Mapping & Benchmarking of Linear Fluorescent Lighting

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Glossary and Abbreviations

Ballast	Device connected between the mains power supply and one or more discharge lamps primarily to limit the current of the lamp(s)
BEE	Bureau of Energy Efficiency (India)
BEF	Ballast efficacy/efficiency factor (2 different acronyms)
BLE	Ballast luminous efficiency
CALI	Chinese Lighting Industry Associations
CCT	Correlated color temperature
Control gear	Lighting ballast or transformer
CRI	Color rendering index
EEI	Energy efficiency index (ballast)
EU	European Union
EC	European Commission
GSFL	General service fluorescent lamp
IEA	International Energy Agency
IEC	International Electrotechnical Commission
K	Kelvin
Lamp	Source of artificial optical radiation
LED	Light emitting diode
lm	Lumen, the international measure of light output (luminous flux)
LOR	Light output ratio (of luminaire)
Luminaire	Apparatus which distributes, filters or transforms the light transmitted from a light source, including lamp(s), control gear and all components necessary for fixing and protecting the lamps
MEPS	Minimum energy performance standards
NEMA	National Electrical Manufacturers Association (USA)
Nominal value	The manufacturer's declared value for a lighting product
NRCAN	Natural Resources Canada
Rated value	The manufacturer's declared value for a lighting product
T12	Linear fluorescent lamp of 12/8" diameter
T5	Linear fluorescent lamp of 5/8" diameter
T8	Linear fluorescent lamp of 8/8" diameter
W	Watt

Executive Summary

Around 3 billion linear fluorescent lamps are manufactured each year, which are responsible for producing around 58% of the world's artificial light (IEA 2006). These lamps, which utilize low pressure mercury-vapour gas-discharge technology, are significantly more efficient than filament-based lamps such as tungsten incandescent and tungsten halogen. Testing undertaken as part of this study revealed that linear fluorescent lamps exhibit efficacies from 55 to more than 100 lumens per Watt.

Their efficacy, long life and cost effectiveness makes linear fluorescent lamps worthy of attention in order to ensure that the optimum benefit is extracted from this technology. This is particularly relevant in the context of the increasing popularity of LED lamps (including replacement linear LED lamps) which have understandably dominated the thinking of lighting energy policy makers in recent years. Whilst LEDs may well be the "light source of the future" linear fluorescent lamps still dominate the current landscape and are likely to remain a viable, cost-effective and energy-efficient option for some time.

This study relates primarily to general purpose double-capped linear fluorescent lamps and ballasts, and to a lesser extent luminaires. Prior to this study, linear fluorescent lamps were suspected of exhibiting a wide range of efficacies, and one of the purposes of this study was to investigate just how large this range is. Note that the study does not cover linear LED lamps, although further resources related to these lamps are provided. This study is focused on linear fluorescent lighting and associated government policies in the following economies:

- Australia
- Canada
- China
- Europe
- India
- USA

These economies were selected for policy and market mapping as they represent a significant proportion of the world market for linear fluorescent lamps and ballasts (around two-thirds as calculated by this study) and include a good cross-section of both small and large economies in the developed and developing worlds. This report also contains limited information about linear fluorescent lighting in Japan, South Korea, Mexico and Thailand.

A small number of lamps from China, Europe (UK), India and the USA were sampled and tested in order to derive insights into the performance of commonly available lamps in large economies. Please note that the sampling and testing of lamps undertaken for this study is intended to provide a limited insight into the fluorescent lamp market – it should not be viewed as a comprehensive global analysis.

Table 1 summarizes the relative performance of linear fluorescent lamp and ballast policies and markets in the economies analysed for this study (noting that there are limitations on the accuracy of some data used in the analysis). A tick/cross system was used in order to create a visual indication of how economies are performing with regard to the relative efficiencies of linear fluorescent lamps and ballasts in those economies. It is accepted that each of these economies is subject to a different set of economic and social circumstances, some of which may make it easier or harder to adopt efficient technologies or effective policies. No judgment is made of any economy - the purpose of this report is simply to point out various aspects of linear fluorescent markets in the target economies.

In Australia, MEPS has effectively removed halophosphate and T12 lamps from the market. The market share of T5 lamps is significant and increasing, and the luminaire/ballast market is now dominated by electronic units.

Canada's MEPS does not currently mandate triphosphor lamps, although Canada has proposed a new MEPS which will harmonize with the USA (see below). Halophosphate T8 and T12 lamps appear to have remained popular in Canada. Sales of T5 lamps are increasing. Similar to the US, the Canadian ballast/luminaire market is a good performer, appearing to have moved considerably towards electronic ballasts.

In China, halophosphate lamps remain popular, although T12 lamp sales appear relatively low. T5 sales are significant and growing. Little is known about the domestic market for ballasts in China, although a MEPS is in place for ballasts.

In the European Union, MEPS has resulted in halophosphate lamps largely being replaced by triphosphor lamps. The market share of T5 lamps is increasing and T12 is decreasing. No robust data was available to make any conclusions about the ballast market in the EU.

India (effectively) has MEPS in place for linear fluorescent lamps (via a mandatory lamp labelling regime) but not for ballasts, which does however have a voluntary label. T12 and halophosphate lamps remain popular. The market share of T5 lamps and electronic ballasts is unknown.

The US has MEPS for fluorescent lamps that should mandate T8 triphosphor lamps, however halophosphate lamps continue to be available due to a MEPS exemption granted until July 2014. The market share of T5 lamps is increasing and T12 lamps decreasing (although these remain significant). The US ballast/luminaire market is an exceptional performer, having moved almost entirely to electronic ballasts.

Table 1: Summary of policy and market mapping for 6 economies

		Australia		Canada		China		Europe		India		USA	
Lamps	Most popular CCT	4100K		4100K		6500K		4100K		6500K		4100K	
	Most popular length	4-foot		4-foot		4-foot		4-foot		4-foot		4-foot	
	Most popular power	36W		32W		36W		36W		36W		32W	
	Low-power retrofit lamps commonly available	no	✗	yes	✔	U		yes	✔	U		yes	✔
	MEPS regulations in force	yes	✔	yes	✔	yes	✔	yes	✔	yes	✔	yes	✔
	MEPS regulations mandate triphosphor	yes	✔	no	✗	no	✗	yes	✔	no	✗	yes	✔
	Market share halophosphate (and trend)	0%	✔	high	✗	high	✗	2% ↓	✔	high	✗	medium	✗
	Market share T5 (and trend)	40% ↑	✔	5% ↑	✔	40% ↑	✔	30% ↑	✔	U		10% ↑	✔
	Market share T12 (and trend)	0%	✔	high	✗	low	✔	1% ↓	✔	high	✗	30% ↓	✗
Ballasts	MEPS regulations in force	yes	✔	yes	✔	yes	✔	yes	✔	no	✗	yes	✔
	Market share electronic (and trend)	80% ↑	✔	high ↑	✔	U		U		U		80-90% ↑	✔

Note U = unknown

From Table 1 the following observations are made regarding linear fluorescent lamp and ballast policies and markets in Australia, Canada, China, Europe, India and the USA:

- All six economies have some form of MEPS in place for linear fluorescent lamps, noting that India's MEPS is effectively created by the mandatory star rating system for lamps.
- MEPS for lamps in Australia, Europe and the USA should mandate triphosphor lamps, although halophosphate lamps continue to be available in the USA (due to an exemption granted until July 2014).
- Halophosphate lamps also remain popular in Canada, China and India.
- The market share of T5 lamps is significant and growing in all economies (India unknown).
- All economies have MEPS in place for linear fluorescent ballasts, with the exception of India which has voluntary comparative labeling.
- Electronic ballasts now dominate in Australia, Canada and the USA (other economies currently unknown).

Figure 1 graphs the minimum linear fluorescent lamp efficacy requirements for ten economies (Japan, Korea, Mexico and Thailand have been added). Note that some simplifications have been applied in order to graph the requirements within a single figure.

Figure 1: MEPS requirements for 10 economies (simplified)

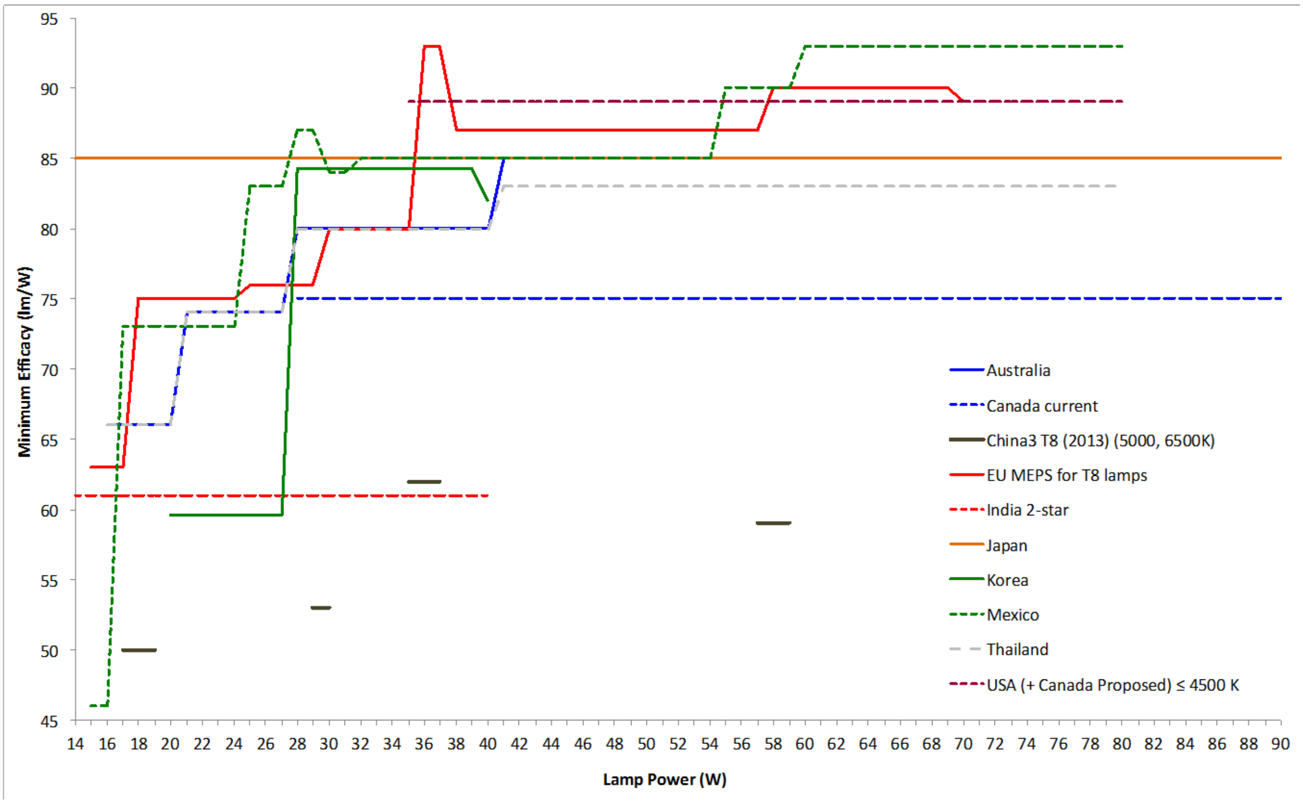


Table 2 lists the MEPS efficacy requirements for each economy, as applies to 4-foot T8 lamps only.

