Evaluation and Monitoring for the EU Directive on Energy End-Use Efficiency and Energy Services

EMEEES bottom-up case application 9: Improvement of Lighting Systems (Tertiary Sector)

Andrew Pindar, Nicola Labanca, Daniele Palma

Andrew Pindar / eERG
Nicola Labanca / eERG
Daniele Palma / eERG

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coordinated by
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The Project in brief

The objective of this project is to assist the European Commission in developing harmonised evaluation methods. It aims to design methods to evaluate the measures implemented to achieve the 9% energy savings target set out in the EU Directive (2006/32/EC) (ESD) on energy end-use efficiency and energy services. The assistance by the project and its partners is delivered through practical advice, technical support and results. It includes the development of concrete methods for the evaluation of single programmes, services and measures (mostly bottom-up), as well as schemes for monitoring the overall impact of all measures implemented in a Member State (combination of bottom-up and top-down).

Consortium

The project is co-ordinated by the Wuppertal Institute. The 21 project partners are:

Project Partner	Country
Wuppertal Institute for Climate, Environment and Energy (WI)	DE
Agence de l'Environnement et de la Maitrise de l'Energie (ADEME)	FR
SenterNovem	NL
Energy research Centre of the Netherlands (ECN)	NL
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Fraunhofer-Institut für System- und Innovationsforschung (FhG-ISI)	DE
SRC International A/S (SRCI)	DK
Politecnico di Milano, Dipartimento di Energetica, eERG	IT
AGH University of Science and Technology (AGH-UST)	PL
Österreichische Energieagentur – Austrian Energy Agency (A.E.A.)	AT
Ekodoma	LV
Istituto di Studi per l'Integrazione dei Sistemi (ISIS)	IT
Swedish Energy Agency (STEM)	SE
Association pour la Recherche et le Développement des Méthodes et Processus Industriels (ARMINES)	FR
Electricité de France (EdF)	FR
Enova SF	NO
Motiva Oy	FI
Department for Environment, Food and Rural Affairs (DEFRA)	UK
ISR – University of Coimbra (ISR-UC)	PT
DONG Energy (DONG)	DK
Centre for Renewable Energy Sources (CRES)	EL

Contact

Dr. Stefan Thomas, Dr. Ralf Schüle
Wuppertal Institute
for Climate, Environment and Energy
Döppersberg 19
42103 Wuppertal, Germany

Tel.: +49 (0)202-2492-110
Fax.: +49 (0)202-2492-250
Email: info@evaluate-energy-savings.eu
URL: www.evaluate-energy-savings.eu
www.wupperinst.org

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1 Summary

1.1 Title of the method

Improvement of Lighting Systems in the Tertiary Sector

1.2 Type of EEI activities covered

End-use EEI action	
Sector	Tertiary
Energy end-use	Lighting
Efficient solution	Use of energy-efficient luminaires, light sources, ballasts and control strategies
EEI Facilitating measure	
Types of EEI facilitating measures	Improvement of lighting system efficiency by: Information and legislative-informative measures: Energy labelling schemes (e.g. CELMA Classification) Financial instruments: Subsidies (Grants), energy efficiency public procurement, Bulk Purchasing Energy services for energy savings: Guarantee of energy savings contracts EEI mechanisms: Public service obligation for energy companies on energy savings including “White certificates”

1.3 Detailed definition of EEI activities covered

The product definition and classification of lighting systems is derived from existing European standards and official classification schemes.

A broadly accepted definition for lighting tasks and related performance criteria can be found in the standard EN 12464-1 “Lighting of indoor work places”. ”Lighting equipment parts” comprising ”luminaires”, ”ballasts” and ”lamps” are defined in standard EN 12665 Light and lighting - Basic terms for specifying lighting requirements. Though the definitions refer specifically to office lighting, the same products can also be used for other indoor lighting applications, e.g. For example in schools or hospitals. The following definition of office lighting equipment is derived from EN 12464-1:

Lighting systems and products are intended to “enable people to perform visual tasks efficiently and accurately, adequate and appropriate”.

An office lighting product system can more generally be considered a ”lighting equipment” as defined in standard EN 12665, containing:

1. A “lamp” as “source made in order to produce an optical radiation, usually visible”.
2. A “ballast” as “device connected between the supply and one or more discharge lamps which serves mainly to limit the current of the lamp(s) to the required value”.

   Note that a ballast may also include means for transforming the supply voltage, correcting the power factor and, either alone or in combination with a starting device, provide the necessary conditions for starting the lamp(s).
3. A ”luminaire” as “apparatus which distributes, filters or transforms the light transmitted from one or more lamps and which includes, except the lamps themselves, all parts necessary for fixing and protecting the lamps and, where necessary, circuit auxiliaries together with the means for connecting the lamps to the electric supply”.

EN 12464-1 does not address the fourth essential element of any lighting system; namely the Control Apparatus. In lack of any official definition a first definition might be:

4. “Control Apparatus” regulates the lighting levels and or the operating hours of the lighting system.

Actions can be undertaken in respect of each of the four principle components of the lighting system, either singularly or combined, which will lead to reduced energy consumption. The following table reports the most common efficiency improvements to lighting systems in the Tertiary sector together with rough estimates of potential energy savings and qualitative evaluation of difficulty of realisation.

Table 1 – Comparison between inefficient and efficient lighting components in terms of potential energy savings and difficulty of realisation on a scale of 1 (easy) to 5 (difficult)

Component	Standard	Efficient	Comments or consequences	Energy savings	Difficulty of realization	
					Retrofit (1-5)	New (1-5)
Lamp	Incandescent	CFL (integrated ballast)	CFLs are packaged in the same glass reflector lamps as incandescent lamps	60-75%	1	1
	Incandescent	CFL (separated ballast)	It is necessary to change the slot of the lamp and probably the lamp shade	60-75%	2	1
	T12 lamps	T8 lamps	Often slot into the same light fittings; energy savings (~8%) are achievable only if this solution is coupled with delamping	8%	1	1
	T12/T8 lamps	T5 lamps	Some manufacturers are offering “retrofit kits” for applying T5-lamps in luminaires designed for T8-lamps with magnetic ballasts. The magnetic ballast is kept and an additional electronic converter is placed in the old socket. This option is not considered in this study, because lamp lumen output and light distribution doesn’t match with the original design. An alternative retrofit solution is also to replace the magnetic ballast by an electronic ballast; this provides an energy saving while the original light output and light distribution is kept but it requires extra luminaire rewiring work.	3%	-	-
Ballast	T8 + Magnetic Ballast	T8 + Electronic Ballast	Require rewiring of the luminaire; can be more cost-effective to replace the entire luminaire	10-15%. Up to 25 % with tri-phosph or	3	1

					Difficulty of realization	
				tubes		
	T8 Electronic Ballast	T8 Dimmable Electronic Ballast	compatibility of the lamp, dimming ballast, and control	Depends on the daylight availability	3	1
Luminaire			A more efficient luminaire can improve the light distribution efficiency; energy savings are achievable only if this solution is coupled with delamping	0 – 30 %		
	Manual Control: centralised switching	Manual Control: Localised switching	Can be simple improved partitioning of the lighting circuits with increased number of wall mounted switches. Alternatively pull down cords can be introduced over single work stations to control of single luminairs in a large centralised system.			
Control	Manual control	Automatic Control: daylight-linked controls (photocells)	Either continuous (i.e. using dimmable ballasts) or on-off (i.e. switching off lights when daylight is above a minimum level)	35-45%, depending on the size of the area covered and the occupancy pattern	4	2
	Manual control	Automatic Control: timer and clocks or occupancy sensors	Lights operated on clock between fixed hours or switched off after fixed time; With occupancy sensors, lights controlled automatically by occupancy	35-45%, depending on the size of the area covered and the occupancy pattern	4	2

Many of the improvements as listed in the above table may be undertaken singularly or combined in integrated actions. Energy savings of up to 80 % on the whole system are possible in the extreme case.

In some cases, one part of a lighting system can be made energy efficient without requiring changes to other components. For example: replacement of incandescent lamps with CFL.

In other cases, modifications to improve energy efficiency of a component require modification of other components. The secondary modifications may themselves lead to improve energy savings or may not.

For example, it may prove cost effective when replacing a ballast with an electronic version to replace the entire luminaire, rather than just the ballast. The new luminaire might be of the same efficiency as the existing or maybe of better efficiency.

Level 1 values provided in this document for the different lighting components are mainly applicable for specific programmes targeting such components and monitoring data on numbers of installed components. In all other cases that use engineering calculations anyway, it is highly recommended to go to level 3 and collect all the data needed to estimate energy savings at the participant as well as the national level.

The approach that will be presented in the following document sections applies to lighting systems installed inside buildings of the tertiary sector. However, in some locations outside lighting may be fed with power from the building. This lighting may be used for illumination of the facade, open-air car park lighting, security lighting, garden lighting, etc. These lighting systems may consume significant energy. It is recommended to evaluate energy savings generated by end-use actions addressing such systems only at an evaluation effort of level 3 and if metering of the outside lighting load is employed at the participant level.

The present EMEEES case application may be used to assess ESD savings yielded by a variety of Energy Efficiency Improvement (EEI) facilitating measures and programmes.

In general, the calculation methodology developed envisages the contribution of the program participants and the program administrator.

- The calculation of unitary gross annual energy savings (i.e., step 1) should be performed by each program participant and verified by the program administrator. Depending on the level of evaluation effort considered, the program participant may be requested to collect relevant data and information for the application of the energy saving calculation formula proposed (e.g., for level 3 evaluation effort) or to just prove that the EEI action being evaluated has actually been implemented (e.g., for level 1 and 2 evaluation efforts).

- The Program administrator will be in charge of performing the calculation steps 2, 3 and 4.

1.3.1 General specifications

Ballasts for fluorescent tubes must be CELMA[1] Classified.

The indications and evaluations in the present methodology do not affect the national statuary or best practice requirements for good lighting design. In particular lighting plant must be designed so as to conform to:

The European standard EN 12464-1 (2002) specifies requirements for lighting systems for most indoor work places and their associated areas in terms of quantity and quality of illumination.

Other Regulations and Standards to be considered are:

- ➢ Light sources
  - → prEN 15193 (2006): 'Energy performance of buildings - Energy requirements for lighting[2]'.
- ➢ Ballasts
  - → EN 60921: 'Ballasts for tubular fluorescent lamps – Performance requirements'.
  - → EN 50294: 'Measurement Method of Total Input Power of Ballast-Lamp Circuits'.
  - → EN 60929: 'AC-supplied electronic ballasts for tubular fluorescent lamps – Performance requirements'.
  - → Directive 2000/55/EC on energy efficiency requirements for ballasts for fluorescent lighting
- ➢ Luminaires
  - → EN 60598-1: 'Luminaires Part 1: General requirements and tests'.
  - → EN 60598-2: 'Luminaires - Part 2: Particular requirements - Chapter 1: Fixed general purpose luminaires'.
  - → EN 60598-2: 'Luminaires - Part 2: Particular requirements - Chapter 2:

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[1] CELMA is the European Federation representing 16 National Manufacturers Associations for Luminaires and Electrotechnical Components for Luminaires in the European Union. Commission Regulation n. 245/2009 published on 18/03/09 related to ecodesign requirements for fluorescent lamps, ballasts and luminaries provides an alternative classification. This regulation was not yet available when the present case application was developed in its almost definitive version. However, the energy saving estimates performed in this document do not vary sensibly (i.e. variations are lower than estimated uncertainties) when these new requirements instead of CELMA classification are considered.

[2] The final and approved version of prEN 15193 was published on September 2007, when the present case application had already been developed in its almost definitive version. However, the case application's final version presented here includes some information and data reported in EN 15193, whereever such data and information have been judged to improve the quality of the calculation methods proposed (see e.g. information related to lighting system operating hours per building category reported in Table 8 and to the determination of the control factors F_O and F_D reported in section 3.4.1)

Recessed luminaires'.

- Other lighting equipment
    - → EN 60927: 'Specification for auxiliaries for lamps. Starting devices (other than glow starters). Performance requirements'.
    - → Directive 2002/95/EC on Restriction of the use of certain Hazardous Substances in electrical and electronic equipment (RoHS)
    - → Directive 2002/96/EC on waste electrical and electronic equipment (WEEE)

1.4 Scope for end-use actions

With the term replacement we also intend the installation of a more efficient equipment in the place of the standard (also termed the baseline) that would have been installed in the absence of the EEI Action. In general, there are mainly three possible kinds of intervention:

- **programmed reinvestment**: replacement of an equipment at the end of its lifetime with a new system more efficient than the standard one (market standard);
- **anticipated reinvestment**: forced replacement of an equipment before the end of its lifetime with a new system more efficient than the standard one (stock standard);
- **add**-on energy efficiency investment: enhancement of the existing lighting system through lighting controls saving energy (stock standard);
- **new installation**: in phase of new construction, installation of an equipment more efficient than the standard one (market standard).

With the term standard system, we intend an equipment characterized by average efficiency, referring to the stock or to the market situation (see step 1.2 for the details).

1.5 Indicative Level 1 default value for annual unitary energy savings

As already noted, end-use (EEI) actions can be undertaken singularly or together as part as a combined comprehensive end-use action. Here we report the energy savings in respect of

- improvements to lamps, ballasts and control apparatus when undertaken as stand alone single actions
- combined improvements to the lamp – ballast system

Other combined actions need to be evaluated using the generalised formula as expressed in Equation (1).

1.5.1 Lamp: Introduction of CFLs

Level 1 estimated energy savings generated by replacing incandescent lamps with Compact Fluorescent Lamps, either with integrated or external ballast. According to general rules proposed by the EMEEES project, a safety factor of 0.8 is applied even on reliable EU average values calculated from literature and statistical data, to consider remaining uncertainties. This holds for all level 1 data on unitary gross annual energy savings given here.

Table 2 - Level 1 default values for annual unitary energy savings provided by substituting an incandescent lamp with a CFL

	Variables in relation to Equation (1)	**Level 1 Data**	
Stock Baseline: Average power absorbed by the standard incandescent lamp:	$(N_{l,st}P_{l,st} + N_{b,st}P_{b,st})$	65,7	W
Market Efficient Technology: Average Power absorbed by the efficient (CFL) lamp:	$(N_{l,eff}P_{l,eff}+ N_{b,eff}P_{b,eff})$	14,8	W
Difference of absorbed power:		50,9	W
Baseline Use: Hours	H	2500	h
Energy Savings:	Δ**E**	0.8 * 127 = **102**	**kWh/year/CFL**

1.5.2 Ballast: Introduction of electronic ballasts

Level 1 estimated energy savings generated by replacing electromagnetic with electronic dimmable or non dimmable ballasts.

Table 3 - Level 1 default values for annual unitary energy savings related to the use of efficient lighting systems (electronic ballast-lamp) in the place of the conventional ones (electromagnetic ballast-lamp)

	Variables in relation to Equation (1)	**Level 1 Data**	
Stock Baseline: Average power absorbed by the existing (stock) ballast/lamp/luminaire system:	$(N_{l,st}P_{l,st} + N_{b,st}P_{b,st})$	95	W
Market Inefficient Baseline: Average power absorbed by the new, not efficient ballast/lamp/luminaire system:	$(N_{l,st}P_{l,st} + N_{b,st}P_{b,st})$	90	W
Market Efficient Technology: Average Power absorbed by the new, efficient ballast/lamp/luminaire system:	$(N_{l,eff}P_{l,eff}+ N_{b,eff}P_{b,eff})$	80	W
Difference of absorbed power vs. stock:		15	W

Difference of absorbed power vs. new not efficient		10	W
Baseline Use: Hours	H	2500	h / year
Average number of luminaires affected per ballast	N_{st}, N_{eff}	0.6	
Energy Savings vs. stock:	**ΔE**	0.8 * 22.5 = **18**	**kWh/year/ ballast**
Energy Savings vs. new not **efficient:**	**ΔE**	0.8 * 15 =**12**	**kWh/year/ ballast**

1.5.3 Luminaire: Using more efficient luminaires using electronic ballasts instead of standard (non-efficient) luminaires

Replacement of non-efficient luminaires using T8 magnetic ballasts with efficient luminaires using T8 electronic ballasts is considered here. Therefore, energy savings to be estimated are supposed to be due both to the higher energy performances of energy efficient luminaires installed (resulting in a lower number of luminaries to be installed and taken into account in equation 1 by the value of N_{eff} to be considered) and the higher performances of the T8 systems with electronic ballasts. End-use actions addressing luminaries and not relating also to the above mentioned replacement of an inefficient T8 system should not be evaluated by using the default values reported in table 4.

