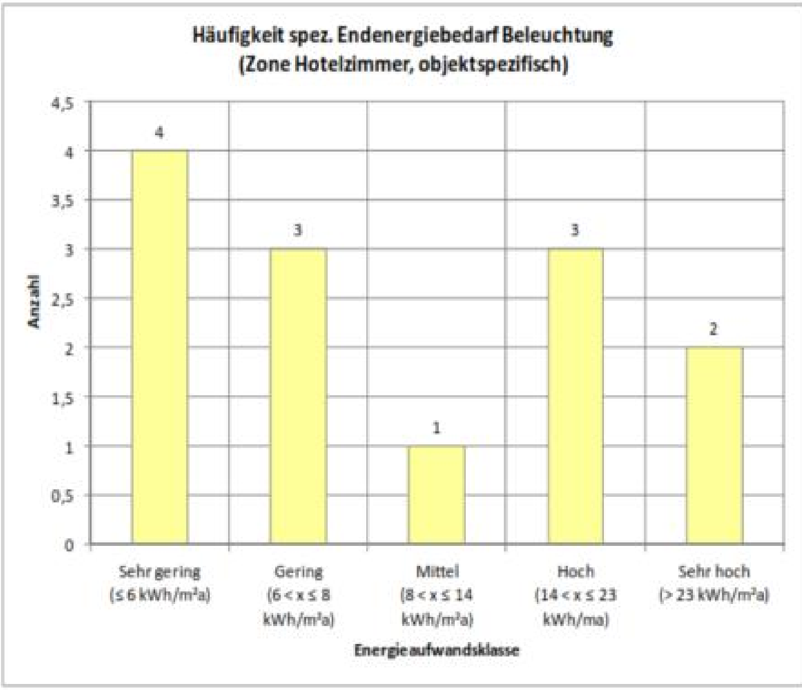


Figure 61 Specific annual electrical lighting energy need (kWh/m²/year) for hotel rooms. Number of offices with specific energy in a given interval. (source: IWU 2014)

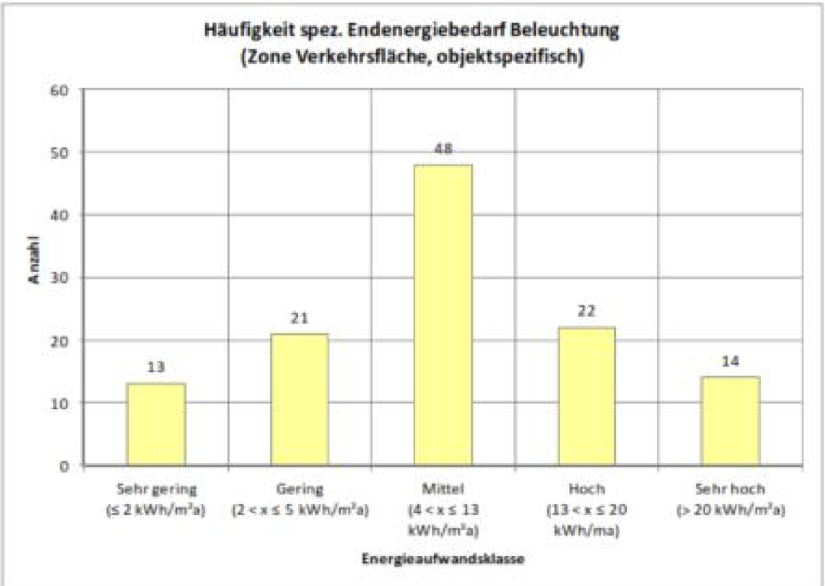


Figure 62 Specific annual electrical lighting energy need (kWh/m²/year) for circulation areas. Number of offices with specific energy in a given interval. (source: IWU 2014)

3.2 Beleuchtung										
Nr. und Name	Std.-nutzung	Fläche	Nr. Beleuch-	Ist-Wert Zone (Endenergie)				Vergleichswert - gering		
		m²	tungsanlage	TEK-Bewert.	kWh/(m²a)	W/m²	h/a	kWh/(m²a)	W/m²	h/a
1) Einzelbüro Nord	01 Einzelbüro	463	1	Gering	17,7	12,4	1428,4	20,0	17,2	1.160
2) Saal-Vorraum	04 Sitzung	39	7	Sehr gering	0,3	5,8	59,4	1,8	15,6	118
3) Einzelbüro Süd	01 Einzelbüro	561	1	Gering	18,0	12,4	1457,0	20,0	17,2	1.160
4) Verkehrsflächen	19 Verkehrsflä	265	2	Hoch	15,9	8,8	1800,0	2,4	4,5	537
5) Foyer	19 Verkehrsflä	87	5	Mittel	8,5	14,2	598,0	2,6	4,5	575
6) WC, Sanitär	16 WC, Sanitäı	76	6	Mittel	18,5	14,9	1246,4	3,5	9,0	390
7) Lager / Technik / Archiv	20 Lager, Tecl	558	3	Hoch	3,6	6,1	593,6	1,3	3,0	423
8) Saal	04 Sitzung	169	4	Gering	0,7	9,4	71,0	0,7	15,6	43
9) Serverraum	21 Rechenzen	5	3	Sehr gering	19,9	6,1	3276,0	29,2	14,6	1.996
10) Nebenflächen	18 Nebenfläch	15	3	Hoch	1,9	6,1	308,2	1,1	3,0	365

Figure 63 Specific annual electrical lighting energy consumption (kWh/m²/year) and installed power density (W/m2) in a single office building. The current situation ('Ist-wert') is compared to a low reference value ('Vergleichswert'); both values derive from the TEK database. (source: IWU 2014)

Annex E. LIFETIMES, DATA COLLECTION

E.1 Lifetime-related requirements in current regulations

Regulation 244/2009 (Non-directional household lamps) specifies lifetime-related requirements in tables 4 and 5 of Annex II. The following lifetimes are specified directly or implied by the requirements on LSF and LLMF:

- CFLi: > 6000 h (LSF≥0.5) from Stage 1 (September 2009)
  > 6000 h (LSF≥0.7) from Stage 5 (September 2013)

- Incandescent and halogen lamps [245]: ≥ 1000 h from Stage 1 (September 2009)
  ≥ 2000 h from Stage 5 (September 2013)

For CFL:

Functionality requirements for compact fluorescent lamps

Functionality parameter	Stage 1	Stage 5
Lamp survival factor at 6 000 h	≥ 0,50	≥ 0,70
Lumen maintenance	At 2 000 h: ≥ 85 % (≥ 80 % for lamps with second lamp envelope)	At 2 000 h: ≥ 88 % (≥ 83 % for lamps with second lamp envelope) At 6 000 h: ≥ 70 %
Number of switching cycles before failure	≥ half the lamp lifetime expressed in hours ≥ 10 000 if lamp starting time > 0,3 s	≥ lamp lifetime expressed in hours ≥ 30 000 if lamp starting time > 0,3 s
Premature failure rate	≤ 2,0 % at 200 h	≤ 2,0 % at 400 h

For all lamps excluding CFL and LED (this implies mainly to incandescent and halogen lamps):

Functionality requirements for lamps excluding compact fluorescent lamps and LED lamps

Functionality parameter	Stage 1	Stage 5
Rated lamp lifetime	≥ 1 000 h	≥ 2 000 h
Lumen maintenance	≥ 85 % at 75 % of rated average lifetime	≥ 85 % at 75 % of rated average lifetime
Number of switching cycles	≥ four times the rated lamp life expressed in hours	≥ four times the rated lamp life expressed in hours
Premature failure rate	≤ 5,0 % at 100 h	≤ 5,0 % at 200 h

Regulation 245/2009 (fluorescent lamps without integrated ballast and HID) specifies lifetime-related requirements in tables 11 thru 14 of Annex III. The following lifetimes are implied by the requirements on LSF and LLMF:

- LFL on HF ballast with warm start: > 16,000 h (LSF≥0.90) from Stage 2 (April 2012)
- LFL on non-HF ballast: > 8,000 h (LSF≥0.90) from Stage 2 (April 2012)

[245] Applies to households lamps excluding CFL and LEDS and also excluding fluorescent lamps without integrated ballasts and HID that are exempted from 244/2009, leaving incandescent lamps and halogens.

- CFLni on HF ballast with warm start: > 8,000 h (LSF≥0.87) from Stage 2 (April 2012)
- CFLni on non-HF ballast: > 8,000 h (LSF≥0.50) from Stage 2 (April 2012)
- HPS with power < 75 W: > 12,000 h (LSF≥0.90) from Stage 2 (April 2012)
- HPS with power ≥ 75 W: > 16,000 h (LSF≥0.90) from Stage 2 (April 2012)
- Metal-halide > 12,000 h (LSF≥0.80) from Stage 3 (April 2017)

Lamp lumen maintenance factors for single and double-capped fluorescent lamps — Stage 2

Lamp lumen maintenance factor	Burning hours			
Lamp types	2 000	4 000	8 000	16 000
Double-Capped Fluorescent lamps operating on non-high frequency ballasts	0,95	0,92	0,90	—
Double-Capped Fluorescent lamps on high frequency ballast with warmstart	0,97	0,95	0,92	0,90
Single-Capped Fluorescent lamps operating on non-high frequency ballasts	0,95	0,90	0,80	—
Single-Capped Fluorescent lamps on high frequency ballast with warmstart	0,97	0,90	0,80	—

Lamp survival factors for single and double-capped fluorescent lamps — Stage 2

Lamp survival factor	Burning hours			
Lamp types	2 000	4 000	8 000	16 000
Double-Capped Fluorescent lamps operating on non-high frequency ballasts	0,99	0,97	0,90	—
Double-Capped Fluorescent lamps on high frequency ballast with warmstart	0,99	0,97	0,92	0,90
Single-Capped Fluorescent lamps operating on non-high frequency ballasts	0,95	0,92	0,50	—
Single-Capped Fluorescent lamps on high frequency ballast with warmstart	0,95	0,90	0,87	—

Lamp lumen maintenance factors and lamp survival factors for high pressure sodium lamps — Stage 2

Burning hours	Lamp lumen maintenance factor	Lamp survival factor
12 000 (P ≤ 75 W)	> 0,80	> 0,90
16 000 (P > 75 W)	> 0,85	> 0,90

Lamp lumen maintenance factors and lamp survival factors for metal halide lamps — Stage 3

Burning hours	Lamp lumen maintenance factor	Lamp survival factor
12 000	> 0,80	> 0,80

Regulation 1194/2012 (Directional lamps and LEDs) specifies lifetime-related requirements in tables 3 thru 5 of Annex III. The following lifetimes are implied by the requirements on LSF and LLMF:

- CFL-R: > 6,000 h (LSF≥0.50) from March 2014
  > 6,000 h (LSF≥0.70) from Stage 3 (September 2016)
- MV-GLS-R, MV-HL-R [246]: ≥ 1,000 h (LSF≥0.50) from Stage 1 (September 2013)
  ≥ 2,000 h (LSF≥0.50) from Stage 2 (September 2014)
- LV-GLS-R, LV-HL-R [247]: ≥ 4,000 h (LSF≥0.50) from Stage 3 (September 2016)
- LED (NDLS & DLS): > 6,000 h (LSF≥0.90, LLMF≥0.80) from March 2014

Functionality requirements for directional compact fluorescent lamps

Functionality parameter	Stage 1 except where indicated otherwise	Stage 3
Lamp survival factor at 6 000 h	From 1 March 2014: ≥ 0,50	≥ 0,70
Lumen maintenance	At 2 000 h: ≥ 80 %	At 2 000 h: ≥ 83 % At 6 000 h: ≥ 70 %
Number of switching cycles before failure	≥ half the lamp lifetime expressed in hours ≥ 10 000 if lamp starting time > 0,3 s	≥ lamp lifetime expressed in hours ≥ 30 000 if lamp starting time > 0,3 s
Premature failure rate	≤ 5,0 % at 500 h	≤ 5,0 % at 1 000 h

Functionality requirements for other directional lamps (excluding LED lamps, compact fluorescent lamps and high-intensity discharge lamps)

Functionality parameter	Stage 1 and 2	Stage 3
Rated lamp lifetime at 50 % lamp survival	≥ 1 000 h (≥ 2 000 h in stage 2) ≥ 2 000 h for extra low voltage lamps not complying with the stage 3 filament lamp efficiency requirement in point 1.1 of this Annex	≥ 2 000 h ≥ 4 000 h for extra low voltage lamps
Lumen maintenance	≥ 80 % at 75 % of rated average lifetime	≥ 80 % at 75 % of rated average lifetime
Number of switching cycles	≥ four times the rated lamp life expressed in hours	≥ four times the rated lamp life expressed in hours
Premature failure rate	≤ 5,0 % at 100 h	≤ 5,0 % at 200 h

Functionality requirements for non-directional and directional LED lamps

Functionality parameter	Requirement as from stage 1, except where indicated otherwise
Lamp survival factor at 6 000 h	From 1 March 2014: ≥ 0,90
Lumen Maintenance at 6 000 h	From 1 March 2014: ≥ 0,80
Number of switching cycles before failure	≥ 15 000 if rated lamp life ≥ 30 000 h otherwise: ≥ half the rated lamp life expressed in hours
Premature failure rate	≤ 5,0 % at 1 000 h

[246] Applies to directional lamps excluding CFLs, LEDs and HID-lamps, leaving incandescent lamps (GLS) and halogens (HL).
[247] Applies to Extra Low Voltage lamps

E.2 ZVEI data on lifetimes

The "Zentralverband Elektrotechnik- und Elektronikindustrie e.V." (ZVEI) is the German Electrical and Electronic Manufacturers' Association. In 2005 they published a guide [248] to support the planning and maintenance of lighting installations, that contains verified data on the lifetimes of discharge lamps (LFL, CFLni, HID) with different types of ballast (magnetic, low-loss magnetic, electronic).

The publication presents detailed graphs for the Lamp Survival Factor (LSF), the Lamp Lumen Maintenance Factor (LLMF), and for the product of these two [249], in function of the burning hours. An average curve and a minimum and maximum curve are reported. The latter two indicate the spread in average data due to lamps of different powers or lamps from different manufacturing batches [250]. In addition a table is presented with lamp lifetimes, in most cases based on a 12 hour switching cycle (11h on, 1 h off) and a 10% lamp failure rate (equivalent to LSF=0.9).

The data presented in Table 73 have been extracted from the data in the reference.

Lamp type	Ballast Type [251]	Life (hours)			Lamp Lumen Maintenance Factor			
		LSF=0.9	LSF=0.5		5000 h	10000 h	15000 h	20000 h
			average	min/max				
LFL								
T5, 14-80W, tri-phosphor	Ew	20000	24000	±1000	0.94	0.92	0.91	0.90
T8, 18-58W, tri-phosphor	Ew	16000	20000	±1000	0.94	0.92	0.91	0.90
	Ms1	11000	15000	±2500	0.94	0.92	0.91	0.90
T8, 18-58W, halophosphor	Ms1	8000	13000	±2500	0.80	0.73	0.70	0.68
CFLni								
5-42W, 2G7, GX24q, 1 or 3 tubes	Ew	8500	12500	±1500	0.86	0.80		
10-26W, G24q, 2 tubes	Ew	10000	15000	±1000	0.86	0.80	0.78	
5-26W, G23, G24d, GX24d, 1, 2, 3 tubes	Ms2	7000	11000	±1500	0.84	0.78		
18-80W, 2G11	Ew	16000	20000	±1500	0.92	0.91	0.90	0.89
18-36W, 2G11	Ms1	11000	15000	±2500	0.91	0.89	0.88	
HID								
HPS, 50/70W	M	12000	22000	±3000	0.91	0.88	0.86	0.85
150-400W, standard light output	M	16000	(26000)	(±2500)	0.92	0.90	0.89	0.88
100-400W, high light output	M	18000	(27000)	(±2500)	0.95	0.92	0.91	0.90
HPM, 50-1000W, standard	M	8000	16000	±3000	0.89	0.81	0.76	0.73

Table 73 Lifetimes for LFL, CFLni and HID-lamps based on a 12 hour switching cycle (11 h on, 1 h off). The life in hours is shown for LSF=0.9 (10% of lamps failed) and LSF=0.5 (50% of lamps failed). In addition LLMF values are shown after 5000h, 10000h, 15000h and 20000h burning hours. (data source: ZVEI 2005; presentation by study team)

For LFL T5 and T8, tri-phosphor on electronic ballast, the above data correspond well with the requirements in Regulation 245/2009, i.e. 16,000 h with LSF=0.9 and LLMF=0.9.

[248] "ZVEI, Lebensdauerverhalten von Entladungslampen für die Beleuchtung Grundlagen, ZVEI Fachverband Elektrische Lampen, November 2005". http://www.licht.de/fileadmin/Publikationen_Downloads/lebensdauerZVEI.pdf or http://en.licht.de/fileadmin/shop-downloads/LifetimeZVEI.pdf (in English)

[249] This is the Maintenance Factor, but limited to the light source, i.e. Luminaire Maintenance Factor (LMF) and Room Surface Maintenance Factor (RSMF) are not included.

[250] The minimum and maximum curves are for the average of batches or for the average of a specific lamp power. Individual lamps may have lower or higher values.