Table 2: MEPS efficacy requirements for 4-foot T8 lamps

Country	Requirement (lm/W)
Europe	93
USA (+ Canada Proposed) ≤ 4500K	89
Japan	85
Mexico	85
Korea	84.3
Australia	80
Thailand	83
Canada (current)	75
China3 (2013) (5000, 6500K)	62
India 2-star	61

From Figure 1 and Table 2 we can roughly group the MEPS requirements for these ten economies into 2 categories:

- High MEPS: MEPS for Australia, Europe, Japan, Korea, Mexico and USA, which require efficacies of 80+ lm/W for 4-foot lamps. Note that Canada currently requires efficacy of 75 lm/W for 4-foot lamps, however Canada has proposed a new MEPS which will harmonize with the USA.
- Low MEPS: countries such as India (note that India has labeling only - no official MEPS program for linear fluorescent lamps exists although labeling acts as a quasi-MEPS) and China, which have relatively low requirements for lamps.

The "high" MEPS requirements (80+ lm/W) will mandate triphosphor lamps, whereas the other MEPS requirements (75 lm/W and lower) will allow halophosphate lamps.

The ten economies studied (Australia, Canada, China, Europe, India, Japan, Korea, Mexico, Thailand and the USA) have well harmonized test procedures for linear fluorescent lamps. Thus lamp metrics from these economies can be compared directly, without any need for adjustment or normalization.

For ballasts, differing approaches are taken by various economies regarding test procedures and associated metrics. The USA is currently transitioning from photometry-based metrics to simplified metrics which are based solely on the electrical efficiency of the ballast.

A small sample of 4-foot linear fluorescent lamps sourced from China, Europe, India and the USA were tested and found to exhibit a very wide spread of efficacy, with luminous flux ranging from around 2150 to 3450 lm and efficacies from 58 to 100 lm/W. It is thought that the MEPS requirements in these countries have had a significant effect on lamp efficacy, particularly where MEPS requirements are more stringent.

The tested US and European lamps had generally higher lamp efficacies, which is to be expected given the higher MEPS requirements in these economies.

All tested Chinese-sourced lamps met the 2013 tier 3 (MEPS) requirements, noting that the Chinese requirements are relatively low.

The tested European lamps were amongst the most efficient of all lamps tested. Most tested lamps claimed efficacies that would meet MEPS (European MEPS is expressed in terms of rated values). All tested lamps claimed to be class A (European lamp label) and all lamps met the rated efficacy requirement for class A.

The tested Indian lamps were clearly grouped into halophosphate and triphosphor lamps. The tested lamps (after 100 hours ageing) did typically not meet their claimed energy label ratings (rating system expressed in terms of measured values). Note however that it is possible that these lamps might have 2000 and 3500 hour measurements that improve the average, and allow what appear to be 2 star lamps to achieve a rating of 3 stars (permissible in the Indian regulation).

Many of the tested US lamps were significantly below the current MEPS requirement, which can be explained by a two-year exemption from current MEPS for certain manufacturers.

Generally, measured lamp luminous flux and efficacy were up to 10% lower than the corresponding rated values claimed by manufacturers.

There is a clear efficacy distinction between halophosphate and triphosphor lamps - halophosphate 60-75 lm/W and triphosphor 80-100 lm/W.

The tested lamps (albeit small sample size) supported the known relationship between color temperature and efficacy – tested lamps with higher color temperatures were less efficient.

There is a slight correlation between CRI and efficacy, which is to be expected (i.e. higher quality lamps exhibit both higher efficacy and color rendering properties). However, the tested European lamps showed a contrasting correlation - the lamps with very high CRI exhibit lower efficacies - it is possible that these products have sacrificed some efficacy for better CRI.

Higher priced lamps are generally more efficient with higher CRI.

Testing conducted using a single set of linear fluorescent lamps, ballast and luminaire revealed that the equation: *luminaire efficacy = BLE x lamp efficacy x LOR* can be used to accurately predict net absolute luminaire efficacy.

It is clear from the work undertaken for this study, that efforts to achieve a complete transition to triphosphor lamps and electronic ballasts, would be well spent. However this should also be viewed in the context of the increasing popularity of LED linear lamps and luminaires in commercial lighting systems, which should not be ignored. A technology neutral approach could be taken in order to ensure the optimum performance of all linear-style lighting.

For linear fluorescent lamps, a two-tier harmonization effort could be implemented, that allows countries to choose from either a single "high" MEPS limit (mandates triphosphor lamps) or a single "low" MEPS limit which allows either halophosphate or triphosphor lamps. This would allow countries to decide which MEPS best suits their circumstances with respect to issues such as lamp cost and supply of phosphors. The "low" MEPS should also result in some countries increasing their current MEPS requirements, in order to ensure that even halophosphate lamps are relatively efficient (e.g. 75 lm/W rather than 55 lm/W). Countries could also adopt a two-tier system to ensure that both halophosphate and triphosphor lamps meet appropriate efficacy requirements. Countries with no MEPS should also be encouraged to introduce MEPS.

Also worthy of consideration are initiatives that seek to encourage lower power lamps where technically feasible. E.g. in the US 25W lamps are commonly available to replace 32W lamps. Promoting this style of lamp, together with an appropriate minimum efficacy requirement, would ensure that MEPS leads <u>directly</u> to reductions in energy usage, rather than simply increasing lamp light output (which relies on fewer lamps being fitted in order to reduce energy consumption).

The European Union and India both have mandatory comparative energy rating labels for linear fluorescent lamps. Labeling for lamps could also be considered, e.g. as a "bolt on" to a MEPS regime. Note however that the wide spread of efficacy between incandescent lamps and fluorescent / LED lamps means that much thought should be invested in the issue of lamp labelling.

Amongst the economies studied, there are a variety of MEPS regimes for ballasts involving differing ballast efficiency metrics. In addition, the international fluorescent ballast market has been in transition for some time, from less efficient magnetic (wire-wound) ballasts to significantly more efficient electronic units (including dimmable and programmable ballasts). A global harmonization effort could be considered, to align ballast test procedures, efficiency metrics and MEPS.

Similar to the lamp halophosphate / triphosphor lamp issue, a two-tier magnetic / electronic ballast MEPS could be considered - with countries able to choose to mandate electronic-only ballasts if desired. A global effort to eliminate magnetic ballasts from the world marketplace could be also be adopted. Countries without ballast MEPS should also be encouraged to introduce MEPS. As ballasts are not typically an off-the-shelf item, labeling is not considered a high priority – efforts are better spent improving MEPS for ballasts. This is an important issue as efficient ballasts lead directly to power savings, which as discussed above is not the case for lamps.

Luminaire design has a significant impact on the efficiency of a fluorescent lighting system, although quantifying and regulating luminaire efficiency can be difficult. Regulators worldwide have been reluctant to develop MEPS for luminaires. One constraint is absence of an agreed international luminaire standard to deal with photometric and electrical characteristics (noting that the method of photometry does exist). Luminaire MEPS may however still be considered a useful regulatory mechanism for buildings or refurbishments which are not effectively captured by building standards, and for luminaires that have minimal aesthetic considerations and where efficiency is a key driver (e.g. recessed troffers, high bay lighting, etc.). Given the intricacies associated with luminaire MEPS, these are considered a secondary priority, behind MEPS for lamps and ballasts.

1. Introduction

1.1. Report Structure

The subject of this report is mapping and benchmarking of linear fluorescent lighting. The report has been structured into the following two key parts:

- **Policy and Market Mapping.** This section covers the relevant policies of the economies studied (undertaken primarily by CLASP personnel) as well as the markets of those economies (undertaken primarily by Beletich Associates and Ballarat Consulting).
- **Lamp Testing.** This section covers the testing undertaken for this study - of linear fluorescent lamps in four large economies (undertaken primarily by Beletich Associates and Erik Page & Associates).

These two parts follow this introductory chapter, which outlines the context, scope and objectives of the report, and introduces the technologies covered. The final chapter draws conclusions for the report.

1.2. Context

Around 3 billion linear fluorescent lamps are manufactured each year, which are responsible for producing around 58% of the world's artificial light (IEA 2006). These lamps, which utilize low pressure mercury-vapour gas-discharge technology, are significantly more efficient than filament-based lamps such as tungsten incandescent and tungsten halogen. Testing undertaken as part of this study revealed that linear fluorescent lamps exhibit efficacies from 55 to more than 100 lumens per Watt.

Their efficacy, long life and cost effectiveness makes linear fluorescent lamps worthy of attention in order to ensure that the optimum benefit is extracted from this technology. This is particularly relevant in the context of the increasing popularity of LED lamps (including replacement linear LED lamps) which have understandably dominated the thinking of lighting energy policy makers in recent years. Whilst LEDs may well be the "light source of the future" linear fluorescent lamps still dominate the current landscape and are likely to remain a viable, cost-effective and energy-efficient option for some time.

