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SUPPLEMENT TO THE LIGHTING POLICY GUIDE:

«ACCELERATING THE GLOBAL ADOPTION OF ENERGY-EFFICIENT LIGHTING»

MODEL REGULATION GUIDELINES
—
SUPPORTING INFORMATION

FEBRUARY 2021

ENERGY EFFICIENCY AND FUNCTIONAL PERFORMANCE REQUIREMENTS FOR GENERAL SERVICE LAMPS AND LINEAR LIGHTING

U4E United for Efficiency

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United Nations Environment Programme – Global Environmental Facility | United for Efficiency (U4E)

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Foreword

UN Secretary-General, Ban Ki-moon, speaking to the Global Efficient Lighting Forum in November 2014 called for a proactive move away from inefficient lighting.

"Efficient lighting can help address climate change – the defining issue of our time. Leaders must set the world on course to limit global warming below 2 degrees [Celsius]. Efficient lighting can help. With more efficient lights, we can reduce greenhouse gas emissions.

"The transition to efficient lighting has started – but there are still vast untapped opportunities ahead. I count on your leadership to show that efficient lighting is reliable, affordable and sustainable."

This document provides context on the rationale underpinning the January 2021 update to the United for Efficiency (U4E) Model Regulation Guidelines for Energy-Efficient Lighting. It includes a brief explanation of the scope, product categories, and market and policy trends in energy-efficient lighting which have undergone a revolution in recent years with the advent of LED technologies, providing a step change in energy saving opportunity. The updated Model Regulation Guidelines build upon, and replace, the original Model Regulation Guidelines for General Service Lamps (released in May 2018). The principal differences between the updated Model Regulation Guidelines and the 2018 version are documented in Section 6 of this document.

From an environmental perspective, LED light sources are preferable to those containing mercury since they are mercury-free, are available at higher efficiencies and with longer lifespans.

The updated Model Regulation Guidelines (January 2021) refer to many International Electrotechnical Commission (IEC) standards for testing performance requirements, as well as those of the International Commission on Illumination (CIE). Countries need to be familiar with either these standards or other approaches that they intend to pursue for their regulatory frameworks.

Acronyms

bn	billion
CCT	Correlated colour temperature
CFL	Compact fluorescent lamp
CIE	International Commission on Illumination
CRI (R_a)	General colour rendering index
CO2	Carbon dioxide
DLC	DesignLights Consortium
ECD	Environmentally conscious design
Ecodesign	Commission regulation (EU) 2019/2020
EU	European Union
GHG	Greenhouse gas
GSL	General service lamp (also known as GLS – general lighting service)
hr(hrs)	hour(hours)
IEA	International Energy Agency
IEC	International Electrotechnical Commission
K	Kelvin
max	maximum
min	minimum
Mt eq/a	Metric ton equivalent per annum
LED	Light emitting diode
LFL	Linear fluorescent lamp
lm	lumens
MEPS	Minimum energy performance standards
MW	Megawatt (106 watts)
NEECA	National Energy Efficiency & Conservation Authority
P_{st}^{LM}	Short term perceived flicker using light flicker meter method
SVM	Stroboscopic visibility measure
TWh/a	Terawatt-hours per annum (1012 watt-hours per year)
U4E	United for Efficiency
UN	United Nations
USD	United States dollars
W	Watts
XLMF	Lumen maintenance factor %

1. Background and Savings Opportunity of Energy-efficient Lighting

Conventional lighting technologies, for example incandescent filament light bulbs, date back over 140 years. Such technologies expend a considerable amount of electricity during normal use, with only some 5% of the energy consumed generating any light at all. Fluorescent tubes date back over 90 years, lasting much longer than incandescent bulbs and are over six times more efficient. They use a gas discharge to excite phosphors to fluoresce, but typically still use less than 30% of the energy consumed to make light. Until LED technology became mainstream in general lighting less than 10 years ago, all electric lighting was based on these two technologies, either incandescent or gas discharge. For example, compact fluorescent lamps (CFL) are just miniature fluorescent tubes and all fluorescent lamps are low pressure mercury discharge lamps. (See Table 1 and Table 2, Source: U4E).

Characteristic	Incandescent	Halogen	Compact Fluorescent	Light Emitting Diode Lamp
				
Efficacy	8-15 lm/W	11-18 lm/W	55-65 lm/W	60-160 lm/W
Lifetime	1000-1500 hrs	2000-3000 hrs	6000-12,000 hrs	15-30,000 hrs
Colour rendering index	100	100	70-90	70-95
Cost to buy*	$	$$	$$	$$
Cost to run*	$$$$$	$$$$	$$	$

* For both of these characteristics, of the four technologies shown, only LED is changing significantly. As LED technology continues to evolve and improve, the cost to purchase will decrease and the cost to run will decrease even more. This technology, therefore, is expected to dominate all end-use lighting applications in the future.

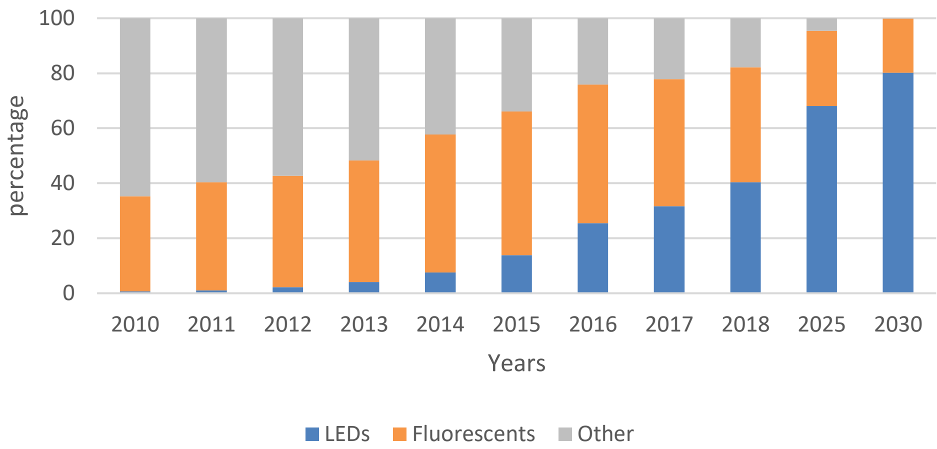
Table 1: Examples of non-directional household lamps, screw-base, mains voltage

						
	T12*		**T8**		**Long T5**	
	efficacy lm/W	**life - hours**	**efficacy lm/W**	**life - hours**	**efficacy lm/W**	**life - hours**
Fluorescent -Halphosphate**	60-75	9,000	65-75	10,000	n/a	n/a
Fluorescent - Triphosphor	75-85	12,000	75-95	15,000	90-105	24,000
LED retrofit for fluorescent	n/a	n/a	100-150	50,000	130-150	50,000
***phased out in many markets*	**running obsolete*					

Table 2: Linear tubes – typical examples

The step change in efficiency from LED technology provides the opportunity to make an energy saving of more than 80% compared to incandescent and 50% compared to fluorescent. The global trend in lighting sales is illustrated in Figure 1, from a study completed by the IEA in 2019, and highlights the need to update the GSL model regulation guidelines and to include all indoor lamp types in the model regulations.