[251] E=electronic ballast, Ew is with warm start. M is magnetic ballast, Ms1 is low-loss magnetic ballast (50% inductive, 50% capacitive), Ms2 is low loss magnetic ballast (inductive)

For LFL T8 on magnetic ballast, comparing the above data with the requirements in Regulation 245/2009, i.e. 8,000 h with LSF=0.9 and LLMF=0.9, means that halo-phosphor lamps will not meet the requirements (but they are phased out anyway for efficiency reasons). For tri-phosphor T8 (11,000 h with LSF=0.9 and LLMF=0.92 according to ZVEI) the requirements in 245/2009 do not seem to be very severe.

For CFLni on electronic ballast, the requirements in Regulation 245/2009, i.e. 8,000 h with LSF=0.87 and LLMF=0.8, more or less correspond to the ZVEI data for the lamps with the lowest lifetimes (5-42W). For the other types the requirements do not seem to be severe.

For CFLni on magnetic ballast, the requirements in Regulation 245/2009, i.e. 8,000 h with LSF=0.50 and LLMF=0.8, do not seem to be severe (11,000 or 15,000 h according to ZVEI).

For HPS lamps, the requirements in Regulation 245/2009 as regards lifetime and LSF are identical to the ZVEI data, but LLMF requirements are slightly lower than those reported by ZVEI.

E.3 Recent examples of long-life LFL

The LFL lifetimes as reported by ZVEI in 2005 (preceding paragraph) are amply exceeded by recent products. Some examples are presented below.

Osram Sylvania offers T8 lamps of different powers with declared lifetimes up to 84,000 hours on the U.S. market [252]. As shown below, the lifetime depends on the switching cycle (3h or 12h) and on the type of start (instant or programmed rapid).

								Avg. Rated Life					
								Instant Start		Programmed Rapid Start			
Item Number	Ordering Abbreviation	Watts	Bulb	Base	Initial Lumens	Mean Lumens[1]	lm/W	3 hrs/ start	12 hrs start	3 hrs/ start	12 hrs/ start	CCT	CRI
4 foot													
21527	F032/830/XP/XL/ECO3	32	T8	Med Bi-Pin	2950	2830	92	36,000	52,000	65,000	67,000	3000K	85
21576	F032/835/XP/XL/ECO3	32	T8	Med Bi-Pin	2950	2830	92	36,000	52,000	65,000	67,000	3500K	85
21577	F032/841/XP/XL/ECO3	32	T8	Med Bi-Pin	2950	2830	92	36,000	52,000	65,000	67,000	4100K	85
22002	F032/850/XP/XL/ECO3	32	T8	Med Bi-Pin	2950	2830	92	36,000	52,000	65,000	67,000	5000K	81
21528	F028/830/XP/XL/SS/ECO3	28	T8	Med Bi-Pin	2600	2470	93	50,000	75,000	80,000	84,000	3000K	85
22166	F028/835/XP/XL/SS/ECO3	28	T8	Med Bi-Pin	2600	2470	93	50,000	75,000	80,000	84,000	3500K	85
22167	F028/841/XP/XL/SS/ECO3	28	T8	Med Bi-Pin	2600	2470	93	50,000	75,000	80,000	84,000	4100K	85
22326	F028/850/XP/XL/SS/ECO3	28	T8	Med Bi-Pin	2600	2470	93	50,000	75,000	80,000	84,000	5000K	81
22349	F032/25W/830/XP/XL/SS/ECO3	25	T8	Med Bi-Pin	2400	2280	96	50,000	75,000	80,000	84,000	3000K	85
22222	F032/25W/835/XP/XL/SS/ECO3	25	T8	Med Bi-Pin	2400	2280	96	50,000	75,000	80,000	84,000	3500K	85
22223	F032/25W/841/XP/XL/SS/ECO3	25	T8	Med Bi-Pin	2400	2280	96	50,000	75,000	80,000	84,000	4100K	85
3 foot													
22493	F025/21W/830/XP/XL/SS/ECO3	21	T8	Med Bi Pin	1850	1760	88	45,000	75,000	80,000	84,000	3000K	85
22494	F025/21W/835/XP/XL/SS/ECO3	21	T8	Med Bi Pin	1850	1760	88	45,000	75,000	80,000	84,000	3500K	85
22495	F025/21W/841/XP/XL/SS/ECO3	21	T8	Med Bi Pin	1850	1760	88	45,000	75,000	80,000	84,000	4100K	85
2 foot													
22490	F017/15W/830/XP/XL/SS/ECO3	15	T8	Med Bi Pin	1150	1095	77	45,000	75,000	80,000	84,000	3000K	85
22491	F017/15W/835/XP/XL/SS/ECO3	15	T8	Med Bi Pin	1150	1095	77	45,000	75,000	80,000	84,000	3500K	85
22492	F017/15W/841/XP/XL/SS/ECO3	15	T8	Med Bi Pin	1150	1095	77	45,000	75,000	80,000	84,000	4100K	85

1. Measured at 40% of rated life.

Table 74 Extract from high-life LFL T8 lamps offered by Osram Sylvania

[252] https://assets.sylvania.com/assets/Documents/FL083R5.00f41d36-53cd-4480-a4f4-c309fdc0e382.pdf

General Electric Lighting [253] offers LFL T5 high-efficiency lamps with 112 lm/W and lifetimes up to 36,000 hours and high-output lamps with 102 lm/W and lifetimes up to 60,000 hours.

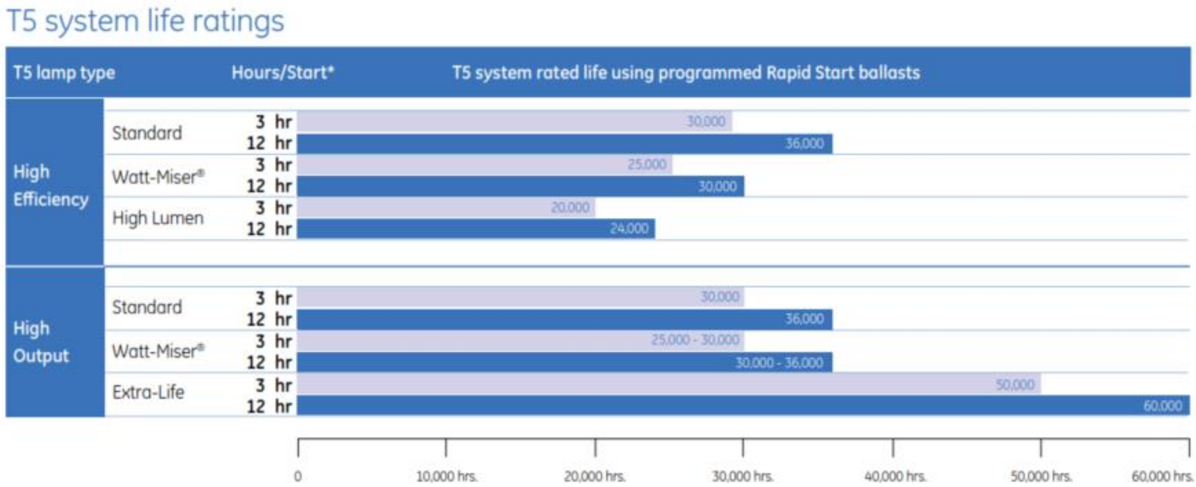


Table 75 Lifetimes of LFL T5 and T8 lamps offered by General Electric Lighting

[253] http://www.gelighting.com/LightingWeb/na/images/60654-GE-LFL-T5-Brochure_tcm201-34678.pdf

Philips Lighting [254] offers T8 with lifetimes up to 90,000 hours (12 h cycle, programmed-starting)

Product number	Full product name	Base	Bulb	Energy Saving	Rated Avg Life [12-Hr Prog St]	Rated Avg Life [12-Hr Inst St]	Rated Avg Life [3-Hr Prog St]	Rated Avg Life [3-Hr Inst St]
434050	F32T8 32W ADV835 2XL/ALTO	Medium Bi-Pin	T8	Energy Saving	70000 hr	52000 hr	60000 hr	46000 hr
434068	F32T8 32W ADV841 2XL/ALTO	Medium Bi-Pin	T8	Energy Saving	70000 hr	52000 hr	60000 hr	46000 hr
434076	F32T8 32W ADV850 2XL/ALTO	Medium Bi-Pin	T8	Energy Saving	70000 hr	52000 hr	60000 hr	46000 hr
434019	F32T8 28W ADV830 2XL/ALTO	Medium Bi-Pin	T8	Energy Saving	90000 hr	68000 hr	80000 hr	60000 hr
434027	F32T8 28W ADV835 2XL/ALTO	Medium Bi-Pin	T8	Energy Saving	90000 hr	68000 hr	80000 hr	60000 hr
434035	F32T8 28W ADV841 2XL/ALTO	Medium Bi-Pin	T8	Energy Saving	90000 hr	68000 hr	80000 hr	60000 hr
434043	F32T8 28W ADV850 2XL/ALTO	Medium Bi-Pin	T8	Energy Saving	90000 hr	68000 hr	80000 hr	60000 hr
433952	F32T8 25W ADV830 2XL/ALTO	Medium Bi-Pin	T8	Energy Saving	90000 hr	68000 hr	80000 hr	60000 hr
433960	F32T8 25W ADV835 2XL/ALTO	Medium Bi-Pin	T8	Energy Saving	90000 hr	68000 hr	80000 hr	60000 hr
433978	F32T8 25W ADV841 2XL/ALTO	Medium Bi-Pin	T8	Energy Saving	90000 hr	68000 hr	80000 hr	60000 hr
433986	F32T8 25W ADV850 2XL/ALTO	Medium Bi-Pin	T8	Energy Saving	90000 hr	68000 hr	80000 hr	60000 hr
281212	F32T8 25W ADV830 XLL ALTO	Medium Bi-Pin	T8	Energy Saving	52000 hr	46000 hr	46000 hr	40000 hr
281220	F32T8 25W ADV835 XLL ALTO	Medium Bi-Pin	T8	Energy Saving	52000 hr	46000 hr	46000 hr	40000 hr
281238	F32T8 25W ADV841 XLL ALTO	Medium Bi-Pin	T8	Energy Saving	52000 hr	46000 hr	46000 hr	40000 hr
281253	F32T8 25W ADV850 XLL ALTO	Medium Bi-Pin	T8	Energy Saving	52000 hr	46000 hr	46000 hr	40000 hr

Table 76 Lifetimes of LFL T8 lamps offered by Philips Lighting

E.4 CLASP 2013 on lifetimes of residential lamps

In their 2013 review study on residential lighting [255], CLASP used the lifetimes presented below.

Table 2-3. Lamp Lifetime and Operating Hours Assumed for Stock Model

Type of Lamp	Lamp Lifetime (hours)	Operating Hours (hours/year)	Operating Hours (hours/day)
Incandescent	1,000	600	1.64
HL-MV-LW	2,000	600	1.64
HL-MV-HW	2,000	600	1.64
HL-LV	3,000	600	1.64
CFLi	6,000	1,000	2.74
LED	20,000	1,000	2.74

Table 77 Lifetimes and operating hours for residential lighting used by CLASP 2013

E.5 CLASP 2014, LFL lifetime

In November 2014 CLASP published the results of a study on LFL [256]. They sampled 4-foot LFL T8 for testing from China, India, United Kingdom and United States of America. Lifetime was not tested, but from the information declared on the packaging and in the catalogue the declared data of Table 78 are reported (data from China and India have not been included).

The lifetimes for lamps sampled in the UK vary from 10,000 to 20,000 hours. Those for the lamps sampled in the USA from 15,000 to 32,000 hours.

[254] http://download.p4c.philips.com/l4bt/3/332475/energy_advantage_extra_long_life_332475_ffs_aen.pdf

[255] "CLASP, Estimating potential additional energy savings from upcoming revisions to existing regulations under the ecodesign and energy labelling directives, Feb. 2013, appendix F, table 2.3". http://www.eceee.org/all-news/press/2013/2013-02-19/eceee-clasp-report-estimating-potential

[256] CLASP, November 2014, "Mapping & Benchmarking of Linear Fluorescent Lighting". http://clasponline.org/en/Resources/Resources/PublicationLibrary/2014/Benchmarking-Analysis-Linear-Fluorescent-Lighting.aspx

Model ID	Origin	$/lamp (USD)	Rated Power (W)	Rated CCT (K)	Rated Life (hrs)	Rated CRI	Phosphor Type	Rated Flux (lm)	Rated Efficacy (lm/W)	Claimed Energy Rating
UK01	UK	$4.15	36	4000	15000	80	triphosphor	3350	93.1	A
UK02	UK	$4.15	36	4000	20000	80	triphosphor	3350	93.1	A
UK03	UK	$4.15	36	4000	20000	80	triphosphor	3370	93.6	A
UK04	UK	$4.15	36	4000	15000	80	triphosphor	3350	93.1	A
UK05	UK		36	4000	10000		triphosphor	3200	88.9	A
UK06	UK	$2.34	36	4000	15000	80	triphosphor	3350	93.1	A
UK07	UK		36	4000	15000	80	triphosphor	3350	93.1	A
UK08	UK		36	4000	15000	90	triphosphor	2800	77.8	A
UK09	UK	$3.73	36	4000	16000	80	triphosphor			A
UK11	UK		36	4000		80	triphosphor	3350	93.1	A
US01	USA	$2.68	32	3500	30000	78	triphosphor	2800	87.5	
US04	USA	$4.30	25	4100	32000	82	triphosphor	2400	96.0	
US05	USA	$2.43	32	4100	20000	73		2850	89.1	
US06	USA	$3.75	32	4100	15000	78	triphosphor	2500	78.1	
US07	USA	$2.50	32	4100	20000	75	triphosphor	2800	87.5	
US08	USA	$2.39	32	4100						
US09	USA	$3.99	32	4100	20000	78	triphosphor	2600	81.3	
US10	USA	$2.06	32	4100	24000	80	triphosphor	3150	98.4	

Table 78 Lifetimes in hours for LFL T8, for samples used by CLASP in the 2014 study.

E.6 IEA 4E data on lifetimes

Source: see footnote [257] and par.F.1.1.

The individual lifetimes of lamps vary considerably between models of a particular type. Similarly there are variations in average lifetimes of lamps between geographical regions and over time. However, for the mapping and benchmarking analysis, 'standard lifetimes' have been used for each lamp types in all markets for all years [258]. These standard lifetimes used are given in the table below.

Lamp type	Assumed lifetime (hours)
Main voltage incandescents	1000
Mains voltage halogens (single ended)	1300
Mains voltage halogens (double ended)	1300
Low voltage (12V) halogens	1300
Mains voltage pin based CFLs	6000
Mains voltage self-ballasted CFLs	6000
Mains voltage linear fluorescent tubes (T5)	15000
Mains voltage linear fluorescent tubes (T8)	10000
Mains voltage linear fluorescent tubes (T12)	10000
Retrofit LED lamps	20000
Dedicated LED lamps	20000

Table 79 Lifetimes in hours of the various types of lamps for the year 2010. (Source: 4E Mapping and Benchmarking, Product definition document)

[257] "4E Mapping Document, European Union, Domestic Lighting". Available through: http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5 . Product definition document, par. 4.3.

[258] Note that 'standard' lamp lifetimes are based on an average of the lifetimes of lamps sold in 2010 as estimated by experts in the USA, Europe and Australia. Lamps in preceding years are likely to have shorter lifetimes and this has not been accounted for in the benchmarking.

E.7 GPP Indoor recommended lamp lifetimes

The 2012 EU GPP criteria for indoor lighting [259] contain the indications for lifetimes of light sources presented in Table 80. As explained in the reference:

- The core criteria are those suitable for use by any contracting authority across the Member States and address the key environmental impacts. They are designed to be used with minimum additional verification effort or cost increases.
- The comprehensive criteria are for those who wish to purchase the best products available on the market. These may require additional verification effort or a slight increase in cost compared to other products with the same functionality.

Core criteria	Comprehensive criteria
3.1 EU GPP criteria for lamps	
SUBJECT MATTER	**SUBJECT MATTER**
Purchasing of resource and energy efficient lamps	Purchasing of resource and energy efficient lamps
TECHNICAL SPECIFICATIONS	**TECHNICAL SPECIFICATIONS**

Core criteria

3. Lamps for new and renovated installations, and replacement lamps in existing installations, shall have a lifetime not less than that given in the table below.

Type of lamp	Lamp life (hours)
Tungsten halogen lamps	2000
Globe shaped, pear shaped, reflector type or chandelier type compact fluorescent lamps	6000
All other compact fluorescent lamps	10000
Circular lamps	7500
T8 tubular fluorescent lamps with electromagnetic ballasts (existing installations only)	15000
Other tubular fluorescent lamps	20000
HID non-directional lamps (primary burning position)	12000
HID directional lamps (primary burning position)	9000
Retrofit LEDs with integrated control gear	15000
Other LEDs	20000

Verification: Products holding a Type I ecolabel shall be deemed to comply, provided that this ecolabel fulfils the requirements listed above. Other appropriate means of proof will be accepted such as the result of lamp life testing according to the test procedure in EN 50285 (except for HID

Comprehensive criteria

3. Lamps for new and renovated installations, and replacement lamps in existing installations, shall have a lifetime not less than that given in the table below.