1.3. Scope

This study relates primarily to general purpose double-capped linear fluorescent lamps and ballasts, and to a lesser extent luminaires. Prior to this study, linear fluorescent lamps were suspected of exhibiting a wide range of efficacies, and one of the purposes of this study was to investigate just how large this range is. Note that the study does not cover linear LED lamps, although further resources related to these lamps are listed in Appendix A.

This study is focused on linear fluorescent lighting and associated government policies in the following economies:

- Australia
- Canada
- China
- Europe
- India
- USA

These economies were selected for policy and market mapping (Chapter 2 of this report) as they represent a significant proportion of the world market for linear fluorescent lamps and ballasts (around two-thirds as calculated by this study) and include a good cross-section of both small and large economies in the developed and developing worlds. This report also contains limited information about linear fluorescent lighting in Japan, South Korea, Mexico and Thailand.

A small number of lamps from China, Europe (UK), India and the USA were sampled and tested in order to derive insights into the performance of commonly available lamps in large economies (chapter 3 of this report). Please note that the sampling and testing of lamps undertaken for this study is intended to provide a limited insight into the fluorescent lamp market – it should not be viewed as a comprehensive global analysis.

1.4. Objectives

The objectives of this study were as follows:

- Map the government policies of key economies, relating to linear fluorescent lighting.
- Establish the basic characteristics of linear fluorescent lamp and ballast markets in key economies.
- Conduct independent testing of linear fluorescent lamps from four large economies, and make intra- and inter-economy comparisons of efficiency parameters.
- Develop high level conclusions regarding linear fluorescent lighting in the economies studied.

1.5. Acknowledgements

The authors would like to thank all respondents who provided information for their co-operation in preparing this report. Without their help this would not have been possible.

1.6. Description of Technologies

1.6.1. Lamps

A number of different lamp types, technologies and attributes are discussed in this study. The following descriptions are provided to assist the reader:

- **Halophosphate lamps**. As found in this study, halophosphate lamps exhibit typical efficacies of 55-75 lm/W (4-foot length).
- **Triphosphor lamps**. Triphosphor lamps use rarer and more expensive phosphors, and (as found in this study) exhibit typical efficacies of 80-100 lm/W (4-foot length).
- **T12 lamps**. T12 lamps have diameter of 12/8" (38mm) and are almost always halophosphate. They have a slightly higher Wattage than equivalent T8 lamps - e.g. in 220/230V economies 4-foot T12 lamps are 40W as compared to 36W for T8 lamps.
- **T8 lamps**. T8 lamps have diameter of 8/8" (25mm) and can be either halophosphate or triphosphor.
- **T5 lamps**. T5 lamps have diameter of 5/8" (16mm) and are always triphosphor. These lamps are designed to operate on an electronic ballast. They have a lower Wattage than equivalent T8 lamps - e.g. in 220/230V economies 4-foot T5 lamps are 28W as compared to 36W for T8 lamps.

Detailed information about the linear fluorescent lamp markets in the target economies is generally not available. Thus, in order to analyse these markets, this study categorizes lamps into the following discrete, mutually exclusive categories:

- T12 (halophosphate)
- T8 halophosphate

- T8 triphosphor
- T5 (triphosphor).

The distinct differences between the efficacies of these lamp categories (driven primarily by the phosphors employed) allows us to use the market shares of these lamp categories to draw conclusions about the linear fluorescent lamp markets in each economy. This is a good compromise in the absence of measured performance data.

1.6.2. Ballasts

Fluorescent lamps require a ballast in order to operate. The ballast is wired in series with the lamp(s) and controls the electrical current supplied to the lamp(s) during operation. Traditionally, ballasts were similar in construction to transformers – comprised of copper (or aluminium) windings around an iron or steel core. Electronic ballasts have now become significantly more common, and the global fluorescent ballast market is currently in transition from the less efficient magnetic (wire-wound) ballasts to significantly more efficient electronic units.

Similar to lamps, detailed information about the efficiency of ballasts for linear fluorescent lamps in the target economies is generally not available. In order to analyse these markets, this study categorizes ballasts into the following mutually exclusive categories:

- **Magnetic ballast**. A magnetic ballast is comprised of a copper (or aluminium) winding on an iron (or steel) core, which operates the lamp at mains frequency (50 or 60 Hz). Magnetic ballasts have power losses in the order of 8-10W.
- **Electronic ballasts**. An electronic ballast operates the lamp at high frequency (typically 20kHz or higher) and has lower power losses (in the order of 1-2W). High frequency lamp operation also produces around 10% more light than when operated at mains frequency (US Federal Register 2011).

Again, the distinct differences between the efficiencies of these ballast types allows us to use the market shares of these types to draw conclusions about the ballast markets in each economy.

Note that, in this report, discussion of "ballasts" relates primarily to the luminaire. For example, when we discuss "sales of electronic ballasts" this relates primarily to luminaires fitted with an electronic ballast.

1.6.3. LEDs

Although this study does not cover linear LED lamps or luminaires, it is worth noting that LED technology is rapidly taking market share from traditional linear fluorescent lighting. This is occurring in two ways:

As forecast by a major Australian supplier interviewed for this study, the linear fluorescent luminaire market (i.e. for new buildings and major refurbishments) is undergoing a "leapfrog" maneuver. The market is jumping from T8 luminaires straight to dedicated LED luminaires, thereby "leapfrogging" T5 luminaires. This supplier estimates that 30% of Australian office luminaire sales are now LED.

The linear fluorescent lamp market (i.e. replacement lamps for existing lighting systems) is also changing - retrofit linear LED lamps are widely available to directly replace fluorescent lamps in existing luminaires.

These influences should be kept in mind when reading this study. For example, this study discusses the market shares of various fluorescent lamp and ballast technologies. These are the market shares purely of fluorescent technologies. LEDs are excluded but are likely to be distorting the market - depressing the fluorescent share of the overall market. For example, if we were to observe declining T5 sales, this may not be a poor outcome, as it may be due to T5 lighting systems being "leapfrogged" by LED. Additionally, as LEDs do not require a ballast, increases in LED sales will mean a proportionate decrease in ballast sales.

2. Policy and Market Mapping

In this chapter, information regarding the linear fluorescent lamp and ballast policies in key economies was taken from publicly available websites, standards and government regulations.

Detailed efficiency information regarding the lamp and ballast markets in various economies is not readily available. This is because, particularly for lamps, these are high volume sales items. Hundreds of millions of lamps are sold annually in some economies, through a wide variety of sales outlets. Unlike say refrigerators, keeping track of these sales, and the performance each model sold, is not possible. Thus the approach taken in this study was to categorize lamps and ballasts into a small number of discrete categories (refer section 1.6) and seek production and sales data for each category.

In some cases sales data is available, such as from other studies or supplier surveys undertaken previously. In the absence of such data, informed estimates were sought from suppliers. In some instances MEPS or labeling model registration data were also used to build a market picture (data as collected by regulators). Trends in product registration quantities are thought to be a reasonable proxy for market trends, in the absence of any actual sales data.

Note that when discussing ballast sales/shipments in this report, we are primarily concerned with ballasts installed in complete luminaires. It should also be noted that this was a desktop study with a modest budget. Thus it relied on direct access to existing sources of data, with limited ability to perform primary research. As a result there is some uncertainty in the results, and this should be kept in mind when drawing any conclusions from this study.

2.1. Australia

In Australia, The Equipment Energy Efficiency (E3) Program is a joint initiative of the Australian, Commonwealth, State and Territory governments and the New Zealand Government. It is managed by The Equipment Energy Efficiency (E3) Committee, which consists of officials from Commonwealth, state and territory government agencies as well as representatives of the New Zealand Government. The E3 Committee reports to the Energy Efficiency Working Group and is ultimately directed by the Select Council on Energy Efficiency (SCCC).

2.1.1. MEPS for Lamps

MEPS for linear fluorescent lamps are regulated by Greenhouse and Energy Minimum Standards (Double-capped Fluorescent Lamps) Determination 2012[1]. The scope of linear fluorescent lamp MEPS is double-capped fluorescent lamps ranging from 550mm to 1500mm in length and having a nominal lamp power of 16 Watts or more. Excluded are lamps that are clearly not intended for general illumination, specifically:

- Lamps with a dominant color or with an output that is predominantly outside the visible spectrum.
- Lamps for color matching and that have a color rendering index (CRI) greater than 90 and a color appearance approximating to a point on the black body locus.
- Lamps that are specifically for use in an industrial or agricultural process.
- Lamps for medical applications.
- Lamps that have been given written exemption by the relevant regulatory authority on the grounds that they are for a specific purpose other than general illumination and are clearly distinguishable from lamps for general illumination.

Linear fluorescent lamps manufactured in or imported into Australia or New Zealand must comply with MEPS requirements which are set out in standard AS/NZS 4782.2. These MEPS are set out as minimum

1 http://www.comlaw.gov.au/Details/F2012L02127

luminous efficacy in lumens per Watt for various lamp sizes. There are also requirements for minimum CRI and mercury content. The test methods[2] for measurement of luminous efficacy are set out in standards AS/NZS 4782.1 and AS/NZS 4782.3.

When measured in accordance with AS/NZS 4782.1 the initial efficacy (after 100 hours ageing) and the maintained efficacy (at 5000 hours) shall exceed the values specified in the table below. Lamps shall also have a CRI which exceeds the value in the table below.

Table 3: Minimum Lamp Efficacy and Color Rendering Requirements - Australia

Lamp nominal length L (mm) mandatory	**550 ⩽ L < 700**	**700 ⩽ L < 1150**	**1150 ⩽ L < 1350**	**1350 ⩽ L < 1500**
Lamp typical power (Watts) (informative)	16 – 24	17 – 40	28 – 50	35 – 80
Initial Efficacy **Maintained Efficacy**	*F* 100 ⩾ 66.0 and *FM* ⩾ 57.5	*F* 100 ⩾ 74.0 and *FM* ⩾ 61.0	*F* 100 ⩾ 80.0 and *FM* ⩾ 70.0	*F* 100 ⩾ 85.0 and *FM* ⩾ 70.0
Minimum CRI	79	79	79	79

The maximum quantity of mercury present in fluorescent lamps shall not exceed 15 mg.