Figure 1: Lighting sales by type in the Sustainable Development Scenario, 2010-2030



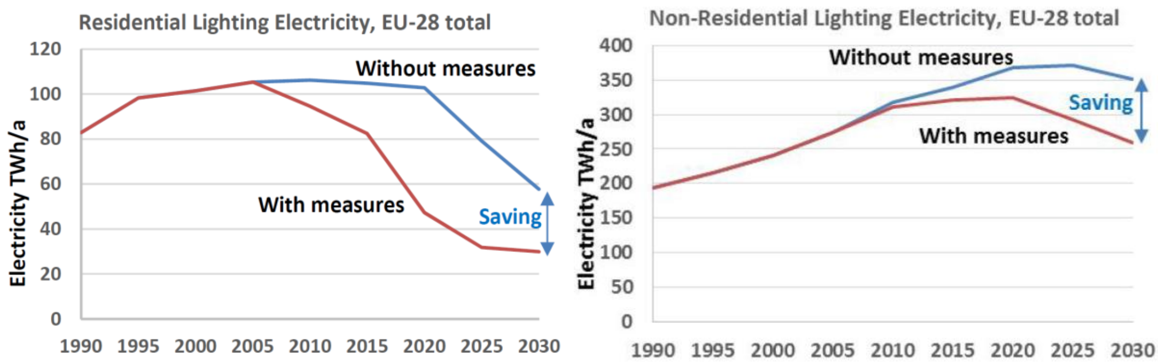
Source: IEA (2019), Tracking Buildings, IEA, Paris https://www.iea.org/reports/tracking-buildings

According to the IEA, "In 2018, LED sales reached a critical milestone, achieving the same share of global residential sales as less-efficient fluorescent lamps (40%). LED deployment is also progressing for commercial lighting and outdoor applications, especially for linear LEDs to replace fluorescent lamps. As LED costs continue to fall, sales of LEDs are on track with the scenario[1], although continued robust growth is needed.

However, to raise the share of LED sales to more than 65% of the residential market by 2025, countries need to take advantage of recent sales trends and update their regulatory policies to keep pace with expected LED performance, which is drastically higher than five years ago."

It is now well documented that countries that have introduced energy saving measures in lighting have accelerated their savings in energy demand and greenhouse gas emissions. For example, Ecodesign impact accounting from the European Commission, updated in 2019[2], shows the effect of measures introduced for light sources in all 28 EU countries as shown in Figure 2.

Figure 2: Effect of measures introduced in EU countries



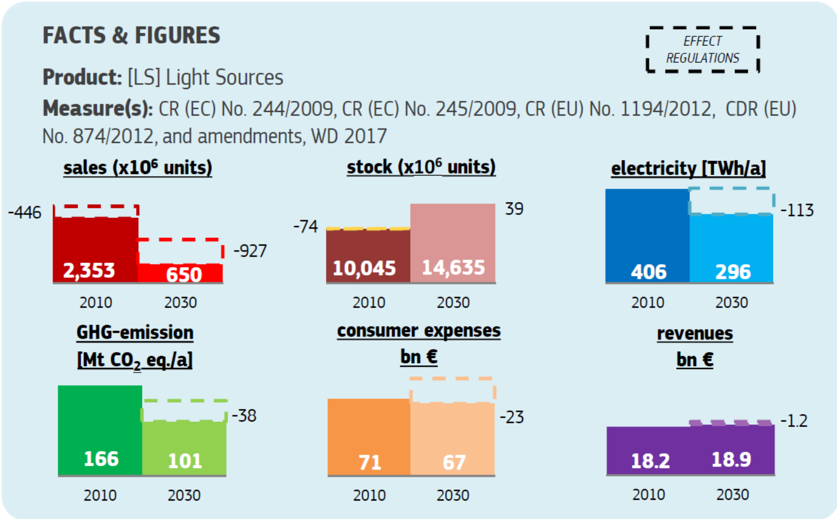
[1] Sustainable Development Scenario of the IEA 2019.

[2] https://www.vhk.nl/downloads/Reports/EIA/EIA%20Overview%20Report%20status%202019%20-%20VHK20201028.pdf

Measures started in 2009 with the staged ban of incandescent lamps, continued in 2012 and are still ongoing with new minimum energy performance requirements in place for 2021.

The net effect of these measures is summarized in Figure 3.

Figure 3: Net effect of measures



An integrated policy approach is encouraged under U4E, including in conjunction with the Model Regulation Guidelines, in order to ensure that minimum energy performance standard (MEPS) levels accelerate energy savings by encouraging volume in the manufacture and sales of more efficient products, which in turn makes them more affordable. This approach recommends making regulations technology neutral, which means they cover all technologies, including all conventional technologies such as incandescent. Regulating LEDs on their own, and not the overall lighting market, may be counterproductive as it could make LEDs less affordable and encourage the conventional, less efficient lighting technology to remain in use for longer. Figure 4 illustrates how increasing sales volumes have reduced the global consumer sales price for LED replacement lamps over time. However, this is not the whole picture as regards cost; as LED lamps last much longer, the real cost to consumers of using LED is much lower.

Figure 4: 60W equivalent LED lamp retail price 2015-2018

Source: LEDinside research August 2018

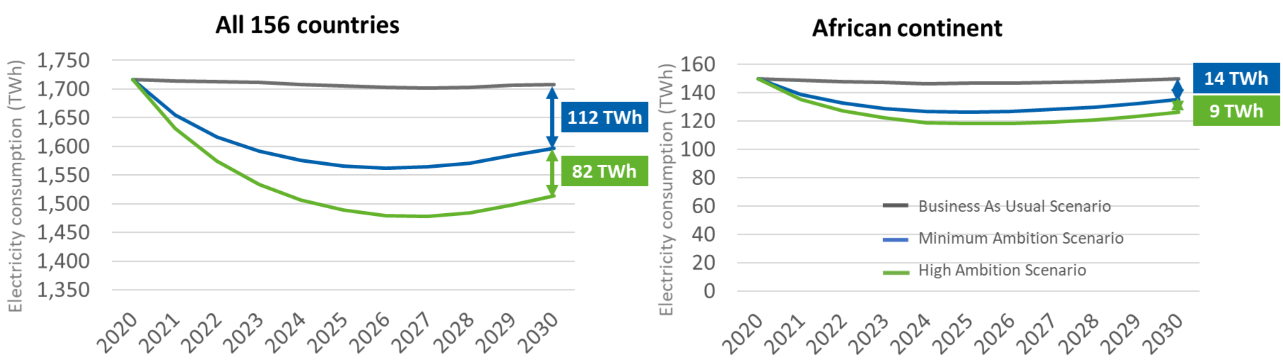
U4E has produced country savings assessments[3] (updated in December 2020) for 156 countries, which project annual electricity savings, greenhouse gas emission reductions, and utility bill savings for consumers if the countries adopt the Model Regulation Guidelines.

Based on these assessments, U4E estimates the 156 countries could save 112 TWh annually by 2030 with energy-efficient lighting. This is equivalent to 51 large (500MW) power plants and to CO_2 savings of almost 99 million tonnes, as well as financial savings of over 9 billion USD as a result of reduced electricity bills.

The African continent (Northern and Sub-Saharan Africa) alone accounts for over 14 TWh of these savings. In equivalents, the African countries could avoid the construction of 7 (500 MW) power stations, save almost 11 million tonnes of CO_2 and almost 900 million of USD.[4] As the figures below show, with a more stringent regulation even higher savings could be achieved.

These electricity consumption figures are shown in graph form in Figure 5 and typical examples of the country savings assessments are discussed in Section 2.1.

Figure 5 Projection of energy consumption for lighting



1.1 MEPS and an energy labelling structure included for 2021 update

MEPS are proposed as a base level for all products on the market and are positioned at the threshold above that which conventional technology can achieve (see Sections 5 and 6 below). Four higher levels are further proposed. These can be used as part of an energy labelling market pull system to help drive ambition for greater savings, to communicate to consumers on energy efficiency, and for product procurement requirements (including sustainable public procurement). The labelling system could be aligned with an existing one where appropriate, or developed from scratch, in which case it should be designed to work across other relevant energy consuming technologies and be a key part of communicating energy efficiency to the end user.

[3] https://united4efficiency.org/countries/country-assessments/

[4] All savings refer to annual savings with the Minimum Ambition Scenario by 2030.

By selecting a base level, all correction factors, which allow a lower efficiency for features outside of mass market volume use, are removed. No products can be below the base level; it is a ‘floor’ level. Added value technology, such as connected lighting or higher colour quality, will require some additional electricity consumption which makes them naturally less efficient on a product level. However, this can be compensated for using more efficient LED packages, and these products will not be the mass market volume product in developing and emerging economies. Removing correction factors is an important consideration as they can easily be exploited as loopholes and the new base level accounts for correction factors effectively, thus eliminating cumulative corrections.