Type of lamp	Lamp life (hours)
Tungsten halogen lamps	2500
Globe shaped, pear shaped, reflector type or chandelier type compact fluorescent lamps	8000
Other compact fluorescent lamps with separate ballast	10000
Other compact fluorescent lamps with integral ballast	12000
Circular lamps	8000
T8 tubular fluorescent lamps with electromagnetic ballasts (existing installations only)	15000
Other tubular fluorescent lamps	25000
HID non-directional lamps (primary burning position)	12000
HID directional lamps (primary burning position)	9000
Retrofit LEDs with integrated control gear	20000
Other LEDs	25000

Verification: Products holding a Type I ecolabel shall be deemed to

Table 80 Lifetimes in hours from the EU GPP criteria for indoor lighting

E.8 GPP Street lighting information on lamp lifetimes

Lifetime-related information from the 2012 EU GPP criteria for street lighting [260] are presented below. With exception of the LSF for MH-lamps these data are identical to those from Regulation 245/2009 (Annex E.1).

[259] "Green Public Procurement , Indoor Lighting , Technical Background Report", BRE 2011, http://ec.europa.eu/environment/gpp/pdf/tbr/indoor_lighting_tbr.pdf
"EU GPP Criteria for Indoor Lighting", 2012, http://ec.europa.eu/environment/gpp/pdf/criteria/indoor_lighting.pdf (currently under revision)

[260] "Green Public Procurement, Street Lighting and Traffic Lights,Technical Background Report", BRE 2011 http://ec.europa.eu/environment/gpp/pdf/tbr/street_lighting_tbr.pdf
"EU GPP Criteria for Street Lighting & Traffic Signals", 2012, http://ec.europa.eu/environment/gpp/pdf/criteria/street_lighting.pdf

7. High pressure sodium lamps and metal halide lamps shall have the following lamp lumen maintenance and lamp survival factors:

Lamp Type	Burning Hours	LLMF	LSF
MH Lamps	12,000 (W ≤ 405)	≥ 0.80	≥ 0.90
HPS Lamps	12,000 (W ≤ 75)	≥ 0.80	≥ 0.90
HPS Lamps	16,000 (75 < W ≤ 605)	≥ 0.85	≥ 0.90

Lamp Lumen Maintenance Factor (LLMF) is defined as the ratio of the luminous flux emitted by the lamp at a given time in its life to the initial luminous flux.

Lamp Survival Factor (LSF) is defined as the fraction of the total number of lamps, which continue to operate at a given time under defined conditions and switching frequency.

AWARD CRITERIA

1. Additional points shall be awarded for lamps that meet the following lamp lumen maintenance factors (LLMF) and lamp survival factors (LSF):

Burning Hours	2000	4000	8000	16000
LLMF	0.98	0.97	0.95	0.92
LSF	0.99	0.98	0.95	0.92

Verification: The tenderer shall provide the technical specification of the lamp or a written declaration to demonstrate this criterion is met.

AWARD CRITERIA

1. Additional points shall be awarded for replacement lamps for existing fittings that meet the following lamp lumen maintenance factors (LLMF) and lamp survival factors (LSF):

Burning Hours	2000	4000	8000	16000
LLMF	0.98	0.97	0.95	0.92
LSF	0.99	0.98	0.95	0.92

Verification: The tenderer shall provide the technical specification of the lamp or a written declaration to demonstrate this criterion is met.

Table 81 Lifetime-related information from the EU GPP criteria for street lighting

E.9 Lifetimes from previous studies and impact assessments

Selected lifetime-related information from the 2007 Lot 9 preparatory study on street lighting [261] follows:

Table 15: Commonly used practice for lifetime of the main lamp type families (Source: based on combination of LSF and LLMF data provided in CIE154:2003)

Lamp family	Lifetime - t_{group}	
	Years	Service hours
HgHP	3	12.000
HgLP (linear and compact non integrated)	3	12.000
HgLP (compact integrated)	2	8.000
NaHP	4	16.000
NaLP	3	12.000
MHHP	1.5	8.000

Table 82 Lifetimes for HID-lamps from 2007 Lot 9 preparatory study

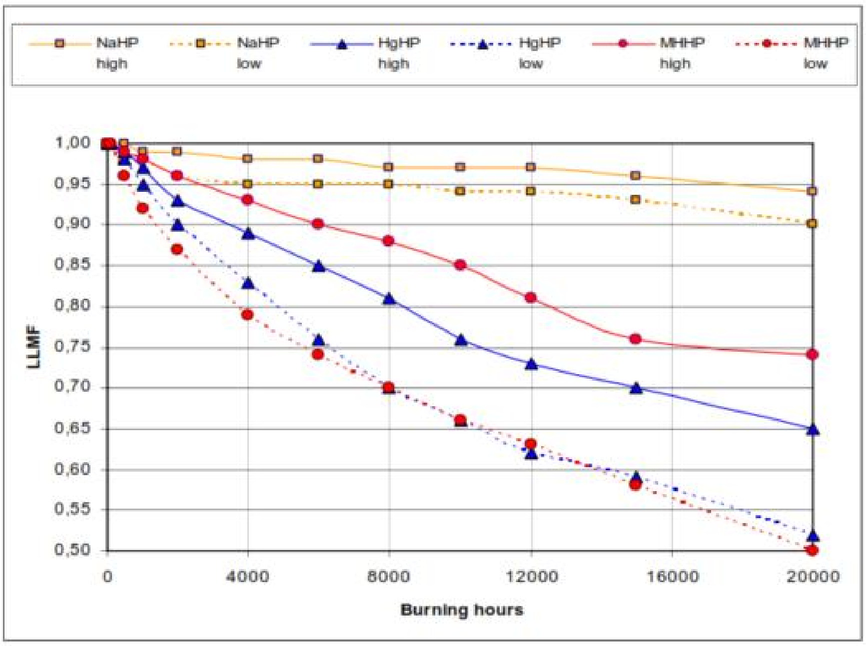
[261] Preparatory Studies for Eco-design requirements of EuPs, Final Report, Lot 9: Public Street lighting, Study for the European Commission DGTREN unit D3, contact Andras Toth, by VITO in cooperation with Laborelec and Kreios, January 2007, Contract TREN/D1/40-2005/LOT9/S07.56457, available through 'eup4light.net'

			Burning hours in thousand hours											
		Differences	0.1	0.5	1	2	4	6	8	10	12	15	20	30
Incandescent	LLMF	Moderate	1.00	0.97	0.93									
	LSF	Big	1.00	0.98	0.50									
Halogen	LLMF	Big	1.00	0.99	0.97	0.95								
	LSF	Big	1.00	1,00	0.78	0.50								
Fluorescent Tri-phospor HF ballast	LLMF	Moderate	1.00	0.99	0.98	0.97	0.93	0.92	0.90	0.90	0.90	0.90	0.90	
	LSF	Moderate	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.98	0.97	0.94	0.50	
Flourescent Tri-phospor Magn. ballast	LLMF	Moderate	1.00	0.99	0.98	0.97	0.93	0.92	0.90	0.90	0.90	0.90		
	LSF	Moderate	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.98	0.92	0.50		
Flourescent halophospate Magn ballast	LLMF	Moderate	1.00	0.98	0.96	0.95	0.87	0.84	0.81	0.79	0.77	0.75		
	LSF	Moderate	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.98	0.92	0.50		
Compact fluorescent	LLMF	Big	1.00	0.98	0.97	0.94	0.91	0.89	0.87	0.85				
	LSF	Big	1.00	0.99	0.99	0.98	0.97	0.94	0.86	0.50				
HP Mercury	LLMF	Moderate	1.00	0.99	0.97	0.93	0.85	0.82	0,78	0,75	0,72	0,70	0,65	
	LSF	Moderate	1.00	1,00	0.99	0.98	0.97	0.94	0.90	0.86	0.79	0.69	0.50	
Metal halide (250-400W)	**LLMF**	Big	**1.00**	**0.98**	**0.95**	**0.90**	**0.87**	**0.83**	**0.79**	**0.65**	**0.63**	**0.58**	**0.50**	
	LSF	Big	**1.00**	**0.99**	**0.99**	**0.98**	**0.97**	**0.92**	**0.86**	**0.80**	**0.73**	**0.66**	**0.50**	
Ceramic metal halide (50-150W)	**LLMF**	Big	**1.00**	**0.95**	**0.87**	**0.75**	**0.72**	**0.68**	**0.64**	**0.60**	**0.56**			
	LSF	Big	**1.00**	**0.99**	**0.99**	**0.98**	**0.98**	**0.98**	**0.95**	**0.80**	**0.50**			
High pressure sodium	LLMF	Moderate	1.00	1.00	0.98	0.98	0.98	0.97	0.97	0.97	0.97	0.96	0.94	0.90
	LSF	Moderate	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.97	0.95	0.92	0.50
LED	LLMF	Big	Data are changing too rapidly											
	LSF	Big	Data are changing too rapidly											

Below the average LLMF over an assumed lifetime is calculated, based on the values in this Table 3-3:

- For incandescent lamps (GLS): 0,965 (life time assumption 1000 h);
- For halogen lamps (HL-types): 0,975 (life time assumtion 2000 h);
- For compact fluorescent lamps (CFLi): 0,925 (life time assumption 10000h).

Table 83 LSF and LLMF factors for various lamp types from CIE-97, as reported in the 2007 Lot 9 preparatory study



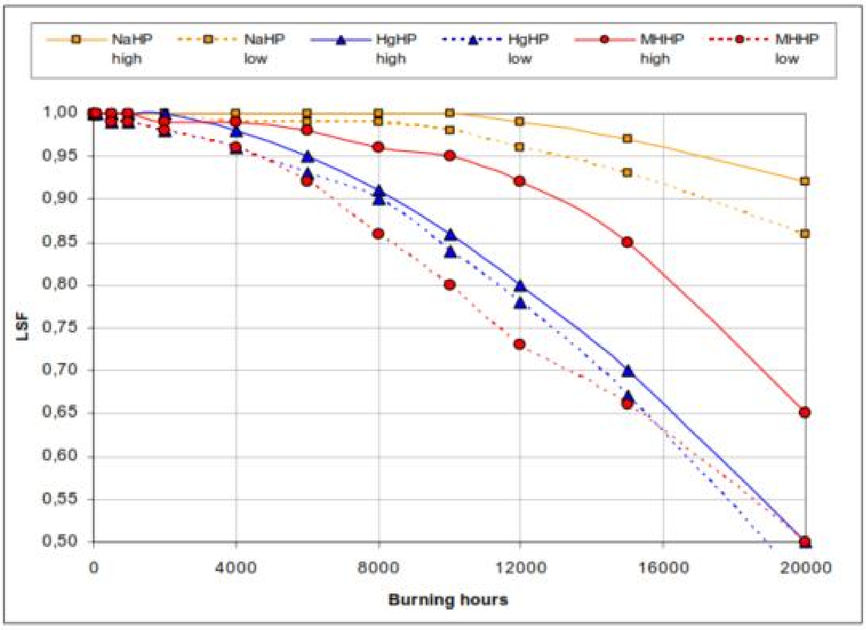


Figure 64 LLMF (top) and LSF (bottom) for HID-lamps in function of burning hours. (Source: ELC, as reported in the 2007 Lot 9 preparatory study)

Lifetime information as reported in Annex IV of the Impact Assessment [262] accompanying Regulation 245/2009 is presented in Table 84.

	Annual lamp sales (millions, 2004 ELC)	Life time (90 % of CIE table)	Installed base in 2005 (millions)	Wattage	Yearly burning hours	Consumption / year (TWh)
Lamps affected by stage 1						
T8 halophosphate lamps	149,0	13000	553,4	32	3500	62,0
Total			**553,4**			**62,0**
Lamps affected by stage 2						
T12 & T10 halophosphate lamps	14,0	13000	52,0	60	3500	10,9
HPS not complying with stage 2	7,5	15000	28,1	140	4000	15,8
MHL not complying with stage 2	0,2	12000	0,6	200	4000	0,5
Total			**80,7**			**27,2**
Lamps affected by stage 3						
high-pressure mercury vapour lamps	8,0	12000	24,0	250	4000	24,0
HPS complying with stage 2 but not with stage 3	0,2	15000	0,8	140	4000	0,4
Total			**24,8**			**24,4**
Lamps affected by stage 4						
T8 triphosphate magnetic ballast	75,0	16000	342,9	30	3500	36,0
CFLni magnetic ballast	26,0	9000	66,9	11	3500	2,6
MHL complying with stage 2 but not with stage 4	0,5	12000	1,5	180	4000	1,1
Total			**411,2**			**39,7**
Lamps complying with all criteria						
T8 triphosphate electronic ballast and T5(+others)	58,0	20000	331,4	28	3500	32,5
CFLni electronic ballast	26,0	13000	96,6	10	3500	3,4
HPS complying with stage 3	2,5	18000	11,3	120	4000	5,4
MHL complying with stage 4	4,5	12000	13,5	150	4000	8,1
Total			**452,8**			**49,4**
Grand total	371,4		**1522,9**			**202,6**
High-intensity discharge lamps	23,4		Figure from studies:			Figure from studies:
Fluorescents	348,0		1579,2			199,6

Table 84 Lifetimes for various lamp-types as used in the Impact Assessment accompanying Regulation 245/2009

[262] Commission Staff Working Document, accompanying document to the Commission Regulation implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps, and repealing Directive 2000/55/EC of the European Parliament and of the Council, Full Impact Assessment, Brussels, 18.3.2009, SEC(2009) 324, available as http://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2009/sec_2009_0324_en.pdf

Selected lifetime-related information from the 2009 Lot 19 preparatory study on domestic lighting [263] follows:

Table 5-15: Market and technical data for the non-domestic sectors in 2007

	Other sectors					
	GLS-F	GLS-C	HL-MV LW	HL-MV HW	HL-LV	CFLi
Stock NDLS (mln)	144.1	61.2	8.8	7.6	88.2	0
Sales NDLS (mln)	182.4	118.2	21.0	29.7	57.3	0
Average wattage (W)	54	54	40	300	30	13
Lifetime (h)	1000	1000	1500	1500	3000	6000
Annual burning hours (h)	1800	1800	1800	1800	1800	1800

Table 5-16: Market and technical data for all sectors in 2007

	All sectors (domestic + other)					
	GLS-F	GLS-C	HL-MV LW	HL-MV HW	HL-LV	CFLi
Stock NDLS (mln)	1800.1	568.5	134.4	119.4	558.3	1010.1
Sales NDLS (mln)	767.4	297.0	97.4	84.1	147.0	353.0
Average wattage (W)	54	54	40	300	30	13
Lifetime (h)	1000	1000	1500	1500	3000	6000
Annual burning hours (h)	505	551	538	536	705	800

Table 85 Lifetimes and other information for various lamp types as used in the 2009 Lot 19 preparatory study.

Lifetime information as reported in Annex 10 of the Impact Assessment [264] accompanying Regulation 1194/2012 is presented below:

Table 2-4. Model-Weighted Average Catalogue Lifetime for Directional Lamps

	GLS-R	HL-MV-R	HL-LV-R	CFLi-R	Notes
Lamp Lifetime (Manufacturer's Catalogues)	1600	2300	4000	8000	
Domestic operating hours per year	400	450	500	800	hours, EuP
Commercial operating hours per year	1800	1800	1800	1800	hours (EuP, 7/d x 250 d/yr)

Table 86 Lifetimes for reflector lamps as used in the 2009 Lot 19 preparatory study.

[263] Preparatory Studies for Eco-design requirements of EuPs, Final Report, Lot 19: Domestic lighting, Study for the European Commission DGTREN unit D3, contact Andras Toth, by VITO in cooperation with Bio Intelligence Service, Energy Piano and Kreios, October 2009, Contract TREN/07/D3/390-2006/S07.72702, available through 'eup4light.net'

[264] Commission Staff Working Document, accompanying document to the Commission Regulation implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for directional lamps, light emitting diode lamps and related equipment, Impact Assessment, Brussels, 2012, available as http://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2012/swd_2012_0418_en.pdf

Annex F. POWER, DATA COLLECTION

F.1 IEA 4E / GfK data on average power

F.1.1 Introduction

Recently the study team obtained GfK [265] sales data for light sources. Since September 2014 these data have also been published in the public domain by IEA 4E [266]. The data have been gathered in Austria, Belgium, France, Germany, Great Britain, Italy and Netherlands for the years 2007-2013, and in Poland and Spain for the years 2011-2013.

These data are reported to have an average coverage of 70% of the non-LED lamp sales in the countries and years considered. A slightly lower coverage might apply for LED lamps. The data regard mainly domestic sales, i.e. lamps for residential use. See Annex D of the Task 2 report for details.

An interesting aspect of the GfK data is that they also provide insight in the distribution of the sales over various wattage ranges, thus enabling an estimate of the average installed powers. Sales-weighted average efficiencies (lm/W) are also reported.

F.1.2 Data elaboration

The 4E/GfK sales data are subdivided, for each lamp technology type, in what they call 'wattage buckets'. These are discrete light source power ranges that have been chosen differently for each lamp technology type in function of the powers that are typically being sold for that type. The upper limit of the range is set at a typical, frequently sold power for that lamp type, with the lower limit set immediately above the preceding typical power. For example 60 W incandescent lamp sales are counted in the bucket of 40 W < power ≤ 60 W, while 40 W lamps would be counted in the preceding bucket of 25 W < power ≤ 40 W.