2.1.2. MEPS for Ballasts

MEPS for Ballasts are regulated by GEMS determination for ballasts[3]. Ballasts for fluorescent lamps manufactured in or imported into Australia or New Zealand must comply with MEPS requirements set out in standard AS/NZS 4783.2. MEPS apply to the following types of ballasts:

- Magnetic and electronic ballasts used with fluorescent lamps with a rated power from 10W to 70W.
- For use on 50 Hz supplies of 230/240/250V (or a range that includes these).
- Ballasts supplied as separate components or as part of a luminaire.

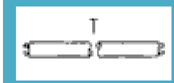
Ballasts within the scope of MEPS must also be marked with their Energy Efficiency Index (EEI) the details of which are also specified in AS/NZS 4783.2. AS/NZS 4783.2 also requires that ballasts within the scope of MEPS be designed to comply with the relevant performance requirements of IEC 60921 for magnetic ballasts and IEC 60929 for electronic ballasts. These standards are also published by Standards Australia and New Zealand as AS/NZS 60921 and AS/NZS 60929. MEPS do not apply to the following types of ballasts:

- Primarily for use on DC supplies or batteries
- Primarily for the production of light (radiation) outside the visible spectrum.
- To exit signs within the scope of AS/NZS 2293.
- To hazardous area lighting equipment within the scope of AS/NZS 2380, AS/NZS 60079 and AS/NZS 61241.

The MEPS requirements are set out as maximum allowable total circuit power when tested in accordance with AS/NZS 4783.1. These are set out in the tables below when tested to AS/NZS4783.1.

2 http://www.energyrating.gov.au/regulations/product-standards/overview/asnzs4782/
3 http://www.comlaw.gov.au/Details/F2012L02133

Table 4: Ballasts for Fluorescent Lamps – EEI Classification for Rated Voltage >250V≤

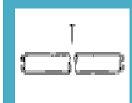
Lamp Type and Arrangement	Nominal Lamp Power* Watts	ILCOS Code	Maximum Corrected Total Input Power, Watts Energy Efficiency Index (EEI) Classification						
			A1#	A2	A3	B1	B2	C	D
Linear 	15	FD-15-E-G13-26/450	≤18.0	≤16.0	≤18.0	≤21.0	≤24.0	≤25.0	>25.0
	18	FD-18-E-G13-26/600	≤21.0	≤19.0	≤21.0	≤24.0	≤27.0	≤28.0	>28.0
	30	FD-30-E-G13-26/895	≤33.0	≤31.0	≤33.0	≤36.0	≤39.0	≤40.0	>40.0
	36	FD-36-E-G13-26/1200	≤38.0	≤36.0	≤38.0	≤41.0	≤44.0	≤45.0	>45.0
	38	FD-38-E-G13-26/1047	≤40.0	≤38.0	≤40.0	≤43.0	≤46.0	≤47.0	>47.0
	58	FD-58-E-G13-26/1500	≤59.0	≤55.0	≤59.0	≤64.0	≤68.0	≤70.0	>70.0
	70	FD-70-E-G13-26/1800	≤72.0	≤68.0	≤72.0	≤77.0	≤81.0	≤83.0	>83.0

NOTES:
1. Refer to AS/NZS 61231, International Lamp Coding System (ILCOS).
2. Applies only to mains frequency magnetic ballasts with two-wire connection and with an external starter.

* Nominal values shown may have different rating values. Refer to the relevant lamp data sheet.

Refer Clause 5.3.2

Table 5: Ballasts for Fluorescent Lamps – EEI Classification for Rated Voltage>240V and <250V - Australia

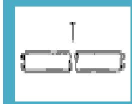
Lamp Type and Arrangement	Nominal Lamp Power* Watts	ILCOS Code	Maximum Corrected Total Input Power, Watts Energy Efficiency Index (EEI) Classification						
			A1#	A2	A3	B1	B2	C	D
Linear 	15	FD-15-E-G13-26/450	≤18.0	≤16.0	≤18.0	≤21.0	≤23.5	≤25.0	>25.0
	18	FD-18-E-G13-26/600	≤21.0	≤19.0	≤21.0	≤24.0	≤26.5	≤28.0	>28.0
	30	FD-30-E-G13-26/895	≤33.0	≤31.0	≤33.0	≤36.0	≤38.5	≤40.0	>40.0
	36	FD-36-E-G13-26/1200	≤38.0	≤36.0	≤38.0	≤41.0	≤43.5	≤45.0	>45.0
	38	FD-38-E-G13-26/1047	≤40.0	≤38.0	≤40.0	≤43.0	≤45.5	≤47.0	>47.0
	58	FD-58-E-G13-26/1500	≤59.0	≤55.0	≤59.0	≤64.0	≤67.5	≤70.0	>70.0
	70	FD-70-E-G13-26-1800	≤72.0	≤68.0	≤72.0	≤77.0	≤80.5	≤83.0	>83.0

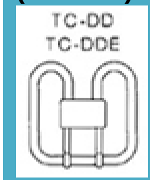
NOTES:
1. Refer to AS/NZS 61231, International Lamp Coding System (ILCOS).
2. Applies only to mains frequency magnetic ballasts with two-wire connection and with an external starter.

* Nominal values shown may have different rating values. Refer to the relevant lamp data sheet.

Refer Clause 5.3.2

Table 6: Ballasts for Fluorescent Lamps - EEI Classification - Australia

Lamp Type and Arrangement	Nominal Lamp Power* Watts	ILCOS Code	Maximum Corrected Total Input Power, Watts Energy Efficiency Index (EEI) Classification						
			A1#	A2	A3	B1	B2	C	D
Linear 	15	FD-15-E-G13-26/450	≤18.0	≤16.0	≤18.0	≤21.0	≤23.0	≤25.0	>25.0
	18	FD-18-E-G13-26/600	≤21.0	≤19.0	≤21.0	≤24.0	≤26.0	≤28.0	>28.0
	30	FD-30-E-G13-26/895	≤33.0	≤31.0	≤33.0	≤36.0	≤38.0	≤40.0	>40.0
	36	FD-36-E-G13-26/1200	≤38.0	≤36.0	≤38.0	≤41.0	≤43.0	≤45.0	>45.0
	38	FD-38-E-G13-26/1047	≤40.0	≤38.0	≤40.0	≤43.0	≤45.0	≤47.0	>47.0
	58	FD-58-E-G13-26/1500	≤59.0	≤55.0	≤59.0	≤64.0	≤67.0	≤70.0	>70.0
	70	FD-70-E-G13-26-1800	≤72.0	≤68.0	≤72.0	≤77.0	≤80.0	≤83.0	>83.0
Compact 2 Tube 	18	FSD-18-E-2G11	≤21.0	≤19.0	≤21.0	≤24.0	≤26.0	≤28.0	>28.0
	24	FSD-24-E-2G11	≤27.0	≤25.0	≤27.0	≤30.0	≤32.0	≤34.0	>34.0
	36	FSD-36-E-2G11	≤38.0	≤36.0	≤38.0	≤41.0	≤43.0	≤45.0	>45.0
	40	FSDH-40-L/P-2G11	≤46.0	≤44.0	≤46.0	-	-	-	-
	55	FSDH-55-L/P-2G11	≤46.0	≤44.0	≤46.0	-	-	-	-
Compact 4 Tube Flat 	18	FSS-18-E-2G10	≤21.0	≤19.0	≤21.0	≤24.0	≤26.0	≤28.0	>28.0
	24	FSS-24-E-2G10	≤27.0	≤25.0	≤27.0	≤30.0	≤32.0	≤34.0	>34.0
	36	FSS-36-E-2G10	≤38.0	≤36.0	≤38.0	≤41.0	≤43.0	≤45.0	>45.0
Compact 4 Tube (not flat) 	10	FSQ-10-E-G24q = 1 FSQ-10-I-G24d = 1	≤13.0	≤11.0	≤13.0	≤14.0	≤16.0	≤18.0	>18.0
	13	FSQ-10-E-G24q = 1 FSQ-10-I-G24d = 1	≤16.0	≤14.0	≤16.0	≤17.0	≤19.0	≤21.0	>21.0
	18	FSQ-18-E-G24q = 2 FSQ-18-I-G24d = 2	≤21.0	≤19.0	≤21.0	≤24.0	≤26.0	≤28.0	>28.0
	26	FSQ-26-E-G24q = 3 FSQ-26-I-G24d = 3	≤29.0	≤27.0	≤29.0	≤32.0	≤34.0	≤36.0	>36.0
Compact 6 Tube 	18	FSM-18-I-GX24d = 2 FSM-18-E-G24q = 2	≤21.0	≤19.0	≤21.0	≤24.0	≤26.0	≤28.0	>28.0
	26	FSM-26-I-GX24d = 3 FSM-13-E-G24q = 1	≤29.0	≤27.0	≤29.0	≤32.0	≤34.0	≤36.0	>36.0
	32	FSSMH-32-L/P-GX24q=4	≤39.0	≤36.0	≤39.0	-	-	-	-
	42	FSMH-42-L/P-GX24q = 4	≤49.0	≤46.0	≤49.0	-	-	-	-

Lamp Type and Arrangement	Nominal Lamp Power* Watts	ILCOS Code	Maximum Corrected Total Input Power, Watts Energy Efficiency Index (EEI) Classification						
			A1#	A2	A3	B1	B2	C	D
Compact 2D (double D) 	10	FSS-10-E-GR10q FSS-10-L/P/H-GR10q	≤13.0	≤11.0	≤13.0	≤14.0	≤16.0	≤18.0	>18.0
	26	FSS-16-I-GR8 FSS-16-E-GR10q FSS-16-L/P/H-GR10q	≤19.0	≤17.0	≤19.0	≤21.0	≤23.0	≤25.0	>25.0
	21	FSS-21-E-GR10q FSS-21-L/P/H-GR10q	≤24.0	≤22.0	≤24.0	≤27.0	≤29.0	≤31.0	>31.0
	28	FSS-28-I-GR8 FSS-28-E-GR10q FSS-28-L/P/H-GR10q	≤31.0	≤29.0	≤31.0	≤34.0	≤36.0	≤38.0	>38.0
	38	FSS-38-E-GR10q FSS-38-L/P/H-GR10q	≤40.0	≤38.0	≤40.0	≤43.0	≤45.0	≤47.0	>47.0
	55	FSS-55-E-GRY10q = 3 FSS-55-L/P/H-GRY10q = 3	≤63.0	≤59.0	≤63.0	-	-	-	-