Table 4 - Level 1 default values for determining unitary annual energy savings provided by substituting standard luminaires with higher efficiency alternative using electronic ballasts

	In relation to Equation (1)	Example data	
Market not efficient Baseline: Power absorbed by the standard systems	$(N_{l,st}P_{l,st} + N_{b,st}P_{b,st})$	90	W
Market Efficient Technology: Power absorbed by the efficient systems	$(N_{l,edd}P_{l,eff} + N_{b,eff}P_{b,eff})$	80	W
Number of standard luminaires removed. **Level 2 or Level 3 data required.**	N_{st}		
Number of efficient luminaires introduced. **Level 2 or Level 3 data required.**	N_{eff}		
Hours of Use	H	**2500**	h/year

As the energy savings are highly dependent on the case-specific situation, no EU default value for the unitary annual energy savings can be defined. Instead, it is recommended to calculate them at level 3 evaluation effort by using equation 1 and the values in table 4.

1.5.4 Luminaire: Using luminaires with T5 lamps instead of standard (non-efficient) luminaires with T8 lamps

Table 5 - Level 1 default values for determining unitary annual energy savings provided by substituting standard luminaires with T5 systems

	In relation to Equation (1)	Example data	
Market not efficient Baseline: Power absorbed by the standard systems	$(N_{l,st}P_{l,st} + N_{b,st}P_{b,st})$	90	W
Market Efficient Value: Power absorbed by the efficient systems	$(N_{l,edd}P_{l,eff} + N_{b,eff}P_{b,eff})$	80	W
Number of standard luminaires removed. **Level 2 or Level 3 data required.**	N_{st}		
Number of efficient luminaires introduced. **Level 2 or Level 3 data required.**	N_{eff}		
Hours of Use	H	**2500**	h/year

Again, no EU default value for the unitary annual energy savings can be defined. Instead, it is recommended to calculate them at the level 3 evaluation effort by using equation 1 and the values in table 5.

1.5.5 Control apparatus: Occupancy Sensors

Table 6 - Level 1 default values for unitary annual energy savings provided by introducing Occupancy Sensors

	In relation to Equation (1)	Example data	
Market Efficient Value (applied in order to be conservative): Power absorbed by the post action system	$(N_{l,edd}P_{l,eff} + N_{b,eff}P_{b,eff})$	80	W
Average number of luminaires affected per sensor	$N_{eff} = N_{st}$	2 x number of sensors sold or distributed in context of action	
Control Factor Stock	$F_{O,st}$	1	

Control Factor post Action (already very conservative)	$F_{O,eff}$	0.8	
Hours of Use	H = H	2500	H
Annual energy savings offered per sensor		**40**	**kWh/Year/Occupancy Sensor**

1.6 Level 2 and Level 3 evaluation efforts

In the present methodology, energy savings are determined through engineering calculations which take account of

- the number and power of installed lamps
- the number and power of installed ballasts
- the hours of use of the lighting system
- the control apparatus type

The Level 1 default values reported in Tables 2 to 6 were determined by considering conservative estimates of these four parameters both in relation to the stock and the market.

It proves possible to define per unit Level 1 values for the following end-use actions

- replacement of incandescent lamps with CFLs (energy savings per lamp)
- substitution of electromagnetic ballasts with electronic ballasts (energy savings per ballast)
- introduction of occupancy sensors (energy savings per sensor)
- introduction of daylight sensors (energy savings per sensor)

Energy savings for the following EEI actions requires instead Level 2 or Level 3 data for at least some of the parameters recalled above

- replacement of standard with high efficiency luminaires using electronic ballasts
- replacement of standard luminaires with T5 systems

In the last two cases, Level 1 data are provided which can assist the evaluation of energy savings deriving from the end-use EEI actions, but such data do not completely define energy savings from end-use actions (i.e. they must be integrated with Level 2 or Level 3 data).

The same calculation procedure used to define Level 1 data as defined by Equation 1 can be used to determine Country- (Level 2) or Measure-Specific (Level 3) energy savings.

This requires collecting Level 2 or Level 3 data related to the above mentioned four parameters.

Potential sources of Level 2 and Level 3 data include:

- End-use Metering campaigns
- Detailed building audits (which may or may not include energy metering)
- Existing studies and databases: Odyssee Database, Previous European (e.g. SAVE 2001, PICOLight) and MS Studies (EEC in UK, White Certificates in France and Italy), case studies (GreenLight)
- Manufacturer and product catalogues

1.7 Formula for total ESD annual energy savings

If all correction factors are included, the formula for the total ESD (net) annual energy savings will be the one presented in section 5 and reported below:

Total ESD annual energy savings =
= total annual energy savings for all participants
* (1 - free-rider ratio + multiplier ratio)
* (1 - double-counting factor)

1.8 Indicative default value for energy savings lifetime

The following value is suggested as a default or a harmonised value.

Category	**End-use EEI action**	**EU Savings Lifetime harmonised values**	**First year for eligibility, if early energy savings are allowed**
Light source	New/renovated office lighting *(Commercial /Public sector)*	12 years	2004
Control strategies	Motion detection light controls *(Commercial /Public sector)*	10 years	2006

1.9 Main data to collect

Data needed in calculation for EU values (level 1)	**Corresponding data sources**
Stock and market ballast and lamp power	Default values given in this report
Average number of ballasts per luminaire	Default values given in this report

Operating hours	Default values given in this report
Number of luminaires installed or replaced	Level 3 (participant-specific) or maybe Level 2 input

Data to be collected national values (level 2)	Corresponding data sources
National Lighting electricity consumption	National databases
Implemented end-use actions with savings to derive national averages for: Stock and market ballast and lamp power; Average number of ballasts per luminaire; Average annual operating hours; Number of luminaires installed or replaced	Evaluation of pilot schemes; Existing MS Studies (e.g. EEC in UK, White Certificates in France and Italy)
Number of luminaires installed or replaced	Level 3 (participant-specific) or maybe monitoring/surveys for participants of pilot schemes
Correction factors	Analysis of national market shares of energy-efficient technologies or surveys for free riders and multiplier effects; database of particiants and actions affected by different facilitating measures for avoiding double-counting

Data to be collected measure-specific (or participants-specific) (level 3)	Corresponding data sources
Specific Lighting electricity consumption	End-use Metering campaigns
Number of lighting operating hours	Detailed building audits
- Improvement of Lighting systems programme participants - Implemented measures with savings	Questionnaires/interviews → Monitoring database Source: CALifornia Measurement Advisory Council (CALMAC)
Lighting equipment power absorption	Manufacturer and product catalogues

2 Introduction

2.1 Twenty bottom-up case applications of methods

Within EMEEES, task 4.1 provided methodological materials in the internal working paper “Definition of the process to develop harmonised bottom-up evaluation methods”, version 20 April 2007; an update has been published as an Appendix to the report on Bottom-up methods at www.evaluate-energy-savings.eu. Based on this draft report, concrete bottom-up case applications were developed by EMEEES partners within task 4.2, and reference values were to be specified within task 4.3.

This report deals with case application 9 “Improvement of lighting systems” developed by eERG.

Eleven project partners have developed concrete bottom-up case applications for a specific type of technology or energy efficiency improvement measure or end-use action. All gave comments and input to the methods developed by the other organisations.

The 20 case applications developed are presented in the table below:

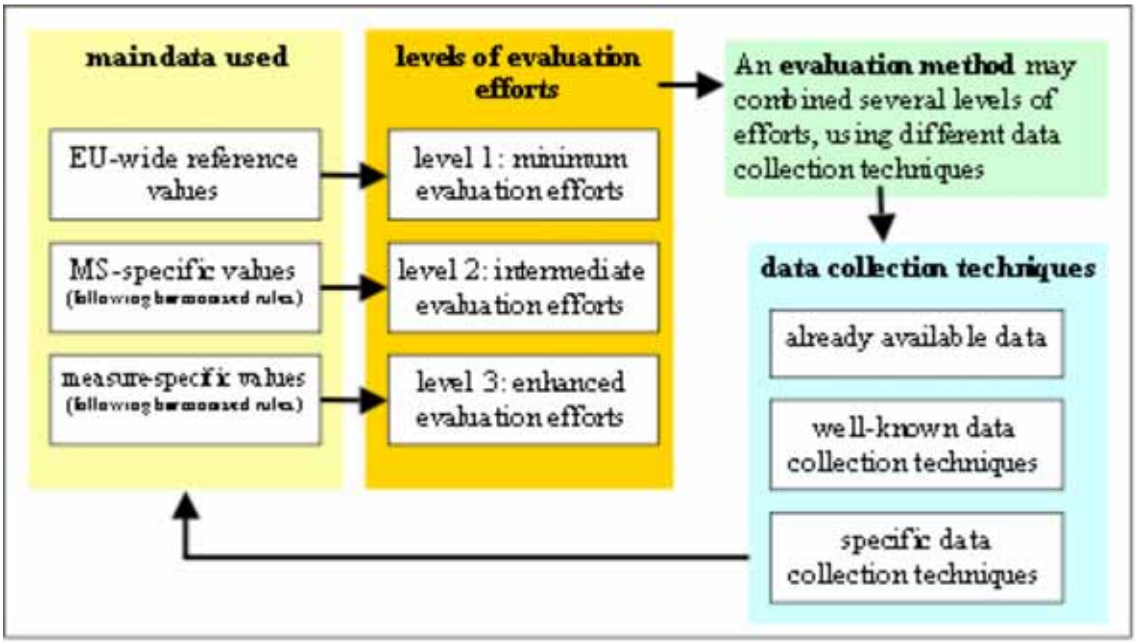
N°	End-use or end-use action, technology, or facilitating measure	Sector	Responsible organisation
1	Building regulations for new residential buildings	Residential	SenterNovem
2	Improvement of the building envelope of residential buildings	Residential	AEA
3	Biomass boilers	Residential	AGH-UST
4	Residential condensing boilers in space heating	Residential	Armines
5	Energy efficient cold appliances and washing machines	Residential	ADEME
6	Domestic Hot Water – Solar water heaters	Residential	AGH-UST
7	Domestic Hot Water - Heat Pumps	Residential	AGH-UST
8	Non residential space heating improvement in case of heating distribution by a water loop	Tertiary	eERG
9	Improvement of lighting systems	Tertiary (industry)	eERG
10	Improvement of central air conditioning	Tertiary	Armines
11	Office equipment	Tertiary	Fraunhofer

N°	End-use or end-use action, technology, or facilitating measure	Sector	Responsible organisation
12	Energy-efficient motors	Industry	ISR-UC
13	Variable speed drives	Industry	ISR-UC
14	Vehicle energy efficiency	Transport	Wuppertal Institute
15	Modal shifts in passenger transport	Transport	Wuppertal Institute
16	Ecodriving	Transport	SenterNovem
17	Energy performance contracting	Tertiary and industry end-uses	STEM
18	Energy audits	Tertiary and industry end-uses	Motiva
19	Voluntary agreements – billing analysis method	Tertiary and industry end-uses	SenterNovem
20	Voluntary agreements with individual companies – engineering method	Tertiary and industry end-uses	STEM

2.2 Three levels of harmonisation

In order to be as practicable as possible and to stimulate continued improvement, the harmonised reporting on bottom-up evaluation is structured on three levels (cf. figure 1).

Figure 1: Three levels of harmonisation



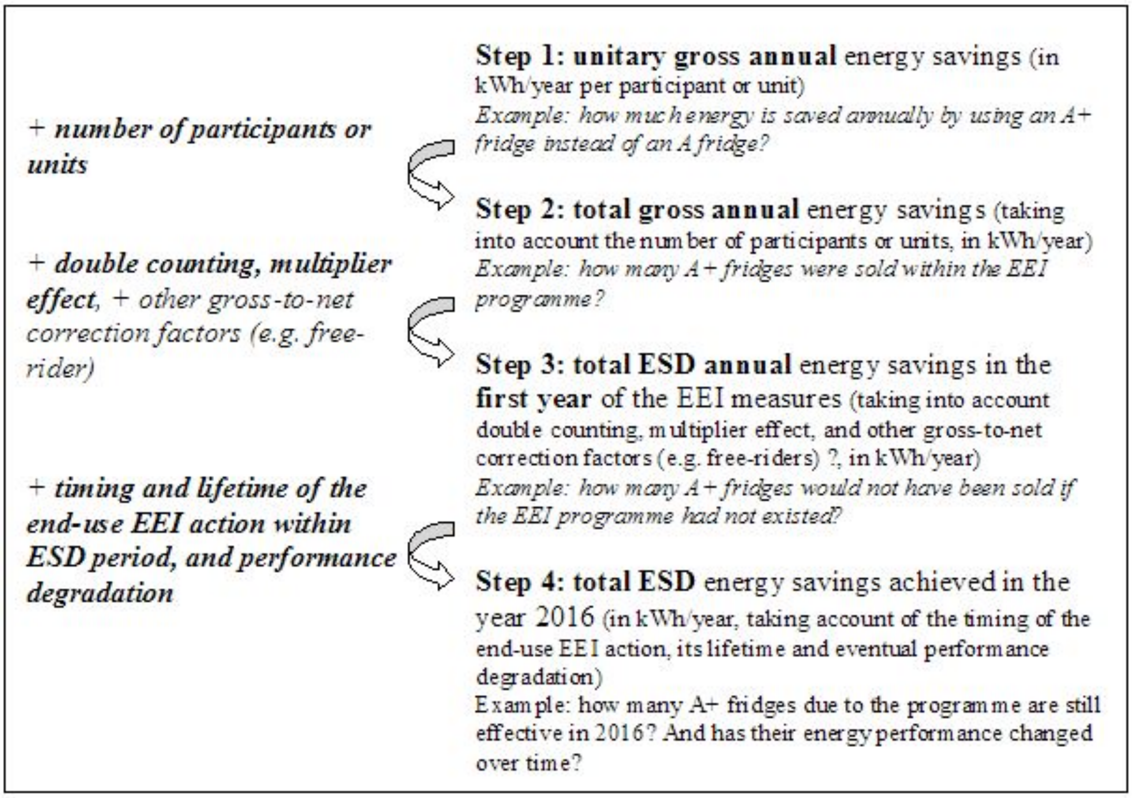
As a consequence, the EMEEES case applications for bottom-up evaluation methods present:

- EU wide reference values, if applicable;
- Guidelines how Member States can use country-specific values following harmonised rules;
- Guidelines how measure- or action-specific (national) values can be developed, following harmonised rules.

2.3 Four steps in the calculation process

The harmonised rules for bottom-up evaluation methods are organised around four steps in the calculation process (cf. figure 2). These steps are presented in detail in the report for WP 4.1.

Figure 2: Four steps in the calculation process



Step 1: unitary gross annual energy savings (in kWh/year per participant or unit)
Example: how much energy is saved annually by using an A+ fridge instead of an A fridge?

*+ **number of participants or units***

Step 2: total gross annual energy savings (taking into account the number of participants or units, in kWh/year)
Example: how many A+ fridges were sold within the EEI programme?

*+ **double counting, multiplier effect**, + other gross-to-net correction factors (e.g. free-rider)*

Step 3: total ESD annual energy savings in the **first year** of the EEI measures (taking into account double counting, multiplier effect, and other gross-to-net correction factors (e.g. free-riders) ?, in kWh/year)
Example: how many A+ fridges would not have been sold if the EEI programme had not existed?

*+ **timing and lifetime of the end-use EEI action within ESD period, and performance degradation***

Step 4: total ESD energy savings achieved in the year 2016 (in kWh/year, taking account of the timing of the end-use EEI action, its lifetime and eventual performance degradation)
Example: how many A+ fridges due to the programme are still effective in 2016? And has their energy performance changed over time?

The reports on the concrete bottom-up case applications follow the format of these four steps and they each hold six chapters plus some annexes:

1. summary
2. introduction
3. step 1: unitary gross annual energy saving
4. step 2: total gross annual energy savings
5. step 3: total ESD annual energy savings
6. step 4: total ESD energy savings for year “i”

2.4 Pilot tests

Additional to the development of the 20 bottom-up case applications, some of these cases were tested in practice in Work Package 8.
Pilot tests of the following case applications were performed by EMEEES partners in Italy, France, Denmark, and Sweden:

EMEEES case application	**Sector**	**Italy**	**France**	**Denmark**	**Sweden**
Building envelope improvement	Residential		X		
Energy-efficient white goods	Residential	X			
Biomass boilers in the residential sector	Residential		X		
Condensing Boilers	Residential	X	X		
Improvement of lighting system	Tertiary (industry)				X
High efficiency electric motors	Industry	X			
Variable speed drives	Industry	X			
Energy audits	Tertiary and industry end uses			X	
Energy performance contracting	Tertiary and industry				X

The following EEI measures were evaluated ex-post using the above-mentioned EMEEES bottom-up case applications:

Country	**Subject**	**Sector(s) addressed**
France	Condensing boilers, building envelope improvements and compact fluorescent lamps under the French White Certificates.	Residential
Italy	Schemes under the Italian White Certificates system	Residential, tertiary, industry
Sweden	Energy Efficiency Investment Programme for Public Buildings (2005-2008)	Public non-residential buildings
Denmark	Energy audits performed in Denmark between 2006 and 2008	Industry, tertiary

As a result of the pilot tests, some of the case applications tested were updated to reflect the findings of the tests.