The energy labelling system clearly indicates the relative efficiency of the product, on a simple scale including higher levels for future use, allowing for more ambitious specification and for the end user to make an informed choice. This makes the 2021 Model Regulation Guidelines clearer and easier to monitor, verify and enforce. Monitoring, verification and enforcement is a vital part of achieving an acceleration in energy savings so the simplification will make enforcement of the regulations much more likely to succeed. Such a structure is also easier to revise and harmonize within and across regions.

In addition to the removal of correction factors, zero negative tolerance is required on baseline MEPS to limit gaming of the system on claimed and measured efficacy. For example, under existing IEC regulations cited under Article 3.3 of the GSL May 2018 Model Regulation Guidelines, average lumens of a sample of 10 lamps could measure 90%, and average watts could measure 110% of claimed values on the packaging but still comply. Combining these tolerances gave a compliant efficacy as low as 82% of the claimed value, this is not permitted. The baseline MEPS levels must be met by nine out of 10 lamps sampled with only one lamp out of 10 allowed at no more than 5% below the baseline MEPS. This encourages the use of more accurate measurement equipment and further illustrates that the proposed MEPS are a true ‘floor’ with greater ambition than first appears. Note that, in a test laboratory, a result within test measurement uncertainty is regarded as indeterminate.

1.2 Managing different scenarios in countries

The simplification of the updated MEPS to one base level, combined with an energy labelling system with higher levels above a strict floor, provides for a more flexible structure for the 2021 Model Regulation Guidelines which allow them to cope with the different scenarios that may be found in developing and emerging markets. Providing updated lighting regulation guidelines, that can more easily dovetail with any relevant existing ones, will help in accelerating the global adoption of more energy-efficient lighting. The approach allows for markets to start at levels of MEPS that realize the savings while keeping alignment with the 2021 Model Regulation Guidelines.

Examples of possible country scenarios include:

1. No relevant MEPS in place for general lighting:
   In this case, the model regulations can be applied (adapting to national and regional circumstances), with base level MEPS, to all technologies which will allow leapfrogging to LED solutions. Sustainable public procurement can be provided for with the high energy performance levels included in the labelling system.

2. Some existing MEPS in place for conventional lighting technologies:
   In this case, the existing regulations for conventional technologies could be left in place but their MEPS level(s) could be aligned with the new regulations over time. The new regulations need only apply to unregulated technologies.

3. An existing energy labelling system for other technologies is in place:
   In this case, the labelling system could be aligned with the existing one so as not to create confusion with the end-users.

1.3 Local manufacturing

There may be local manufacturing of conventional lighting technology, so care must be taken to address this as part of the process in adopting the model regulation guidelines. A transition programme needs to be considered for local manufacturers who could adapt to making more energy-efficient lighting thus turning a business threat into an opportunity.

An example of this would be incandescent lamp manufacturing where the production machinery seals a tungsten filament mounted on a glass stem in a glass envelope and the glass bulb is then filled with an inert gas. LED filaments can be mounted in very much the same way so machinery and expertise can be transferred as part of a transition programme.

2. Overview Model Regulation Guidelines Scope and Product Characteristics for all Indoor Lighting Products

The scope of products included in the 2021 Model Regulation Guidelines aims to incorporate all the higher energy consuming lighting products with significant savings opportunity. A limited number of exemptions have been defined for lighting products that are used for a particular speciality purpose and where a more energy-efficient product is not available that can provide the required quality of service or meet safety concerns.

2.1 Product scope

The scope of products incorporated in the 2021 Model Regulation Guidelines is summarized in Table 3.

Product	Typical Use	Included	Not Included
General service lamps and directional reflector lamps	Residential lighting.	All common types defined by lamp base/cap with light outputs between 60 and 3300 lumens.	Exceptions allowed for specialized uses.
Fluorescent tubes	Mainly commercial usage for general lighting often in modular ceiling systems. They are also widely used in the residential sector in some emerging markets.	Most common T8 size (26 mm diameter) in lengths between 2 foot and 8 foot (mostly 2 foot, 4 foot and 5 foot), with outputs ranging from 1000 to 8000 lumens. The old style T12 LFL (38 mm diameter) tube is becoming practically obsolete globally but is in scope as the T8 can replace it in the same circuits. T5 LFL is included to avoid loopholes as T8 LFL is removed from the market; budget level LED is now higher efficacy than the best T5.	Exceptions allowed for specialized uses.
Linear luminaires	Most commonly used in commercial installations	All types in indoor general lighting.	Exceptions allowed for specialized uses.

Table 3: Scope of products incorporated in the 2021 Model Regulation Guidelines

Notes to table:

i. **General service lamps (GSL)**
A typical GSL (a conventional 60W) emits about 800 lumens (lm) and its efficiency is expressed in lumens per watt (lm/W) and known as luminous efficacy.

ii. **Fluorescent tubes**

The installed base of fluorescent tubes before LED tubes were viable some 5 years ago, was reported as: T8 – 67%, T12 – 20% and T5 – 12%. The T5 is no longer gaining market share as it is not a retrofit lamp for the volume market, and new T5 luminaires are being directly substituted by LED tubes. There are also T5 adaptors that allow fitting to T8 circuits. T5 LFL are in scope since there is a risk that T5 becomes a loophole as LED linear tubes progress but T5 LFL have an additional delay in effective date to facilitate transition. The dates are tabulated in Article 4 of the 2021 Model Regulation Guidelines: luminaires and T12 LFL one year after publication, T8 LFL two years and T5 LFL three years, but all have a fixed end date to avoid gaming of the system.

iii. **Compact fluorescent – non-integrated (CFLni or pin ended)**

For simplicity, these lamps are not included as they are not a well-known lamp in emerging markets, but they could usefully be included at the first revision.

iv. **Luminaires (light fittings)**

It is common in lighting today that many new build and refurbishment projects use integrated LED luminaires. This is because of the long life of LED technology; for example, a 25,000-hour GSL could easily last 10 years in normal use, so it makes sense to use integrated luminaires where the light source is not a user replaceable lamp (i.e. not a retrofit). This means luminaires are an important consideration in the model regulation guidelines to ensure that the energy saving opportunity is fully realized and that poor-quality lower energy solutions are not substituted. The first focus is to consider linear luminaires in scope (those used in place of fluorescent tube fittings) as they are most likely to be used in volume commercial installations.

2.2 Key parameters

i. **Energy performance,** measured in lumens per watt, is known as luminous efficacy. This is a measure of how much visible light (known as luminous flux) generated for every watt of electricity consumed. This is one of the primary concerns of the U4E programme because an increase in this parameter is fundamental to accelerating energy savings. The light output in lumens is also a useful parameter for comparison of LED performance with conventional technology; for example, it is not particularly useful to use wattage as a measure of output, since a 60W LED bulb would be over 70 times brighter than a conventional '60W lightbulb' therefore claims on equivalence need to use lumens.

ii. **Lifetime** of LED lighting is much longer than conventional incandescent or fluorescent lighting, and this adds considerably to the payback when moving to such light sources. However, it is not always easy to verify. A 3,000-hour test method which can give a good indication of lifetime is becoming accepted (such as in the European Union with Ecodesign). This test will also identify the early failure rate, which is a good indicator of reliability.[5] With long life lamps, the degradation in light output is an indicator of lifetime.