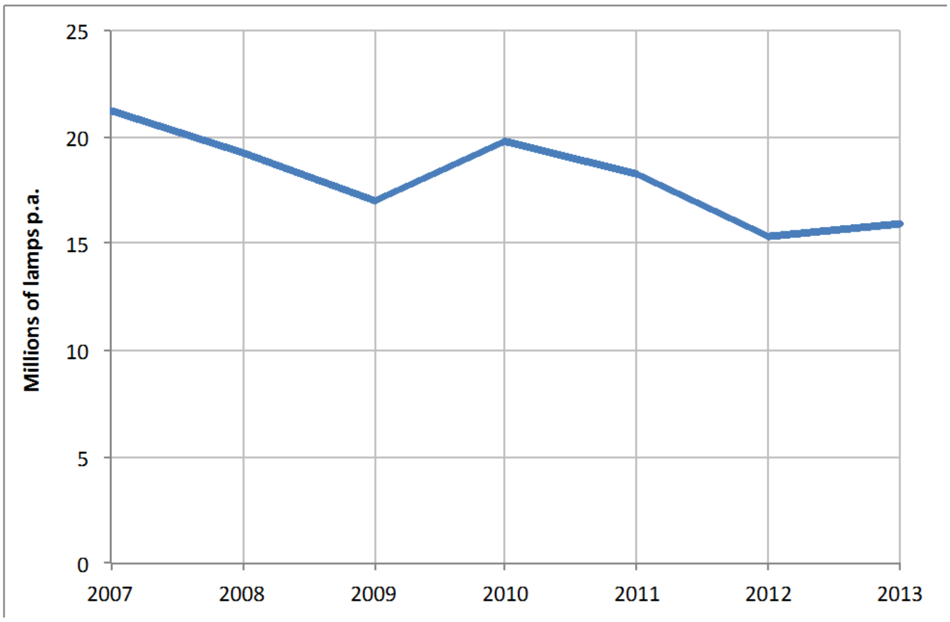
NOTE: Refer to AS/NZS 61231, International Lamp Coding System (ILCOS)
* Nominal values shown may have different rating values. Refer to the relevant lamp data sheet.

2.1.3. Lamp Market

Like many 220/230V economies, linear fluorescent lighting in Australia is currently dominated by 4-foot (36W) T8 lamps, which represent around 65% of all linear fluorescent lamp sales (based on estimates from 2 major suppliers). The bulk of the remaining market is split roughly evenly between 2-foot (18W) and 5-foot lamps (58W). The most common colour temperature of Australian linear fluorescent lamps is 4100K (~60% of total sales) although sales of 6500K lamps are significant (~25% of total sales) (based on estimates from 2 major suppliers).

Figure 2 graphs Australian linear fluorescent lamp imports over the period 2007-2013 (ABS 2013). Imports represent a good proxy for sales, as no linear fluorescent lamps have been manufactured in Australia since 2002. From this figure we can see that total lamp imports appear to be on a downward trend over the period 2007-2013.

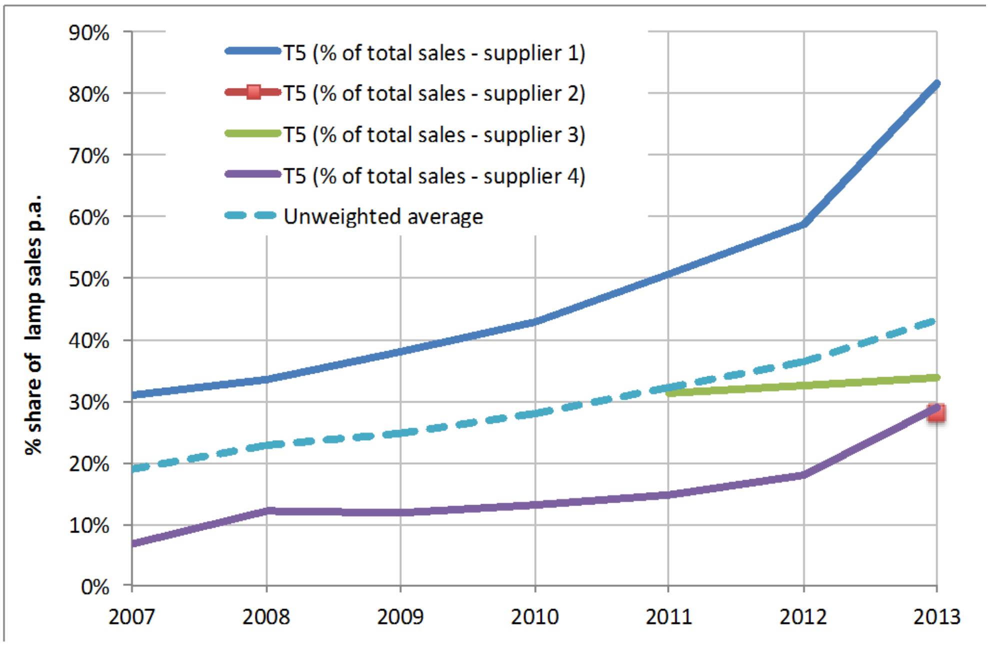
Figure 2: Imports of linear fluorescent lamps into Australia (source: ABS 2013)



In Australia, MEPS for linear fluorescent lamps has been in place since 2004 and this effectively eliminates T12 and T8 halophosphate lamps from the market (e.g. 4-foot lamp minimum efficacy requirement of 80 lm/W on measured values). This conclusion is supported by estimates provided by the major Australian lamp suppliers.

Thus we do not need to further consider T12 and T8 halophosphate lamp sales in Australia, as these are effectively zero. The only lamp types we need to consider are T5 and T8 triphosphor. Figure 3 graphs T5 lamp sales share estimates from the 4 largest lamp suppliers (as a percentage of total T5 + T8 sales). These are estimates of the sales share within each company rather than market-wide estimates. These 4 companies are estimated to represent a combined total of around 80% of the linear fluorescent lamp market in Australia.

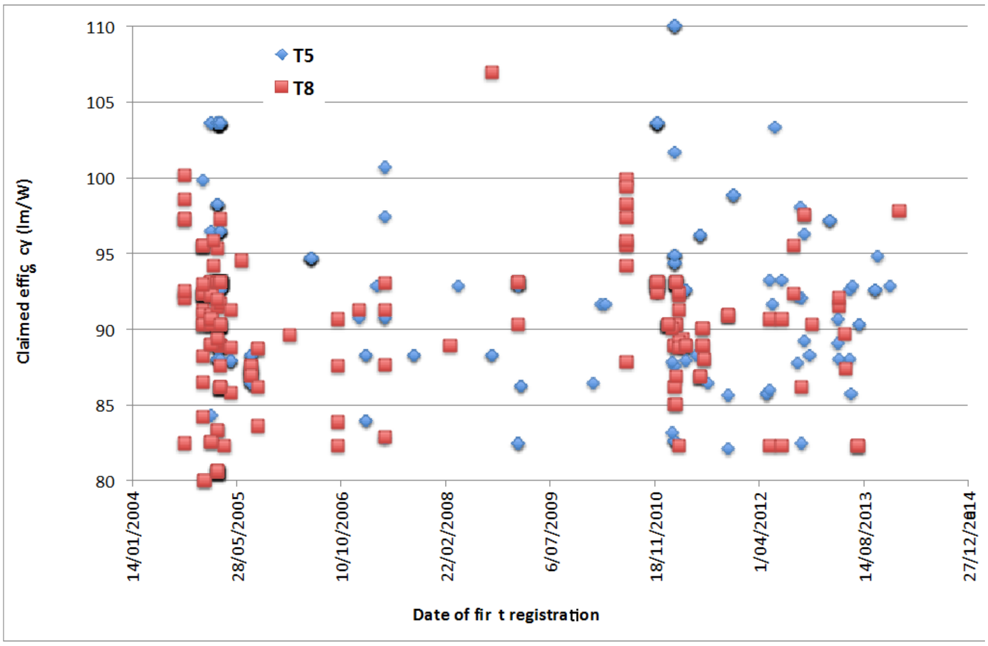
Figure 3: Australian (company) T5 lamp sales share estimates (source: industry estimates)



The company estimates of T5 lamp sales share in Figure 3 vary, although all trend upwards as expected. A simple unweighted average of these estimates shows T5 lamp sales share increasing from 20% to 45% over 2007-2013.

Figure 4 graphs MEPS registration data for 4-foot lamps - the date of first registration against the claimed efficacy. T8 and T5 lamps are identified separately.

Figure 4: MEPS registrations for Australian 4-foot lamps (source: Australian MEPS registry[4])



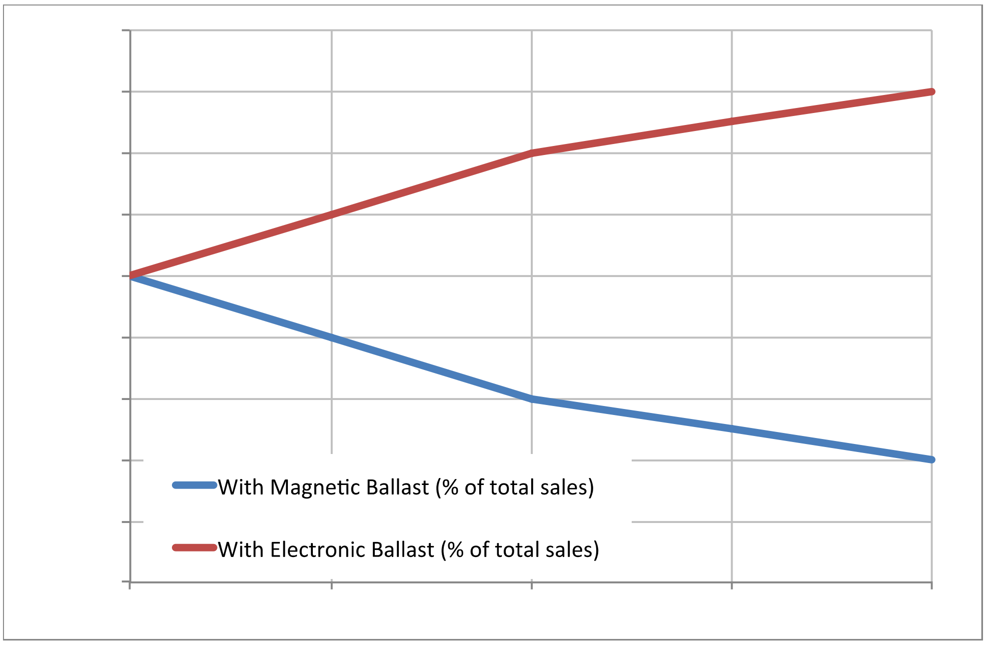
The above figure does not show any real discernable trends in lamp registration in Australia.