3 Step 1: Unitary gross annual energy savings

3.1 Step 1.1: General formula and calculation model

Annual energy savings (kWh/year/participant) are determined using the following engineering calculation.

$$\Delta E = H \cdot \left[F_{O,st} \cdot F_{D,st} \cdot \sum_{i=1}^{Nst} \left(N_{l,st} \cdot P_{l,st} + N_{b,st} \cdot P_{b,st} \right)_i - F_{O,ef} \cdot F_{D,ef} \cdot \sum_{i=1}^{Nef} \left(N_{l,ef} \cdot P_{l,ef} + N_{b,ef} \cdot P_{b,ef} \right)_i \right]$$

(equation 1)

- ΔE = Total gross annual energy savings from end-use action per participant
- H : number of operating hours [hours/year]
- N_{st} : number of standard luminaires [n.]
- F_O = occupancy dependency factor; factor relating the usage of the total installed lighting power to occupancy period in the room or zone; $0 \leq F_O \leq 1$
- F_D = daylight dependency factor; factor relating the usage of the total installed lighting power to daylight availability in the room or zone; $0 \leq F_D \leq 1$
- N_{ef} : number of efficient luminaires [n.]
- $N_{l,st}$: Number of standard lamps per luminaire [n.]
- $N_{l,ef}$: Number of efficient lamps per luminaire [n.]
- $N_{b,st}$: Number of standard ballasts per luminaire [n.]
- $N_{b,ef}$: Number of efficient ballasts per luminaire [n.]
- $P_{l,st}$: electrical power (effective, not simply nominal) absorbed by the standard lamps [W]
- $P_{l,ef}$: electrical power (effective, not simply nominal) absorbed by the efficient lamps [W]
- $P_{b,st}$: electrical power absorbed by the standard ballasts [W]
- $P_{b,ef}$: electrical power absorbed by the efficient ballasts [W]

Instead of addressing lamps and ballasts separately as in equation 1, it is also possible to address lamp-ballast systems, as done in chapter 3.2.4.

The following sections present Level 1 estimates of energy savings by using data from existing studies or by making reasoned guesses (where no specific data exists) for the overall situation in European countries.

The same formula can be used to develop more precise Level 2 and Level 3 Country and Action specific estimates of energy savings. While developing Level 2 and Level 3 estimates, special attention must however be given to the hours of use of the standard and efficient lighting system (variable H in equation 2).

As equation (1) makes explicit, a reduction in the hours of use can only be achieved by the introduction of improved specific control apparatus whose effects reflect in the values of the parameters F_{Oef} and F_{Def} of this equation . Energy audits or end use measurement campaigns might reveal a change in the number of hours of use in correspondence with the introduction of the end-use action. However a change in the number of operating hours can be caused by a change in use of the indoor spaces subject to monitoring and not reflect any inherent increase in energy efficiency of the lighting plant. Therefore any reductions in operating derived from audits or metering must nevertheless be explicitly shown to be due to improved control apparatus

Equation (1) allows energy savings derived from nearly all possible improvements to lighting systems to be evaluated.

The formula reported above has been proposed in order to cover all the possible cases involving lighting systems, as defined in par. 1.3 . In fact:

- improvements of lamps are considered by the parameters N_l and P_l
- improvements of ballasts are considered by the parameters N_b and P_b
- improvements of luminaires imply possible changes in the parameter N_{ef} with respect to N_{st} (delamping)
- improvements of control strategies reflect in the values of the parameters F_{Oef} and F_{Def} (see section 3.4.1).

3.2 Step 1.2 : Baseline and reference energy savings

We use Equation (1) together with data from existing studies and reasonable hypotheses to establish two baselines and the after action efficiency level:

- (inefficient) stock baseline
- inefficient market baseline
- efficient market technology

The present section determines Level 1 estimates for each of the three items for lamps, ballasts, ballast-lamp combinations, luminaires, and improved control strategies.

The ESD definition of energy savings states the baseline is the situation before implementing an EEI measure. This "before" situation may be interpreted either:

- as the "before" annual energy consumption, i.e. energy consumption of the equipment or site in the year before the implementation of the EEI measure,
- or as "before" the decision, i.e. whether implementing an end-use action would have occurred or not if the EEI measure had not existed.

The question is, therefore, which situation is prevailing in a specific EEI measure. A general guiding principle is that the answer depends on what would have happened in the absence of the EEI measure. In the specific case of the lighting systems, we have assessed the stock situation and the market share of the equipments in EU and:

- use the (inefficient) **stock baseline** in case of **anticipated reinvestment or improving the control strategies of an existing lighting system, as well as when calculating all energy savings;**
- use the **inefficient market baseline when calculating additional energy savings**

in case of **programmed (normal) reinvestment or of completely new lighting systems (e.g., in new buildings), including their control strategies.**

The terms all and additional energy savings are defined in the overall summary report on bottom-up methods by EMEEES.

Both baselines need to be adapted to technical progress from time to time.

3.2.1 Data Sources

The following sections make much use of data reported in the following study:

- SAVE II funded DEFU Project "Market research on the use of energy efficient lighting in the commercial sector" , 2001. DEFU (2001)

  This document reports the results of audits undertaken in respect of the lighting system in five principle categories of building type in the commercial sector; education, health care, public offices, private offices and retail in six European countries (Denmark, UK, Greece, Italy, Spain, Belgium). Audits were completed on 10 buildings from each category for a total of 50 buildings per country. In the UK and Denmark audits were undertaken on 100 buildings.

  Though recognizing that the data set is not statistically representative of the entire building stock it nevertheless represents one of the most comprehensive analysis of lighting systems in the commercial sector in recent years in Europe, and is taken as the principle reference point in this paper in lack of more detailed data[3].

3.2.2 Operating hours (Hst)

The estimates of stock and market baseline energy savings all make reference to lighting system operating hours (variable H in Equation (1)). The operating hours are estimated based on data from DEFU (2001), CIE 97 (2005) and EN 15193 (2007).

Table 7 – Average yearly operating hours according to DEFU and CIE studies for the five principle categories in the tertiary sector

Building category	**Average yearly operating hours**	
	DEFU (2001)	CIE 97 (2005)[4]
Education	2000	1900
Health care	2700	5000
Public Office	2600	2580

---

[3] A preliminary study related to the implementation of the EuP directive reporting the same statistics contained in the DEFU report became available after the almost definitive version of this case application had been produced. However it has been verified that EuP directive preliminary study statistics (although referring to 2004 instead of 2001) are not significantly different from those produced in the DEFU report.

[4] CIE 97 (2005) : Guide on the maintenance of indoor electric lighting systems, Commission Internationale de l´Eclairage, 2005

Private Office	2600	2580
Retail store	2900	3100
Average:	2560	3030

Table 8 – Average yearly operating hours according to EN 15193 for the main categories in the tertiary sector

Building category	**Operating hours***
Office	2500
Education	2000
Hospital	5000
Hotel	5000
Restaurant	2500
Sport places	4000
Retail	5000
Manifacture	4000
Average:	3750

* Annual operating time: annual number of operating hours of the lamp(s) and luminaires with the lamps on.

Average baseline **operating hours (H)** are taken as the more conservative of the three average values derived form the three information sources above mentioned, namely **2.500 hours/year**

Lighting system operating hours can be normalised on the basis of latitude and hence availability of natural daylight as described in Chapter 3.3.

In case the energy savings yielded by EEI facilitating measures addressing a specific building category have to be estimated, the yearly operating hours for such building category may be derived from information reported in table 8 and be used to perform more reliable Level 1 estimates.

3.2.3 Lamps

The main lamp categories that are used in the tertiary sector are:

- Linear fluorescent lamps
- Compact fluorescent Lamps with non integrated ballast
- Compact Fluorescent Lamps with integrated ballast

Though Light Emitting Diodes (LED's) are available these are considered as Best Not yet Available Technology.

The main potential end-use actions to Lamps are:

- replacement of incandescent lamps with CFLs
- replacement of T12 with T8 linear fluorescent lamps.

3.2.3.1 Replacing Incandescent Lamps with CFLs: Level 1 Data

Though the technical characteristics of CFLs might hinder their use in some applications, generally they can provide a direct substitute for incandescent lamps offering energy savings in the region of 75-80%.

Compact Fluorescent lamps may have integral or separate ballasts. In all cases each single lamp is always associated with a single ballast and thus numbers of lamps equate the number of installed ballasts. (Note that this is not the case with linear fluorescent tubes where a single ballast might power up to 4 fluorescent tubes).

Thus in all cases: $N_{l,sta}=N_{l,eff}=N_{b,eff}$

The following sections determine the default Level 1 values for $P_{l,st}$ and $P_{b,st}$

3.2.3.1.1 Stock Baseline ($P_{l,st}$ and $P_{b,st}$)

Table 9 gives the stock distribution of incandescent lamps as a function of power and building category according to the DEFU (2001) study.

Table 9 – Percentage distribution of the most common incandescent lamps in respect of the total number of installed incandescent light sources (based on DEFU 2001)

	Incandescent Lamps				**Weighted average**
EU	**40 W**	**60 W**	**75 W**	**100 W**	**W**
Education	26,3%	47,4%	7,5%	18,8%	63,4
Health care	10,1%	15,8%	62,7%	11,4%	72,0
Offices	21,1%	61,7%	6,5%	10,6%	61,0
Retail	26,3%	47,4%	7,5%	18,8%	70,2
Stock Baseline ($P_{l,st}$ e $P_{b,st}$)					**65,7**

The **Stock Baseline** ($P_{l,st}$ and $P_{b,st}$) is taken as the weighted average of the distribution reported in Table 9 , namely **65,7 W**

In the case of incandescent lamp no ballast is required and thus $N_{b,st}=P_{b,st}=0$.

3.2.3.1.2 Market Inefficient Baseline ($P_{l,st}$ and $P_{b,st}$)

Incandescent and CFL currently compete for roughly the same applications on the market. However we consider current sales of CFLs in the context of Free Riders (See chapter 5.5) and determine the Market Baseline only with respect to incandescent Lamps.

The UK has a plan to remove incandescent lamps from the market by 2011 and we can expect the efficiency of light sources of the market there to increase afterwards. However it is not clear how far the countries hold similar objectives to that of the UK. Thus in the lack of specific regulation or technology development to improve the efficiency of incandescent lamps we suppose that every incandescent lamp burned out is replaced with a new incandescent lamp, of the same type and power.

In consequence the **Market Inefficient Baseline** ($P_{l,st}$ e $P_{b,st}$) is taken as the same value of the Stock Baseline as determined in the previous section namely **65,7 W**

3.2.3.1.3 Market Efficient Technology ($P_{l,eff}$ and $P_{b,eff}$)

As already noted, Incandescent Lamps and CFLs currently compete for roughly the same applications on the market with CFLs representing the efficient solution.

The exact equivalence between CFLs and Incandescent lamps is debatable. Often manufacturers market CFLs by using a (Incandescent Power/5) rule by which, for example, a 20 W CFL is supposed to provide an equivalent output of an 100 W

Incandescent.

In fact, this rule leads to CFLs which provide similar though on the whole slightly lower lumen output than the Incandescent “equivalent”. For example a common 100 W incandescent lamp emits 1360 lm, and a 20 W CFL 1200 lm.

Marketing CFLs in this way can lead to disappointment by the user which find the CFLs “dark”, and ultimately could lead to technology rejection. We feel that it is in the interests of energy efficiency policy that CFLs are chosen so as to provide at least equivalent if not more lumen output than the Incandescent model which they are replacing.

Table 10 reports typical values of lumen output offered by Incandescent lamps of different power ratings together. To each is associated the CFL of lowest power offering at least the same lumen output.

Table 10 – Equivalence between incandescent lamps and CFLs

Incandescent			**Equivalent CFL**		
W	**lm**	**lm/W**	**W**	**lm**	**lm/W**
40	420	11	11	630	57
60	710	12	15	900	60
75	940	13	20	1200	60
100	1360	14	23	1500	65

Lamp power for CFLs refers to the combined power of ballast and lamp.

To determine the Market Efficient Value we suppose that distribution of CFLs purchased may replace the stock of Incandescent Lamps of equivalent lumen. Table 11 applies the power equivalence reported in Table 10 to the stock distribution of Incandescent Lamps as reported in Table 9.

Table 11 – Market distribution of CFLs supposing sales replace stock of “equivalent” incandescent lamps

	CFL				**Weighted average**
EU	**11 W**	**15 W**	**20 W**	**23 W**	**W**
Education	26,3%	47,4%	7,5%	18,8%	15,8
Health care	10,1%	15,8%	62,7%	11,4%	16,0
Offices	21,1%	61,7%	6,5%	10,6%	12,9
Retail	26,3%	47,4%	7,5%	18,8%	9,1
Market Efficient Baseline (Pl,eff + Pb,eff)					***14,8***

From Table 11 the **Market Efficient Technology value** (2008) ($P_{l,eff}$ $P_{b,eff}$) **14,8 W**

The baseline power of the efficient lamps [14,8 W] refers to the combined power of the ballast and the lamp [$N_{eff} \cdot P_{eff}$].

EuP[5] data indicates that total sales of incandescent lamps will increase by 3.5%/year and CFL's by 7.1 %/year in the period 2008-2009. (Thus the market share of CFL's increases). However as already noted we take account of CFLs in the context of Free Riders described later. Though the overall sales of Incandescent Lamps is projected to increase in the period 2008-2009, and by protection beyond to 2016, we assume that the distribution of sales will follow that reported in Table 9 and thus the Market Efficient value remains constant for the period

From Table 11 the **Market Efficient Technology value** (2009-2016 $P_{,eff}$) **14,8 W**

3.2.3.1.4 Level 1 Data Summary

$N_{l,st}=N_{b,st}=N_{l,eff}=N_{b,eff}$

Stock Inefficient Baseline ($P_{l,st} + P_{b,st}$) = 65,7 W

Market Inefficient Baseline ($P_{l,st} + P_{b,st}$)= 65,7 W

Market Efficient Technology (2008-2016) ($P_{l,eff} + P_{b,eff}$) 14,8 W

3.2.3.1.5 Examples

We apply Equation 1 and the Stock and Market Baseline values reported in the previous section to determine energy savings resulting from programmes to promote CFL penetration. According to the general rules proposed by the EMEEES project, a reliability factor of 0.8 is applied even on reliable EU average values calculated from literature and statistical data, to take into account remaining uncertainties. This holds for all level 1 data on unitary gross annual energy savings given here.

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[5] EuP - Directive 2005/32/EC on eco-design requirements for energy-using products.

Programmes directed strictly to improving existing systems.

Standard System – Stock Inefficient Baseline.

Efficient System – Market Efficient Value.

Table 12 - Average energy savings from the replacement of incandescent lamps with CFLs

	Variables in relation to Equation (1)	Level 1 Data	
Average power absorbed by the standard incandescent lamp:**Stock Baseline**:	$(N_{l,st}P_{l,st} + N_{b,st}P_{b,st})$	65,7	W
Average Power absorbed by the efficient (CFL) lamp:**Market Efficient value**:	$(N_{l,eff}P_{l,eff} + N_{b,eff}P_{b,eff})$	14,8	W
Difference of absorbed power:		50,9	W
Baseline Use: Hours	H	2500	h
Energy Savings	ΔE	0.8 * 127 = **102**	**kWh/year/CFL**

Note that:

$(N_{l,st}P_{l,st} + N_{b,st}P_{b,st}) = N_{l,st}P_{l,st}$ since $P_{b,st} = 0 = N_{b,st}$

$(N_{l,eff}P_{l,eff} + N_{b,eff}P_{b,eff}) = N_{CFL}P_{CFL}$ for CFL's with integral ballast.

Programmes directed strictly to improving market sales.

Standard System – Market Inefficient Baseline.

Efficient System – Market Efficient Value

Table 13 - Average energy savings from promoting the sale of CFLs

	Variables in relation to Equation (1)	Level 1 Data	
Average power absorbed by the standard incandescent lamp on market:**Market Standard Baseline**	$(N_{l,st}P_{l,st} + N_{b,st}P_{b,st})$	65,7	W
Average Power absorbed by the efficient (CFL) lamp:**Market Efficient Value**	$(N_{l,eff}P_{l,eff} + N_{b,eff}P_{b,eff})$	14,8	W
Difference of absorbed power:		50,9	W
Baseline Use: Hours	H	2500	h
Energy Savings:	Δ**E**	0.8 * 127 = **102**	**kWh/year/CFL**

3.2.3.2 Replacing Incandescent with CFLs: Level 2 and 3 Requirements

Country or EEI-measure specific data for all variables in Equation 1 can be collected through energy audits and end-use measurements or other data sources as detailed in Section 2.9.

3.2.3.3 Replacing Linear T12 with T8 fluorescent lamps

Linear and Compact Fluorescent lamps are the most common lighting source in the five main commercial categories of the Tertiary sector, reaching penetration rates of 95%.