[5] Ecodesign: Commission Regulation (EU) 2019/2020 where Annex V refers (see Appendix B attached)

This is known as lumen maintenance and is defined as the lumen output remaining after a certain time, expressed as a percentage. To ensure long term savings, it is vital that energy-efficient replacement lamps last. For example, a lumen maintenance of at least 90% at 3,000 hours effectively ensures a minimum lifetime of 10,000 hours.[6] However, care must be taken not to over specify minimum lifetime to avoid 'lock-in' with less efficient lamps as LED efficacy improves further over time. Therefore, the model regulation guidelines take into account typical duty cycles of the relevant categories and specify lumen maintenance accordingly in the early failure test. (90% for GSL, 95% for linear, 96% for luminaires).

iii. **Light quality** is important for customer satisfaction as they must see an acceptable colour and by comparison with conventional technology. For example, LEDs can produce any shade of colour, unlike incandescent lighting. White shade and its colour rendering must be good enough. The white shade is measured as correlated colour temperature relating to the colour of a blackbody radiator when heated to a particular temperature. A typical incandescent lamp has a colour temperature of 2700 Kelvin (K). The measure of colour rendering is the general colour rendering index (CRI (R_a) in Table 4) and, from Table 5 in Section 4,[7] one can see that the consensus is that this measure must be ≥80 for normal indoor use. Higher values for more critical tasks are possible. Note that conventional incandescent lamps have a CRI (R_a) of 100. Other colour considerations include maintenance through lifetime and the consistency from lamp to lamp, which also need minimum quality limits to maintain performance.

iv. **Health and safety** related parameters specific to lighting products clearly need to be regulated to guard against adverse effects on the end user. For example, flicker can affect the end user directly. Two key measures are short term perceived flicker (P_{st}^{LM}) and stroboscopic effect (SVM). EU regulations on SVM are becoming a benchmark and, following new research in the last year, have been evaluated and a lower SVM introduced (see Section 4, Trends in Performance Requirements – GSL & linear).

v. **Electrical performance** parameters must provide for compatibility with the local power supply and operational controls such as dimming, occupancy sensors and photocells. For example, the fundamental power (or displacement) factor parameters need to be defined to protect the local supply network. Some electrical performance parameters need specific limits in regulations and others can be incorporated in labelling requirements. For example, compatibility with controls and sensors is difficult to regulate due to legacy devices on the market, so clear labelling and product information are essential to indicate what is compatible.

[6] X_{LMF} % lumen maintenance calculation
[7] U4E GSL Model Regulation Guidelines 2018 & Ecodesign 2019/2020).

vi. Separate regulation

Some parameters may already be covered by generic safety regulations and it is important to cross reference these rather than have parallel requirements which could overcomplicate the lighting regulations, making it more difficult to enforce and have revisions out of step thereby having conflicting requirements. For example, electromagnetic compatibility (EMC) and harmonics are more often separate requirements for all electrical appliances to protect the electrical power supply network and to help ensure compatibility of equipment. Similarly, photobiological hazard has been evaluated by the CIE and is regarded not to be an issue for LED white light sources in general lighting.[8] Therefore, these are not included in the model regulation guidelines.

A comparison of characteristics of the products included in the scope is shown in Table 4.

	LAMP TECHNOLOGY						
	General service Lighting (GSL) Category					**Linear T8* Category**	
	Conventional low efficiency		**Conventional More efficient**	**Most efficient**		**Conventional**	**Most efficient**
CHARACTERISTIC	**Incandescent tungsten**	**Incandescent halogen**	**Compact fluorescent**	**LED**		**Fluorescent tube**	**LED tube**
Luminous efficacy range	8-15 lm/W	11-18 lm/W	55-65 lm/W	70-160 lm/W		65-95 lm/W	100- 185 lm/W
Lamp lifetime	1,000-2,000hrs	2,000-4,000hrs	6,000-15,000hrs	15,000-30,000hrs		12,000-20,000hrs	20,000-60,000hrs
Colour rendering index - CRI (Ra)	100	100	70-90	70-95		80-90	80-95
Correlated colour temperature - CCT (Kelvin)	2700K	2800-3000K	2500-6500K	2700-6500K		2700-6500K	2700-6500K
Dimmable or not	yes	yes	with compatible dimmer & control gear	with compatible dimmer & control gear		with compatible dimmer & electronic control gear	with compatible dimmer & electronic control gear
Luminaires are a diverse product range supplied by a very large fragmented global manufacturing base so are difficult to cross reference in a table. The optical control causes large variation in system lumen per watt so more usefully a base level MEPS can be specified to ensure conventional more inefficient technology cannot be used.							

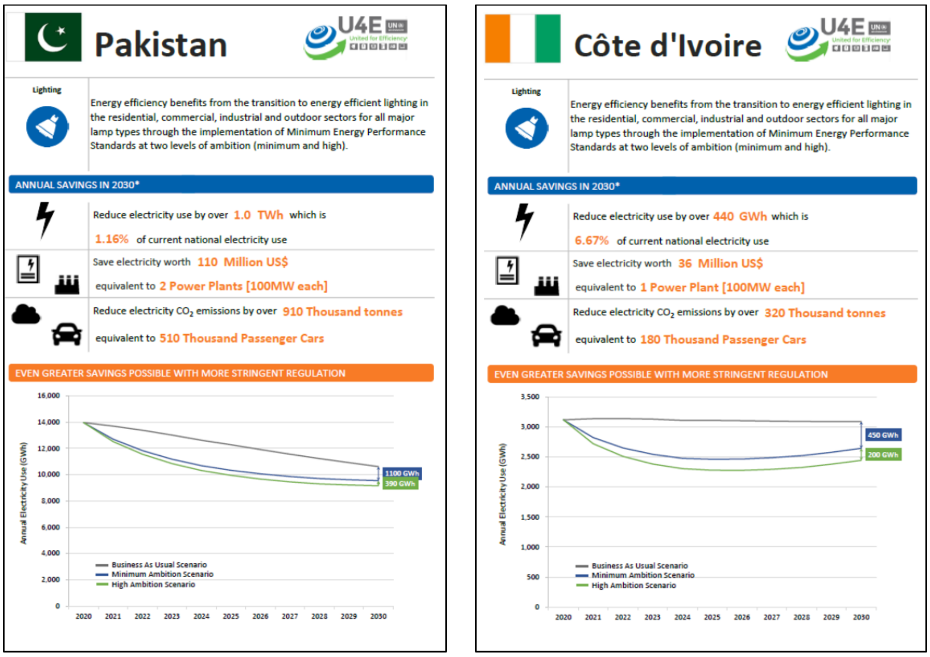
Table 4: Comparison of product characteristics

[8] See position statement of the CIE 23rd April 2019.

3. Potential Energy Savings and Analysis of Performance Requirements

There is significant possibility to improve lighting in terms of energy efficiency, such as moving from incandescent to LED lamps. The U4E country savings assessments[9] provide an insight into the potential financial, environmental, energy, and societal benefits that are possible with a transition to energy-efficient lighting. Two examples are shown in Figure 6, which illustrates that even a relatively small country such as the Côte d'Ivoire, with a population of 25 million, could save the equivalent of two small power stations' worth of energy.

Figure 6: Country savings assessment examples



Based on the estimated savings for the 156 countries for which country savings assessments have been developed, the estimated global savings potential of the transition to energy-efficient lighting is 112 TWh/a by 2030. This is equivalent to 51 large (500MW) power plants and CO_2 savings of almost 99 million tonnes, as well as financial savings of over 9 billion USD due to reduced electricity bills.

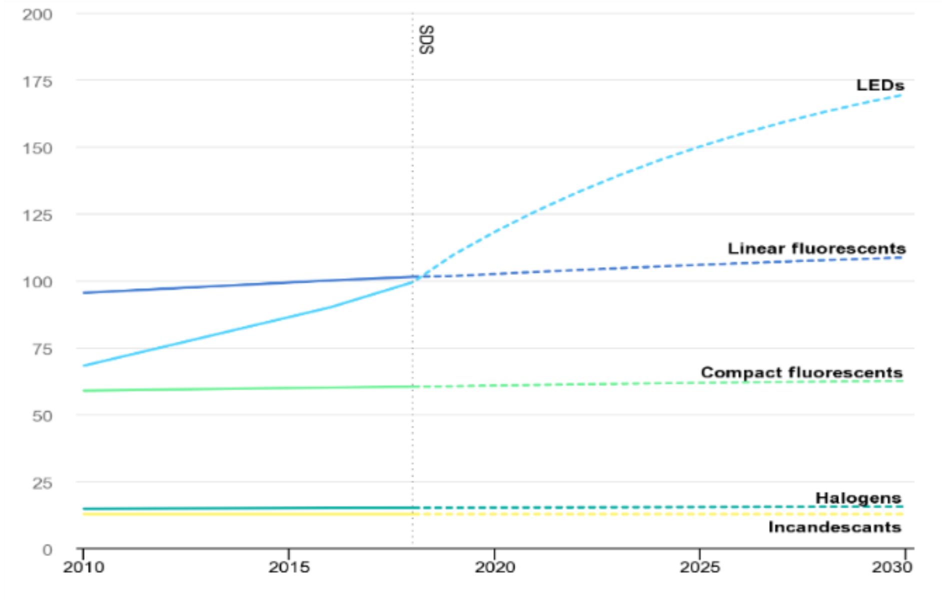
Many emerging markets are still using oil lamps, and some are just starting with incandescent lamps or replacing them with unregulated battery products. Regulation is essential to accelerate climate control in line with the mandate from Ban Ki-moon.