2.1.4. Ballast Market

Some magnetic ballasts are still manufactured in Australia, and production was estimated (by a major supplier) to drop from 3 million p.a. in 2007 to 0.8 million p.a. in 2013. No electronic ballasts are manufactured in Australia. Figure 5 graphs an estimate, from the same supplier, of the share of magnetic versus electronically-ballasted luminaires in Australia over 2009-2013.

[4] www.energyrating.gov.au

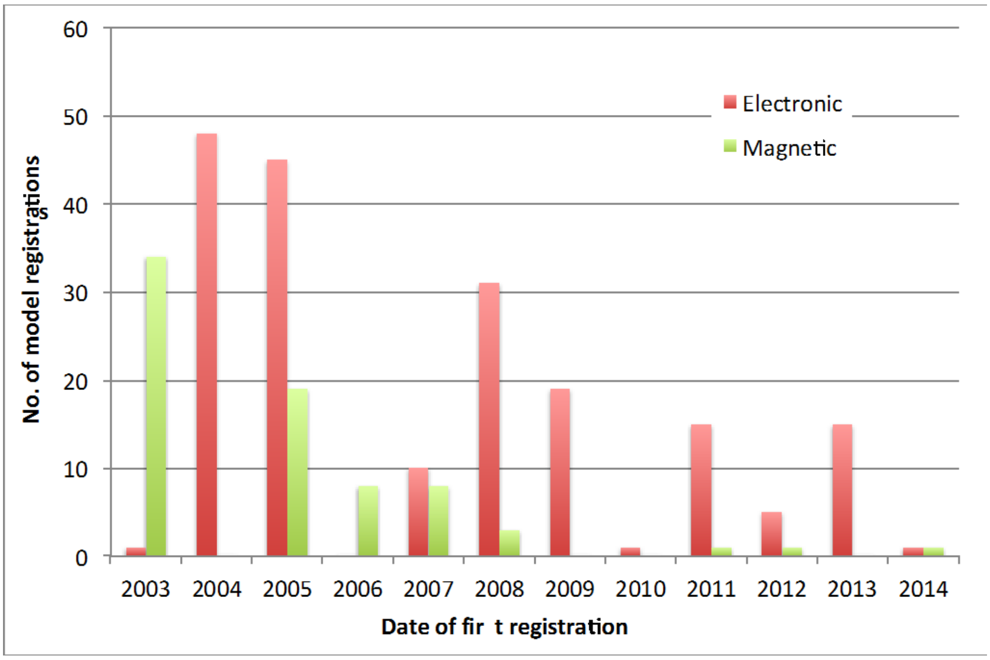
Figure 5: Share of magnetic versus electronic ballasted luminaires in Australia (source: estimate from major supplier)



From the estimates in Figure 5, we can see that the sales share of electronically-ballasted luminaires appear to have increased to around 80% in recent years.

Figure 6 graphs MEPS registration data for ballasts (including those incorporated into luminaires) - the date of first registration against the quantities of magnetic and electronic ballasts registered. Note that ballasts for T5 lamps are not required to meet MEPS in Australia - the ballasts graphed are primarily for driving T8 lamps.

Figure 6: Quantities of MEPS registrations for Australian T8 ballasts (source: Australian MEPS registry - energyrating.gov.au)



The above figure supports a conclusion that the Australian ballast (luminaire) market is trending to electronic. Even though the total numbers of registrations have declined (once products are registered they do not need to be registered again for 5 years), the ratio of electronic to magnetic ballast registrations has changed significantly.

2.1.5. Notes on Market Data Sources and Assumptions

The assumptions required in order to apply the findings of this section to the entire Australian market, are as follows:

- Lamp imports represent a good proxy for lamp sales.
- Lamp and ballast sales share estimates made by made by major lamp suppliers are indicative of the broader market.
- MEPS registration quantities are a good proxy for the efficiency of products being sold in the Australian market.

A summary of the Australian market is provided in the following section.

2.1.6. Market Summary

The domestic linear fluorescent lighting market for Australia is summarised in Table 7, which uses a tick/cross system to indicate the progress of this market towards energy efficiency.

Table 7: Australian domestic market summary

Lamps	**Most popular CCT**	**4100K**	
	Most popular length	4-foot	
	Most popular power	36W	
	Low-power retrofit lamps commonly available	no	✗
	MEPS regulations in force	yes	✔
	MEPS regulations mandate triphosphor	yes	✔
	Market share halophosphate (and trend)	0%	✔
	Market share T5 (and trend)	40% ↑	✔
	Market share T12 (and trend)	0%	✔
Ballasts	MEPS regulations in force	yes	✔
	Market share electronic (and trend)	80% ↑	✔

In Australia, MEPS has effectively removed halophosphate and T12 lamps from the market. The market share of T5 lamps is significant and increasing, and the luminaire/ballast market is now dominated by electronic units.

2.2. Canada

The Energy Efficiency Act was passed by the Canadian Parliament in 1992. It provides for the making and enforcement of regulations concerning minimum energy-performance levels for energy-using products, as well as the labelling of energy-using products and the collection of data on energy use. The first Energy Efficiency Regulations came into effect in February 1995 and linear fluorescent lamps were amongst the earliest batch of regulated products. The Regulations are administered by Natural Resources Canada (NRCAN). The lamp regulations are currently under review as part of Amendment 135 to the Energy Efficiency Regulations.

2.2.1. MEPS for Lamps

MEPS for fluorescent lamps was introduced in Amendment 1 of the Energy Efficiency Regulation. The MEPS is named Energy Efficiency Regulations Technical Requirements for Energy-Using Products - General Service Fluorescent Lamps and is administered by NRCAN.

MEPS covers a variety of fluorescent lamps with different shapes, configurations and rated power. The detailed scope is as follows:

- Rapid-start straight-shaped fluorescent lamps with a nominal overall length of 1200 mm (48 inches) a medium bi-pin base and a nominal power of not less than 28W.
- Rapid-start straight-shaped fluorescent lamps with a nominal overall length of 2400 mm (96 inches) a recessed double-contact base, a nominal power of not less than 95W and a nominal current of 0.8 A.
- Rapid-start U-shaped fluorescent lamps with a nominal overall length of not less than 560 mm (22 inches) and not more than 635 mm (25 inches) a medium bi-pin base and a nominal power of not less than 28 W.
- Instant-start straight-shaped fluorescent lamps with a nominal overall length of 2400 mm (96 inches) a single-pin base and a nominal power of not less than 52 W.
- Any fluorescent lamp that is a physical and electrical equivalent of a lamp described above.

Excluded are:

- Fluorescent lamps that are specifically marked and marketed for plant-growth use.
- Cold-temperature fluorescent lamps.
- Colored fluorescent lamps.
- Fluorescent lamps designed to be impact-resistant.
- Reflectorized or aperture fluorescent lamps.
- Fluorescent lamps designed for use in reprographic equipment.
- Fluorescent lamps primarily designed to produce ultraviolet radiation.
- Fluorescent lamps with a color-rendering index of 82 or greater.

The minimum efficacies for general service fluorescent lamps are listed in Table 8.

[5] See http://www.nrcan.gc.ca/energy/regulations-codes-standards/6853 for details

Table 8: Minimum average lamp efficacies for general service fluorescent lamps - Canada

Lamp type	Nominal lamp wattage	Average CRI	Minimum average lamp efficacy (lm/w)
1200 mm (48 in.) medium bi-pin base, rapid-start	> 35 W	69	75.0
	≤ 35 W	45	75.0
560 to 635 mm (22 to 25 in.) U-shaped, rapid-start	> 35 W	69	68.0
	≤ 35 W	45	64.0
2400 mm (96 in.) High output, recessed double-contact base, rapid-start	> 100 W	69	80.0
	≤ 100 W	45	80.0
2400 mm (96 in.) Slimline, single-pin base, instant-start	> 65 W	69	80.0
	≤ 65W	45	80.0
Where CRI = colour-rendering index, lm/W = lumens per watt			

Note that Canada has proposed a new MEPS which will harmonize with the USA - at the time of writing of this report the NRCAN website stated that these new MEPS were proposed[6]. Refer section 2.6.1 for US MEPS details.

2.2.2. Labeling for Lamps

The ENERGUIDE label and Energy Star label programs are implemented in Canada. However linear fluorescent lamps are not included in either program.

2.2.3. MEPS for Ballasts

Canadian MEPS for fluorescent lamp ballasts is described in Energy Efficiency Regulations Technical Requirements for Energy-Using Products - Fluorescent Lamp Ballasts and is administered by NRCAN. It applies to the following fluorescent lamp ballasts:

- Used to start and operate fluorescent lamps by providing a starting voltage and current, limiting the current during normal operation, and where necessary to facilitate lamp operation, providing cathode heating,
- Designed for input of 120, 277 or 347 volts, and
- Designed to operate with an F32T8, F34T12, F40T10 or F40T12 rapid-start fluorescent lamp or an F96T12IS, F96T12ES, F96T12HO or F96T12HO ES fluorescent lamp.

The detailed requirements of the MEPS are listed in Table 9. The ballast efficacy factor is the relative lamp light output divided by power input.