Table 14 - Penetration of linear T8 and T12 fluorescent lamps as a total of number of installed lamps in the tertiary sector. Based on DEFU (2001)

	Denmark	**UK**	**Greece**	**Italy**	**Spain**	**Beglium**
Education	75,8%	96,5%	95,0%	70,5%	95,0%	85,5%
Health care	56,0%	81,0%	82,0%	82,0%	89,0%	68,0%
Public Office	73,0%	97,5%	64,0%	85,0%	86,0%	N.A.
Private Office	56,5%	N.A.	53,0%	79,0%	84,5%	N.A.
Retail store	32,0%	34,0%	90,0%	83,5%	55,0%	N.A.

Of these 18, 36 and 58 W linear T8 fluorescent lamps are by far the most common type of lamp (Figure 1).

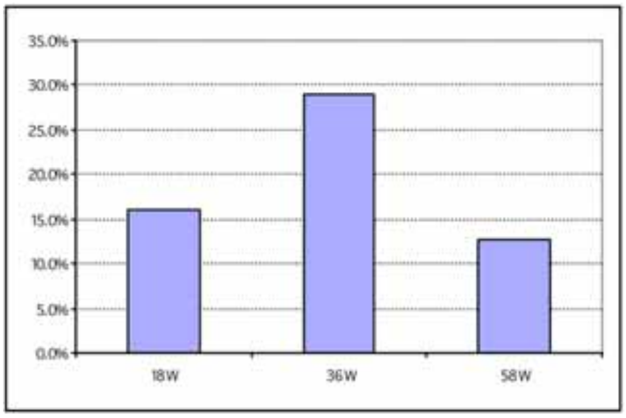


Figure 1 – Penetration of linear T8 and T12 fluorescent lamps as a function of total lamp numbers (Based on DEFU 2001)

T8 fluorescent lamps provide roughly 10% energy savings when used in substitution of T12 equivalents. Current penetration of T12 lamps is now quite low representing probably less than 10% of existing stock. However it is reasonable to suppose programmes and actions designed to remove the remainder of these existing systems, for which default Level 1 values would be useful. However no Level 1 default values have yet been defined.

3.2.3.4 Replacing Linear T8 halophosphate with triphosphor lamps

Triphosphor lamps are roughly 8% more efficient than halophosphate equivalents (more lm/W) and lumen levels remain higher for longer time periods.

Substituting halophosphate with triphosphate lamps will lead to a roughly 8% increase in lumen output from the system. In larger indoor spaces therefore it is potentially possible to remove roughly one in twelve lamps whilst maintaining the same overall total lumen output of the system. However, though total lumen output might remain unaltered, delamping can lead to local variations in lighting levels which can be in contrast with good lighting design.

Substituting halophosphate with triphosphor lamps also reduces mercury use and potential emissions; with typical mercury content of 10 mg compared to 5 mg per lamp respectively.

It is reasonable to suppose programmes and actions designed to remove the remainder of these existing systems, for which default Level 1 values would be useful. However, no Level 1 default values have yet been defined.

3.2.4 Ballasts

Ballasts are required by all compact and linear fluorescent lamps to provide the initial voltage to kick-start the discharge process and then subsequently to limit the current. Ballast power can represent up to 30% of the total power of the lamp ballast system.

There are roughly three ballast technologies; electromagnetic, low loss electromagnetic and electronic, the latter of which includes electronic dimmable ballasts.

Electronic ballasts offer energy savings in the region of 20-30% considering the combined lamp-ballast systems using standard electromagnetic models.

Though it is possible to analyse the efficiency improvements by considering ballasts in isolation, it is more practical to consider the combined lamp-ballast system for two reasons:

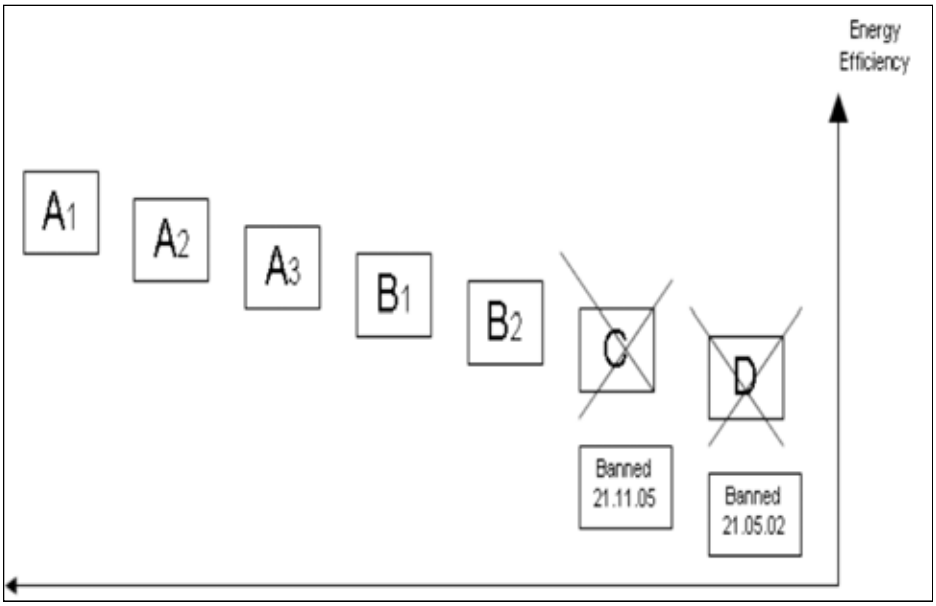
- electronic ballasts can replace more than one electromagnetic ballast
- electronic ballasts, apart from consuming less power than the electromagnetic equivalents, also reduce the power absorbed by the lamps which they are powering

Both reasons make the direct comparison of electronic and electromagnetic ballasts difficult.

The following analysis, though worded in terms of ballast replacement, considers the entire lamp-ballast system.

EU directive 2000/55/EC aimed to improve the efficiency of lighting systems by limiting ballast losses. To respond to the requirements of the Directive, CELMA developed a classification system of the lamp-ballast system which characterised system energy performance in terms of an energy efficiency index (EEI) and a 7 class scale from A1 to D.

Ballasts in classes C and D were progressively phased out from the market as of 2002. In accordance with Article 2 of the Directive only ballasts with EEI B2 or better can be sold in the EU since 21st of November 2005.



Though ballast classification is based on lamp-ballast power, and not on technology type, in reality it is possible to roughly associate different technologies to the different CELMA Classes:

- Classes A1, A2 and A3 identify electronic ballasts,
- Class B1 low-loss electromagnetic ballasts
- Classes B2, C and D standard electromagnetic ballasts.

3.2.4.1 Replacing electromagnetic with electronic ballasts: Level 1 Data

As already noted, 18, 36 and 58 W linear T8 fluorescent lamps represent the most common lamp (Figure 1) in the tertiary sector. We consider ballast replacement for these three lamp types.

3.2.4.1.1Stock Baseline ($N_{l,st}$, $P_{l,st}$ + $N_{b,st,}P_{b,st}$)

To determine the average power of the installed stock, it is necessary to establish the distribution of ballast types in terms of:

- distribution of electronic and electromagnetic
- distribution of system configurations (2x18W, 4x18 W, 1x36 W, 2x36W and 1x58W, 2 x58W)

Data from DEFU (2001) distinguish generically between conventional (electromagnetic) and electronic ballasts, without considering the more detailed CELMA classification. According to DEFU (2001), the number of electronic ballasts in 2000 represented roughly 10% of total number of ballasts installed and electromagnetic version 90%. More precise figures for the different countries considered in the study are given in Table 15.

Table 15 – Stock share of the ballasts in six European countries DEFU (2001)

Country	Electronic Ballast	Conventional Ballast
Denmark	11,0%	89,0%
UK	27,5%	72,5%
Greece	11,5%	88,5%
Italy	6,3%	93,7%
Spain	5,4%	94,6%
Belgium	1,5%	98,5%
Average*	**9,8%**	**90,2%**

Taking as a starting point the distribution reported in the last table, we make a best guess to achieve a more detailed breakdown of ballast stock based on the CELMA ballast classification scheme (Table 16).

Table 16 – Distribution of ballast efficiency classes for T8 fluorescent lamps based on DEFU (2001) data integrated with eERG expert opinion. We assume that the distribution of CELMA class type is the same across all T8 system types

Stock (DEFU)		CELMA Classification	Relative Distribution for Ballast Type eERG expert opinion)	Absolute Distribution
Electronic	9.8%	A1	5%	0.5%
		A2	50%	4.9%
		A3	45%	4.4%
Standard	90.2%	B1	5%	4.5%
		B2	5%	4.5%
		C	85%	76.7%
		D	5%	4.5%

Though DEFU (2001) data indicates that 18, 36 and 58 W represent the most common system types, no data is available to indicate the exact type of system. We make a reasoned guess and suppose the distribution is that reported in Table 17.

Table 17 – Distribution of T8 system types based on DEFU (2001) data and eERG expert opinion

Nominal Lamp Power	**Distribution (as % of T8 lamps)**	**System Type**	**Relative Distribution (eERG expert opinion)**	**Absolute Distribution**
[W]				
18	26	2 x 18	10%	2.6%
		4 x 18	90%	23.4%
36	51	1 x 36	10%	5.1%
		2 x 36	90%	45.9%
58	23	1 x 58	10%	2.3%
		2 x 58	90%	20.7%

Combining the data reported in Table 16 and Table 17, we estimate the distribution of system types in terms of ballast efficiency for each system type.

Table 18 – Overall stock distribution of T8 system types by ballast efficiency

System Type	**A1**	**A2**	**A3**	**B1**	**B2**	**C**	**D**
2 x 18	0.0%	0.1%	0.1%	0.1%	0.1%	2.0%	0.1%
4 x 18	0.1%	1.1%	1.0%	1.1%	1.1%	17.9%	1.1%
1 x 36	0.0%	0.2%	0.2%	0.2%	0.2%	3.9%	0.2%
2 x 36	0.2%	2.2%	2.0%	2.1%	2.1%	35.2%	2.1%
1 x 58	0.0%	0.1%	0.1%	0.1%	0.1%	1.8%	0.1%
2 x 58	0.1%	1.0%	0.9%	0.9%	0.9%	15.9%	0.9%

The Stock Baseline is given by combining the distribution of systems (Table 18) with the relative specific power of each type of system (Table 20). Table 20 reports corrected values for systems using Class A1 ballasts, since the nominal values reported in the CELMA classification scheme (Table 19) do not indicate the maximum allowed power of A1 systems but rather the power of A1 systems when operated on a dimming cycle; more specifically declared values indicate maximum system power (ballast and lamps) when providing 25% of nominal light output.

Table 19 – Maximum system power for systems using class A1 CELMA classification for ballasts. The value indicates system power when providing 25% of nominal light output.

System Type	**A1**
2 x 18	21
4 x 18	42
1 x 36	19
2 x 36	38
1 x 58	29.5
2 x 58	59

However, energy savings offered by dimming and daylight integration are considered in the present methodology by using the F_o and F_D factors in equation 1. To avoid to double count the contribution by dimming, we therefore choose to correct the power values for A1 ballasts and introduce the maximum allowed system power when providing 100% light output.

To receive A1 classification, ballasts must fulfil the following requirements:

- when providing 100% light output the ballast fulfils at least class A3 specifications;
- when providing 25% light output the total input power is equal to or less than 50% of the power at the 100% light output setting;
- the ballast must be able to reduce the light output to 10% or less of the maximum light output.

Table 20 reports the maximum allowed power for all CELMA classes when providing 100% light output, A1 system maximum allowed power having been estimated from values reported in table 19 and above mentioned requirements.

Table 20 – The maximum system power [W] for the most common T8 system according to CELMA classification

System Type	A1	A2	A3	B1	B2	C	D
2 x 18	42	38	42	49	52	56	60
4 x 18	84	76	84	85	88	92	96
1 x 36	38	36	38	41	43	45	47
2 x 36	76	72	76	82	86	90	94
1 x 58	59	55	59	64	67	70	72
2 x 58	118	110	118	128	134	140	144

Table 21 reports the results and the overall weighted power of installed stock which equates with the Stock Baseline for T8 lamps and ballasts.

Table 21 – Weighted power of T8 system types and T8 system distribution [W]

System Type	A1	A2	A3	B1	B2	C	D
2 x 18	0.01	0.05	0.05	0.06	0.06	1.12	0.07
4 x 18	0.1	0.87	0.86	0.9	0.93	16.51	1.01
1 x 36	0.01	0.09	0.09	0.09	0.1	1.76	0.11
2 x 36	0.17	1.62	1.53	1.69	1.78	31.68	1.94
1 x 58	0.01	0.06	0.06	0.07	0.07	1.23	0.07
2 x 58	0.12	1.12	1.07	1.19	1.25	22.23	1.34

3.2.4.1.2 Market inefficient baseline ($N_{l,st}$, $P_{l,st}$ + $N_{b,st}$,$P_{b,st}$)

CELMA (2004) data breaks down sales of ballasts generically between electronic and electromagnetic for the period 1998 to 2008. Extending the CELMA projections forward to 2016, we estimate a projected penetration of electronic ballasts of 90% in that year (Figure 2).

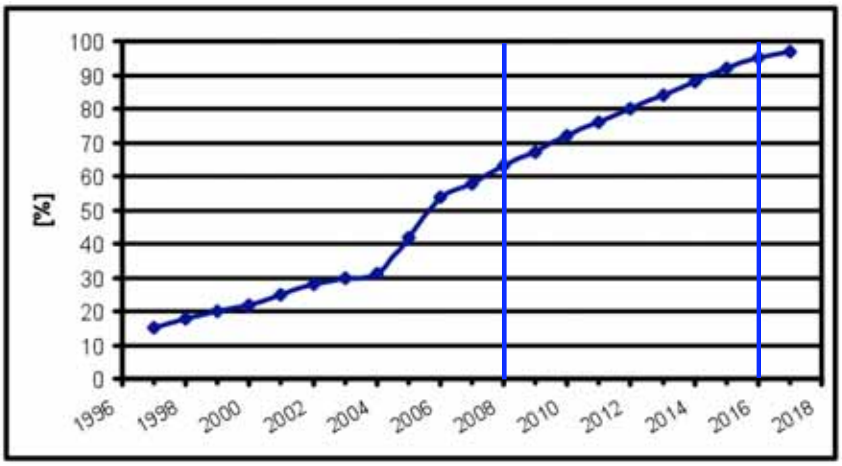


Figure 2 - Market share (1997 to 2004) and expected market share (2005 to 2016) of electronic ballasts in Europe. Data from 1997 to 2010 are based on CELMA data, while the extrapolation between 2010 and 2016 is an eERG forecast

Thus electronic ballasts currently represent an important part of the ballast market (just over 50%) and their penetration is expected to increase over the 2008- 2016 period.

However in defining the Market Inefficient Baseline, we ignore the sales of Class A (Electronic) ballasts in that these are taken account of in the context of Free Riders.

The Market Inefficient Baseline therefore considers only sales of standard electromagnetic ballasts. We propose a more detailed breakdown of electromagnetic ballasts sales based on the CELMA ballast classification scheme as reported in Table 22 in which the relative distribution of Class B ballasts remains constant for the 2008-2016 period. Sales of Class D and C ballasts are assumed to be zero in that the industry voluntary agreement saw them phased out from the market in 2002 and 2005.

Table 22 – Market breakdown of ballast types according to the CELMA classification scheme

Ballast Type	**CELMA Classification**	**Relative distribution for Ballast Type** **(eERG expert opinion)**
Standard	B1	70%
	B2	30%

Following the same method as described in the previous section to determine the Stock Baseline, we consider the breakdown of ballast types according to CELMA class in relation to the different system types.

Table 23 – Overall market sales of standard T8 system types in terms of ballast efficiency

System Type	B1	B2
2 x 18	1.8%	0.8%
4 x 18	16.4%	7.0%
1 x 36	3.6%	1.5%
2 x 36	32.1%	13.8%
1 x 58	1.6%	0.7%
2 x 58	14.5%	6.2%
	70.00%	**30.00%**

Table 24 below reports the calculation results and the overall weighted power of standard T8 systems sold on the market which equates the Market standard baseline for T8 lamps and ballasts

Table 24 – Weighted power of standard T8 systems on the market [W]

System Type	B1	B2
2 x 18	0.89	0.41
4 x 18	13.92	6.18
1 x 36	1.46	0.66
2 x 36	26.35	11.84
1 x 58	1.03	0.46
2 x 58	18.55	8.32
Overall Weighted Power ($N_{l,st}P_{lst}$ + $N_{b,st}P_{b,st}$)		**90**

3.2.4.1.3 Market efficient Value (Nl,effPl,eff + Nb,effPb,eff) and Neff

Without more detailed information to indicate differently, we propose that facilitating measures to promote the sale of electronic ballasts would lead to the sale of Class A according to the distribution reported in Table 25. The distribution is considered as constant for the period 2008 to 2016. The portion of Class A1 dimmable ballasts is assumed at 10%, as they currently have a high market price compared to the Class A2 and A3 ballasts.