The study team used these data to compute average powers per lamp type technology. Some details on the elaboration of the data:

- The 4E product definition document recommends to use as reference power for a wattage bucket its upper limit value (assumed to be a typical frequently sold power) minus 5% of its width. For example for the bucket of 40 W < power ≤ 60 W this would give 60 –5%*(60-40) = 59 W. The study team used this method, but also evaluated the outcome of an alternative method where the reference power is the centre of the bucket (which corresponds to using 50% instead of 5%). For the example range this would give 50 W.

- For the top-most range (for example power > 100 W) it is difficult to assign a reference power. If not specified otherwise, the study team evaluated the effect of using 1.5 or 2.0 times the maximum power limit (would give 150 W or 200 W in the example).

- The combination of '5% and 2.0 times' leads to the maximum average power estimate; the combination of '50% and 1.5 times' to the minimum estimate. Both minimum and maximum are reported below.

Note that sales data reported in the following subparagraphs are the original data as reported by 4E/GfK. They have NOT been scaled to EU-28 level. See the Task 2 report for scaled data.

[265] GfK ('Gesellschaft für Konsumforschung') is an institute for market research based in Germany and now represented in more than 100 countries. http://www.gfk.com/de/Seiten/default.aspx

[266] "4E Mapping Document, European Union, Domestic Lighting". Available through: http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5 together with other supporting material.

Although not clear from the 4E documents, it is expected that the reported powers are rated powers and that for lamps with integrated control gear the effects of this gear are included.

F.1.3 Incandescent lamps, mains voltage

Table 87 shows the computation of the average wattage for MV incandescent lamps, based on 4E/GfK data. Comments:

- Sales in the highest wattage range are low and consequently the computation result is not very sensitive to the reference power assumed for this range.
- The average wattage shows a decreasing tendency with the years. This is expected to be due to the ecodesign measures, that gradually phased out the incandescent lamps, starting with the higher lumen/wattage lamps.
- Average wattage seems to be higher for Spain and Poland.

In the opinion of the study team the most realistic estimate, based on these data, is close to the maximum shown in the table, i.e. **40-45 W** for year 2013.

Mains voltage incandescents		Sales volume (millions of lamps) per wattage range							
Wattage range		0-25	26-40	41-60	61-75	76-100	>100	average wattage estimate (W)	
Reference wattage (at 5%, 2x)		23.8	39.3	59.0	74.3	98.8	200		
Countries AT, BE, FR, DE, UK, IT, NL	sum							MAX	MIN
2007	390	48.7	149.1	140.4	11.3	39.1	1.2	51.9	43.6
2008	338	45.7	132.3	117.5	10.5	31.3	0.6	51.0	42.7
2009	342	50.9	136.3	123.6	10.4	20.5	0.5	49.0	40.8
2010	240	41.6	112.2	78.3	5.7	2.3	0.1	44.5	36.6
2011	231	42.0	113.2	72.4	1.9	1.7	0.1	43.4	35.5
2012	147	37.6	83.5	24.2	0.6	1.4	0.1	39.4	31.4
2013	57	15.8	27.6	11.6	0.5	1.3	0.1	41.0	32.6
Countries ES, PL	sum								
2011	17	2.3	6.8	6.6	0.9	0.3	0.0	47.8	39.9
2012	21	4.2	10.9	4.0	0.7	0.9	0.0	44.1	36.1
2013	10	1.8	4.1	2.2	0.7	0.9	0.0	49.8	41.5

Table 87 Average wattage for MV incandescent lamps, computed by the study team from 4E/GfK data. The table provides the sales volumes in millions of units per wattage range and per year, for two country groups. The reference wattage is the one leading to the maximum average wattage estimate (using 5% and 2x, see F.1.2).

F.1.4 Halogen lamps, single ended, mains voltage

Table 88 shows the computation of the average wattage for MV single ended halogen lamps, based on 4E/GfK data. Comments:

- Sales in the highest wattage range are relatively low and consequently the computation result is moderately sensitive to the reference power assumed for this range.
- The average wattage shows a decreasing tendency with the years.

In the opinion of the study team the most realistic estimate, based on these data, is close to the minimum shown in the table, i.e. **38-40 W** for year 2013.

MV halogens (single ended)		Sales volume (millions of lamps) per wattage range								
Wattage range		0-17	18-20	21-28	29-43	44-53	54-73	>73	average wattage estimate (W)	
Reference wattage (at 5%, 2x)		16.15	19.90	27.65	42.30	52.55	72.05	146.00		
Countries AT, BE, FR, DE, UK, IT, NL	sum								MAX	MIN
2007	45	0.0	0.8	2.1	13.9	25.6	1.4	1.0	50.3	44.7
2008	52	0.0	1.2	3.7	18.7	26.2	1.5	0.9	48.6	43.1
2009	68	0.1	1.8	8.0	27.2	26.8	2.7	1.6	47.5	41.8
2010	97	0.2	3.7	14.1	41.5	30.3	5.1	2.4	46.6	40.8
2011	137	0.3	5.7	20.8	60.8	37.3	9.7	2.7	46.0	40.3
2012	198	0.2	9.7	36.0	96.2	37.8	14.6	3.4	44.4	38.7
2013	259	0.3	17.4	52.7	132.4	35.0	17.5	4.2	42.9	37.2
Countries ES, PL	sum									
2011	7	0.0	0.2	1.2	3.5	1.7	0.6	0.2	46.2	40.3
2012	11	0.0	0.4	2.0	5.7	2.2	0.8	0.3	45.4	39.4
2013	16	0.0	0.8	3.0	8.1	2.8	1.3	0.3	44.6	38.8

Table 88 Average wattage for MV single ended halogen lamps, computed by the study team from 4E/GfK data. The table provides the sales volumes in millions of units per wattage range and per year, for two country groups. The reference wattage is the one leading to the maximum average wattage estimate (using 5% and 2x, see Annex F.1.2).

F.1.5 Halogen lamps, double ended, mains voltage

Table 89 shows the computation of the average wattage for MV double ended halogen lamps, based on 4E/GfK data. Comments:

- Sales in the highest wattage range are high and consequently the computation result is sensitive to the reference power assumed for this range. For example when using a reference power of 400 W instead of 500 W, the 2013 maximum average power of 243 reduces to 221 W.
- The average wattage shows a decreasing tendency with the years.
- Average wattage seems to be slightly higher for Spain and Poland.

In the opinion of the study team the most realistic estimate, based on these data, is **200-240 W** for year 2013.

MV halogens (double ended)		Sales volume (millions of lamps) per wattage range						
Wattage range		0-100	101-150	151-200	201-250	>250	average wattage estimate (W)	
Reference wattage (at 5%, 2x)		95	148	198	248	500		
Countries AT, BE, FR, DE, UK, IT, NL	sum						MAX	MIN
2007	15	1.3	4.2	0.9	0.1	8.6	347	264
2008	15	1.4	4.2	0.8	0.2	8.6	346	263
2009	13	1.6	3.7	1.0	0.4	6.6	324	248
2010	10	1.7	2.6	1.2	1.4	3.3	273	213
2011	10	1.9	2.7	1.1	1.9	2.9	258	204
2012	10	1.9	2.7	1.0	2.2	2.5	248	197
2013	11	2.2	2.8	1.1	2.4	2.4	243	194
Countries ES, PL	sum							
2011	1	0.2	0.4	0.1	0.2	0.4	264	207
2012	2	0.2	0.4	0.1	0.2	0.5	274	215
2013	2	0.3	0.4	0.1	0.3	0.5	271	213

Table 89 Average wattage for MV double ended halogen lamps, computed by the study team from 4E/GfK data. The table provides the sales volumes in millions of units per wattage range and per year, for two country groups. The reference wattage is the one leading to the maximum average wattage estimate (using 5% and 2x, see Annex F.1.2).

F.1.6 Halogen lamps, low voltage (12 V)

Table 90 shows the computation of the average wattage for low voltage (12 V) halogen lamps, based on 4E/GfK data. Comments:

- Sales in the highest wattage range are zero and consequently the computation result is not influenced by the reference power assumed for this range.
- Sales are concentrated in the 0-34 W range and consequently the average power is very sensitive to the reference power selected for this range.
- The average wattage is relatively constant with the years.
- Average wattage seems to be higher for Spain and Poland.

In the opinion of the study team the most realistic estimate, based on these data, is close to the maximum shown in the table, i.e. **around 35 W** for year 2013.

Low voltage (12V) halogens		Sales volume (millions of lamps) per wattage range						
Wattage range		0-34	35-38	39-50	51-100	>100	average estimated wattage (W)	
Reference wattage (at 5%, 2x)		32.3	37.9	49.5	97.6	200.0		
Countries AT, BE, FR, DE, UK, IT, NL	sum						MAX	MIN
2007	34	23.8	4.2	6.1	0.0	0.0	36.2	24.5
2008	37	26.6	4.4	5.6	0.0	0.0	35.7	23.7
2009	36	26.1	4.2	5.4	0.0	0.0	35.6	23.5
2010	37	26.8	4.4	5.5	0.0	0.0	35.5	23.5
2011	37	27.1	4.6	5.7	0.0	0.0	35.6	23.6
2012	38	27.3	4.9	5.4	0.0	0.0	35.5	23.5
2013	38	28.0	4.6	5.2	0.0	0.0	35.4	23.2
Countries ES, PL	sum							
2011	3	1.4	0.5	0.7	0.0	0.0	38.4	28.7
2012	4	2.2	0.8	1.0	0.0	0.0	38.2	28.2
2013	4	2.1	0.7	0.8	0.0	0.0	37.2	26.8

Table 90 Average wattage for low voltage (12 V) halogen lamps, computed by the study team from 4E/GfK data. The table provides the sales volumes in millions of units per wattage range and per year, for two country groups. The reference wattage is the one leading to the maximum average wattage estimate (using 5% and 2x, see Annex F.1.2).

F.1.7 CFLni (pin based)

Table 91 shows the computation of the average wattage for mains voltage pin based CFL lamps (CFLni), based on 4E/GfK data. Comments:

- This is not a typical lamp type for residential use and consequently the sales data captured by GfK are low. It is not certain that the sales and the corresponding wattage distribution are representative for the use of these lamps in non-residential applications.
- Sales in the highest wattage range are significant and consequently the computation result is sensitive to the reference power assumed for this range. This is true in particular for the sales in Spain and Poland.
- The average wattage has a tendency to increase with the years.
- The average wattage is much higher for Spain and Poland, most sales being concentrated in the highest wattage group.

In the opinion of the study team these data are not sufficiently reliable to derive a reference wattage for CFLni.

Mains voltage pin based CFLs		Sales volume (millions of lamps) per wattage range												
Wattage range		0-3	4-5	6-7	8	9-11	12-13	14-15	16-20	21-25	>25		average estimated wattage (W)	
Reference wattage (at 5%, 2x)		2.85	4.95	6.95	8.00	10.90	12.95	14.95	19.80	24.80	50.00			
Countries AT, BE, FR, DE, UK, IT, NL	sum												MAX	MIN
2007	1.1	0.0	0.0	0.1	0.0	0.6	0.1	0.0	0.2	0.0	0.1		15.6	13.7
2008	1.2	0.0	0.0	0.2	0.0	0.6	0.1	0.0	0.2	0.0	0.1		15.7	13.7
2009	1.4	0.0	0.0	0.2	0.0	0.6	0.1	0.0	0.2	0.0	0.1		15.5	13.5
2010	1.3	0.0	0.0	0.1	0.0	0.6	0.1	0.0	0.3	0.0	0.2		17.5	15.1
2011	1.4	0.0	0.0	0.1	0.0	0.6	0.1	0.0	0.3	0.0	0.2		17.9	15.4
2012	1.5	0.0	0.0	0.2	0.0	0.7	0.1	0.0	0.3	0.0	0.2		18.0	15.4
2013	1.6	0.0	0.0	0.1	0.0	0.7	0.1	0.0	0.3	0.0	0.2		18.5	15.8
Countries ES, PL	sum													
2011	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6		44.2	33.5
2012	0.8	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.7		44.4	33.6
2013	0.8	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.6		44.2	33.5

Table 91 Average wattage for pin based CFLni lamps, computed by the study team from 4E/GfK data. The table provides the sales volumes in millions of units per wattage range and per year, for two country groups. The reference wattage is the one leading to the maximum average wattage estimate (using 5% and 2x, see Annex F.1.2).

F.1.8 CFLi (self-ballasted)

Table 92 shows the computation of the average wattage for mains voltage self-ballasted CFL lamps (CFLi), based on 4E/GfK data. Comments:

- Sales in the highest wattage range are relatively small and consequently the computation result is not very sensitive to the reference power assumed for this range.
- The average wattage is relatively constant over the years but there seems to be a tendency to increase in the last two years.

In the opinion of the study team the most realistic estimate, based on these data, is **around 14 W** for year 2013.

MV self-ballasted CFLs		Sales volume (millions of lamps) per wattage range												
Wattage range		0-3	4-5	6-7	8	9-11	12-13	14-15	16-20	21-25	>25		average estimated wattage (W)	
Reference wattage (at 5%, 2x)		2.85	4.95	6.95	8.00	10.90	12.95	14.95	19.80	24.80	50.00			
Countries AT, BE, FR, DE, UK, IT, NL	sum												MAX	MIN
2007	68.5	0.1	3.3	4.5	5.8	24.4	3.4	8.8	13.6	3.6	0.7		13.6	12.6
2008	80.8	0.1	3.8	6.3	7.5	30.1	4.2	9.9	14.6	3.9	0.4		13.1	12.2
2009	102.3	0.1	4.8	6.6	10.7	35.3	5.5	19.5	15.3	4.2	0.4		13.0	12.1
2010	116.0	0.2	5.7	7.5	12.8	37.1	6.7	22.9	18.1	4.5	0.6		13.1	12.2
2011	96.0	0.2	4.8	6.9	9.6	30.7	5.7	18.3	14.9	4.2	0.6		13.1	12.2
2012	73.6	0.1	4.3	6.2	7.2	21.4	4.8	11.5	12.5	4.4	1.4		13.8	12.7
2013	66.6	0.1	3.8	5.1	5.9	19.2	4.9	9.5	11.4	4.4	2.2		14.5	13.2
Countries ES, PL	sum													
2011	14.2	0.0	0.2	0.5	1.0	5.4	0.4	3.5	2.4	0.7	0.1		14.0	13.0
2012	14.6	0.0	0.3	0.7	0.9	5.1	0.7	3.4	2.5	1.0	0.1		14.3	13.3
2013	13.4	0.0	0.2	0.5	0.7	4.4	1.0	3.3	2.2	1.1	0.1		14.6	13.6

Table 92 Average wattage for self-ballasted CFLi lamps, computed by the study team from 4E/GfK data. The table provides the sales volumes in millions of units per wattage range and per year, for two country groups. The reference wattage is the one leading to the maximum average wattage estimate (using 5% and 2x, see Annex F.1.2).

F.1.9 Linear fluorescent tubes (T5, T8, T12)

Table 93 shows the computation of the average wattage for **LFL T5** tube lamps, based on 4E/GfK data. Comments:

- This is not a typical lamp type for residential use and consequently the sales data captured by GfK are low. It is not certain that the sales and the corresponding wattage distribution are representative for the use of these lamps in non-residential applications.
- Nearly all sales are in the lowest wattage bucket and consequently the average wattage depends mainly on the reference wattage that is chosen for this range.

In the opinion of the study team these data are not sufficiently reliable to derive a reference wattage for LFL T5 tubes.

MV LFL tubes (T5)		Sales volume (millions of lamps) per wattage range				
Wattage range		0-28	29-50	>50	average estimated wattage (W)	
Reference wattage (at 5%, 2x)		26.60	48.95	100.00		
Countries AT, BE, FR, DE, UK, IT, NL	sum				MAX	MIN
2007	1.4	1.4	0.0	0.0	27.0	14.4
2008	1.4	1.4	0.0	0.0	26.9	14.4
2009	1.5	1.5	0.0	0.0	26.8	14.3
2010	1.4	1.4	0.0	0.0	26.7	14.1
2011	1.5	1.5	0.0	0.0	26.7	14.1
2012	1.5	1.5	0.0	0.0	26.8	14.2
2013	1.6	1.6	0.0	0.0	26.8	14.2
Countries ES, PL	sum					
2011	0.1	0.1	0.1	0.0	36.5	25.2
2012	0.2	0.1	0.1	0.0	34.5	22.9
2013	0.2	0.2	0.1	0.0	33.9	22.2

Table 93 Average wattage for LFL tubes (T5), computed by the study team from 4E/GfK data. The table provides the sales volumes in millions of units per wattage range and per year, for two country groups. The reference wattage is the one leading to the maximum average wattage estimate (using 5% and 2x, see Annex F.1.2).

Table 94 shows the computation of the average wattage for **LFL T8** tube lamps, based on 4E/GfK data. Comments:

- This is not a typical lamp type for residential use and consequently the sales data captured by GfK are relatively low. It is not certain that the sales and the corresponding wattage distribution are representative for the use of these lamps in non-residential applications.
- A significant quantity of sales is in the highest wattage bucket, implying that the average wattage is very sensitive to the reference wattage assigned to this bucket.
- The average wattage seems to be lower for Spain and Poland.
- It is not specified if sales refer to Halo-phosphor or to Tri-phosphor lamp technology. For later years they should refer to tri-phosphor.