[6] http://www.nrcan.gc.ca/energy/regulations-codes-standards/bulletins/7095

Table 9: Minimum Ballast Efficacy Factor for fluorescent lamp ballasts - Canada

Application for Operation of:	Ballast Input Voltage V	Total Nominal Lamp Wattage W	Minimum Ballast Efficacy Factor
One F40T12 Lamp*	120	40	2.29
	277	40	2.29
	347	40	2.22
Two F40T12 Lamps	120	80	1.17
	277	80	1.17
	347	80	1.12
Two F34T12 Lamps	120	68	1.35
	277	68	1.35
	347	68	1.29
Two F96T12(IS) Lamps**	120	150	0.63
	277	150	0.63
	347	150	0.62
Two F96T12(ES) Lamps	120	120	0.77
	277	120	0.77
	347	120	0.76
Two 110W F96T12 HO Lamps	120	220	0.390
	277	220	0.390
	347	220	0.390
Two F96T12 HO(ES) Lamps	120	190	0.42
	277	190	0.42
	347	190	0.41
Two F32TS Lamps	120	64	1.250
	277	64	1.230
	347	64	1.200

*Also for use on 40W/48T10/RS lamps, **Also for use on 60W/96T12/IS lamps

Other Requirements for ballasts are as follows:

- All ballasts must have a power factor of at least 0.9 except for ballasts designed for 120V input and to operate F32T8 rapid-start fluorescent lamps that have a color rendering index greater than 75 where the power factor must be at least 0.5.

The test procedure is summarised as follows:

- Test Standard: CSA C654-M91
- Aging: per ANSI C82.2
- Ambient temp: per ANSI C82.2
- Ambient relative humidity: per ANSI C82.2
- Voltage and frequency: ANSI C82.2
- Methodology: per ANSI C82.2
- Key equipment: per ANSI C82.2
- Tolerances: ANSI C82.2
- Calculations/algorithms/assumptions: ANSI C82.2

2.2.4. Lamp Market

Most of the domestic market data in this section is based on information supplied by Natural Resources Canada (NRCAN) from its product registration database archive (NRCAN 2014). It is a requirement of the Canadian Energy Efficiency Regulations that all products covered by the regulations are listed on a public database. Database entries are made by responsible manufacturers, suppliers or importers, who are responsible for ensuring entries are correct and current.

From the database the product listings for products registered for sale from 2007 to 2013 were extracted by NRCAN. In the absence of sales information, this is used as a proxy for share of the Canadian domestic market.

NRCAN were able to supply data on the trends in overall lamps sales, sales of fluorescent lamps and T5 lamps in particular. These are shown by volume in Figure 7 and by value in Figure 8 with 2003 as the base year. T5 lamps accounted for about 0.5% of Canadian lamp sales by value in 2003, but had grown to about 4.4% by 2012. They also accounted for only 0.1% of lamps by quantity in 2003, growing to about 1.8% in 2012. Overall the quantity of lamp sales in Canada has fallen but those of fluorescent lamps has remained reasonably robust.

Figure 7: Total lamp, fluorescent lamp and T5 lamp sales by quantity relative to 2003 - Canada

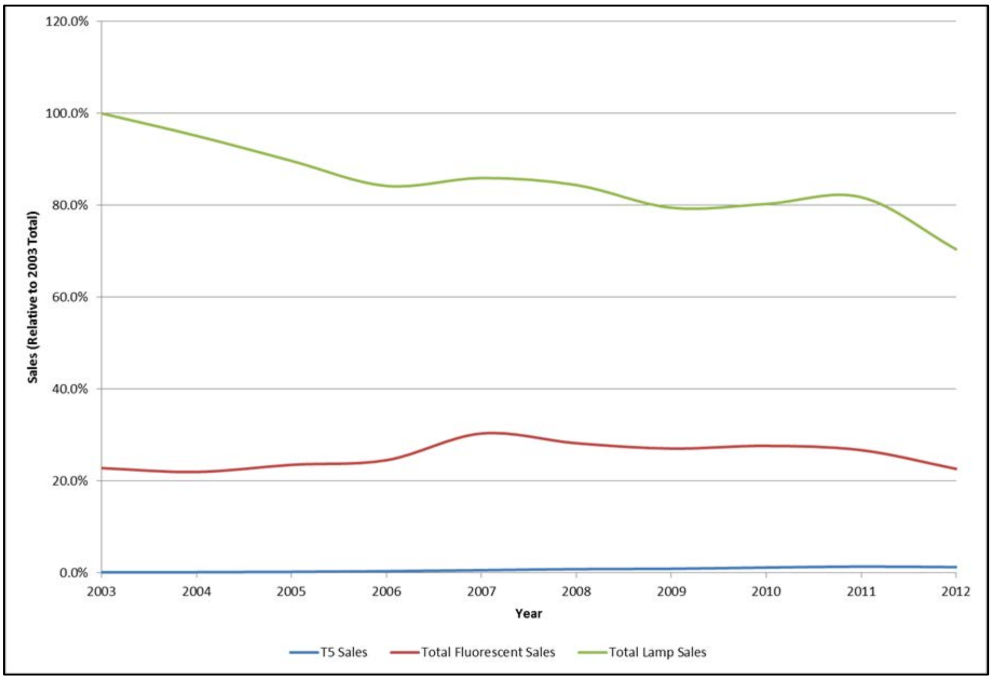
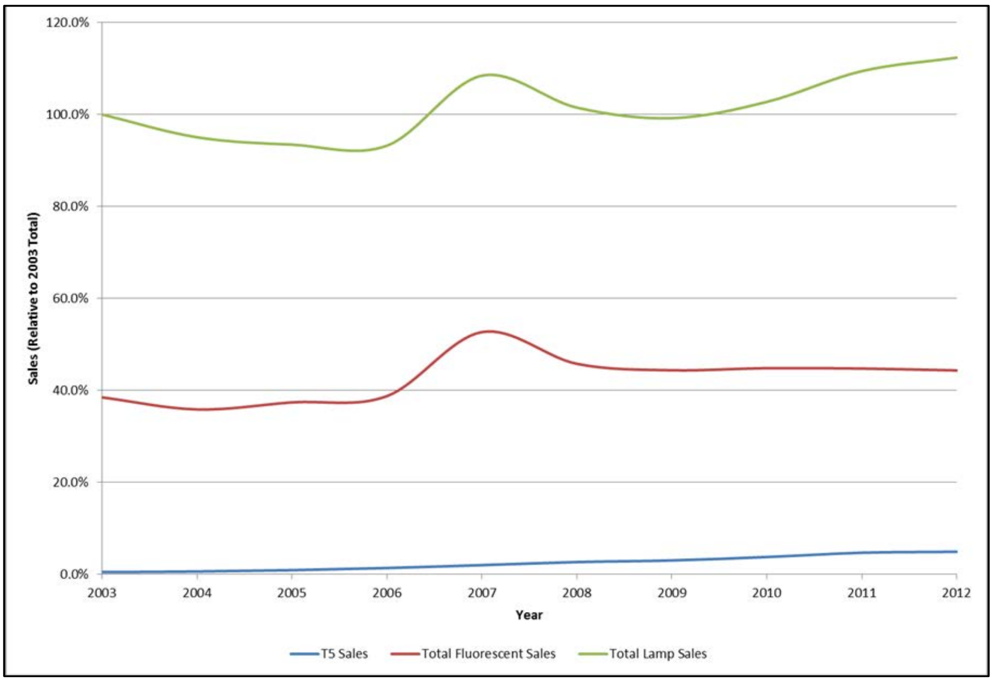
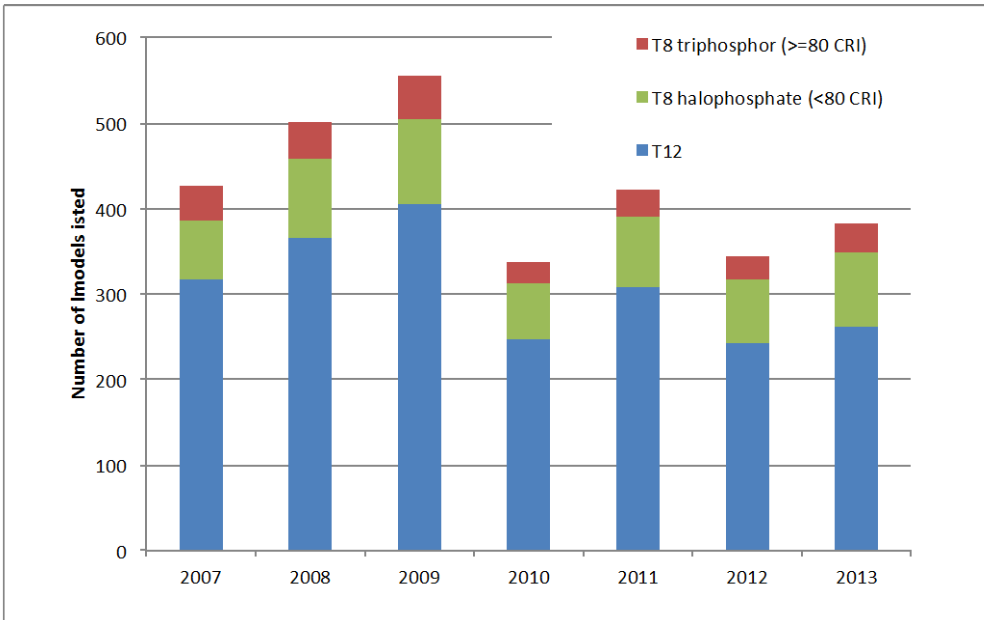


Figure 8: Total lamp, fluorescent lamp and T5 lamp sales by value relative to 2003 - Canada



The data from NRCAN database (based on listings, not sales) shows that linear fluorescent lamps in the Canada are dominated by 4-foot (32W) lamps (70% of all listings) with the most popular colour temperature being 4100k (around half of all registrations). Figure 9 shows the number of T8/T12 lamp models listed for sale, which has varied considerably from year to year. Note that T5 lamps are not regulated and thus no data is available for T5 lamps from this source.