Table 25 – Overall market sales of T8 system types by ballast efficiency

Ballast Type	CELMA Classification	Relative distribution for Ballast Type (eERG expert opinion)
Electronic	A1	10%
	A2	60%
	A3	30%

Following the same method described in the previous section to determine the Stock inefficient baseline, we consider the breakdown of ballast types according to CELMA classification reported below.

Table 26 – Market distribution of T8 systems employing electronic ballasts in terms of system type and system efficiency

System Type	A1	A2	A3	Total
2 x 18	0.3%	1.6%	0.8%	2.60%
4 x 18	2.3%	14.0%	7.0%	23.40%
1 x 36	0.5%	3.1%	1.5%	5.10%
2 x 36	4.6%	27.5%	13.8%	45.90%
1 x 58	0.2%	1.4%	0.7%	2.30%
2 x 58	2.1%	12.4%	6.2%	20.70%
	10.0%	**60.0%**	**30.0%**	**100.0%**

Table 27 reports the results and the overall weighted power of standard T8 systems sold on the market which equates the Market efficient value for T8 lamps and ballasts. As happened for the Stock Baseline estimate the power of A1 ballasts has been corrected to take account of the fact that values reported in the CELMA classification scheme consider A1 ballasts operating on a dimming cycle.

Table 27 – Weighted power of T8 systems using electronic ballasts on the market [W]

System Type	A1	A2	A3
2 x 18	0.11	0.59	0.33
4 x 18	1.97	10.67	5.9
1 x 36	0.19	1.1	0.58
2 x 36	3.49	19.83	10.47
1 x 58	0.14	0.76	0.41
2 x 58	2.44	13.66	7.33
	Weighted Power ($N_{l,eff}P_{l,eff} + N_{b,eff}P_{b,eff}$) = 80		

We also need to determine the number of luminaires N_{eff}, in terms of the number of electronic ballasts sold or otherwise distributed under the EEI measure. (See example below for better understanding). To determine the average number of electronic ballast per luminaire we follow a similar method as applied to determine the average power per luminaire. We make a best guess as to the number of electronic ballasts per luminaire, for each of the various system types. Though electronic ballasts can in theory power up to 4 x

36 W T8 lamps, it is reasonable to assume that in a large fraction of multi-lamp luminaires more than one electronic ballast is installed to allow better light control.

Table 28 – Number of electronic ballasts per luminaire according to system configuration

System Type	No of ballasts per luminaire	Relative Distribution	Average no. of ballasts per luminaire type
2 x 18	1	90.0%	1.1
	2	10.0%	
4 x 18	1	30.0%	1.7
	2	70.0%	
1 x 36	1	100.0%	1.3
2 x 36	1	30.0%	1.7
	2	70.0%	
1 x 58	1	100.0%	1.3
2 x 58	1	30.0%	1.7
	2	70.0%	

Considered in relation to the sales distribution of the each of the different system types (Table 26) we arrive at the average number of ballasts per luminaire sold.

Table 29 - Marketed weighted number of ballasts per luminaire

System Type	Weighted No. of ballasts per luminaire
2 x 18	0.03
4 x 18	0.4
1 x 36	0.07
2 x 36	0.78
1 x 58	0.03
2 x 58	0.35
Average	**1.65**

The number of luminaires **N_{eff} = N_{st} = 0.60 times the** number of ballasts sold or distributed under the facilitating measure (= reciprocal of average value reported in Table 29)

3.2.4.1.4 Level 1 Data Summary

Stock Inefficient Baseline ($N_{l,st}P_{l,st} + N_{b,st}P_{b,st}$) = **95 W**

Market Inefficient Baseline ($N_{l,st}P_{l,st} + N_{b,st}P_{b,st}$) = **90 W**

Market Efficient Value (2008-2016) ($N_{l,eff}P_{l,eff} + N_{b,eff}P_{b,eff}$) = **80 W**

Number of Luminiares N_{eff} = N_{st} = **0.6** times the number of electronic ballasts distributed in the context of an EEI measure

3.2.4.1.5 Examples

We apply Equation 1 and the Stock and Market Baseline values reported in the previous section to determine energy savings results from programmes to promote the penetration of **electronic ballasts.**

Programmes directed strictly to improving existing systems.

N_{eff}= N_{st} = 0.6 x (no of luminaires sold or distributed under programme)

Standard System – Stock Inefficient Baseline (also to be used in any case when calculating all energy savings)

Efficient System – Market Efficient Value

Table 30 - Energy savings from the introduction of electronic ballasts – advanced replacement of existing ballast-lamp systems

	In relation to Equation (1)	Example data	
Power absorbed by the standard systems: Stock Baseline	($N_{l,st}P_{l,st} + N_{b,st}P_{b,st}$)	95	W
Power absorbed by the efficient systems: Market Efficient Value	($N_{l,edd}P_{l,eff} + N_{b,eff}P_{b,eff}$)	80	W
Number of luminaires affected per ballast	N_{st}=N_{eff}	0.6	
Average hours of Use	H	2500	h/year
Unitary annual energy savings based on average data from literature	Savings	22.5	kWh/year/ballast
Unitary annual energy savings – proposed EU default value	**ΔE**	0.8 * 22.5 = **18**	**kWh/year/ballast**

Programmes directed strictly to improving market sales.

N_{eff}= N_{st} = 0.6 x (no of luminaires sold or distributed under programme)

Standard System Consumption = Market Inefficient Baseline

Efficient System Consumption = Market Efficient Value

Table 31 - Energy savings from the introduction of electronic ballasts – normal replacement or new ballast-lamp systems

	In relation to Equation (1)	Example data	
Power absorbed by the standard systems: Market Inefficient Baseline	$(N_{l,st}P_{l,st} + N_{b,st}P_{b,st})$	90	W
Power absorbed by the efficient systems: Market Efficient Value	$(N_{l,edd}P_{l,eff} + N_{b,eff}P_{b,eff})$	80	W
Number of luminaires affected per ballast	N_{st}	0.6	
Average hours of Use	H	2500	h/year
Unitary annual energy savings based on average data from literature		15	kWh/year/ballast
Unitary annual energy savings – proposed EU default value	**ΔE**	0.8 * 15 = **12**	**kWh/year/ballast**

Programmes without preconditions

This represents the most likely scenario, i.e. incentives are used to improve both programmed purchases as well as anticipated replacement of stock. To what degree the incentive actually promotes the forced replacement of existing stock depends on the level of the incentive, with high incentive favouring the anticipated replacements.

Table 32 provides a purely indicative assessment of how the size of the economic incentive could influence the anticipated replacement of stock. The table serves only to roughly assess how relevant it might be distinguishing between anticipated and programmed replacement. The share between these two kinds of subs replacement titution reported below is merely indicative. To develop more reliable estimates would require an analysis of the market to determine the difference in price of standard and electronic T8 systems.

Table 32 – Possible influence of economic incentive on type of ballast replacements (Guestimates !)

EIA Incentive	Proportion of total replacements		Per ballast energy savings		
	attributed to anticipated substitution	attributed to improved sales	For anticipated stock	For improved sales	**Average for EEI measure**
[Euro/ballast]			[kWh/yr/unit]	[kWh/yr/unit]	**[kWh/yr/unit]**
< 10	10%	90%	22.5	15	15.75 * 0.8 = **12.6**
10 - 50	30%	70%	22.5	15	17.25 * 0.8 = **13.8**
50 - 100	50%	50%	22.5	15	18.75 * 0.8 = **15.0**
> 100	90%	10%	22.5	15	21.7 * 0.8 = **17.4**

3.2.4.2 Replacing electromagnetic with electronic ballasts: Level 2 and 3 Requirements

Level 2 (Country-specific) and Level 3 (Measure-specific) data can be integrated with or replace the Level 1 data.

3.2.5 Luminaires

Luminaire efficiency is most influenced by the reflector and shielding:

- Reflector: The surface reflectance of materials used varies from 60% for white painted reflectors to 95% for silver film. However the efficiency of the luminaires also depends on the optics as well as surface reflectance and can at best achieve values around 85%. Table 33 lists the efficiency range of some common reflector types.
- Shielding: Many luminiares also include shielding to reduce vision of the lamp at normal viewing angles and thus limit discomfort and glare, and distribute the light evenly (Table 34).

Table 33 – Examples of the relationship between luminaire light delivered and light produced for the reflector installation

Fixture	**Light delivered / Light produced**
Seasoned and cleaned white troffer	50-67%
Aluminium reflector	65-73%
Silver reflector	81-85%

Table 34 – Examples of the relationship between luminaire efficiency and VCP values for different shieldings. The VCP index (Visual Comfort Probability) provides an indication of the percentage of people in a given space that would find the glare from a fixture to be acceptable. We should ensure a minimum VCP rating of 70 for commercial interiors and 80 for computer areas

Shielding material	Luminaire efficiency range (%)	VCP range (%)
Standard Clear Lens	60 - 80	50 – 70
Low-Glare Clear Lens	60 - 80	75 – 85
Deep-Cell Parabolic Louver	50 - 90	75 – 99
Translucent Diffuser	40 - 60	40 – 50
White Metal Louver	35 - 45	65 - 85
Small-Cell Parabolic Louver	40 - 65	99

Using luminaires of higher efficiency potentially leads to a reduced number of luminaires installed, with consequentially less installed power and thus energy savings. Energy savings due to reduction in the number of luminaires can be evaluated by using Equation 1.

Although efficiencies may vary by up to 30% between different luminaire types, this does not automatically translate into a reduction in the number of luminaires. The number of installed luminaires depends on the geometry of the interior space and the surface reflections of the floor, walls and ceiling as well as the light distribution provided by the specific luminaire.

As a consequence it is difficult if not impossible to establish the change in the number of installed number of luminires, and hence the energy savings, on the basis of relative luminaire efficiency.

To evaluate energy savings offered by introducing higher efficiency luminaires, it is necessary to identify the number of installed luminaires before (N_{st}) and after (N_{eff}) the end-use action. Thus, evaluating the energy savings resulting from the introduction of high efficiency luminaires would require at least some Level 2 (Country-Specific) or Level 3 (Measure-Specific) data. However, Country- and Measure-Specific data could be used together with the Stock and Market Baseline Values reported in the last Section to determine energy savings resulting from the reduction in the number of installed T8 luminaires resulting from the adoption of luminaires of higher efficiency.

3.2.5.1 Examples

3.2.5.1.1 Introduction of luminaires of higher efficiency

We suppose an end-use Action involving the use of high efficiency T8 luminaires incorporating electronic ballasts provides the following data:

Number of standard luminaires removed = 100

Number of efficient luminaires introduced = 90

Specific or average power of standard luminaires = unknown

Specific or average power of efficient luminaires = unknown

Table 35 - Energy savings from the introduction of electronic ballasts

	In relation to Equation (1)	Example data	
Power absorbed by the standard systems: We suppose Market inefficient Baseline	$(N_{l,st}P_{l,st} + N_{b,st}P_{b,st})$	90	W
Power absorbed by the efficient systems: We suppose Market Efficient Value	$(N_{l,edd}P_{l,eff} + N_{b,eff}P_{b,eff})$	80	W
Number of standard luminaires removed: From Level 2 or Level 3 data	N_{st}	100	
Number of efficient luminaires introduced: From Level 2 or Level 3 data	N_{eff}	90	
Average hours of Use	H	2500	h/year
Total Energy savings offered by end-use action	ΔE	4,500	kWh/year

As the energy savings are highly dependent on the case-specific situation, no EU default value for the unitary annual energy savings can be defined. Instead, it is recommended to calculate it using equation 1 and the values for the power absorbed by the standard and efficient systems as well as the average hours of use in table 35, but with case-specific N_{st} and N_{eff}.

3.2.6 Luminaires – T5 Systems

Systems based on new generation T5 tubes that can only be powered by electronic ballasts represent an efficient lighting source. Manufacturers often promote T5 systems as an energy efficient solution compared to T8 alternatives. Certainly, T5 systems provide savings compared to T8 tubes powered by electromagnetic ballasts. However, T5 systems are probably no more efficient that T8 systems using electronic ballasts; indeed electronic ballasts powering T8 36 W (nominal) tubes probably provide the highest lumen/watt output of any of the T5, T8 or T12 systems.

It is possible to design luminaires for T5 systems of slightly higher efficiency since the lamp is more compact compared to T8 lamps. Indeed, a T5 luminaire will usually have 2-3% higher efficiency compared to the T8 luminaire of the same “product line”.

T5 systems are a relative new technology and their penetration can be considered marginal if we consider the entire stock of linear fluorescent lighting. For this reason they are not considered when determining the Stock Baseline in Section 3.2.4.1.1.

3.2.6.1 Replacing T8 systems with T5 alternatives: Level 1 Data

It is not simple to determine default Level 1 Data for energy savings offered by the introduction of T5 systems, since these systems (luminaires) are not directly substitutable with T8 or T12 alternatives. Table 34 lists typical lumen output of the most common T5 and T8 systems.

Table 36 – Comparison between T8 and T5 lamps

T8 Lamps			T5 lamps		
W	**lm**	**lm/W**	**W**	**lm**	**lm/W**
			14	1200	
18	1350	75	21	1900	90
30	2400	80	28	2600	93
36	3350	93	35	3300	94
58	5000	86	54	4450	
			80	6150	77

Given that tube powers differ, T5 systems offering the same lighting levels as T8 systems will contain a different number of luminaires, which only in part is due to the efficiency gain (if not at all). The exact number of luminaires depends on the the lumen output of the respective system, but also on the geometry of the interior space and the surface reflections of the floor, walls and ceiling as well as the light distribution provided by the specific luminaire.

We can determine an average baseline power rating for T5 systems on the market (Market Efficient Value). However, to determine Energy Savings requires specific data to identify the number of luminaires before (N_{st}) and after (N_{eff}) the end-use action since they can not be assumed the same (thus the evaluation requires some Level 3 or possibly Level 2 data).

3.2.6.1.1 Market efficient Value (Nl,effPl,eff + Nb,effPb,eff)

The DEFU 2001 study does not provide any explicit data in relation to T5 systems, either stock or sales. We therefore make the assumption that sales of T5 systems follows sales of the T8 “equivalents” according to Table 37. Though as already noted this equivalence is tenuous.

Table 37 – Proposed equivalence between T5 and T8 lamps

T8 Lamps			**T5 lamps**		
W	**lm**	**lm/W**	**W**	**lm**	**lm/W**
18	1350	75	14	1200	86
36	3350	93	35	3300	94
58	5000	86	54	4450	82

We can use this equivalence to modify Table 26 (which considers T8 systems) to determine the Market distribution of T5 systems in terms of system type and system efficiency (Table 38).

Table 38 – Market penetration of efficient T5 systems in terms of system type and ballast efficiency

System Type	**A1**	**A2**	**A3**	**Total**
2 x 14	0.3%	1.6%	0.8%	2.60%
4 x 14	2.3%	14.0%	7.0%	23.40%
1 x 35	0.5%	3.1%	1.5%	5.10%
2 x 35	4.6%	27.5%	13.8%	45.90%
1 x 54	0.2%	1.4%	0.7%	2.30%
2 x 54	2.1%	12.4%	6.2%	20.70%
	10.0%	**60.0%**	**30.0%**	**100.0%**

Considering system penetration together with system power (lamp + ballasts) of the different type of T5 system, as reported in Table 38 we estimate the average power of T5 systems on the market (Table 40).

Table 39 – The maximum system power [W] for the most common T5 system according to CELMA classification. For A1 systems we consider the system power when providing 75% light output[6].

System Type	A1	A2	A3
2 x 14	24	34	38
4 x 14	49	68	76
1 x 35	28	39	42
2 x 35	57	78	84
1 x 54	44	60	63
2 x 54	88	120	126

Table 40 – Overall weighted power of T5 systems on the market

System Type	A1	A2	A3
2 x 14	0,1	0,5	0,3
4 x 14	1,1	9,5	5,3
1 x 35	0,1	1,2	0,6
2 x 35	2,6	21,5	11,6
1 x 54	0,1	0,8	0,4
2 x 54	1,8	14,9	7,8
	Weighted Power ($N_{l,eff}$ $P_{l,eff}$ + $N_{b,eff}P_{b,eff}$): 80 W		

We note that the overall weighted power of T5 systems (The Market Efficient Value) equals the overall weighted power of T8 systems (see table 27).

This is partly a consequence of using the CELMA classification scheme which defines slightly higher power levels for T5 systems than it does for “equivalent” T8 systems of the

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[6] Actually the values reported under the A1 class were derived from the Commission Regulation n. 245/2009 published on 18/03/09 related to ecodesign requirements for fluorescent lamps, ballasts and luminaries, whereas values under A2 and A3 classes refer to CELMA classification.

same class. Thus, for example, the power limit of Class A2 1x54W T5 tubes sytems is 60 W, whereas the power limit of Class A2 T8 1x58W tubes systems is 55W.

Among others, this would seem to indicate that T5 systems are not so efficient as manufacturers claim.