In the opinion of the study team the most realistic estimate for **LFL T8 tubes**, based on these data, is close to the minimum shown in the table, i.e. **33-35 W** for year 2013.

MV LFL tubes (T8)		Sales volume (millions of lamps) per wattage range						
Wattage range		0-24	25-27	28-31	>31		average estimated wattage (W)	
Reference wattage (at 5%, 2x)		22.80	26.90	30.85	62.00			
Countries AT, BE, FR, DE, UK, IT, NL	sum						MAX	MIN
2007	7.0	2.5	0.0	0.5	4.0		45.8	33.0
2008	7.1	2.5	0.0	0.5	4.1		46.0	33.2
2009	7.2	2.5	0.0	0.5	4.2		46.2	33.4
2010	7.0	2.5	0.0	0.5	4.0		45.8	33.1
2011	6.6	2.4	0.0	0.5	3.7		45.3	32.6
2012	6.6	2.4	0.0	0.5	3.7		45.3	32.6
2013	6.8	2.5	0.0	0.5	3.8		45.4	32.6
Countries ES, PL	sum							
2011	0.9	0.5	0.0	0.0	0.4		40.8	28.0
2012	1.3	0.7	0.0	0.0	0.6		40.4	27.7
2013	1.2	0.6	0.0	0.0	0.5		40.7	28.0

Table 94 Average wattage for LFL tubes (T8), computed by the study team from 4E/GfK data. The table provides the sales volumes in millions of units per wattage range and per year, for two country groups. The reference wattage is the one leading to the maximum average wattage estimate (using 5% and 2x, see Annex F.1.2).

Table 95 shows the computation of the average wattage for **LFL T12** tube lamps, based on 4E/GfK data. Comments:

- As also shown by the sales numbers, this type of lamp has been phased out.
- This is not a typical lamp type for residential use and consequently the sales data captured by GfK are low. It is not certain that the sales and the corresponding wattage distribution are representative for the use of these lamps in non-residential applications.

In the opinion of the study team these data are not sufficiently reliable to derive a reference wattage for LFL T12 tubes.

MV LFL tubes (T12)		Sales volume (millions of lamps) per wattage range						
Wattage range		0-33	34-40	>40			average estimated wattage (W)	
Reference wattage (at 5%, 2x)		31.35	39.70	80.00				
Countries AT, BE, FR, DE, UK, IT, NL	sum						MAX	MIN
2007	0.4	0.0	0.2	0.2			58.1	46.2
2008	0.2	0.0	0.1	0.0			48.7	38.7
2009	0.1	0.0	0.0	0.0			49.9	38.2
2010	0.1	0.0	0.1	0.0			53.0	41.8
2011	0.1	0.0	0.0	0.0			53.7	43.1
2012	0.0	0.0	0.0	0.0			52.5	42.0
2013	0.0	0.0	0.0	0.0			37.3	29.3
Countries ES, PL	sum							
2011	0.0	0.0	0.0	0.0			36.3	28.7
2012	0.0	0.0	0.0	0.0			55.1	45.4
2013	0.0	0.0	0.0	0.0			40.9	37.7

Table 95 Average wattage for LFL tubes (T12), computed by the study team from 4E/GfK data. The table provides the sales volumes in millions of units per wattage range and per year, for two country groups. The reference wattage is the one leading to the maximum average wattage estimate (using 5% and 2x, see Annex F.1.2).

F.1.10 LED lamps (retrofit and dedicated)

Table 96 shows the computation of the average wattage for **Retrofit LED** lamps, based on 4E/GfK data.

Table 97 shows the same computation for **Dedicated LED** lamps. Comments:

- Sales volumes are rapidly increasing with the years, both for Retrofit LED lamps and for Dedicated LED lamps [267].
- For both lamp types the average wattage increases significantly with the years. This is an indication that LED lamps are increasingly being used for higher lumen/power applications.
- There are hardly any sales in the highest wattage bucket, so the calculated averages are not sensitive to the reference power assumed for this bucket.

In the opinion of the study team these data indicate an average power for LED lamps in 2013 around **5.5-6.0 W for retrofit lamps** and **4.0-4.5 W for dedicated LED lamps**.

Retrofit LED lamps		Sales volume (millions of lamps) per wattage range									
Wattage range		0-1	1-2	2-4	4-8	8-11	12-14	15-20	>20	average estimated wattage (W)	
Reference wattage (at 5%, 2x)		0.95	1.95	3.90	7.80	10.85	13.90	19.75	40.00		
Countries AT, BE, FR, DE, UK, IT, NL	sum									MAX	MIN
2007	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.7	1.2
2008	0.5	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	1.6	1.2
2009	1.1	0.5	0.5	0.1	0.0	0.0	0.0	0.0	0.0	1.8	1.3
2010	1.7	0.5	0.9	0.2	0.1	0.0	0.0	0.0	0.0	2.2	1.7
2011	2.5	0.5	1.0	0.6	0.3	0.0	0.0	0.0	0.0	3.2	2.5
2012	5.0	0.6	0.9	1.7	1.3	0.4	0.1	0.0	0.0	5.0	3.9
2013	11.0	0.6	0.9	4.0	3.2	1.8	0.3	0.0	0.1	6.5	5.2
Countries ES, PL	sum										
2011	0.3	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	3.6	2.7
2012	0.9	0.1	0.2	0.4	0.2	0.0	0.0	0.0	0.0	4.3	3.3
2013	2.0	0.1	0.2	0.9	0.6	0.2	0.0	0.0	0.0	5.8	4.6

Table 96 Average wattage for Retrofit LED lamps, computed by the study team from 4E/GfK data. The table provides the sales volumes in millions of units per wattage range, for two country groups. The reference wattage is the one leading to the maximum average wattage estimate (using 5% and 2x, see Annex F.1.2).

Dedicated LED lamps		Sales volume (millions of lamps) per wattage range									
Wattage range		0-1	1-2	2-4	4-8	8-11	12-14	15-20	>20	average estimated wattage (W)	
Reference wattage (at 5%, 2x)		0.95	1.95	3.90	7.80	10.85	13.90	19.75	40.00		
Countries AT, BE, FR, DE, UK, IT, NL	sum									MAX	MIN
2007	0.8	0.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	1.6	1.1
2008	1.7	0.6	1.1	0.0	0.0	0.0	0.0	0.0	0.0	1.6	1.2
2009	2.6	1.0	1.3	0.2	0.0	0.0	0.0	0.0	0.0	1.8	1.3
2010	4.2	1.1	1.7	1.3	0.1	0.0	0.0	0.0	0.0	2.4	1.8
2011	4.6	1.1	1.3	1.8	0.4	0.0	0.0	0.0	0.0	2.9	2.2
2012	6.7	0.9	1.5	2.6	1.8	0.0	0.0	0.0	0.0	4.1	3.1
2013	11.4	0.7	2.5	3.8	4.4	0.0	0.0	0.0	0.0	4.9	3.7
Countries ES, PL	sum										
2011	1.6	0.2	0.3	0.8	0.2	0.0	0.0	0.0	0.0	3.7	2.8
2012	3.7	0.3	0.7	2.1	0.5	0.0	0.0	0.0	0.0	3.9	3.0
2013	5.0	0.3	0.7	2.3	1.6	0.0	0.0	0.0	0.0	4.8	3.7

Table 97 Average wattage for Dedicated LED lamps, computed by the study team from 4E/GfK data. The table provides the sales volumes in millions of units per wattage range, for two country groups. The reference wattage is the one leading to the maximum average wattage estimate (using 5% and 2x, see Annex F.1.2).

[267] The sales reported here are the original 4E/GfK data and they have NOT been scaled to EU-28 level. See Annex D.3 of the Task 2 report for such scaled data.

F.2 GPP indoor on lighting power density

The following data on lighting power density have been extracted from the GPP Indoor [268] requirements:

Core criteria	Comprehensive criteria
3.2 EU GPP criteria for design of indoor lighting	
SUBJECT MATTER	**SUBJECT MATTER**
Resource and energy efficient design of new lighting systems or renovation of the existing lighting system	Resource and energy efficient design of new lighting systems or renovation of the existing lighting system
TECHNICAL SPECIFICATIONS	**TECHNICAL SPECIFICATIONS**
1. Where lighting is to be installed throughout a building, the maximum lighting power consumed in the whole building, divided by its total floor area, must not exceed the following values:	**1.** Where lighting is to be installed throughout a building, the maximum lighting power consumed in the whole building, divided by its total floor area, must not exceed the following values:

Type of building	Lighting power density W/m² (Core criteria)	Lighting power density W/m² (Comprehensive criteria)
Car park	2.5	2.2
Court	14	13
Exhibition space, museum	9	7.5
Fire station	12	11
Further education	13	11
Hospital	12	11
Library	12	11
Office (mainly cellular)	13	11
Office (mainly open plan)	11	10
Police station	14	13
Post office	14	13
Prison	9	8
Public hall	9	7.5
Residential	11	9
Residential (communal spaces only)	6	4.5
School	8	7
Sports centre	9	7.5
Town hall	13	12

Core criteria	Comprehensive criteria
Verification: A calculation provided by the lighting designer showing the total power consumed by the lighting, including lamps, ballasts, sensors and controls, divided by the total floor area of all the indoor spaces in the building. The lighting designer should also show that the lighting meets the relevant performance standards in EN 12464-1, equivalent national standards or best practice guides, or those set by the public authority. Depending on the type of space and its requirements, these may include illuminance, uniformity, control of glare, colour rendering and colour appearance.	**Verification:** A calculation provided by the lighting designer showing the total power consumed by the lighting, including lamps, ballasts, sensors and controls, divided by the total floor area of all the indoor spaces in the building. The lighting designer should also show that the lighting meets the relevant performance standards in EN 12464-1, equivalent national standards or best practice guides, or those set by the public authority. Depending on the type of space and its requirements, these may include illuminance, uniformity, control of glare, colour rendering and colour appearance.

Table 98 Recommended values for lighting power density (W/m²) from GPP Indoor lighting

[268] "Green Public Procurement , Indoor Lighting , Technical Background Report", BRE 2011, http://ec.europa.eu/environment/gpp/pdf/tbr/indoor_lighting_tbr.pdf
"EU GPP Criteria for Indoor Lighting", 2012, http://ec.europa.eu/environment/gpp/pdf/criteria/indoor_lighting.pdf

2. Where lighting is to be installed in an individual space or part of the building, the maximum lighting power consumed in the space, divided by its total floor area and by its illuminance in units of 100 lux, must not exceed the following values:

Type of space	Normalised lighting power density ($W/m^2/100$ lux)
Bedrooms	7.5
Canteens	3.5
Car parks	2.2
Circulation inc lifts, stairs	3.2
Conference rooms	2.8
Gyms	2.8
Halls	2.8
Hospital wards and examination rooms	4
Kitchens (domestic)	5
Kitchens (restaurants)	2.8
Laboratories	2.8
Libraries	3.2
Lounges – large area	6
Lounges – small area	7.5
Offices (open plan)	2.3
Offices (cellular)	3
Plant rooms	3.2
Post rooms/ switchboards	3.2
Prison cells	4
Reception	4
Rest rooms, toilets, bathrooms	5
Retail	3.5
School classrooms	2.3
Store rooms	3.2
Waiting rooms	3.2

Verification: The lighting designer shall provide a calculation showing the total power consumed by the lighting, including lamps, ballasts, sensors and controls, divided by the total floor area of the space, and by one hundredth of the illuminance in the space. Thus if the illuminance were 500 lux, the lighting power would be divided by the floor area and by 5.

The illuminance used in the calculation shall be the recommended illuminance in EN 12464-1 or equivalent national standard, or the installed maintained illuminance if it is lower. If EN 12464-1, or the equivalent national standard, does not give a recommendation for the type of space, the installed maintained illuminance shall be used.

For stairwells, the total floor area may include the area of the risers on the stairs as well as horizontal surfaces.

For unusually small spaces, the contracting authority may increase the target power densities, or compliance with the criterion need not be enforced.

2. Where lighting is to be installed in an individual space or part of the building, the maximum lighting power consumed in the space, divided by its total floor area and by its illuminance in units of 100 lux, must not exceed the following values:

Type of space	Normalised lighting power density ($W/m^2/100$ lux)
Bedrooms	6
Canteens	3.2
Car parks	2
Circulation inc lifts, stairs	3
Conference rooms	2.6
Gyms	2.6
Halls	2.6
Hospital wards and examination rooms	3.5
Kitchens (domestic)	4
Kitchens (restaurants)	2.6
Laboratories	2.6
Libraries	3
Lounges – large area	4.5
Lounges – small area	6
Offices (open plan)	2
Offices (cellular)	2.8
Plant rooms	3
Post rooms/ switchboards	3
Prison cells	3.5
Reception	3.5
Rest rooms, toilets, bathrooms	4
Retail	3.2
School classrooms	2
Store rooms	3
Waiting rooms	3

Verification: The lighting designer shall provide a calculation showing the total power consumed by the lighting, including lamps, ballasts, sensors, and controls, divided by the total floor area of the space, and by one hundredth of the illuminance in the space. Thus if the illuminance were 500 lux, the lighting power would be divided by the floor area and by 5.

The illuminance used in the calculation shall be the recommended illuminance in EN 12464-1 or equivalent national standard, or the installed maintained illuminance if it is lower. If EN 12464-1, or the equivalent national standard, does not give a recommendation for the type of space, the installed maintained illuminance shall be used.

For stairwells, the total floor area may include the area of the risers on the stairs as well as horizontal surfaces.

For unusually small spaces, the contracting authority may increase the target power densities, or compliance with the criterion need not be enforced.

Table 99 Recommended values for normalised lighting power density (W/m^2/100lux) from GPP Indoor lighting

F.3 Power factor

In the Impact Assessment for non-directional household lamps [269], the following description was given for the 'power factor':

> *"The power factor of an AC electric power system is defined as the ratio of the real power to the apparent power and is a number between 0 and 1. Real power is the capacity of the circuit for performing work in a particular time. Apparent power includes the reactive power that utilities need to distribute even when it accomplishes no useful work. Low-power-factor loads increase losses in a power distribution system and result in increased energy costs. GLS and halogen lamps (HL) have a power factor equal to 1. For lamps operating on a ballast or electronics such as CFLi's, this power factor can go down to 0.50; the lower the power factor, the higher the electrical current that is needed to result in the same real power. This higher current causes 5% more losses in the electrical grid that feeds the lamp."*
>
> However, one has to consider that there exists inductive, reactive power as well as capacitive, reactive power in the electrical grid and the two compensate each other. Motors (e.g. refrigerators, elevators, vacuum cleaners, pumps, ...) or inductors (magnetic ballasts for fluorescent or high intensity discharge lamps) are typically inductive loads, while many electronic sources (CFL, PCs, TVs, …) are capacitive. In general the grid tends to be more inductive due to the high amount of motor loads, and in industrial applications power factor compensation capacitors are frequently installed. Hence CFL that are capacitive are unlikely to create strong negative grid influences because they rather compensate inductive loads and are unlikely to dominate the total active power demand of the grid.
>
> The preparatory study already quantified in its modelling the extra power needed when operating a CFL (in the order of 5%), if no inductive loads are present on the grid. The study used such corrected figures in the CFL-related parts of the scenario analysis, so the obtained savings already include a worst-case assumption on the impact of their lower power factor. A massive switch to lower power factor lamps has never been experimented on the European scale, and some sources have also reported harmonic interference issues in grids with high number of CFLs.
>
> For security, requirements on minimum power factor for CFLs are proposed to be set in the measure.

<u>Power factor requirements in the current regulations</u>

Regulation 244/2009 prescribes the following minimum power factors for CFL's:

- Stage 1 (September 2009): PF ≥ 0.50 if power < 25W ; PF ≥0.90 if power ≥ 25W
- Stage 5 (September 2013): PF ≥ 0.55 if power < 25W ; PF ≥0.90 if power ≥ 25W

while for other lamps subject to 244/2009 but excluding CFL and LED (applies mainly to halogen) the power factor should be at least 0.95 from September 2009.

Regulation 1194/2012 prescribes the following minimum power factors for directional CFLi's (these are the same as above for non-directional lamps, but with different dates):

- Stage 1 (September 2013): PF ≥ 0.50 if power < 25W ; PF ≥0.90 if power ≥ 25W

[269] Commission Staff Working Document, accompanying document to the Commission Regulation implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for non-directional household lamps, Full Impact Assessment, Brussels, 18.3.2009, SEC(2009) 327, available as http://ec.europa.eu/energy/efficiency/ecodesign/doc/legislation/sec_2009_327_impact_assesment_en.pdf

- Stage 3 (September 2016): PF ≥ 0.55 if power < 25W ; PF ≥0.90 if power ≥ 25W

For other directional lamps with integrated control gear, excluding LED, CFL and HID, the following limits apply for the power factor [270]:

- Stage 1 (September 2013): PF ≥ 0.50 if power ≤ 25W ; PF ≥0.90 if power > 25W
- Stage 3 (September 2016): PF ≥ 0.50 if power ≤ 25W ; PF ≥0.90 if power > 25W

For non-directional and directional LED lamps with integrated control gear the power factor PF) limits are (from Stage 1, September 2013):

- No requirement if power ≤ 2W
- PF > 0.4 if 2W < power ≤ 5W
- PF > 0.5 if 5W < power ≤ 25W
- PF > 0.9 if power > 25W

An explanation of Power Factor for electrical non-experts

The **real power** (usual symbol **P**) of an electric or electronic device (such as a lamp, including its control gear) is the power that is actually consumed. This power is converted by the device in useful work (light for lamps) and in losses (mainly heat for lamps; depending on the efficacy/efficiency of the device).