3.1 Typical efficacy levels by lighting technology, projected levels and analysis

The chart in Figure 7 shows the trend in residential lighting efficiency (luminous efficacy in lm/W), with the current best available LED technology in the market already at the 2030 level. This also highlights the need for a progressive integrated approach so that regulations set MEPS and labelling levels that accelerate energy savings with LEDs over time.

[9] https://united4efficiency.org/countries/country-assessments/

Figure 7: Typical efficacy of residential lighting in the IEA Sustainable Development Scenario, 2010-2030[10]



As part of the 2021 Model Regulation Guidelines review, various appropriate databases have been analyzed to determine the spread of LED efficacies. A US Energy Star example is shown in Figures 8, 9 and 10 for GSL. This allows the analysis of typical efficacies for LED since the first U4E GSL model regulation guidelines were published in 2018. It has a substantial number of lamps, from a large variety of manufacturers. From a database of close to 9,000 LED lamps measured, over 5,000 have been registered in the last two years from over 150 suppliers, including all the major brands. Analyzing only the last two years to evaluate how the market has changed since the first model regulation, and setting the range to be the same as the original scope with a CRI(R_a) ≥80, three charts are shown to illustrate the current GSL market levels.

Figure 8: Energy Star database analysis – all lamps

Figure 8 — Energy Star database analysis

Parameters

Lamp type	All
Min Lumens (250)	60
Max Lumens (3200)	3,300
Min CCT (2700)	2,700
Max CCT (6500)	6,500
Min CRI (80)	80
Max CRI (99)	100
Earliest year to market	2018

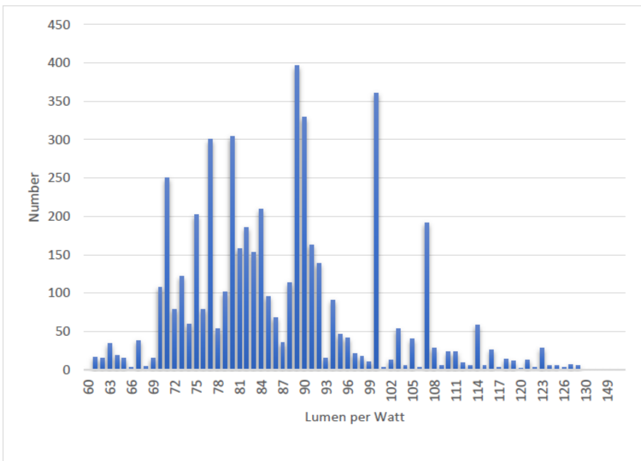
Results

Max Efficacy	154.50
Average Efficacy	86.75
Min Efficacy	60.00
Lamps included	5,086
Number above: 80 lm/W	3,271
	64%

All lamps registered in the last 2 years are included in this chart, that is both directional and non-directional.

About one third are below 80lm/W but by splitting the group into non-directional (fig 7) and then directional (fig 8) one can see two distinct groups.

Efficacy spread — All GSL registered in last 2 years



[10] IEA (2019), Tracking Buildings, IEA, Paris https://www.iea.org/reports/tracking-buildings

Figure 9: Energy Star database analysis – non-directional lamps

Figure 9 **Energy Star database analysis**

Parameters

Lamp type	Non-directional
Min Lumens (250)	60
Max Lumens (3200)	3,300
Min CCT (2700)	2,700
Max CCT (6500)	6,500
Min CRI (80)	80
Max CRI (98)	100
Earliest year to market	2018

Results

Max Efficacy	145.50
Average Efficacy	94.81
Min Efficacy	74.60
Lamps included	2,285
Number above: 80 lm/W	2,077
	91%

Around half the lamps are non-directional and over 90% are above 80lm/W

Efficacy spread **Non-directional GSL registered in last 2 years**

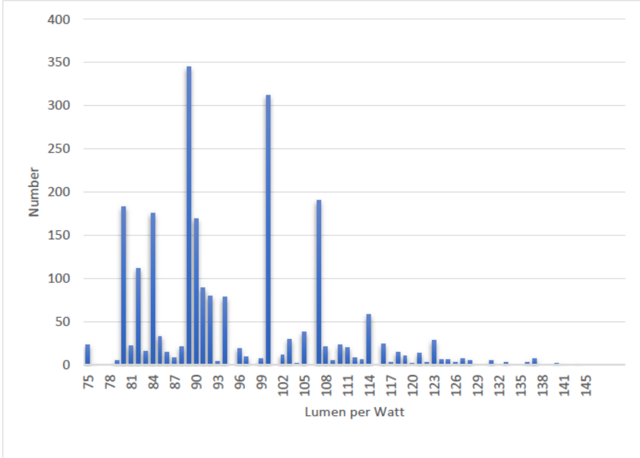


Figure 10: Energy Star database analysis – directional lamps

Figure 10 **Energy Star database analysis**

Parameters

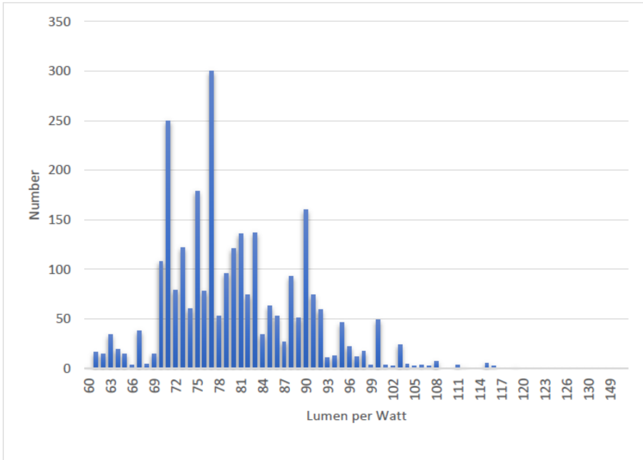
Lamp type	Directional
Min Lumens (250)	60
Max Lumens (3000)	3,300
Min CCT (2700)	2,700
Max CCT (6500)	6,500
Min CRI (80)	80
Max CRI (99)	100
Earliest year to market	2018

Results

Max Efficacy	154.50
Average Efficacy	80.17
Min Efficacy	60.00
Lamps included	2,801
Number above: 70 lm/W	2,535
	91%

Around half the lamps are directional and only 43% are above 80lm/W (not shown here) but reducing the threshold to 70lm/W gives 91% above.

Efficacy spread **Directional GSL registered in last 2 years**



Similarly, for linear lighting products, various appropriate databases have been analyzed. Figures 11 and 12 show a DesignLights Consortium (DLC) database analysis example from their standard product category; only tested data is used, and the number of manufacturers is much higher for fittings as it is a much more fragmented business. CRI(R_a) >80 was selected for consistency but over 90% are over 80 in any case.

Figure 11: DesignLights Consortium database analysis – linear tubes

Figure 11 **Design Lights Consortium database analysis** **Efficacy spread** **Linear T8 LED tubes**

Select products to see results for :

Lamp type	ALL
Min Lumens (779.84)	60
Max Lumens (8074)	10,000
Min CCT (2701)	2,700
Max CCT (5291)	6,500
Min CRI (80)	80
Max CRI (96.5)	100
Earliest year to market	2000

Results

Max Efficacy	182.60
Average Efficacy	128.03
Min Efficacy	106.82
Lamps included	5,031
Number above: 110 lm/W	4,960
	99%

571 different manufacturers, 80% are 4ft.
over 90% have CRI bwtween 80 and 85
CCT ranges between 2600 & 5300, with nearly 90% between 2700 & 4000.