3.2.6.1.2 Examples

Replacement of existing T8 luminaries with T5 equivalents

We suppose an end-use Action involving high efficiency T5 luminaires incorporating electronic ballasts provides the following data:

Number of standard T8 luminaires removed (Level 2 or Level 3 data) = 100

Number of efficient T5 luminaires introduced (Level 2 or Level 3 data) = 95

Specific or average power of standard luminaires = unknown

Specific or average power of efficient luminaires = unknown

Table 41 - Energy savings from the introduction T5 systems

	In relation to Equation (1)	Example data	
Power absorbed by the standard systems: We suppose T8 Market Inefficient Baseline:	$(N_{l,st}P_{l,st} + N_{b,st}P_{b,st})$	90	W
Power absorbed by the efficient systems: We suppose T5 Market Efficient Value:	$(N_{l,edd}P_{l,eff} + N_{b,eff}P_{b,eff})$	80	W
Number of T8 standard luminaires removed: From Level 2 or Level 3 data	N_{st}	100	
Number of T5 efficient luminaires introduced: From Level 2 or Level 3 data	N_{eff}	95	
Average hours of Use	H	2500	H
Total Energy savings offered by end-use action	ΔE	3500	kWh/year

As the energy savings are highly dependent on the case-specific situation, no EU default value for the unitary annual energy savings can be defined. Instead, it is recommended to calculate it by using equation 1 and the values for the power absorbed by the standard and efficient systems as well as the average hours of use reported in table 40, but with case-specific N_{st} and N_{eff}.

3.2.7 Control strategies

Variable lighting levels will be often desired in areas with large occupancy,. Studies in open plan offices have shown wide variations in user preference for lighting with some occupants switching their lighting on under almost all conditions and others doing so only on rare occasions. Possible improvements to lighting control include:

- Manual control
    - → Localised control

      Localised control produces noticeable energy savings compared to controlling lighting in an entire building area with a single switch. Localised switching can be implemented in a variety of ways with varying degrees of complexity and technicality. Some of the methods of implementation include breakdown lighting circuits into small units, associating pull chords on each lamp, or introducing hand held infra-red remote controls.
    - → Manual dimmers
- Automatic control
    - → **Time switching**

      Large open offices can work well with simple time scheduling, e.g. automatic switching at fixed hours of the day. Overrides allow users to turn on the lights after hours (using wall switches or telephone dial-up codes). Time scheduling can be accomplished with simple time clocks or more sophisticated computer controls. To save more energy, time scheduling systems can be designed so that lights are turned on manually rather than automatically at the beginning of the day, but are turned off automatically at 1 or 2-hours after closing business activities.
    - → **Occupancy sensors**

      Occupancy sensors are the most common lighting control used in buildings today and usually employ either infrared or ultrasonic sensors. Infrared sensors detect temperature changes in a room created by body heat. Ultrasonic sensors use high frequency sound to detect motion. Dual-technology sensors use both methods, increasing accuracy and flexibility, but have higher prices.
    - → **Daylight-linked control**

      Automatic daylight dimming, or “daylighting”, uses a light sensor to measure the amount of illumination in a space and adjust light output power in order to maintain the desired level of illumination or the work place. The combination of daylight dimming with appropriate task lighting is often very effective.

The effectiveness of any control strategies in producing energy savings depends on the type of building space. Corridors and open cubicles near windows, particularly those with task lighting, are good candidates for daylighting controls. Occupancy sensors will provide savings in store rooms, stair wells and toilettes.

From the point of view of treatment in Equation (1), daylight Integration is conceptually slightly different in that most control strategies reduce the hours of use of the lighting plant, whereas systems using daylight control achieve energy savings by reducing power levels (though when power levels arrive at 0% of the nominal power, the daylight system also effectively reduces the operating hours).

3.2.7.1 Introducing improved control: Localised Switching, Occupancy Sensors, Time Switching and Daylight Sensors: Level 1 Data

Most EEI Measures aimed at improving lighting system control strategies will identify the number of technology units sold or otherwise distributed in the context of the measure (for example number of Occupancy Sensors, the number of Light Sensors). To evaluate Energy Savings in the relation to Equation (1), it proves necessary to:

- determine the energy saving offered by each luminaire subject to the improved control strategy.
- determine the number of luminaires affected by the end-use actions taken at one participant (N_{eff}). When dealing with Occupancy and Daylight Sensors we can attempt to provide default values (i.e. we can translate sales of occupancy sensors to the number of luminaires affected by these sales and thus apply Equation 1). However, it proves more difficult to provide default values for Actions, which result in localised control.

3.2.7.1.1 Stock Baseline ($F_{O,st}$, $F_{D,st}$)

Though the use of some efficient Control Strategies are relatively (common , for example occupancy sensors) it is reasonable to assume that as a whole in the majority existing stock centralised manual switching is the most common solution.

We assume that all luminaires have manual control, for which we define the Stock Baseline as $F_{O,st}$= 1 and $F_{D,st}$ = 1

3.2.7.1.2 Market Inefficient Baseline

A number of improved control strategies are becoming more common (occupancy sensors, time control using automatic building control systems) in the tertiary sector. However, the market inefficient baseline can still be assumed to be manual control. An autonomous market uptake of energy-efficient control strategies can be included in the estimate of the Free-rider effect (cf. chapter 5.5). Therefore:

We assume that all luminaires have manual control, for which we define the Market Inefficient Baseline as $F_{O,st}$= 1 and $F_{D,st}$ = 1

3.2.7.1.3 Market Efficient Values ($F_{O,ef}$, $F_{D,ef}$, N_{ef})

Table 42 lists typical values of energy savings obtained by implementing the most common types of improved control strategies. To each control strategy the table associates a value of F_{Oeff} or $F_{D,ef}$ to be used in the context of Equation 1.

Table 42 – Control factor to estimate energy savings by introducing efficient control systems

Control	**Typical Energy savings**	**Assumed Energy savings**	$F_{O,ef}$	$F_{D,ef}$
Manual control	0 (base)	0	1	1
Partialization switch	10-20%	10%	0.9	1
Time switching	10-35%	10%	0.9	1
Occupancy sensor	20-30%	20%	0.8	1
Daylighting	20-30%	20%	1	0.8

We translate sales of Occupancy Sensors and Daylight Sensors to number of controlled Luminaires (N_{eff}) on the basis of a simple 1 to 2 ratio. That is we assume that each Occupancy Sensor or Daylight Sensor sold or distributed within the context of an EEI Measure will control 2 luminiares. This is simply based on expert opinion.

Thus N_{eff} = 2 x number of Occupancy or Daylight Sensors sold

3.2.7.1.4 Examples

Introduction of Occupancy Sensors

Number of luminaires affected = 2 x number of occupancy sensors distributed in context of action

Table 43 – Default Level 1 values for energy savings offered by Occupancy Sensors

	In relation to Equation (1)	Example data	
Power absorbed by the post action system: We suppose T8 Market Efficient Value (applied in order to be conservative)	$(N_{l,edd}P_{l,eff} + N_{b,eff}P_{b,eff})$	80	W
Average number of luminaires affected per sensor	$N_{eff} = N_{st}$	2	
Control Factor Stock	$F_{O,st}$	1	
Control Factor post Action	$F_{O,ef}$	0.8	
Hours of Use	H	2500	h
Annual energy savings offered per sensor	ΔE	80	kWh/Year/Occupancy Sensor

Integration of natural daylight

Number of luminaires affected = 2 x number of daylight sensors distributed in context of action

Table 44 – Default Level 1 values for energy savings offered by Daylight Sensors

	In relation to Equation (1)	Example data	
Power absorbed by the post action system: We suppose T8 Market Efficient Values (applied in order to be conservative)	$(N_{l,edd}P_{l,eff} + N_{b,eff}P_{b,eff})$	80	W
Average number of luminaires affected per sensor	$N_{eff} = N_{st}$	2	
Dimming Factor Stock	$F_{D,st}$	1	
Dimming Factor post Action	$F_{D,ef}$	0.8	
Hours of Use	H	2500	h
Annual energy savings offered per sensor	ΔE	80	kWh/Year/ Daylight Sensor

3.2.7.2 Introducing improved control: Localised Switching, Occupancy Sensors, Time Switching and Daylight Sensors: Level 2 and Level 3 Requirements

Level 2 (Country Specific) and Level 3 (Action specific) data can be integrated with or replace the Level 1 data. In particular, though it proves possible to define default values of F_O for Localised Switching and Time Switching, Level 2 and Level 3 data are required to define the number of luminaires (N_{eff}) affected by the EEI Measure. It is too difficult to parametrise actions to introduce localised control or automatic building control systems at Level 1.

Table 45. Improved lighting controls - Data needed for levels 2 and 3

Level 2	Guidelines: data from national surveys, samples Data required: Average number of operating hours saved with efficient control strategies Source: surveys, samples
Level 3	Guidelines: data from registries and measurements Data required: individual number of operating hours saved with efficient control strategies Source: end-use metering, registries

3.3 Step 1.3: Normalisation factors

We consider Normalisation Factors for the following variables of Equation 1:

- Operating hours (H) depend on latitude, and are higher in countries in Northern Europe and lower in the South.

To determine the effect of latitude on operating hours we refer to data reported in the Greenlight project[7] (Table 46) which provides average operating hours for lighting systems for education and offices in four macro climate zones.

Table 46 – Average operating hours for the education and commercial sectors according to the Greenlight study for different EU countries

Zone	Country	Hours of Use	
		Education [hours/year]	Offices [hours/year]
North	Denmark	1700	2500
West	UK	1500	2675
Central	Belgium	1375	2200
South	Italy Greece Spain	1422	1947

We normalise the operating hours in Table 46 by considering each of the country specific operating hours in relation to the Central Europe climate zone. We simplify the resulting average normalised values to arrive at a Normalisation Factor N_H depending on the four macro climate zones (Table 47).

Table 47 -Normalised operating hours and simplified Normalisation factor N_H for Operating Hours (H) proposed for three EU macro-climatic zones

Climate Zone	Education	Offices	Average	Assumed Normalisation Factor (N_H)
North	1.24	1.14	1.19	**1.2**
West	1.09	1.22	1.15	**1.1**
Central	1	1	1	**1**
South	1.03	0.89	0.96	**0.9**

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[7] Green Light – Study on European Green Light, SAVE Report October 1999, Novem

We make a qualitative association and assign each of the 27 EU Member States to one of the four macro zones (Table 48).

Table 48 – EU countries divided in macro-climatic zones

West	North	Central	South
United Kingdom	Denmark	Germany	Italy
Ireland	Finland	France	Spain
	Sweden	Czech Republic	Portugal
	Estonia	Hungary	Malta
	Latvia	Austria	Greece
	Lithuania	Slovakia	Bulgaria
		Poland	Romania
		Belgium	Slovenia
		Netherlands	Cyprus
		Luxembourg	

Energy savings (E) as determined by Equation (1) are adjusted by multiplying by the normalisation factor N_H.

3.3.1 Examples

3.3.1.1 Adjustment of savings from the introduction of occupancy sensors

We suppose an EEI Measure which results in the diffusion of occupancy sensors as described in Section 5.6.2.4.1 for which Δ E = 80 kWh/year/Occupancy Sensor

	Normalisation Factor N_H	Energy Savings	
Standard Energy savings offered per sensor		80	kWh/Year/Occupancy Sensor
Energy savings offered by EIA in countries in **Western Europe**	1.1	88	
Energy savings offered by EIA in countries in **Northern Europe**	1.2	96	kWh/Year/Occupancy Sensor
Energy savings offered by EIA in countries in **Central Europe**	1	80	kWh/Year/Occupancy Sensor
Energy savings offered by EIA in countries in **Southern Europe**	0.9	72	kWh/Year/Occupancy Sensor

3.4 Step 1.4: Calculation method and its three related levels

The method used here is

- for level 1, a deemed savings method that, however, needs the number of units counted;
- for level 2, a mixed deemed and ex-post method and
- for level 3, an enhanced engineering analysis method.

The EMEEES case application presented here may be used to assess ESD savings yielded by a variety of Energy Efficiency Improvement (EEI) facilitating measures and programs.

In general, the calculation methodology developed envisages the contribution of the programme participants and the programme administrator.

The calculation of unitary gross annual energy savings (i.e. step 1) should be performed by each programme participant and verified by the programme administrator. Depending on the level of evaluation effort considered, the programme participant may be requested to collect relevant data and information for the application of the energy saving calculation formula proposed (e.g. for level 3 evaluation effort) or to just prove that the EEI action being evaluated has actually been implemented (e.g. for level 1 and 2 evaluation efforts).

The programme administrator will be in charge of performing the calculation steps 2, 3 and 4.

3.4.1 Default values for energy consumption and related parameters (level 1)

In Step 1, we have defined per unit Level 1 values for the following end-use actions (cf. tables 11, 12, 28, 29, and 41):

- replacement of incandescent lamps with CFLs (energy savings per lamp)
- replacement of electromagnetic ballasts with electronic ballasts (energy savings per ballast)
- introduction of occupancy sensors (energy savings per sensor)
- introduction of daylight sensors (energy savings per sensor)

To determine total energy savings from individual end-use actions requires simply multiplying the per unit savings with the number of units sold or otherwise distributed to a participant under the Measure.

Energy savings for the following types of end-use actions requires Level 2 or Level 3 data for at least for some of the parameters recalled in Equation 1

- replacement of standard with high efficiency luminaires using electronic ballasts
- replacement of standard luminaires with T5 systems

In the last two cases, Level 1 data is provided which can assist the evaluation of energy savings deriving from the end-use actions, but does not completely define them. In particular to determine Total Gross Annual Energy Savings per participant (ΔE in Equation 1) requires the number of luminaires before and after the end-use action to be explicitly defined using Level 2 or Level 3 data sources.

Making evaluations at level 1 using default values is the easiest way to apply the methodology, but it provides conservative estimations. However, in the absence of an adequately accurate National or measure-specific data enabling level 2 or level 3 evaluation, this may be the only possibility for quantitative evaluation.

The same calculation procedure used to define Level 1 data as defined for Equation 1 can be used to determine Country- (Level 2) or Measure-Specific (Level 3) energy savings. In certain circumstances, it may prove possibile to complement, rather than completely substitute, Level 1 data with more specific country and EEI Measure data.

3.4.2 Definition of level 2 and level 3 values

No specific requirements (e.g. thresholds) can be established for level 2 or level 3 values. The applied level depends on the availability of stock/market data. If there are no resources for collecting additional data, level 1 is the only option.

If actual stock/market data is available, evaluation can be made at level 2 or 3. Given the conservative default values for level 1, there is a clear incentive to opt for levels 2 and 3.

Specific Level 2 data: → National Data

Specific Level 3 data: → Facilitating Measure Specific Data

- Measurement issues: To determine energy savings with reasonable accuracy and repeatability, good measurement practices should be followed.
- Sampling issues: Samples of the measures selected for monitoring at a particular site shall be representative of all measures at the site and shall be selected at random.
- Modelling issues: Unitary energy savings and engineering parameters collected during the M&V analysis should include a reference indicating their source, uncertainty estimates (when available), and limits of their applicability. These data should be delivered and stored in a standard format.

As regards the determination of the control factors, F_O and F_D, we suggest using the method reported in Annex C and Annex D of the EN 15193, for a Measure-Specific (Level 3) energy savings evaluation. However, in the following a simplified approach is provided, in order to obtain more accurate values with respect to those reported in Table 42.

Detailed determination of F_O *(excerpt from EN 15193)*

When $F_O = 1$

In the following cases, F_O should always be equal to 1

– If the lighting is switched on 'centrally', i.e. in more than one room at once (e.g. a single automatic system – for instance with timer or manual switch for an entire building, or for an entire floor, or for all corridors, etc.). This applies whatever the type of 'off-switch' (automatic or manual, central or per room, etc.).

– If the area illuminated by a group of luminaires that are (manually or automatically) switched together, is larger than 30 m^2.

Exceptions are meeting rooms where this area limitation does not apply (see below).

When $F_O \leq 1$

In the following cases, F_O should always be less than 1:

a) in meeting rooms (whatever the area covered by 1 switch and/or by 1 detector), as long as they are not switched on 'centrally', i.e. together with luminaires in other rooms.

b) in other rooms, if the area illuminated by a luminaire or by a group of luminaires that are (manually or automatically) switched together, is not larger than 30 m^2, and if the luminaires are all in the same room. In addition, in the case of systems with automatic presence and/or absence detection the area covered by the detector should closely correspond to the area illuminated by the luminaires that are controlled by that detector.

In both cases, also the conditions with respect to timing and dimming level outlined below should be fulfilled. If these conditions are not satisfied, $F_O = 1$.

In these instances, F_O should be determined as follows:

When $0.0 \leq F_A < 0.2$

$$F_O = 1-[(1-F_{oc}) \cdot F_A/0.2]$$

When $0.2 \leq F_A < 0.9$

$$F_O = (F_{oc} + 0.2 - F_A)$$

When $0.9 \leq F_A \leq 1.0$

$$F_O = [(7-10\cdot F_{oc}) \cdot (F_A-1)]$$

Where F_A is the proportion of the time that the space is unoccupied.