Some devices temporarily draw more power from the electricity grid than they actually consume in that moment. This power is temporarily stored in the device and given back to the grid some moments later. This additional power is called **reactive power** (usual symbol **Q**). This power is NOT consumed by the device (lamp) but has to be transferred from and to the device by the grid and leads to additional power losses there.

The vector sum of real power and reactive power is called **apparent power** (usual symbol **S**), i.e. $S^2=P^2+Q^2$. The **power factor** (PF) is the ratio between real power and apparent power, i.e. **PF=P/S**. It gives the part of the power transferred by the electricity grid that is actually consumed by the lamp.

The components of the power, i.e. **voltage and current**, are basically **sine waves** with a frequency of 50 Hz (or 60 Hz for example in the US), meaning that in 1/50 seconds they first show positive values (positive sine half wave), a zero-crossing, and then negative values (negative sine half wave). This sequence is repeated 50 times in a second. The arithmetic average of all instantaneous values over the 1/50 seconds is zero because the positive and negative values compensate each other. To express the 'strength' of the sine wave, the **root mean square** (**rms**) of the instantaneous values is used, meaning that the instantaneous values are first squared (making the negative values positive), then averaged, and then the square root is taken. In this case, negative and positive values no longer compensate each other. For a perfect sine wave, the rms-value is the peak value of the sine wave divided by √2 (square root of 2 = 1.41). The common 230 V mains voltage in Europe is a rms value, the peak voltage of the sine wave being around 325 V.

In the ideal reference situation the voltage and current are **in-phase**, meaning that the zero-crossings of their sine waves correspond in time and that they are positive and negative in the same moments. In a non-ideal situation the **current may be shifted in time with respect to the voltage**, meaning that the zero crossings no longer correspond in time, and that voltage and current are out-of-phase. The amount by which they are **out-of-phase** is expressed as a **phase angle** (usual symbol **ϕ**). The first zero crossing of the voltage is normally taken at an angle of 90˚; if the current has its corresponding zero crossing for example

[270] This seems applicable only to incandescent and halogen lamps. Strange that the value here is not PF>0.95 as in Regulation 244/2009 for non-directional.

at 135˚, the phase angle ϕ=45˚, and the current is trailing the voltage, i.e. its zero crossing is later in time than that of the voltage.

If voltage and current remain pure sine waves (see remarks later), the power factor is the cosine of the phase angle, i.e. **PF= cos ϕ**. This value is often reported in device specifications.

For purely resistive loads (such as incandescent lamps), voltage and current are in phase, the phase angle is zero, and PF=1.0.

For capacitive loads such as CFLs and LED lamps, the current will lead the voltage (zero crossings in the current occur before those of the voltage), leading to a PF < 1.0.

For inductive loads such as motors, and LFL and HID lamps operating on magnetic ballast, the current will trail the voltage (zero crossings in the current occur after those of the voltage), leading to a PF < 1.0.

The effects of capacitive loads and inductive loads attached to the same electricity grid can compensate each other.

For examples of phase-shifted current, see Figure 65.

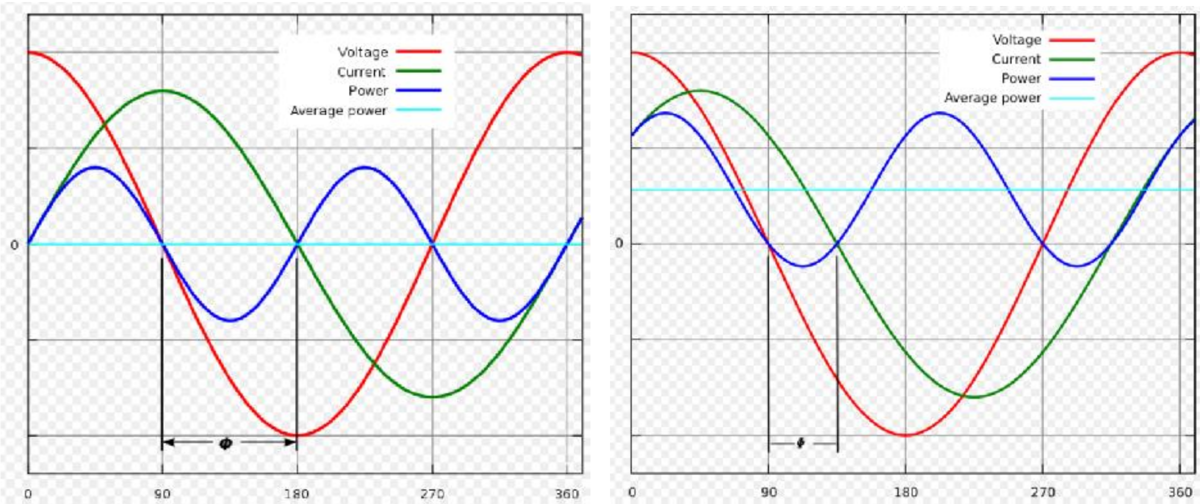


Figure 65 Two examples of power factor related to a phase angle shift between voltage and current. Left: the current trails the voltage by ϕ=90˚, PF=cos ϕ= 0. The average power is zero: all power is reactive, and there is no real power (no power consumption). Right: the current trails the voltage by ϕ=45˚, PF=cos ϕ= 0.71. The average power is non-zero and this is the real (consumed) power (P). The apparent power is higher: S=P/0.71. (source: Wikipedia, power factor, public domain)

In many literature sources and discussions the power factor is the one defined above as cos(ϕ). However, the above is **valid only if voltage and current remain pure sine waves** with the fundamental frequency of 50 (or 60) Hz. In many situations, the **harmonic distortion** in non-linear loads has also to be taken into account. Harmonics are sine waves of a higher frequency (a multiple of the fundamental 50 or 60 Hz) that are superimposed on the fundamental sine wave, creating a distortion of this latter. Harmonics are generated for example by diode bridge rectifiers that are used in LED control gears to convert the alternating current (AC) in direct current (DC).

In the presence of relevant harmonic distortion the power factor as described above is no longer adequate and the **true power factor** (TPF) should be used, which is defined as the ratio of the average power and the apparent power, i.e. **TPF = P_{avg} / (V_{rms}*I_{rms})**.

The average power (real consumed power) is computed by multiplying all instantaneous values of voltage and current (instantaneous powers) and taking the average over a certain time span (i.e. negative values can occur and will count as negative contributions to the average). On the contrary, the apparent power is computed by multiplying the rms value of the (distorted) voltage wave by the rms value of the (distorted) current wave (i.e. negative values are squared and thus contribute positively to the rms).

Alternatively, the true power factor can be computed as the product of a **displacement factor** ($\kappa_{displacement}$) and a **distortion factor** ($\kappa_{distortion}$).

In this case, according to a LightingEurope position paper on power factor [271] :

$$PF = \kappa_{displacement} \cdot \kappa_{distortion}$$

with

$$\kappa_{displacement} = \cos\varphi_1$$

and

$$\kappa_{distortion} = \frac{1}{\sqrt{1+THD_i^2}}$$

resulting in

$$PF = \frac{\cos\varphi_1}{\sqrt{1+THD_i^2}}$$

Note: Linear loads have no distortion ($THD_i = 0$). In that case $PF = \cos\varphi_1$

Angle φ_1 is the phase angle between the fundamental of the supply voltage and the fundamental of the mains current. The Total Harmonic Distortion (THD_i) is quantified by the harmonics of the mains current, which is already regulated according to the international standard IEC 61000-3-2. The relation between the individual harmonics of the mains current and the THD_i is explained in the equation:

$$THD_i = \sqrt{\sum_{n=2}^{\infty}\left(\frac{i_n}{i_1}\right)^2}$$

where i_n is the amplitude of the n^{th} harmonic of the mains current.

For additional details on the effect of harmonic distortions on the power factor, see an article by Grady and Gilleskie in the PQA'93 conference proceedings [272]. They also present an example for an fluorescent ceiling lamp with:

- Displacement factor: 0.956 (current leading the voltage)
- Total Harmonic Distortion: 39.5%
- Distortion factor: 0.930
- (True) Power Factor: 0.889

[271] http://www.lightingeurope.org/uploads/files/Position_Paper_Power_Factor_Sept_2014.pdf

[272] HARMONICS AND HOW THEY RELATE TO POWER FACTOR, W. Mack Grady and Robert J. Gilleskie, Proc. of the EPRI Power Quality Issues & Opportunities Conference (PQA'93), San Diego, CA, November 1993. https://hostdb.ece.utexas.edu/~grady/POWERFAC.pdf

According to the same reference, the distortion factor is particularly relevant for televisions and personal computers, that have a displacement factor close to 1 (almost no phase shift), but a low distortion factor (around 0.6) and hence a low true power factor. In addition the reference observes that:

> "*It is important to point out that one cannot, in general, compensate for poor distortion power factor by adding shunt capacitors. Only the displacement power factor can be improved with capacitors. This fact is especially important in load areas that are dominated by single-phase power electronic loads, which tend to have high displacement power factors but low distortion power factors. In these instances, the addition of shunt capacitors will likely worsen the power factor by inducing resonances and higher harmonic levels. A better solution is to add passive or active filters to remove the harmonics produced by the nonlinear loads, or to utilize low-distortion power electronic loads*."

Annex G. LUMINOUS FLUX, DATA COLLECTION

G.1 IEA 4E data on average luminous flux

The data presented below have been derived by the study team by multiplying the IEA 4E data on average efficacies (in lm/W, from Annex H.2) by the IEA 4E data on average powers (in W, from Annex F.1). For the latter a minimum and a maximum power have been estimated and as a consequence a range also results for the average luminous flux. For additional comments see Annex F.1.

Table 100 shows the estimated range for the average luminous flux of the various lamp types for the years 2007-2013. Comments:

- For **MV incandescent lamps (GLS)** the most realistic estimate is considered to be close to the maximum shown in the table, i.e. **400-430 lm** for the year 2013. The average luminous flux shows a decreasing tendency with the years. This is expected to be due to the ecodesign measures, that gradually phased out the incandescent lamps, starting with the higher lumen/wattage lamps.

- For **MV HL single ended**, the most realistic estimate is considered to be close to the minimum shown in the table, i.e. **520-560 lm** for the year 2013.

- For **MV HL double ended**, the most realistic estimate is considered to be **3700-4400 lm** for the year 2013.

- For **LV HL (12 V)**, the most realistic estimate is considered to be close to the maximum shown in the table, i.e. **around 620 lm** for the year 2013.

- For **self-ballasted CFLi**, the most realistic estimate, based on these data, is **around 840 lm** for the year 2013.

- For **LFL-T8 tubes**, the most realistic estimate is considered to be close to the minimum shown in the table, i.e. **2700-3000 lm** for the year 2013.

- For **retrofit LED lamps**, the most realistic estimate, based on these data, is **around 400-420 lm** for the year 2013. For LEDs the luminous flux shows a strong increase in recent years.

- For **dedicated LED lamps**, the most realistic estimate, based on these data, is **around 400-420 lm** for the year 2013. For LEDs the luminous flux shows a strong increase in recent years.

- For **pin based CFLni**, **LFL-T5 tubes, LFL-T12 tubes** no values are reported in the table because average wattage estimates are considered to be unreliable, see remarks in Annex F.1.

Estimate for average Luminous flux (lm)	Mains voltage incandescent		MV HL single ended		MV HL double ended		Low voltage HL (12 V)		Self-ballasted CFLi	
Countries AT, BE, FR, DE, UK, IT, NL	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
2007	597	502	729	649	6626	5046	634	428	783	723
2008	581	487	700	621	6603	5031	622	412	754	700
2009	554	461	680	598	6153	4707	623	412	748	698
2010	485	399	667	584	5125	4012	622	410	756	706
2011	469	383	658	576	4830	3814	627	415	766	714
2012	413	330	631	550	4631	3678	625	414	813	749
2013	438	349	604	525	4574	3638	627	412	864	789
Countries ES, PL										
2011	536	447	665	580	4956	3898	692	516	821	764
2012	485	397	649	564	5187	4063	687	507	849	788
2013	573	477	638	554	5154	4042	666	479	872	811

Estimate for average Luminous flux (lm)	LFL T8 tubes		LED retrofit		LED dedicated	
Countries AT, BE, FR, DE, UK, IT, NL	MAX	MIN	MAX	MIN	MAX	MIN
2007	3611	2603	62	45	73	52
2008	3640	2628	67	48	83	60
2009	3664	2646	82	58	105	76
2010	3635	2621	114	85	150	112
2011	3596	2588	184	141	207	156
2012	3601	2591	324	254	327	249
2013	3613	2599	473	381	430	330
Countries ES, PL						
2011	3140	2158	206	158	262	199
2012	3114	2135	274	212	311	238
2013	3148	2164	419	333	419	322

Table 100 Average luminous flux (lm) per lamp technology type for the years 2007-2013, computed by the study team from 4E/GfK data on average efficacy and average power. See comments in text.

Annex H. EFFICACIES, DATA COLLECTION

H.1 Minimum efficacies from EU-regulations

The main lamp efficacy requirements from **Regulation 244/2009** are reported in Table 101. Figure 66 shows the graphical representation in terms of efficacy versus luminous flux. These data do not cover exceptions and correction factors: see the text of the regulation.

The curve for non-clear lamps (green) mainly applies to CFLi.

The 2009-2012 curve for clear lamps phased out most incandescent lamps.

The 2016 curve for clear lamps is the subject of the Stage 6 discussion and regards mainly halogen lamps.

Application date	Maximum rated power (P_{max}) for a given rated luminous flux (Φ) (W)	
	Clear lamps	Non-clear lamps
Stages 1 to 5	$0,8 * (0,88\sqrt{\Phi}+0,049\Phi)$	$0,24\sqrt{\Phi}+0,0103\Phi$
Stage 6	$0,6 * (0,88\sqrt{\Phi}+0,049\Phi)$	$0,24\sqrt{\Phi}+0,0103\Phi$

Table 101 Maximum rated power for a given rated luminous flux, according to table 1 of Regulation 244/2009 for non-directional household lamps.

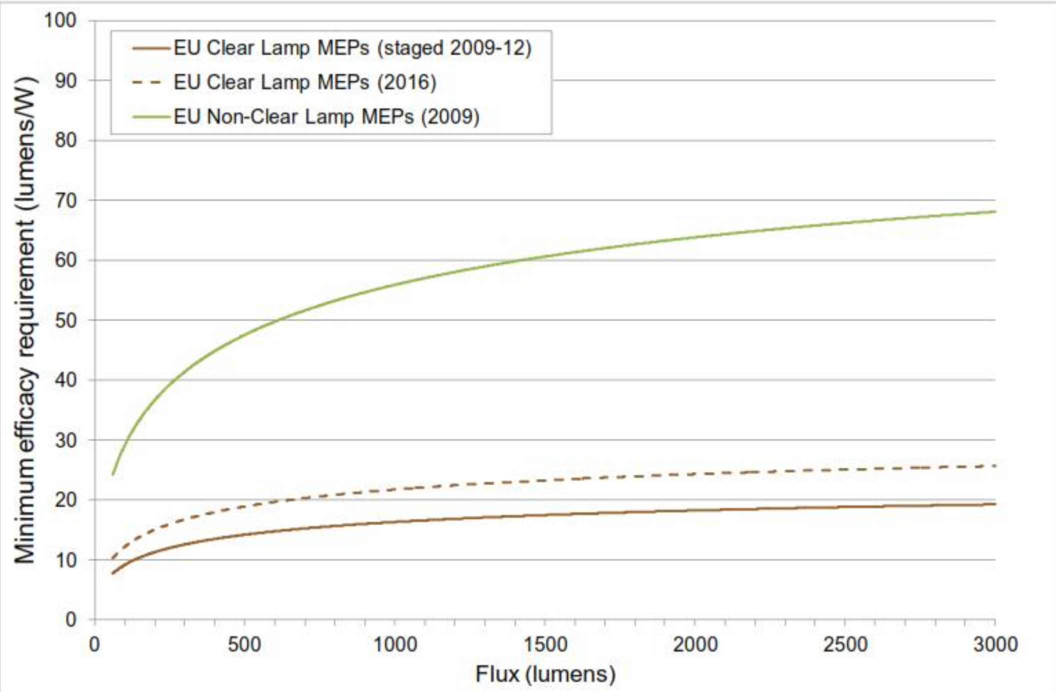


Figure 66 Minimum efficacies (lm/W) in function of the luminous flux (lm), as required by Regulation 244/2009 for non-directional lamps. The graph only covers the general requirement: for exceptions and correction factors see the regulation. (source [273])

[273] "4E Mapping Document, European Union, Domestic Lighting". Available through: http://mappingandbenchmarking.iea-4e.org/shared_files/643/download .