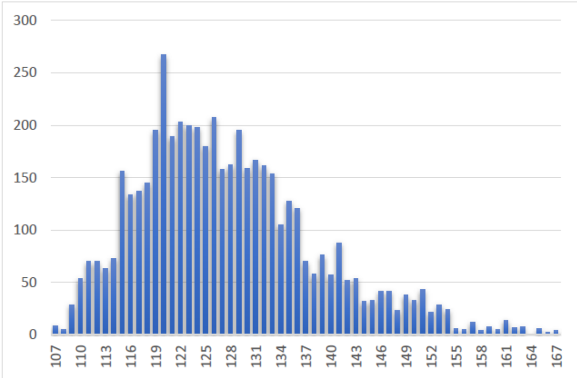


Figure 12: DesignLights Consortium database analysis – luminaires

Figure 12 **Design Lights consortium database analysis - standard level** **Efiicacy spread** **LED Modular(troffer) & LED linear ambient luminaires**

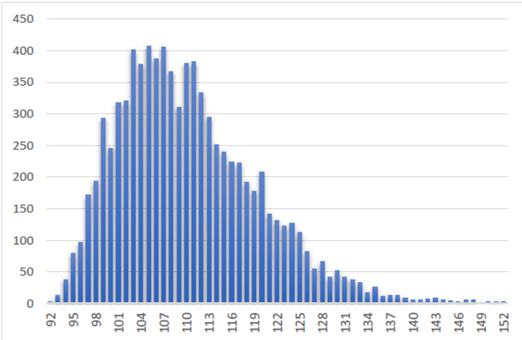
Select products to see results for :

Lamp type	ALL
Min Lumens (446.828)	0
Max Lumens (9963)	10,000
Min CCT (2591)	2,500
Max CCT (5311)	5,500
Min CRI (80)	80
Max CRI (96.45)	100
Earliest year to market	2000

Results

Max Efficacy	156.80
Average Efficacy	110.28
Min Efficacy	92.20
Lamps included	8,525
Number above: 100 lm/W	7,525
	88%

871 different maufacturers included, all from test results not claims.
88% are above 100lm/W, over 90% with CRI between 80 & 90.
CCT - 80% between 2500 & 4000



4. Trends in New and Upcoming Country Level MEPS

This section provides an overview of current energy efficiency and functional requirement policy trends in different countries for lighting products. For example, in China, MEPS for directional downlights have been aligned with those for general light sources; and the global regulatory trend for luminaires is to ensure that they are readily repairable/maintainable and to specify MEPS based on the LED modules they contain.

4.1 General service lamps MEPS comparison

Table 5 shows a comparison for MEPS for general service lamps.

	COUNTRIES WHERE NEW MEPS ARE IMPLEMENTED OR ARE IN FINAL DRAFT					REGULATIONS	
	Côte d'Ivoire	**Pakistan**	**Philippines**	**China**	**Kenya**	**Ecodesign**	**U4E 1st model**
TECHNOLOGY SCOPE	Neutral	LED only	Neutral	LED only	Neutral	Neutral	Neutral
MEPS range, 60 to 3300 lm in lm/W	LED 60 to 80 CFL 50 to 60	80 to 100	LED 80 CFL 41 to 65	60 to 110	LED 76.5 to 90 CFL 68.4 to 72	28 to 105	LED 60 to 80 CFL 50 to 60
Corrections	Directional Colour Tuneable Connected	None, and directional not included	None, and directional not included	None	Directional Colour Tuneable Connected	Directional Colour Tuneable Connected	Directional Colour Tuneable Connected
Energy labelling levels	No	Yes – 5 levels	Yes – 5 levels	Yes – 3 levels	No	New ecolabel has 7 levels	No
Colour rendering index - CRI (Ra)	≥80	≥80	≥80	≥80	≥80	≥80	≥80
Correlated Colour temperature – CCT (Kelvin)	Not dependent	<6500 until July 2021, then <6000	MEPS vary with CCT and power for CFL only	MEPS vary with CCT	Not dependent	Not dependent	Not dependent
Flicker Pst/SVM	None	Pst ≤ 1 only	LED has visible modulation frequency limits ≤1250hz	None	Pst ≤ 1 and SVM ≤ 0.4	Pst ≤ 1 and SVM ≤ 0.4	Pst ≤ 1 only
Lifetime (hours)/early failure	6000 minimum CFL, 15000 minimum LED/1000 hour ≤5% failures	8000 - 10000/One year warranty	CFL 6000 LED 15000/3000 hour zero failures of 10	3000-hour lumen maintenance test	3000-hour lumen maintenance test	3000-hour early failure test	1000-hour early failure test
Dimming requirement	None	Only for streetlights	None	None	Label and information	Label and information	Label and information
Implementation date	Expected 2020	Expected December 2020	Out for comment, expected 2020	2019	Out for comment, expected 2020	01/09/2021, replacing 2012 ban on incandescent	21/05/2018

Table 5: Comparison of MEPS for general service lamps

4.2 Linear T8 LED MEPS Comparison

There are few new MEPS for LED T8 tubes, with the EU Ecodesign December 2019 regulations most prominent in this field. 'Plug & play' is a term used for lamps that directly retrofit into existing linear fluorescent circuits and can easily be fitted by the end user without professional help (i.e. no re-wiring). This is the most common usage in the LED T8 tube sector, so MEPS are best defined for this lamp type; circuits using a separate driver are less common and if used, are some 5 to 10% more efficient. An example of the applicable EU Ecodesign MEPS levels is shown in Table 6, calculated from the maximum power based on lumen output; this example uses a CRI (R_a) of 80 and a CCT of 3000K.

	2	4	5	Length in feet
Φ_{use} Useful lumens	1350	3350	5200	Lumen output*
P_{onmax} Max power	12.8	29.4	44.8	Maximum watts with driver
P_{onmax} Max power	13.8	31.8	48.4	Maximum watts for plug & play
MEPS lm/W	106	114	116	Minimum lm/W with driver
MEPS lm/W	98	105	107	Minimum lm/W for plug & play
**LFL values, LED lumen output is lower due to their photometric curve which makes them even more efficient.*				

Table 6: EU Ecodesign T8 MEPS

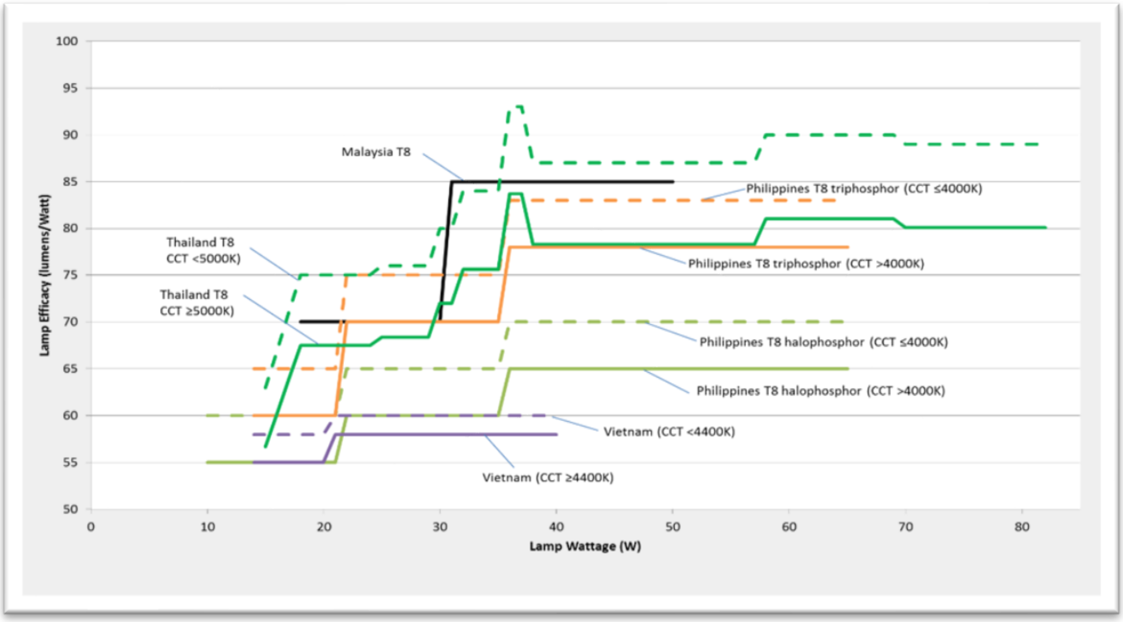
As an example, for comparison, the Philippines include linear within their GSL draft currently out for comment and the MEPS are simply set at 90 lm/W, with an energy labelling system comprising five levels up to a maximum of 125 lm/W. These regulations are due to come into effect in September 2023 and many of the other parameters are in line with the Ecodesign parameters listed in Table 5.