In these expressions:

The default value of F_{OC} is fixed as a function of the lighting control system, as given in Table 49.

The default value of F_A is determined at either building or room level as given in Table 50.

Table 49 — F_{OC} values

Systems without automatic presence or absence detection	F_{OC}
Manual On/Off Switch	1.00
Manual On/Off Switch + additional automatic sweeping extinction signal	0.95

Systems with automatic presence and/or absence detection	F_{OC}
Auto On / Dimmed	0.95
Auto On / Auto Off	0.90
Manual On / Dimmed	0.90
Manual On / Auto Off	0.80

For systems without automatic presence or absence detection the luminaire should be switched on and off with a manual switch in the room.

An automatic signal may also be included which automatically switches off the luminaire at least once a day, typically in the evening to avoid needless operation during the night.

For systems with automatic presence and/or absence detection the following situations are valid:

a) 'Auto On / Dimmed': the control system switches the luminaire(s) automatically on whenever there is presence in the illuminated area, and automatically switches them to a state with reduced light output (of no more than 20 % of the normal 'on state') no later than 5 minutes after the last presence in the illuminated area. In addition, no later than 5 minutes after the last presence in the room as a whole is detected, the luminaire(s) are automatically and fully switched off.

b) 'Auto On / Auto Off': the control system switches the luminaire(s) automatically on whenever there is presence in the illuminated area, and automatically switches them entirely off no later than 15 minutes after the last presence is detected in the illuminated area.

c) 'Manual On / Dimmed': the luminaire(s) can only be switched on by means of a manual switch in (or very close to) the area illuminated by the luminaire(s), and, if not switched off manually, is/are automatically switched to a state with reduced light output (of no more than 20 % of the normal 'on state') by the automatic control system no later than 15 minutes after the last presence in the illuminated area. In addition, no later than 15 minutes after the last presence in the room as a whole is detected, the luminaire(s) are automatically and fully switched off.

d) 'Manual On / Auto Off': the luminaire(s) can only be switched on by means of a manual switch in (or very close to) the area illuminated by the luminaire(s), and, if not switched off manually, is automatically and entirely switched off by the automatic control system no later than 15 minutes after the last presence is detected in the illuminated area.

Table 50 **– Sample F_A values**

Overall building calculation		**Room by room calculation**		
Building type	**F_A**	**Building type**	**Room type**	**F_A**
Offices	0.20	**Offices**	Cellular office 1 person.	0,4
			Cellular office 2-6 persons.	0,3
			Open plan office >6persons sensing/30m^2	0
			Open plan office >6persons sensing/10m^2	0,2
			Corridor (dimmed)	0,4
			Entrance hall	0
			Showroom/Expo	0,6
			Bathroom	0,9
			Rest room	0,5
			Storage room/Cloakroom	0,9
			Technical plant room	0,98
			Copying/Server room	0,5
			Conference room	0,5
			Archives	0,98
Educational buildings	0,2	**Educational buildings**	Classroom	0,25
			Room for group activities	0,3
			Corridor (dimmed)	0,6
			Junior common room	0,5
			Lecture hall	0,4
			Staff room	0,4
			Gymnasium/Sports hall	0,3
			Dining hall	0,2
			Teachers' staff common room	0,4
			Copying/storage room	0,4
			Kitchen	0,2
			Library	0,4
Hospitals	0	**Hospitals**	Wards/Bedroom	0
			Examination/Treatment	0,4
			Pre-Operation	0,4
			Recovery ward	0
			Operating theatre	0
			Corridors	0
			Culvert/conduct/(dimmed)	0,7
			Waiting area	0
			Entrance hall	0
			Day room	0,2
			Laboratory	0,2
Manufacturing factory	0	**Manufacturing factory**	Assembly hall	0
			Smaller assembly room	0,2
			Storage rack area	0,4
			Open storage area	0,2
			Painting room	0,2
Hotels and restaurants	0	**Hotels and restaurants**	Entrance hall/Lobby	0
			Corridor (dimmed)	0,4
			Hotel room	0,6
			Dining hall/cafeteria	0
			Kitchen	0
			Conference room	0,4
			Kitchen/storage	0,5

Wholesale and retail service	0	**Wholesale and retail service**	Sales area	0
			Store room	0,2
			Store room, cold stores	0,6
		Other areas	Waiting areas	0
			Stairs (dimmed)	0,2
			Theatrical stage and auditorium	0
			Congress hall/Exhibition hall	0,5
			museum/ Exhibition hall	0 0
			Library/Reading area	0,9
			Library /Archive Sports hall	0,3
			Car parks office -Private	0,95
			Car parks -Public	0,8

Determination of the daylight dependency factor F_D *(excerpt from EN 15193)*

This paragraph specifies a simplified approach for determining the daylight dependency factor F_D for a specific room or zone. The complete method is described in Annex C of the EN 15193.

The daylight dependency factor F_D for a room or zone in a building is determined as a function of the daylight supply factor $F_{D,S}$ and the daylight dependent electric lighting control factor $F_{D,C}$ and given by

$$\mathbf{F_D = 1- (F_{D,S} \cdot F_{D,C})}$$

where

$F_{D,S}$ is the daylight **supply** factor that takes into account the general daylight supply in the zone n. It represents, for the considered time interval, the contribution of daylight to the total required illuminance in the considered zone n. $F_{D,S}$ is a function of local climate, maintained illuminance and daylight factor.

$F_{D,C}$ is the daylight **control** factor that accounts for the daylight depending electric lighting control system's ability to exploit the daylight supply in the considered zone n.

$F_{D,C}$ is a function of the exploitation of the available daylight by the type of lighting control.

Daylight supply factor F_{DS}

The daylight supply factor $F_{D,S}$ can be approximated as a function of latitude γ_{Site} for latitudes ranging from 38° to 60° north by the relation

$$\mathbf{F_{D,S} = a + b \cdot \gamma_{Site}}$$

For different maintained illuminance and daylight penetration classifications the coefficients a and b are listed in Table 51. Table 52 shows the daylight supply factor $F_{D,S}$ for selected sites across Europe. The daylight supply factor $F_{D,S}$ is valid for a daily operation hour period of 08.00 hours to 17.00 hours. For longer daily day time operating periods the values should be multiplied by a correction factor of 0.7. For longer non-daylight periods during the operating time the following applies $F_{D,S} = 0$, i.e. $F_D = 1$.

Table **51** — Coefficients for determining the daylight supply factor $F_{D,S}$ for vertical facades as function of daylight penetration and maintained illuminance.

Maintained illuminance	**Daylight penetration**	**a**	**b**
[lux]			
300	weak	1.2425	-0.0117
	medium	1.3097	-0.0106
	strong	1.2904	-0.0088
500	weak	0.9432	-0.0094

	medium	1.2425	-0.0117
	strong	1.3220	-0.0110
750	weak	0.6692	-0.0067
	medium	1.0054	-0.0098
	strong	1.2812	-0.0121

Table **52**: Daylight supply factor $F_{D,S}$ for vertical facades as function of the daylight penetration and the maintained illuminance for different sites

Site	**Latitude g**	**Daylight Supply factor F_{DS} ranges from 0-1**								
		300 lx			500 lx			750 lx		
	[°]	weak	medium	strong	weak	medium	strong	weak	medium	strong
Athens	38	0.80	0.91	0.96	0.59	0.80	0.90	0.41	0.63	0.82
Lyon	46	0.70	0.82	0.89	0.51	0.70	0.82	0.36	0.55	0.72
Bratislava	48	0.68	0.80	0.87	0.49	0.68	0.79	0.35	0.54	0.70
Frankfurt	50	0.66	0.78	0.85	0.47	0.66	0.77	0.33	0.52	0.68
Watford	52	0.63	0.76	0.83	0.45	0.63	0.75	0.32	0.50	0.65
Gävle	60	0.54	0.67	0.76	0.38	0.54	0.66	0.27	0.42	0.56

Daylight dependent artificial lighting control, $F_{D,C}$

$F_{D,C}$ describes the efficiency of how a control system or control strategy exploits the given saving potential, i.e. the daylight supply in the considered space, described by $F_{D,S} \cdot F_{D,C}$ does not consider the power consumption of the control gear itself. Table 53 provides the correction factor $F_{D,C}$ of the daylight supply.

Table **53** — $F_{D,C}$ as a function of daylight penetration

Control of artificial lighting system	**$F_{D,C}$ as function of daylight pentration**		
	weak	**medium**	**strong**
Manual	0,20	0,30	0,40
Automatic, daylight dependent	0,75	0,77	0,85

3.4.3 Direct rebound effect

It is difficult to foresee a rebound effect from improving the efficiency of lighting systems in tertiary sector. In most cases the decision to switch on or off lighting systems in the tertiary sector is made by the user of the space (for example office space), in which the lighting system is installed and in which the user works. Though the decision to switch on space lights is a function of a number of factors (for example the level of natural lighting levels, personal choice, working hours) energy costs are usually not one of them. Economic savings provided by end-use actions in most cases will not lead to direct signals to users and hence no change in behaviour.

Certainly, there are exceptions to the general case. For example a number of exemplary schemes exist, which attempt to influence workers’ behaviour in the work place and reduce energy consumption by providing workers with a share of the economic savings, which result from improved behaviour (for example switching off lights in empty rooms). Savings which mature from such schemes are most often distributed to worker associations rather than individuals, such as workers' recreational clubs. Thus in these cases end-use actions do lead to direct economic signals to workers, which in consequence change their behaviour. However the signal works to reduce energy consumption rather than increase it and thus no rebound effect can be expected.

In the case of Building Management Systems (BMS), management both receives the economic signal from energy savings and controls the lighting plant (by the Building Management Plant). It is reasonable to think therefore of using BMS in such a way that management may take the opportunity offered by reduced energy costs to increase lighting levels or hours of use. However there is no evidence to suggest that this is the case and anyway the number of lighting points controlled by centralised Building Management Systems in the tertiary sector are, overall, negligible.

For these reasons we consider that there is no rebound effect for EEI measures addressing tertiary sector lighting.

4 Step 2: Total gross annual energy savings

4.1 Step 2.1: Formula for summing up the number of unitary actions

The total gross annual energy savings of an EEI measure are the sum of the annual energy savings of all participants. The “elementary unit of action” is one participant with its energy savings arising from several improvement measures and calculated according to equation 1. The calculation of the savings by one participant is performed as described in chapter 3.

$$\text{Total Gross Annual Energy Savings} = \sum_{i=1}^{Np} \Delta E_i \qquad \text{(equation 4)}$$

where:

Np = total number of participants

ΔE = Gross Annual Energy Savings of one participant (Equation 1)

4.2 Step 2.2: Methods for accounting for the number of actions

Methods proposed for monitoring the number of actions (always level 3):

Table 54 - Methods for monitoring the number of actions

Direct accounting methods:
Collection of accounting documents (e.g. invoices, vouchers): e.g., for financial incentive schemes, energy audits etc. registry/database to collect details about participants: e.g., for targeted energy audits, lighting energy performance contracting, voluntary agreements
Indirect accounting methods:
surveys among the participants to assess the portion/number of implemented end-use actions: for targeted information campaigns, or for energy audits or voluntary agreements, for which no detailed registry of participants AND end-use actions exists surveys among the whole population targeted to assess the participant rate: for targeted information campaigns

Finally, ex-post verification for a sample of participants should be done: monitoring of implementation and of energy consumption to ensure that end-use (EEI) actions are actually in place and operational, as specified initially.

5 Step 3: Total ESD annual energy savings

5.1 Step 3.1: Formula for ESD annual savings

Total ESD annual energy savings =

= total gross annual energy savings for all participants
* (1 - free-rider ratio + multiplier ratio)
* (1 - double-counting factor)

or, in brief

TNES = equation (1) · gross number of units· (1 - FR + MR) · DOC (equation 5)

Coefficients definition:

TNES: Total Net Energy Savings

Free-rider (FR): share [0,1]

Multiplier ratio (MR): >=0

Double Counting (DOC): coefficient [0,1]

5.2 Step 3.2: Avoiding double counting

When several EEI measures/programmes are related to same sector or end-use, it is better to evaluate them as a package.

In case of overlap, the decision to allocate the corresponding energy savings to one or another EEI measure is up to the Member-States. Possible overlaps include:

- Overlap of national EEI measures using different types of (EEI) facilitating measures and addressing the same types of end-use actions

- Overlap among different EEI measures implemented at national, local or EU level

In order to avoid double-counting issues we suggest the following approach:

Level **1**	Not possible
Level **2**	evaluating one consistent package of measures related to a specific action
Level **3**	sharing results according to priority rules

Table 55 - Risk of overlap

	Energy Performance Contracting	**White Certificates Schemes**	**Energy Taxations**	**Subsidies schemes**	**Risk of Overlap**
Energy Efficient Luminaires	X	X	X	X	X
Energy Efficient Ballasts&Lamps	X	X	X	X	X
Improved Control	X			X	X

Double counting can best be avoided by cross-cutting information available in a central database of registered participants.

How to address double counting:

- to group facilitating measures targeting the same type of end-use action in a single package, reporting one global result by type of end-use action, or

- to associate each targeted end-use with a particular facilitating measure or programme, allocating the corresponding energy savings only to this measure.

5.3 Step 3.3: Technical interactions

Technical interactions are possible with end-use actions addressing HVAC, because of the potential reduction of cooling or increase of heating loads due to a reduction of lighting loads.

Difficulties: monitoring the cases where it occurs. This is likely to have to be dealt with at level 3, e.g., through building simulation. Further study is needed to analyse whether level 2 national average values for technical interaction factors can be developed.

5.4 Step 3.4: Multiplier energy savings

It is relevant to evaluate the multiplier potential of EEI measures targeting energy-efficient lighting, as a desirable outcome to achieve higher market penetration of efficient lamps/ballasts.

Assessment of the Multiplier effect:

Ex-post evaluation of multiplier effect should be considered, through the following indicators:

- Sales data analysis.
- Surveys among representative samples of (non-)participants.

- Surveys with trade allies and/or other relevant stakeholders.

In order to carry on a more accurate assessment of the multiplier effect (level of effort 2 and 3) we suggest applying the procedure reported in “Statewide Market Assessment and Evaluation Non-Residential New Construction Program Area Building Efficiency Assessment Quarterly Report, 2001” (http://www.calmac.org).

5.5 Step 3.5: Free Rider effect

This section provides data for evaluating the Free Riders in the context of the end-use actions detailed in Chapter 3.

The free-rider effect is not explicitly mentioned in the ESD. Free riders are final energy users who are counted when monitoring the effects of facilitating measures but would have taken the end-use actions promoted also without the facilitating measure. Consequently, including energy savings achieved by free riders in the total ESD annual energy savings would mean to include a part of the autonomous energy efficiency improvements. It has not yet been decided by the European Commission and the ESD committee, whether this effect shall be included in the total ESD annual energy savings or eliminated from them. In the latter case, the following requirements apply.

Energy savings as determined in Step 1 step are adjusted to take account of the fraction of participants in EEI Measures that would have purchased the energy efficient solutions in absence of the measure.

We define the Free Rider Factor (F_{FR}) in such a way that (cf. equation 5):

- ➢ where there is no Free Rider effect F_{FR}=0
- ➢ where all savings can be distributed to Free Riders F_{FR}=1

The present section aims to determine the Free Rider effect in case of Programmed Substitution. In all cases we propose that the number of units (N_{eff} in Equation 1) be reduced by the F_{FR} (Free Rider Factor). A separate Free Rider Factor is defined for each of the five types of energy efficient solution described in Step 1.

5.5.1 Lamps: Replacing Incandescent Lamps with CFLs: Free Riders

Data from DG TREN shows that CFLs accounted for just more than 40% of total incandescent and CFL sales in 2004. Projecting the DGTREN data forward results in predicted CFL sales of around 45% in 2008 and 50% in 2016.

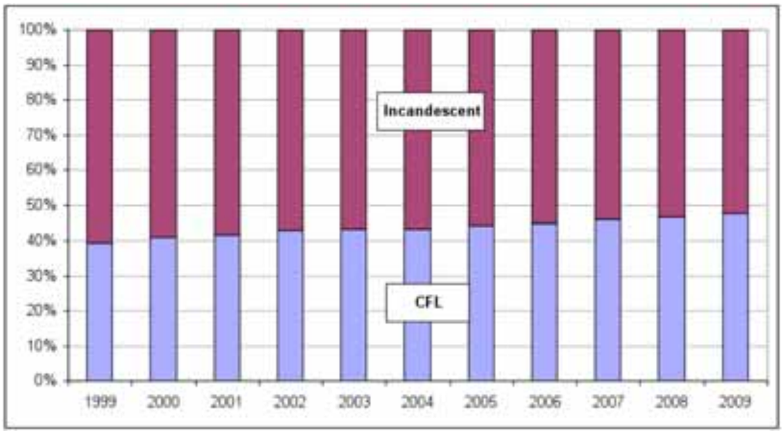

Figure 3 - Market share (1999 to 2004) and expected market share (2005 to 2009) of CFL in Europe respect to incandescent lamps. Data from 1997 to 2010 are based on DGTREN data, while the extrapolation between 2004 and 2009 is an eERG forecast

Consider that sales of CFLs currently account for roughly 50% of the market we can define the F_{FR}. We simplify the annual trend in CFL sales and propose a Free Rider Factor for the period 2008 to 2009. Free rider factors from 2010 onwards can only be estimated then, also taking into account current considerations to completely phase out incandescent lamps.