The efficacy requirements for LFL from **Regulation 245/2009** are reported in Table 102. Figure 67 shows the graphical representation in terms of efficacy versus luminous flux. These data do not cover exceptions and correction factors: see the text of the regulation.

For CFLni the requirements in Regulation 245/2009 are too complex to be graphed: see the regulation.

T8 (26 mm Ø)		T5 (16 mm Ø) High Efficiency		T5 (16 mm Ø) High Output	
Nominal wattage (W)	Rated luminous efficacy (lm/W), 100 h initial value	Nominal wattage (W)	Rated luminous efficacy (lm/W), 100 h initial value	Nominal wattage (W)	Rated luminous efficacy (lm/W), 100 h initial value
15	63	14	86	24	73
18	75	21	90	39	79
25	76	28	93	49	88
30	80	35	94	54	82
36	93			80	77
38	87				
58	90				
70	89				

Table 102 Rated minimum efficacy values for T8 and T5 lamps, according to table 1 of Regulation 245/2009 for linear fluorescent lamps without integrated ballast.

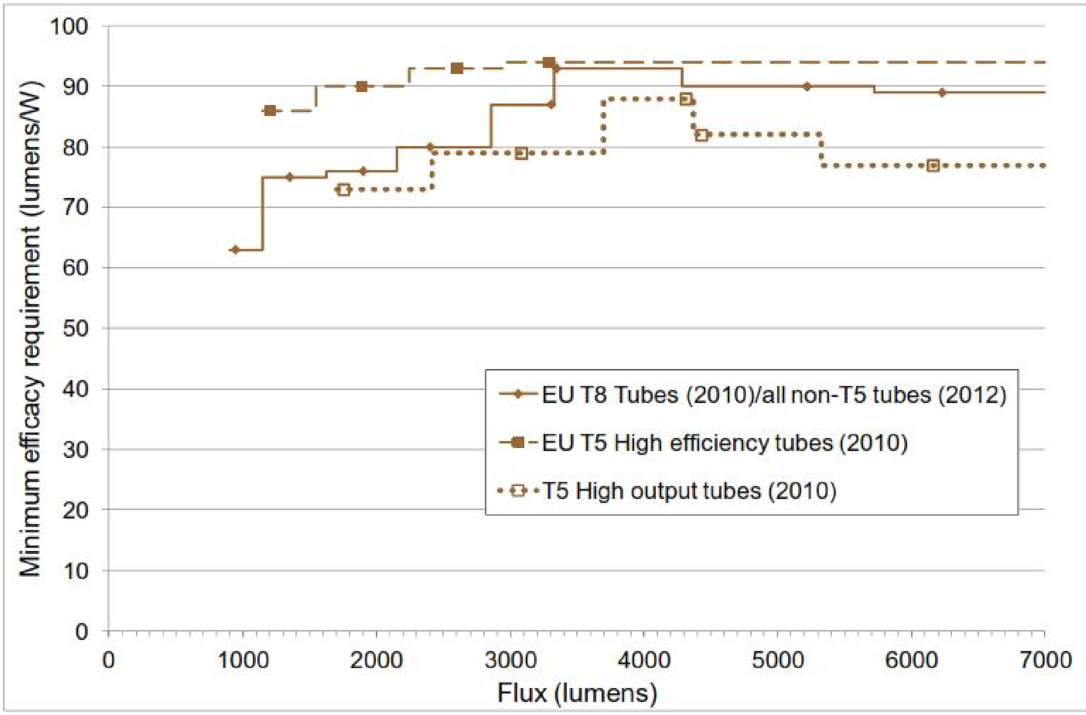


Figure 67 Minimum efficacies (lm/W) in function of the luminous flux (lm), as derived from requirements in Regulation 244/2009 for LFL. The graph only covers the general requirement: for exceptions and correction factors see the regulation. (source [274])

[274] "4E Mapping Document, European Union, Domestic Lighting". Available through: http://mappingandbenchmarking.iea-4e.org/shared_files/643/download .

In **Regulation 1194/2012** the efficacy for directional lamps is defined in terms of the Energy Efficiency Index (EEI) that is defined as:

$EEI = P_{cor} / P_{ref}$

where:

P_{cor} = the rated lamp power, corrected by a correction factor >1 for lamps with external control gear [275].

P_{ref} = the reference power obtained from the useful light output of the lamp (Φ_{use}) by the following formulae:

If $\Phi_{use} < 1300$ lm, $P_{ref} = 0.88\sqrt{\Phi_{use}} + 0.049\Phi_{use}$

If $\Phi_{use} \geq 1300$ lm, $P_{ref} = 0.07341\Phi_{use}$

Φ_{use} is defined as follows:

- For non-directional lamps, Φ_{use} = total rated luminous flux.
- For directional lamps with beam angle ≥ 90° (other than filament lamps) [276], Φ_{use} = the rated luminous flux in a 120° cone.
- For other directional lamps, Φ_{use} = the rated luminous flux in a 90° cone.

Table 103 shows the maximum EEI allowed for directional lamps according to 1194/2012 table 2. See the regulation itself for exceptions and correction factors. Stage 1 is September 2013, Stage 2 September 2014 and Stage 3 September 2016.

Application date	Maximum energy efficiency index (EEI)			
	Mains-voltage filament lamps	Other filament lamps	High-intensity discharge lamps	Other lamps
Stage 1	If $\Phi_{use} > 450$ lm: 1,75	If $\Phi_{use} \leq 450$ lm: 1,20 If $\Phi_{use} > 450$ lm: 0,95	0,50	0,50

Application date	Maximum energy efficiency index (EEI)			
	Mains-voltage filament lamps	Other filament lamps	High-intensity discharge lamps	Other lamps
Stage 2	1,75	0,95	0,50	0,50
Stage 3	0,95	0,95	0,36	0,20

Table 103 Maximum energy efficiency index (EEI), according to table 2 of Regulation 1194/2012 for directional lamps.

The light source efficacy $\eta = \Phi_{use} / P_{cor} = \Phi_{use} / (EEI*P_{ref})$. This value is plotted in Figure 68 in function of Φ_{use} for the EEI limit values of the table.

[275] See table 1 of Regulation 1194/2012 or table 2 of Regulation 874/2012. In Regulation 1194/2012 there are also correction factors < 1 for CFL with CRI≥90 (0.85) and for lamps with anti-glare shield(0.80).

[276] and carrying a textual or graphical warning on their packaging that they are not suitable for accent lighting

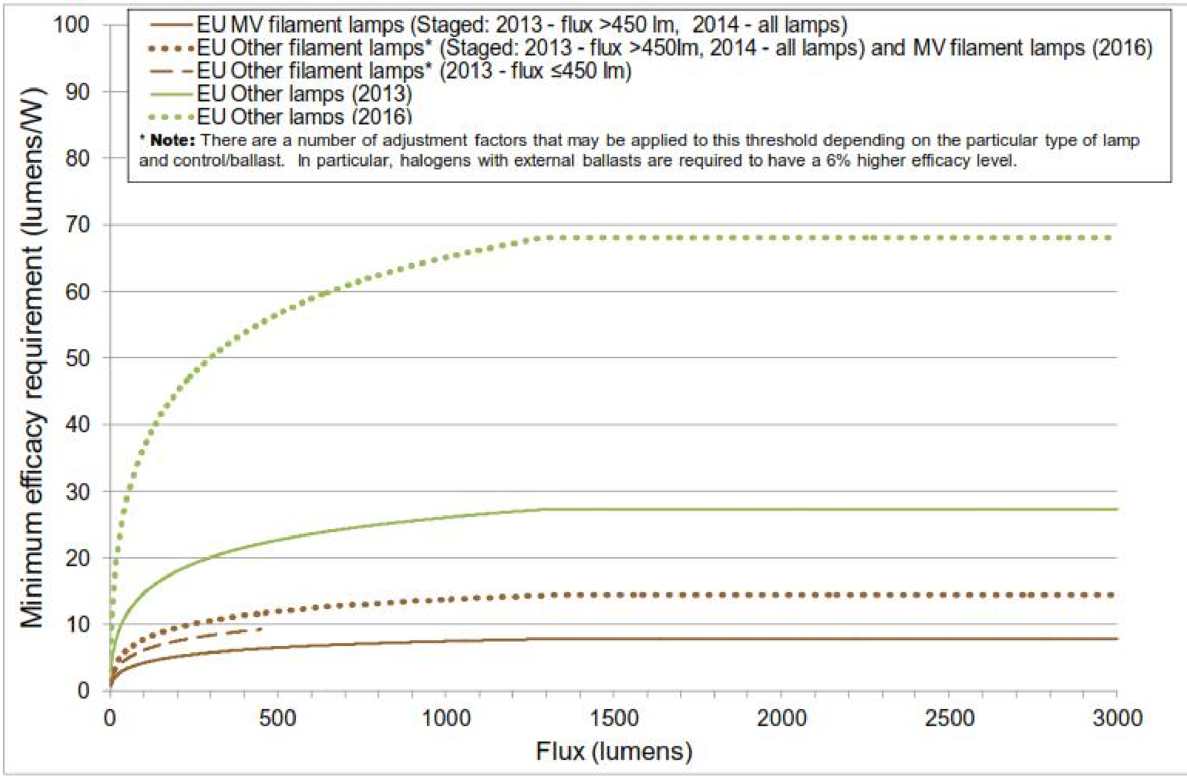


Figure 68 Minimum efficacies (lm/W) in function of the luminous flux (lm), as derived from requirements in Regulation 1194/2012 for directional lamps. The graph only covers the general requirement: for exceptions and correction factors see the regulation. (source [277])

Note that the market study on mains voltage directional filament lamps, that is part of the assignment of this study, regards the Stage 3 (September 2016) curve for MV filament lamps (dotted, brown).

[277] "4E Mapping Document, European Union, Domestic Lighting". Available through: http://mappingandbenchmarking.iea-4e.org/shared_files/643/download .

The energy labelling Regulation **874/2012** uses the same definition for EEI as shown above for Regulation 1194/2012. It then defines energy efficiency classes for lamps in its table 1 as follows:

Energy efficiency classes for lamps

Energy efficiency class	Energy efficiency index (EEI) for non-directional lamps	Energy efficiency index (EEI) for directional lamps
A++ (most efficient)	EEI ≤ 0,11	EEI ≤ 0,13
A+	0,11 < EEI ≤ 0,17	0,13 < EEI ≤ 0,18
A	0,17 < EEI ≤ 0,24	0,18 < EEI ≤ 0,40
B	0,24 < EEI ≤ 0,60	0,40 < EEI ≤ 0,95
C	0,60 < EEI ≤ 0,80	0,95 < EEI ≤ 1,20
D	0,80 < EEI ≤ 0,95	1,20 < EEI ≤ 1,75
E (least efficient)	EEI > 0,95	EEI > 1,75

Table 104 Energy efficiency classes for lamps, according to table 1 of Regulation 874/2012.

The light source efficacy $\eta = \Phi_{use} / P_{cor} = \Phi_{use} / (EEI*P_{ref})$ can be plotted in function of Φ_{use} for the EEI upper limit values of the table, showing the efficacy values that correspond to the class limits.

Similarly, the powers $P_{cor} = EEI*P_{ref}$ can be plotted in function of Φ_{use} for the EEI upper limit values of the table, showing the lamp (corrected) powers that correspond to the class limits.

This has been done in the following graphs, for non-directional and directional lamps. The power graphs indicate the maximum allowable power for the indicated class. The efficacy graphs indicate the minimum required efficacy for the indicated class. No line is presented for the E-class as this class does not have an upper EEI limit.

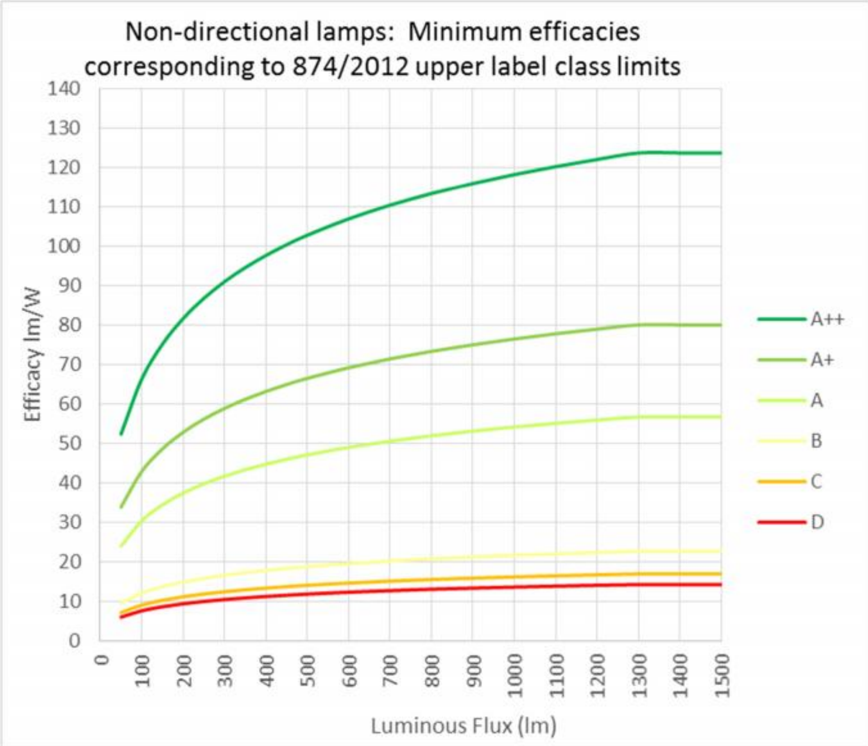


Figure 69 Non-directional lamps: minimum efficacies (lm/W) corresponding to upper EEI class limits of Regulation 874/2012. Efficacies have to be above the curve for the lamps to be assigned to the corresponding energy label class.

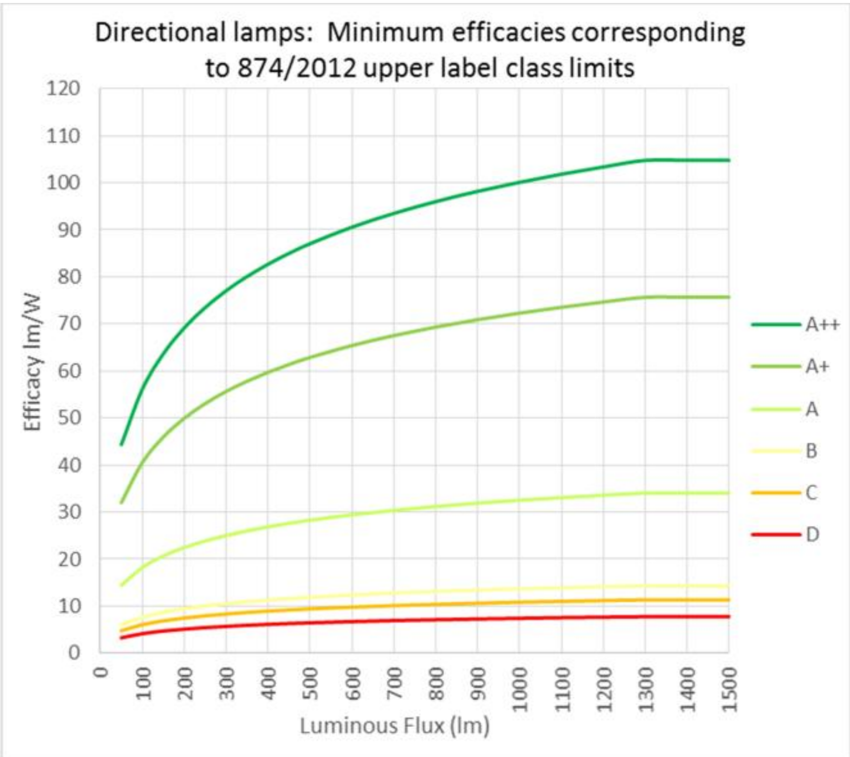


Figure 70 Directional lamps: minimum efficacies (lm/W) corresponding to upper EEI class limits of Regulation 874/2012. Efficacies have to be above the curve for the lamps to be assigned to the corresponding energy label class.