Linear fluorescent tubes are widely regulated globally. The values in Table 6 can be compared with typical existing MEPS for T8 Fluorescent tubes in Asia[11], an example of which is shown in Figure 13.

Using Figure 13 to illustrate the point, the highest MEPS level a typical T8 fluorescent tube product can reach is 90 to 95 lm/W which means that in Europe with the new 2019 lighting regulations, fluorescent T8 tubes are effectively banned from September 2023 with only LED technology capable of meeting the EU MEPS requirements. Standard conventional triphosphor fluorescent tubes used in high volumes have efficacies of 75 to 85 lm/W as shown in Figure 13. For halophosphor fluorescent tubes, this level is typically 60 to 75 lm/W. Both of these fluorescent tube types are still widely used in developing and emerging markets, though halophosphor types are banned in much of the developed world.

[11] *Minimum energy performance standards for T8 linear fluorescent lamps from ASEAN SHINE report October 2016*

Figure 13: Minimum energy performance standards for T8 linear fluorescent lamps in ASEAN



4.3 Trends in performance requirements – GSL and linear

i. **Flicker (also known as temporal light artifacts)**

There are two types of flicker that are commonly considered to help ensure replacement lamps do not adversely affect health:

(a) Short-term perceptibility 'P_{st}^{LM}', where 'st' stands for short term and 'LM' for light flicker meter method. A value P_{st}^{LM} = 1 means that the average observer has a 50% probability of detecting flicker. Many regulations now specify a P_{st}^{LM} ≤1.

(b) A stroboscopic visibility measure 'SVM', where again a value of 1 means the average observer has a 50% chance of detecting it. Recently this value has been revised downwards to a lower value of ≤0.4 in the relevant 2019 EU Ecodesign regulations and may be phased in over a period of years starting at a value of ≤0.9. The first edition of the U4E GSL model regulation guidelines did not specify this parameter but the issue is becoming more of a concern, so a cautionary note is added in the 2021 Model Regulation Guidelines to review the specific level.[12]

ii. **Compatibility with control devices**

Occupancy sensors, daylight sensing with photocells, and dimming controls all provide significant additional energy savings, particularly in commercial installations of linear product. Options for compatibility with such devices are therefore required in the model regulation guidelines for linear luminaires.

[12] *NRC-CSTB report of December 2018*

iii. Resource efficiency, the circular economy and environmentally conscious design (ECD)

The key considerations here are:

1. Resource conservation and material efficiency.
2. Energy conservation.
3. Pollution prevention.
4. Avoidance of waste, modularity and reuse.

IEC Guide 109 provides a very useful reference on this subject that all policymakers should consider. This will be included in the model regulation guidelines as an advisory note. This is subject to revision now by technical committee TC111, *Environmental Standardization for Electrical and Electronic Products and Systems*, of the IEC and will be updated. More detail on IEC Guide 109 is given in Appendix A.

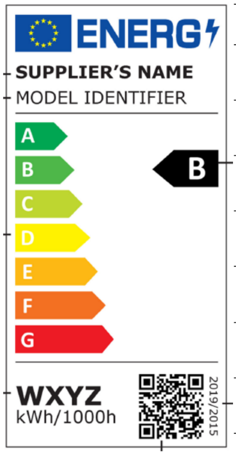
Article 4 of the European Commission regulation (EU) 2020/2019, also known as the Ecodesign Single Lighting Regulation 2019, requires serviceability and modularity. More detail on this is given in Appendix B.

5. Labelling

An energy labelling system, using a simple indication of performance levels, is all about clearly communicating to the end user the efficiency rating and relative benefits of the product concerned. It also provides national authorities with an effective way to incentivize the take up of more efficient products in the market, including levels suitable for sustainable public/private procurement, as well as for national new building codes. The energy labelling system can be built into the MEPS regulation (as in Pakistan and China) or it can be stand-alone (as with the Ecolabel in the European Union or the Energy Star label in the US). It can also form part of the monitoring and verification process awarding the relevant label as part of the process to qualify a product. Current examples of labelling systems include:

a. **EU Ecolabel example – updated regulation 2019/2015 in force September 2021**
The label (as illustrated in Figure 14) must be shown on the product. It is worth noting that the worst level class is 85 lm/W for this label. As time goes on and efficiency levels rise, regulations can exclude the lower levels to accelerate further energy savings. The ambition of this new EU label is clear with the top-level set at ≥210 lm/W

Figure 14: Example of EU Ecolabel



Energy efficiency class	Total mains efficacy η_{TM} (lm/W)
A	$210 \leq \eta_{TM}$
B	$185 \leq \eta_{TM} < 210$
C	$160 \leq \eta_{TM} < 185$
D	$135 \leq \eta_{TM} < 160$
E	$110 \leq \eta_{TM} < 135$
F	$85 \leq \eta_{TM} < 110$
G	$\eta_{TM} < 85$

b. **Efficacy levels in China - GB 30255-2019 in force now**
Details for the efficacy levels for non- directional self-ballasted LED lamps specified under GB 302255-2019 are shown in Table 7.

Lamp Type	Color temperature CCT	Efficacy (lm/W)		
		Level 1	Level 2	Level 3
Omnidirectional light distribution	CCT<3500K	95	80	60
	CCT≥3500K	100	85	65
Quasi-omnidirectional/ Semi-spatial light distribution	CCT<3500K	105	90	70
	CCT≥3500K	110	95	75

Table 7: The efficacy level for non-directional self-ballasted LED lamps

c. Star ratings in Pakistan - NEECA regulation to come into force from December 2020

Details of these ratings are given in Figure 15.

Figure 15: Details of Pakistan star ratings

Flux (lm)	60 ≤ Φ < 600	600 ≤ Φ < 1200	1200 ≤ Φ
1 star*	≥ 80 lm/W	≥ 90 lm/W	≥ 100 lm/W
2 stars**	≥ 90 lm/W	≥ 100 lm/W	≥ 110 lm/W
3 stars***	≥ 100 lm/W	≥ 110 lm/W	≥ 120 lm/W
4 stars****	≥ 110 lm/W	≥ 120 lm/W	≥ 130 lm/W
5 stars*****	≥ 120 lm/W	≥ 130 lm/W	≥ 140 lm/W

6. Revision of the U4E 2018 GSL Model Regulation Guidelines

The model regulation guidelines were originally published in May 2018. As already stated, LED technology continues to evolve, and all the indicators show that the MEPS levels need to be revised. Figures 1 and 7 show the upward trends, and recent country MEPS, as shown in Table 5, are being set at higher levels. CFLs are being pushed out of the market in favour of more efficient LEDs, with the instant 'on' characteristic, longer lifetime and lack of hazardous waste advantages, among others, driving consumer preferences. The price of LED technology (as shown in Figure 4) has converged with CFL over time, so they are equally or more affordable for the consumer, can save more energy and last longer. This leads to the requirement to update the U4E 2018 GSL model regulation guidelines:

a. Simplifications in updated Model Regulation Guidelines

i. Option B, a gradual transition via a "medium/higher energy-efficiency" which allows the on-going sales of compact fluorescent lamps (CFLs) is no longer necessary, so one clear MEPS requirement driving an LED solution can be considered.

ii. The MEPS level can clearly be increased to help accelerate energy savings, and LED efficacy is good enough to allow a simplification of correction factors for lumen levels and value-added products (e.g. smart or tuneable lamps).

b. With reference to Figures 8, 9 and 10 on GSL lamps in the Energy Star database

After analysis, an appropriate level of 80 lm/W was selected as a possible MEPS level, being above CFL and at the lower end of LED levels to help ensure affordability. Results in Figure 8 show that, at this level for all lamps in the Energy Star database with registration dates from 2018 to date, 36% were below this level. Looking at only at non-directional lamps (Figure 9) this number drops to just 9%.