Table 56 – Free-rider factor for CFLs

Period	**CFL sales as % of total**	**F_{FR}**
2008 - 2009	50	0.50

5.5.2 Ballast: Replacing electromagnetic with electronic ballasts

CELMA provides data on the penetration of electronic ballasts for the period 1997 to 2004 which we extend forward for the period 2008 to 2016.

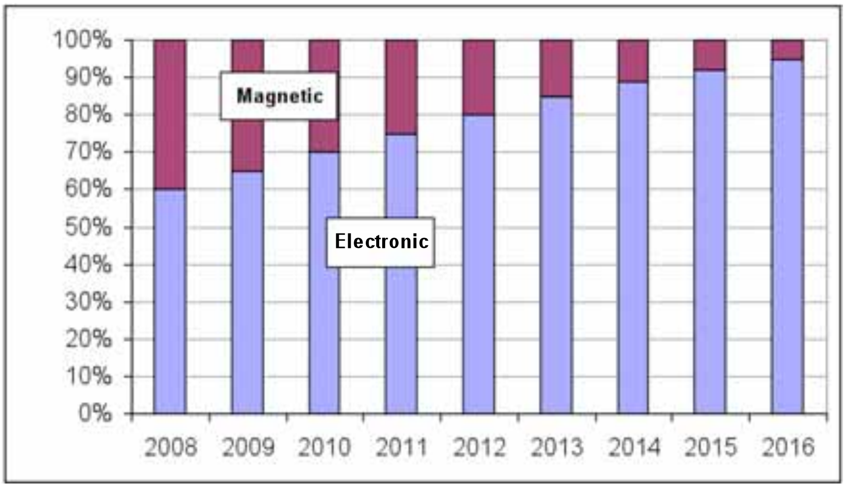

Figure 4 – Predicted market share (2008 to 2016) of electronic ballasts in Europe respect to magnetic ballasts. The extrapolation between 2008 and 2016 is an eERG forecast following on CELMA growth rate for the period 1997-2004

Given the rapid growth rate in electronic ballasts sales, we propose different Free Rider Factors for each year in the 2008-2009 period. Factors for later years would need to be determined at a later stage.

Table 57 – Free Rider Factor for Electronic Ballasts

Year	**Electronic ballasts (Class A) sales as % of total**	**F_{FR}**
2008	60	0.60
2009	65	0.65

5.5.3 Luminaires

On the one hand it becomes difficult to determine the Free Rider effect for Luminaires, since currently no classification scheme exists, which categorises Luminaires based on their efficiency. In the absence of a classification scheme, it becomes impossible to separate inefficient from efficient models (the case application authors refrain from making any proposal in this sense) and thus impossible to determine how many “efficient” luminaires would be sold in the absence of the EE Action (since as said there is no definition of efficient luminaire).

However, on the other hand we note that the purchase price of luminaires is only loosely connected to Luminaire efficiency. Table 58 reports purchase price of luminaires of standard and recommended (higher) efficiency levels as determined by the EU PROST Study in 2002. The average price of Louvered luminiares with efficiencies in the range 67% - 73% was only 1 Euro higher than luminaires with efficiencies in the range of 63-67%.

Table 58 – Purchase price of luminaires of standard and PROST recommended efficiency levels

Luminaire Type	**no. of models in database**			**List Purchase Price**	
	total	**at recommended efficiency and above**		**All models**	**At recommended level and above**
	no.	**no.**	**% of total**	**[Euro]**	**[Euro]**
Standard Work Place/Office, Louvered for VDT	44	10	23%	77	78
Special Work Place (e.g. laboratories, kitchens)	8	2	25%	128	169
Industrial	17	4	24%	73	77

It is therefore reasonable to assume that Luminaire Efficiency plays little role in the design phase since there is no price signal which under normal circumstances directs designers towards lower efficiency models. In consequences in normal circumstances it is reasonable to suppose that a designer will choose on average an “efficient” Luminaire with the same probability as an “inefficient” luminaire.

We therefore propose that the **Free Rider Factor (F_{FR})** for efficient Luminaires is **0.5.**

5.5.4 Luminaires – Replacing T8 systems with T5 alternatives

T5 lamps were introduced onto the market in the early 1990's and in recent years have been marketed aggressively. When designing new plant with particularly high usage, such as in supermarkets, T5 systems seem to be the default choice. In schools, T8 systems still seem to predominate, probably both in consequence of the fact that given the relatively low operating hours, the energy savings are insufficient to cover the extra price of T5 systems (T5 systems have a price premium with respect to T8 “equivalents”).

However we have no specific data and it is difficult to provide reliable figures on the penetration of T5 systems in the linear fluorescent market. In lack of real data we make a best guess estimate and suppose that T5 lamps and luminaires account for on average 30% of the market.

We therefore propose that **Free Rider Factor (F_{FR})** for efficient T5 systems is **0.3.**

5.5.5 Control factors

To determine the Free Rider effect of Occupancy Sensors is not easy. Here we offer a mainly qualitative reasoning to arrive at a F_{FR} factor, knowing fully well its limits.

Table 59 shows the control strategies adopted by light sources in the buildings audited in the context of in the DEFU (2001) study. By far manual control remains the predominant strategy accounting for nearly 100% of light sources in Greece and just over 70% in the UK. Thus automatic control strategies, including occupancy sensor, control at most 30% of light sources (in the UK)

Table 59 – Percentage of lamps under manual control by sector and country

	Denmark	UK	Greece	Italy	Spain	Belgium
Education	98.7%	72.1%	100.0%	100.0%	100.0%	99.3%
Health care	96.8%	45.5%	100.0%	97.4%	73.9%	-
Public Office	91.3%	84.9%	99.6%	99.1%	-	90.3%
Private Office	98.8%	-	100.0%	99.2%	44.1%	-
Retail store	67.1%	85.8%	100.0%	100.0%	42.9%	-
Weighted average →	96.4%	77.0%	99.95%	98.4%	80.2%	95.1%

Though we have no precise data we think it is reasonable to assume that the sale of automatic control systems is growing annually, both in part due to increased energy costs (user awareness) and in part due to cheaper products.

Therefore we can make a reasonable assumption that the market penetration of automatic sensors is higher that the stock penetration. If on average 1 out of 10 lamps are automatically controlled in the tertiary building stock (automatic control strategies account on average for the five countries for 9% - simple country average) then we assume that on average 20% lamps installed within the context of new systems are subject to some kind of automatic control. However occupancy sensors represent only one of the many different types of automatic control system (others include Building Management Systems, Timing, Natural Light Integration). Thus we assume that only 5% of lamps in new systems are subject to control by occupancy sensors.

Given the large inaccuracy of this reasoning we equate lamps with luminaires and propose a **Free Rider Factor (F_{FR})** for Occupancy Sensors of **0.05**

Similarly we propose a **Free Rider Factor (F_{FR})** for daylighting of **0.05**

5.5.6 Levels of effort 2 and 3

In order to carry on an accurate assessment of the free-ridership (at level 2 and 3) we suggest applying the procedure reported in “Statewide Market Assessment and Evaluation Non-Residential New Construction Program Area Building Efficiency Assessment Quarterly Report, 2001” (http://www.calmac.org).

6 Step 4: total ESD energy savings for year "i"

6.1 Step 4.1: Energy saving lifetimes

For the energy saving lifetimes of the lighting energy efficiency actions analysed here, CWA values from CWA27 are proposed (cf. table 60).

Table 60 - List of values defined within the CWA27 for lighting systems

Category	End-use EEI action	**EU Savings Lifetime harmonised values**	**First year for eligibility, if early energy savings are allowed**
Light source	New/renovated office lighting *(Commercial /Public sector)*	12 years	2004
Control strategies	Motion detection light controls *(Commercial /Public sector)*	10 years	2006

Therefore, only EEI measures implemented after the years indicated in the last column should be considered as eligible, even if early energy savings are allowed to count towards the ESD energy saving targets.

6.1.1 Timing and Lifetime of End-Use actions

Default lifetimes (conservative estimate) of lamps/ballasts are provided in table 60.

However, persistence of savings is also a potential issue.

Persistence of savings = f (measure retention, performance degradation);

Definitions:

- Measure Retention is the degree to which measures are retained in use after they are installed.

- Performance Degradation is any over time degradation that includes both technical operational characteristics of the measures

6.1.2 Measure Retention

Measure retention studies collect data to determine the proportion of measures that are in place and operational. The primary evaluation components of a measure retention study are research design, survey-site visit instrument design, establishing the definition of an operable status condition, identifying how this condition will be measured, and establishing the data collection and analysis approach.

The withdrawal of the installed lamps/ballasts, although not recommended, is easily done. Hence, ex-post verification to a sample of participants is recommended to evaluate what is the status of the factors that influence the lifetime of a lamp/ballast:

- Rate of effective installation
- Risk of failures
- Operation conditions and maintenance
- Removal: economical and technical reasons (in some rare occasions lamps/ballasts may lead to problems such as early failure)

The reasons for lack of retention, and the rates of non-retention, should be gathered when feasible for use in developing Effective Useful Life (EUL) values and in future retention studies.

6.1.3 Performance Degradation

Factors to consider:

- Performance or energy efficiency decay
- Conditions of operation (behaviour) and maintenance

Degradation of electronic components and interactions between lamps/ballasts can lead to a performance degradation.

Example of performance degradation of a light source:

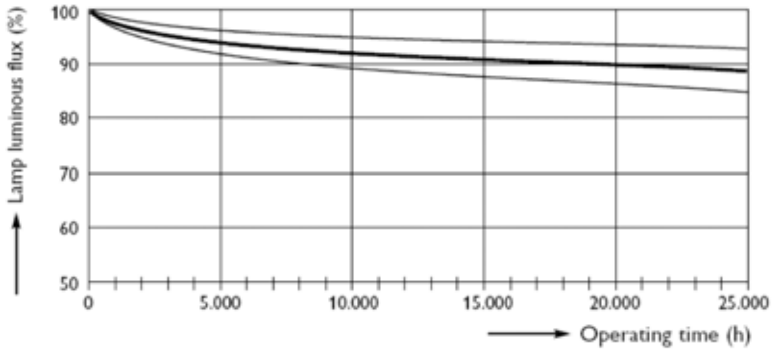

Figure 5 - Fluorescent lamps T8 18-58 W, 3-Band-Phosphor, electronic ballast

• Lamp lumen maintenance factor – LLMF (Lamp luminous flux in %):

Is the Ratio of the luminous flux of a specific quantity of lamps at a defined number of hours of operation to their luminous flux at 100 h.

However, even if performance degradation causes a progressive reduction of efficiency of the lighting systems, the variation of energy consumption may be neglected. In fact, the luminous flux decreases during the lifetime, but the power load and, hence, the energy savings, does not change significantly.

6.1.4 Effective Useful Life (EUL)

Main factors which may affect the lifetime of a lamp/ballast measure:

- Installation quality
- Performance or efficiency decay
- Operating conditions, namely power quality
- Maintenance
- Removal
- Changes in operation profile

6.1.5 Skills Required to Conduct Retention, EUL, and Technical Degradation Evaluations

EUL analysis evaluation efforts need to have the specific skills and experience in regression and statistics proving an ability to be able to conduct classic survival analysis and handle EUL functional form and issue analysis.

Technical degradation studies require senior experienced engineers that are quite familiar with the equipment to be studied, with best practice procedures, and the components, mode of operation, and effects of changes in the operational conditions on the components and function of the equipment.

Surveys and interviews need to be conducted by experienced personnel. These studies and their instruments must be designed with personnel with experience in energy efficiency markets, and interview and survey instrument design, implementation and analysis.

Behavioural degradation studies could be based upon survey and interview analysis methods and/or statistical/econometric methods.

6.2 Early actions

The definition of early actions may include two possibilities (to be clarified by the European Commission and the ESD Committee):

early (EEI) facilitating measures, and only those energy savings that result from end-use actions that are implemented during 2008-2016, as a result of these facilitating measures that still have a lasting effect during 2008-2016, are eligible

OR

early energy savings from end-use actions initiated between 1995 and 2008, with the end-use actions having a lasting effect in 2010 (for the intermediate target) or 2016 (for the overall target).

Note:

If early energy savings are accepted, a contribution to the target in 2016 can only be counted from end-use actions complying with the requirements of Table 60. As far as 2010 intermediated target is concerned only actions implemented as of 1998 (light sources) or 2000 (control strategies) may be counted for target achievement.

6.3 Uncertainties

Level 1 values developed and presented in this methodology are mainly determined using data obtained from stock and market studies or using lighting component data as defined by manufacturers or their associations (for example be CELMA). In other cases Level 1 data are defined using simple guesses based on the "expert opinion" of the authors

Errors can be associated to each data source and affect above estimated Level 1 values. Important source of errors are:

- statistical representation: The DEFU study is based on audits of just 400 buildings in the tertiary sector in the six Member States. A statistical representative sample set of the several million commercial buildings in the 27 EU countries would be of the order of thousands. Thus data used here does provide a truly representative picture of the condition of lighting systems in the EU commercial sector. In addition data collected in stock and market studies will itself be subject to error, both in observation and in registration[8].

- Sample error of component data: Manufacturer declared data for ballasts and lamps will itself be a nominal value based on the performances of a limited sample set of components taken from the production process. The performance of any single component bought and installed will not necessarily conform the performance of the sample.

To take account of these uncertainties, we assume to consider the following tolerance ranges:

- Quality assurance / uncertainties
  - For light sources we estimate:
    - for efficiency : ± 2 %
    - for operating hours at level 2 for building classes: ± 10 %
    - for unitary energy savings calculated with these operating hours: ± 10 %
  - For ballasts we estimate:
    - for efficiency : ± 2 %

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[8] However other data sources presently available (e.g. EuP directive preparatory studies) do not seem to provide statistics that are significantly different from the ones used in the present study,

for operating hours at level 2 for building classes: ± 10 %

for unitary energy savings calculated with these operating hours: ± 10 %

Appendix I: Justifications and sources

Legislation

Directive 2005/32/EC on eco-design requirements for energy-using products.

Directive 2000/55/EC on energy efficiency requirements for ballasts for fluorescent lighting

Directive 2002/95/EC on Restriction of the use of certain Hazardous Substances in electrical and electronic equipment (RoHS)

EN 12464-1(2002) 'Lighting of work places- Part 1: Indoor work places'

EN 12665 *Light and lighting- Basic terms for specifying lighting requirements*

EN 13032 *Lighting applications — Measurement and presentation of photometric data of lamps and luminaires*.

Directive 2002/91/EC on the energy performance of buildings

Directive 2002/96/EC on waste electrical and electronic equipment (WEEE)

Directive 2004/108/EEC on Electromagnetic Compatibility (EMC)

Directive 2006/32/EC on energy end-use efficiency and energy services (repealing Council Directive 93/76/EEC)

Directive 73/23/EEC Low Voltage Directive (LVD)

Directive 98/11/EC of 27 January 1998 implementing Council Directive 92/75/EEC with regard to energy labelling of household lamps

Directive 98/11/EC on Energy labelling of household lamps

EN 50294 , Measurement Method of Total Input Power of Ballast-Lamp Circuits

EN 60081 , Double-capped fluorescent lamps - Performance specifications

EN 60598-1 (2004), Luminaires - Part 1: General requirements and tests

EN 60598-2 , Luminaires - Part 2: Particular requirements - Chapter 1: Fixed general purpose luminaires

EN 60598-2 , Luminaires - Part 2: Particular requirements - Chapter 2: Recessed luminaires

EN 60901 , Single-capped fluorescent lamps – Performance specifications

EN 60921 , Ballasts for tubular fluorescent lamps – Performance requirements

EN 60927 , Specification for auxiliaries for lamps. Starting devices (other than glow starters). Performance requirements

EN 60929 , AC-supplied electronic ballasts for tubular fluorescent lamps – Performance requirements

EN 61048 , Auxiliaries for Lamps - Capacitors for Use in Tubular Fluorescent and Other Discharge Lamp

Circuits - General and Safety Requirements

EN 61049 , Capacitors for Use in Tubular Fluorescent and Other Discharge Lamp Circuits Performance Requirements

Energy Efficient Lighting in Commercial Buildings, Aronsson S., Nilsson P., CADDET Analyses Series N. 6

Ballasts, www.facilitiesnet.com/NS/NS3ball.html

Saving energy with efficient lighting in commercial buildings, CADDET Maxi Brochure 01

Electronic ballasts: more than energy savings, www.facilitiesnet.com/NS/NS3b7cb.html

Market research on the use of energy efficient lighting in the commercial sector, SAVE Project 4.1031/Z/97-029, 2001