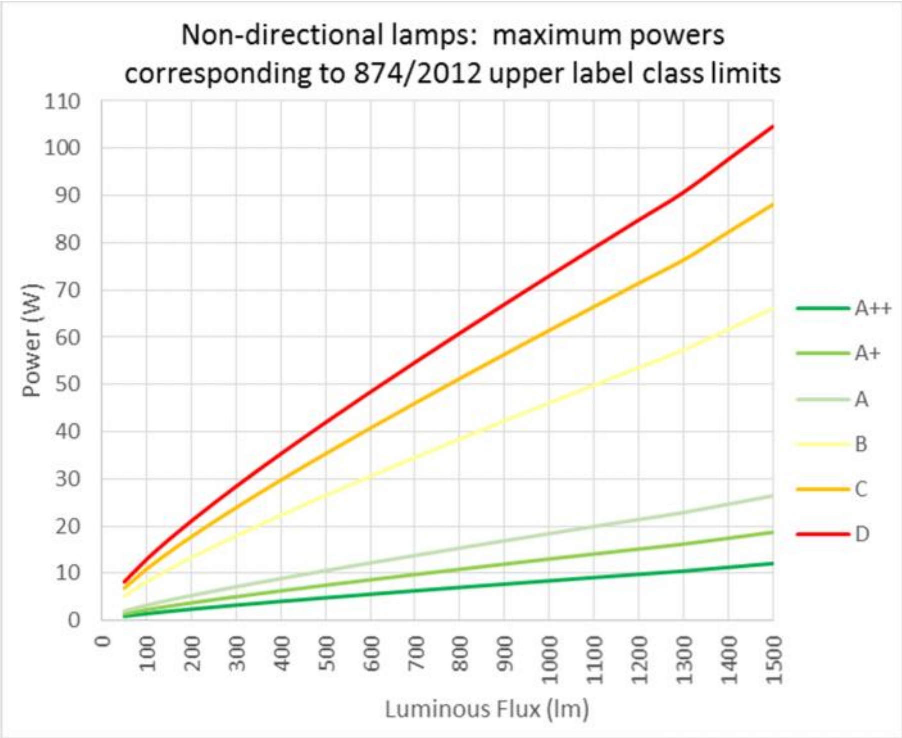


Figure 71 Non-directional lamps: maximum (corrected) powers (W) corresponding to upper EEI class limits of Regulation 874/2012. Powers have to be below the curve for the lamps to be assigned to the corresponding energy label class.

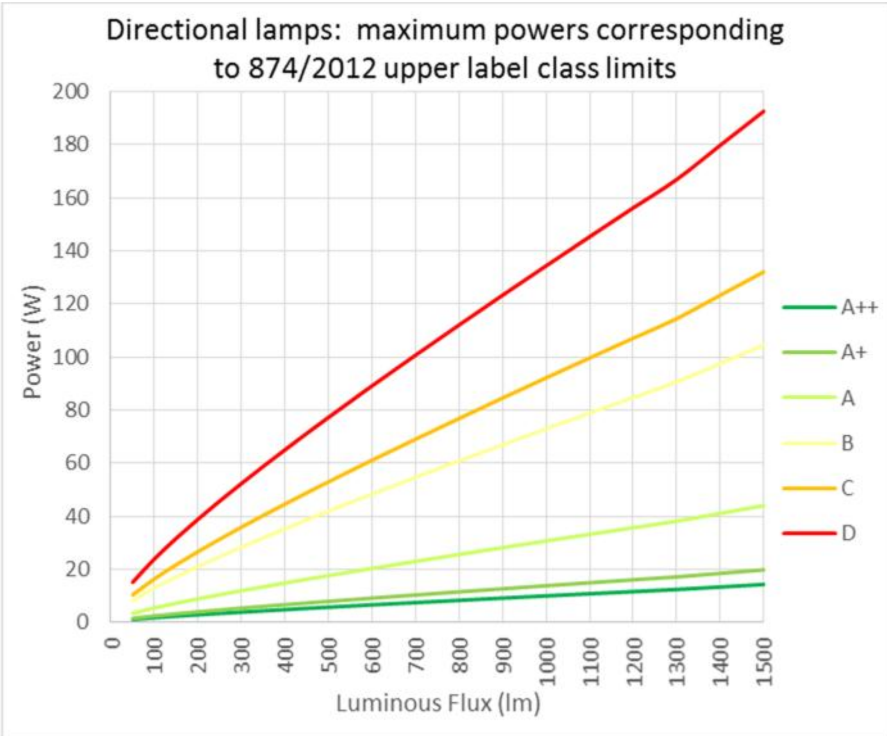


Figure 72 Directional lamps: maximum (corrected) powers (W) corresponding to upper EEI class limits of Regulation 874/2012. Powers have to be below the curve for the lamps to be assigned to the corresponding energy label class.

H.2 IEA 4E data on efficacies

Source: see footnote [278] and Annex F.1.1.

In the 2011 Benchmarking report, average efficacies of new lamps (in 2010) in each wattage bucket (at 220-250 V) were created based on a combination of actual test data of lamps purchased in Australia, China and Europe, and where test data was not available, by a review of manufacturer declared efficacies for a range of lamps in those buckets. These average 2010 lamp efficacies for 220-250V are shown in the table below.

	W	0-25	26-40	41-60	61-75	76-100	>100			
Incandescent, MV	**lm/W**	**8.7**	**10.2**	**11.8**	**12.5**	**13.5**	**14.8**			
Halogen, MV, single	W	0-17	18-20	21-28	29-43	44-53	54-73	>73		
ended	**lm/W**	**11.5**	**11.9**	**12.0**	**13.5**	**15.0**	**17.3**	**18.5**		
Halogen, MV, double	W	0-100	101-150	151-200	201-250	>250				
ended	**lm/W**	**16.0**	**17.5**	**17.8**	**19.0**	**20.0**				
	W	0-34	35-38	39-50	51-100	>100				
Halogen, LV (12 V)	**lm/W**	**17.0**	**18.2**	**18.8**	**21.7**	**23.0**				
	W	0-3	4-5	6-7	8.0	9-11	12-13	14-15	16-20	21-25
Pin based CFLni, MV	**lm/W**	**50.0**	**51.5**	**59.0**	**62.0**	**65.2**	**69.0**	**72.0**	**66.9**	**74.2**
	W	0-3	4-5	6-7	8.0	9-11	12-13	14-15	16-20	21-25
Self-ballasted CFLi, MV	**lm/W**	**40.0**	**50.0**	**51.1**	**52.2**	**56.4**	**56.0**	**57.5**	**62.5**	**61.4**
	W	0-28	29-50	>50						
LFL tubes (T5), MV	**lm/W**	**87.8**	**94.0**	**94.0**						
	W	0-24	25-27	28-31	>31					
LFL tubes (T8), MV	**lm/W**	**67.2**	**73.0**	**79.1**	**84.4**					
	W	0-33	34-40	>40						
LFL tubes (T12), MV	**lm/W**	**73.0**	**74.0**	**75.0**						
	W	0-1	1-2	2-4	4-8	8-11	12-14	15-20	>20	
Retrofit LED lamps	**lm/W**	**48.0**	**49.6**	**51.2**	**54.4**	**56.0**	**57.6**	**60.0**	**64.0**	
	W	0-1	1-2	2-4	4-8	8-11	12-14	15-20	>20	
Dedicated LED lamps	**lm/W**	**60.0**	**62.0**	**64.0**	**68.0**	**70.0**	**72.0**	**75.0**	**80.0**	

Table 105 Efficacies of the various types of lamps in function of their wattage, year 2010, for 220-250 V lamps. (Source [278])

[278] "4E Mapping Document, European Union, Domestic Lighting". Available through: http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5. Product definition document, par. 4.2.1 and 4.2.2, and Mapping document, all tables and graphs for individual lamp types.

Variability of efficiencies with the years

The following data can be collected from the various tables and graphs in the 4E Mapping Document as regards the variation of the efficiencies with the years. These data are expected to be sales-weighted averages over the various wattage intervals, taking into account the data from Table 105.

Year	2007	2008	2009	2010	2011		2012		2013	
Country group	1	1	1	1	1	*2*	1	*2*	1	*2*
Incandescent, MV	11.5	11.4	11.3	10.9	10.8	*11.2*	10.5	*11.0*	10.7	*11.5*
Halogen, MV, single ended	14.5	14.4	14.3	14.3	14.3	*14.4*	14.2	*14.3*	14.1	*14.3*
Halogen, MV, double ended	19.1	19.1	19.0	18.8	18.7	*18.8*	18.7	*18.9*	18.8	*19.0*
Halogen, LV (12 V)	17.5	17.4	17.5	17.5	17.6	*18.0*	17.6	*18.0*	17.7	*17.9*
Pin based CFLni, MV	66.4	66.8	66.8	68.2	68.8	*75.1*	69.3	*75.5*	69.9	*76.0*
Self-ballasted CFLi, MV	57.4	57.5	57.6	57.9	58.3	*58.8*	59.1	*59.3*	59.7	*59.7*
LFL tubes (T5), MV	87.2	87.4	87.6	87.8	88.1	*91.7*	88.4	*91.4*	88.7	*91.4*
LFL tubes (T8), MV	78.8	79.1	79.3	79.3	79.3	*77.0*	79.4	*77.0*	79.6	*77.3*
LFL tubes (T12), MV	74.2	74.0	74.0	74.3	74.4	*73.7*	74.4	*74.5*	73.9	*74.3*
Retrofit LED lamps	37.2	40.9	45.5	50.9	57.4	*57.4*	64.9	*63.7*	72.6	*71.7*
Dedicated LED lamps	46.3	51.0	56.9	63.2	70.6	*71.5*	79.5	*78.9*	88.4	*88.0*
All lamp types	15.0	15.6	16.0	17.3	16.8	*20.7*	17.2	*20.6*	18.3	*22.5*

Table 106 Efficacies in lm/W for various types of lamps, for years 2007-2013, and for two country groups (for 2011-2013). Average over all wattages. Country group 1 = Austria, Belgium, France, Germany, Great Britain, Italy and Netherlands; country group 2 = Spain and Poland. (Source [278])

Annex I. EN 15193, REFERENCE DATA

I.1 Default operating hours from proposed EN 15193

The proposed standard for lighting in buildings (EN15193) [279] presents default operating hours per type of building (Table 107). The "*values are based on the estimated time people are likely to occupy or be in the premises and will require some form of illumination*". These hours are calculated based on the hours of activity in the building (working hours) and on astronomical calculations as regards the potential availability of daylight and the subdivision in daytime hours and night-time hours [280]. During these hours the required lighting may be fully or partially provided by daylight instead of artificial light. In addition artificial lighting might be dimmed or switched off because of the non-occupancy of the rooms. For the determination of the real operating hours for artificial lighting to be used in energy calculations, the prEN15193 potential operating hours are significantly reduced by means of daylight dependent factors and occupancy dependent factors. Consequently the default operating hours presented in prEN15193 are not comparable to those in MELISA.

Building types	Default annual operating hours		
	t_D	t_N	t_{tot}
Domestic buildings	1 820	1 680	3 800
Offices	2 250	250	2 500
Education buildings	1 800	200	2 000
Hospitals	3 000	2 000	5 000
Hotels	3 000	2 000	5 000
Restaurants	1 250	1 250	2 500
Sports facilities	2 000	2 000	4 000
Wholesale and retail services	3 000	2 000	5 000
Manufacturing factories	2 500	1 500	4 000

Table 107 Default operating hours for lighting per type of building (proposed EN15193-2, table B.2.3.2)

I.2 Installed powers for residential lighting

The proposed prEN 15193-1:2014 in tables B.3.3.7 and B.3.3.8 provides guideline information regarding the installed lighting power in domestic buildings. Data are provided for a standard lighting solution with an average efficacy of 15 lm/W and for an optimized solution with 60 lm/W. The tables present the installed lighting power per residential room type, for general ambient lighting and for local 'task' lighting [281], and for small, medium and large dwellings. The latter are defined in terms of typical useful areas for the various types of rooms.

The data from the prEN 15193 tables have been elaborated by the study team as shown in Table 108. In the elaboration, the centre-values of the area-ranges have been used. Totals for the entire dwelling have

[279] Draft prEN 15193-1/-2 "Energy performance of buildings – Module M9 – Energy requirements for lighting – Part 1: 'Specifications' and Part 2: 'Technical report to EN 15193-1', CEN/TC 169, August 2014.

[280] prEN 15193-1:2014 annex F.7

[281] Kitchen worktop lighting, dining table lighting, reading lights in living room, mirror lighting in bathroom, bedside and desk lamps in bedroom.

been computed by summing the room contributions for general ambient lighting (small, medium or large) and adding the areas for local lighting (same value for all dwelling sizes).

			Average area m²				lux * area = lumen (at 'task' level)			
	E(lux)	E(lux)	local	general ambient			local	general ambient		
Room type	specific	gen.amb.		small	medium	large		small	medium	large
Kitchen	300	150	2	7	9	11	600	1050	1350	1650
Dining room	300	150	3	10	14	18	900	1500	2100	2700
Living room	300	150	1	10	14	18	300	1500	2100	2700
Bathroom, toilet	300	100	1	5	7	9	300	500	700	900
Bedroom	300	100	1	7	10	14	300	700	1000	1400
Entrance hall, corridor, stairs		100		2	4	6		200	400	600
Storeroom, cellar, laundry		200		5	7	9		1000	1400	1800
Total				54	73	93		8850	11450	14150

	Installed lighting power (W)				Installed lighting power (W)			
	Optimized lighting solution (60 lm/W)				Standard lighting solution (15 lm/W)			
	local	general ambient			local	general ambient		
Room type		small	medium	large		small	medium	large
Kitchen	30	20	30	40	90	60	80	120
Dining room	35	35	50	75	120	100	135	200
Living room	25	35	50	75	60	100	135	200
Bathroom, toilet	25	20	30	40	70	50	70	100
Bedroom	30	30	50	70	80	90	110	140
Entrance hall, corridor, stairs		20	30	40		40	60	80
Storeroom, cellar, laundry		25	35	50		60	80	120
Total		330	420	535		920	1090	1380

	Installed lighting capacity (lm)				Installed lighting capacity (lm)			
	Optimized lighting solution (60 lm/W)				Standard lighting solution (15 lm/W)			
	local	general ambient			local	general ambient		
Room type		small	medium	large		small	medium	large
Kitchen	1800	1200	1800	2400	1350	900	1200	1800
Dining room	2100	2100	3000	4500	1800	1500	2025	3000
Living room	1500	2100	3000	4500	900	1500	2025	3000
Bathroom, toilet	1500	1200	1800	2400	1050	750	1050	1500
Bedroom	1800	1800	3000	4200	1200	1350	1650	2100
Entrance hall, corridor, stairs		1200	1800	2400		600	900	1200
Storeroom, cellar, laundry		1500	2100	3000		900	1200	1800
Total		12600	16500	21300		8250	9975	12750

Table 108 Typical useful areas (top), installed lighting powers (centre) and installed lighting capacities (bottom) for rooms in domestic buildings (based on data provided in prEN 15193-1:2014; elaboration by the study team)

The **installed lighting power** ranges from 920 to 1380 W for the standard lighting solution and from 330 to 535 W for the optimized solution (central part of the table).

The **installed lighting capacity** ranges from 8250 to 12750 lm for the standard lighting solution and from 12600 to 21300 lm for the optimized solution (bottom part of the table). Note that lumens are significantly higher for the optimized solution: prEN 15193 seems to assume that higher efficiency lighting will entail installation of a higher lighting capacity.

The above lumens are interpreted to be at light source level. In the top part of the table, the required illumination in lux (= lm/m² at 'task' level) is multiplied by the areas to yield lumens at task level. These range from 8850 to 14150 lm. These values are higher than those at light source level for the standard solution, suggesting that people now install less than ‘required’.

I.3 LENI benchmark values for spaces and lighting installations

Table K.1 – Some examples of LENI benchmark values for spaces and lighting installations

No.			Space type	Electric lighting system	Installed Power Density (P_j)	Annual operating hours		Illumination control				LENI
									Dependency factors			
				Type	[W/m²]	t_D	t_N	Type	F_O	F_D	F_C	
						hours			[-]	[-]	[-]	[kWh/m²y]
1	a	I	Circulation area	Standard, direct	7,74			Automatic				4,31
		II						Manual				6,81
	b	I		Existing, direct	29,47			Manual				25,94
2	a	I	Personal office	Efficient, direct	12,18			Automatic				6,00
		II						Manual				10,97
	b	I		Efficient, dir / ind	14,28			Automatic				7,04
		II						Manual				12,86
	c	I		Standard, direct	16,43			Manual				14,80
	d	I		Standard, dir / ind	17,85			Manual				16,08
	e	I		Existing, direct	34,95			Manual				31,47
	f	I		Existing, direct/indirect	43,40			Manual				39,09
3	a	I	Conference	Efficient, dir / ind	12,37			Automatic				9,91
		II						Manual				15,30
4	a	I	Open floor office	Efficient, dir / ind	10,73			Automatic				19,43
		II						Manual				23,23
	b	I		Existing, direct	26,84			Manual				58,08
5	a	I	Kitchen in NRB	Efficient, direct	11,54			Automatic				18,66
		II						Manual				23,60
	b	I		Existing, direct	33,12			Manual				67,75
6	a	I	Manufacturing hall with roof lights	SON, direct	7,09			Manual				1,75
	b	I		HMI, direct	13,29			Manual				3,29
	c	II		T16, direct	12,76			Automatic				2,01
	d	I		Existing, direct	34,48			Manual				8,53
7	a	I	Manufacturing hall without roof lights	SON, direct	7,09			Manual				27,17
	b	I		HMI, direct	13,29			Manual				50,94
	c	II		T16, direct	12,76			automatic				41,57
	d	I		Existing, direct	34,48			manual				132,10

$LENI = \{F_C \times (P_j / 1000) \times F_O [(t_D \times F_D) + t_N]\} + 1 + \{1,5 / t_y \times [t_y - (t_D + t_N)]\}$ [kWh / (m² year)]

Table 109 LENI (kWh/m²/year) benchmark values for non-residential spaces (source: prEN 15193)