Conclusion: 80 lm/W is an appropriate base level for non-directional lamps.

For directional lamps, 57% are below this level so clearly another level is needed. A level of 70 lm/W was selected, which is a similar reduction to that made by correction factors used in the past for directional lamps. At this level only 9% are below.

Conclusion: 70 lm/W is an appropriate base level for directional lamps.
Note: CFL does not have directional options so there is no loophole.

c. **Base levels**

Comparing these levels with the benchmarked levels in Table 5 they fit in well. Using these base levels and having no variation in MEPS based on lumen output is a reasonable approach, as further analysis of the data shows these effects are minimal.

d. Removal of correction factors

Apart from the ‘directional’ aspect, these factors in the first U4E model regulation guidelines related to value-added products such as connected lamps or colour tuneable lamps. At the base MEPS levels proposed, value-added lamps can reasonably achieve the MEPS allowing for the additional losses for the value-added aspects, so for simplicity these corrections can be removed.

e. Conclusion on MEPS levels

i. To simplify GSL MEPS to two base levels of 80 lm/W for non-directional and 70 lm/W for directional lamps with no variation due to lumen output or value-added features.

ii. A five-level energy labelling system to be included to promote higher efficiency and as part of the verification process to help drive users, procurers and new building specifiers to adopt more efficient products. These base levels will allow national authorities to leapfrog to affordable LEDs easily with two simple MEPS values.

7. Linear Model Regulation Guidelines

The linear MEPS proposed are divided by product group, one for linear luminaires and one for linear double capped lamps for retrofit.

a. **Group 1: Linear luminaires** – the proposed MEPS have been defined at an efficiency level that provides for the use of only LED solutions in all new build or refurbishment works. This can be a significant step towards accelerating energy savings in this important sector. The effective date will be one year after publication of the regulations but with a fixed end date of 1 January 2023.

b. **Group 2: Linear double capped lamps for retrofit (fluorescent or LED)** – this group is important as data shows more than half are used for retrofit (for example, data from Asia indicates that 60% of linear lamps are used to replace lamps in existing luminaires). Promoting the use of LED retrofit solutions can therefore achieve energy savings more rapidly.

   Since linear double capped lamps will only be used on legacy circuits there are no real savings from defining MEPS for linear fluorescent lamps because the existing control gear determines the energy consumed. A more efficient linear fluorescent lamp simply produces more light. Linear fluorescent lamps are already well regulated in the most relevant markets (as shown in Figure 13 for ASEAN region, for example) so this means that the model regulation guidelines can focus on defining MEPS for more efficient LED solutions.

   Therefore, MEPS are defined for LED retrofit only, and linear fluorescent come into scope in a phased transition in order to accelerate the energy savings with more efficient LEDs. The phased transition proposed brings linear fluorescent into scope over time by diameter; T12 after one year after publication, T8 after two years and finally T5 after three years. As each type comes within scope, they will be non-compliant removing the category from the market and replacing them with more efficient LED solutions. Note that all have a fixed end date to avoid gaming of the system.

   Linear fluorescent lamps do not have to be tested under the regulation, once each category comes into scope then they will not be able to meet the MEPS.

c. **MEPS levels**

   i. **Integrated LED luminaires** can be designed more readily with optimum thermal control so that the LED can achieve a higher efficiency in this integrated configuration. This is because the constraint of having to fit the technology into the more restrictive envelope of a retrofit lamp is removed. There are also no legacy issues to provide for as this part of the model regulation concerns new build and refurbishment.

      Luminaires are required to have specific photometric distributions suited to the application. Some of this optical control results in efficiency losses, in particular for glare control which is often specified in commercial office spaces. However, glare control is an added-value feature so if the base level is selected carefully this can be accommodated without a correction factor. The resulting proposed base level is 100 lm/W which is reasonably achievable by all relevant luminaires (as shown in the example in Figure 12).

ii. **Linear tubes** – analysis of the DLC database (Figure 11), the new EU Ecodesign levels (shown in Table 6) and efficacy levels for entry level LED tubes from four well-known brands (shown in Table 8), suggests an appropriate base level of 110 lm/W would be reasonable for 'plug & play' solutions and again require an energy rating system to help drive higher efficacies while keeping it an affordable retrofit for emerging markets. For linear tubes, the entry level selected is also low enough to accommodate all tube lengths without further allowances and any value-added products can also readily achieve the MEPS proposed. The Ecodesign MEPS level is shown for comparison along with the best available technology (BAT).

lm/W	**Brand 1**	**Brand 2**	**Brand 3**	**Brand 4**	**Ecodesign**	**BAT***
Entry level	100	99	117	117	105	n/a
High Level	172	149	143	172	n/a	175
	3000K/4000k 4 foot tube used as most common types *higher levels are possible with remote driver circuits					

Table 8: Benchmark lm/W for T8 LED linear retrofit on legacy EM circuits[13]

d. Conclusion on linear MEPS levels

i. Luminaires for new build and refurbishment – 100 lm/W with no corrections.

ii. Linear lamps – 110 lm/W for plug & play lamps with no corrections.

iii. A five-level energy labelling system to be included to promote higher efficiency and as part of the verification process to help drive users, procurers and new building specifiers to adopt more efficient products. This base level will allow national authorities to leapfrog to affordable LEDs easily with one simple MEPS value.

[13] Data taken from published data as of January 2021 for four major brands (Brands 1 to 4 above)

Appendix A. IEC Guide 109 – advisory checklist

Consideration of Environmental Aspects in Product Regulations

As far as possible provisions in product regulations should support, or at least not hamper, the environmental objectives that are specified in the following check list.

Resource conservation and material efficiency

- Minimal material content in the product
- Minimal material content in the packaging
- Minimal number of different materials
- Maximum separability of different materials
- Maximum recyclability of used materials
- Reusability of product parts and components
- Reusability and upgradability of the product as a whole
- Possibility of using recycled materials
- Possibility of using refurbished product parts and components
- Minimal size of product
- Minimal mass of product

Energy conservation

- Minimal energy consumption during the product´s operation
- Power management, e.g. automatic change to standby mode

Pollution prevention

- Avoidance of hazardous substances
- Avoidance of substance emissions into the environment (air, water, soil)
- Avoidance of other releases e.g. radiation, noise, dust

Avoidance of waste, modularity and reuse

- Modularity allowing multiple use of components

Appendix B. Commission Regulation (EU) 2019/2020, 1 October 2019

Also known as the Ecodesign Single Lighting Regulation 2019
For implementation September 2021

Article 4

Removal of Light Sources and Separate Control Gear

1. Manufacturers, importers or authorized representatives of containing products shall ensure that light sources and separate control gears can be replaced with the use of common available tools and without permanent damage to the containing product, unless a technical justification related to the functionality of the containing product is provided in the technical documentation explaining why the replacement of light sources and separate control gear is not appropriate.

   The technical documentation shall also provide instructions on how light sources and separate control gears can be removed without being permanently damaged for verification purposes by market surveillance authorities.

2. Manufacturers, importers or authorized representatives of containing products shall provide information about the replaceability or non-replaceability of light sources and control gears by end-users or qualified persons without permanent damage to the containing product. Such information shall be available on a free-access website. For products sold directly to end-users, this information shall be on the packaging, at least in the form of a pictogram, and in the user instructions.

3. Manufacturers, importers or authorized representatives of containing products shall ensure that light sources and separate control gears can be dismantled from containing products at end of life. Dismantling instructions shall be available on a free access website.

United Nations Environment Programme – Global Environmental Facility | United for Efficiency (U4E)