Figure 9: Number of lamp models listed for sale, by year (source: NRCAN 2014) - Canada

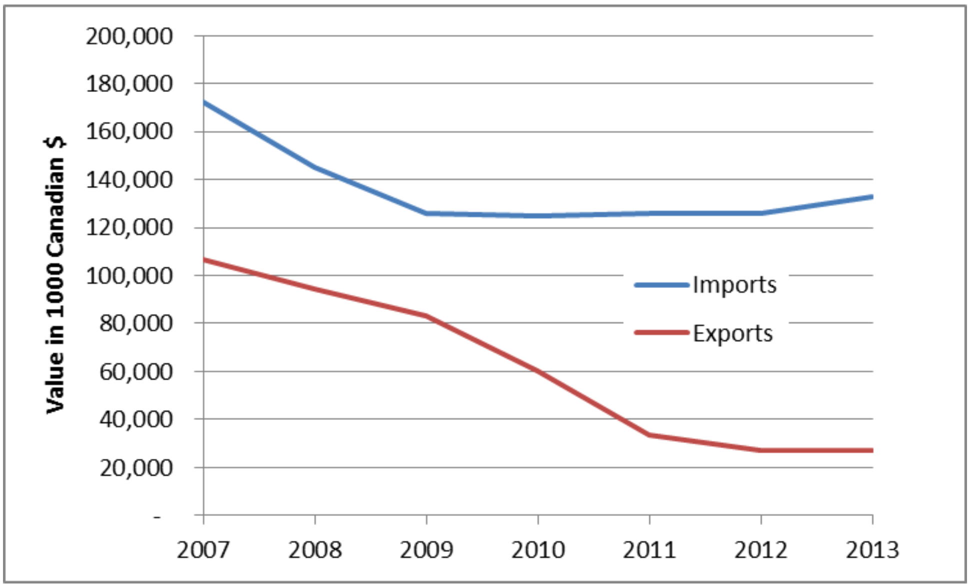


The NRCAN database does not differentiate between triphosphor and halophosphate lamps. Thus a CRI of 80 or greater is taken as an indicator that the lamp is triphosphor (an industry rule of thumb). Using this method we are able to estimate the split of triphosphor versus halophosphate lamps. This is shown in Figure 9. If this analysis is accurate, we can see that registrations remain dominated by T12 and halophosphate lamps. Note that Canadian MEPS (currently minimum efficacy of 75 lm/W for 4-foot lamps) still allows halophosphate lamps.

There is also some manufacture of all lamps types (T5, T8 halophosphate and tri-phosphor and T12) in Canada. Industry Canada produces statistics for the import and export of products[7] including fluorescent lamps[8] by value in dollars. These are shown in Figure 10. Imports exceed exports and exports have fallen substantially since 2007.

[7] See Trade Data Online https://www.ic.gc.ca/app/scr/tdst/tdo/crtr.html?&lang=eng
[8] The description used against the code for this product (HS 853931) is 'Fluorescent (Discharge) Lamps, Hot Cathode' so presumably include circular as well as linear lamps

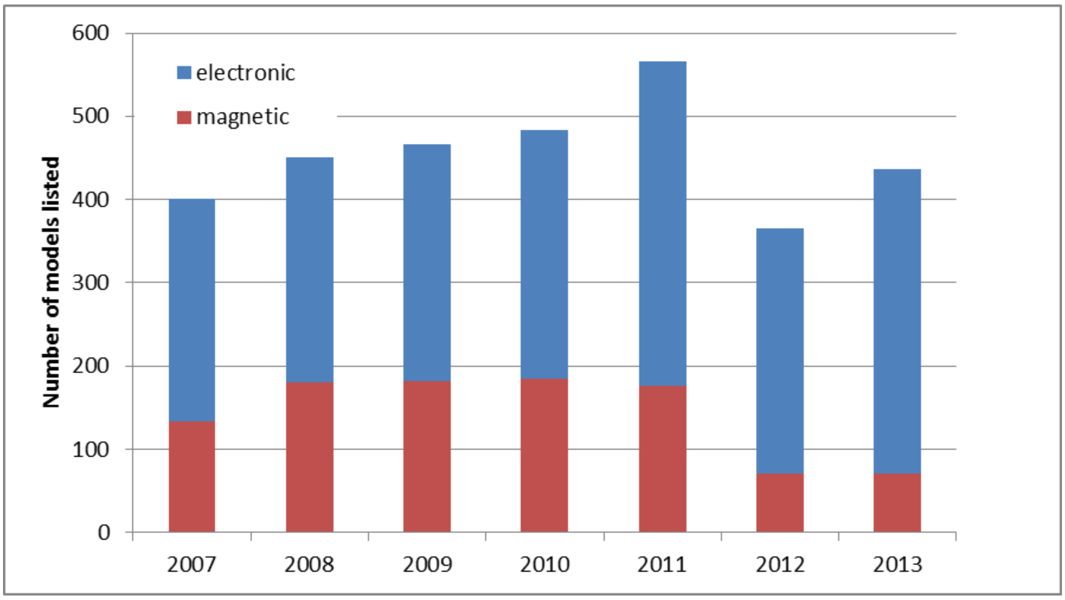
Figure 10: Trade figures for fluorescent lamps for Canada



2.2.5. Ballast Market

The NRCAN registration database (NRCAN 2014) lists ballast models including whether the ballast is magnetic or electronic. Figure 11 shows the listings by year.

Figure 11: Number of ballast models listed for sale, by year (source: NRCAN 2014)

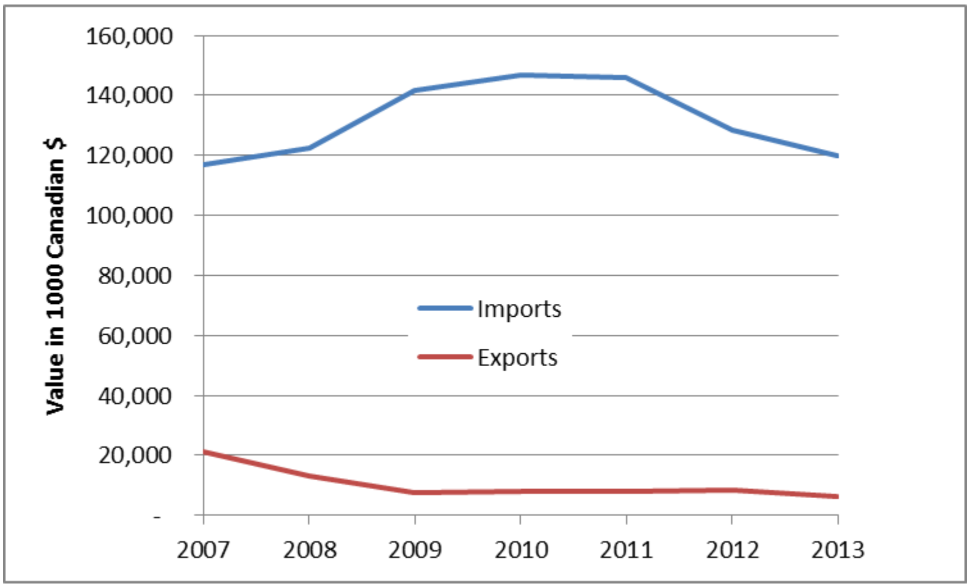


In this figure we can see declining numbers of magnetic ballast listings, which is similar to the US market.

Electronic ballasts are manufactured in Canada (not clear regarding magnetic ballast manufacture).

Industry Canada also produce trade data for ballasts but do not distinguish between magnetic and electronic[9]. These are shown by value in Figure 12.

Figure 12: Trade figures for ballasts for Canada



From the figure above we can see that ballast imports consistently exceed exports by a wide margin.

2.2.6. Notes on Market Data Sources and Assumptions

Much of the data in this section was kindly supplied by Natural Resource Canada (NRCAN) from archive data held in their product registration database. NRCAN are reliant on responsible companies to accurately create entries and keep them current, including entering a removal date when the product becomes unavailable. It is possible therefore that there are products which are no longer available that remain on the database.

The data have been separated by the authors into products which were available for sale in a given calendar year. In doing this an inclusive approach has been taken – if a product has been listed on the database at any point during the year in question then it has been included in the analysis (that is if the product listing date was in that year or earlier and the product removal date was in or after that year or blank the product was included). This is true for all models including those have the same commencement and removal date.

The data only includes regulated lamps which are currently 4-foot and 8-foot T8 and T12 lamps as well as ballasts for U-shaped and double-ended linear lamps. There is no way of distinguishing between these so the data presented here includes ballasts for U-shaped lamps.

The T8 lamps were split into halophosphate and triphosphor on the basis of the listed CRI. Models with a CRI of 80 or above were considered to be triphosphor - those with a CRI of 79 or below were considered to be halophosphate.

Note again that most of the data presented in this section is product registration data, not sales data.

[9] The code used was HS 850410 with the description 'Ballasts For Discharge Lamps Or Tubes'

2.2.7. Market Summary

The domestic linear fluorescent lighting market for the Canada is summarised in Table 10, which uses a tick/cross system to indicate the progress of this market towards energy efficiency.

Table 10: Canadian domestic market summary

Lamps	**Most popular CCT**	**4100K**	
	Most popular length	4-foot	
	Most popular power	32W	
	Low-power retrofit lamps commonly available	yes	✔
	MEPS regulations in force	yes	✔
	MEPS regulations mandate triphosphor	no	✗
	Market share halophosphate (and trend)	high	✗
	Market share T5 (and trend)	5% ↑	✔
	Market share T12 (and trend)	high	✗
Ballasts	MEPS regulations in force	yes	✔
	Market share electronic (and trend)	high ↑	✔

Canada's MEPS does not mandate triphosphor lamps (noting that Canada has proposed a new MEPS which will harmonize with the USA[10]). Halophosphate T8 and T12 lamps appear to have remained popular. Sales of T5 lamps are increasing. Similar to the US, the Canadian ballast market is a good performer, appearing to have moved considerably towards electronic ballasts.

Note that most of these conclusions are based on product registration data, not sales data. Thus they contain some inherent uncertainty.

[10] http://www.nrcan.gc.ca/energy/regulations-codes-standards/bulletins/7095

2.3. China

Since 1989, China has implemented over 48 MEPS for energy-using products. China's mandatory comparative labeling scheme started in 2005 and now covers over 29 categories of products. A voluntary energy efficiency program named the Voluntary Energy-saving Certification Mark is also in place and now covers over 100 products. Linear fluorescent lamps are covered by both in the MEPS program and by the voluntary Energy-saving Certification program.

2.3.1. MEPS for Lamps

MEPS for linear fluorescent lamps in China was first introduced in 2003 and revised in 2013. The standard - Minimum allowable values of energy efficiency and the energy efficiency grades of double-capped fluorescent lamps for general lighting service (GB 19043-2013) - defines energy efficiency tiers, energy efficient performance requirements, minimum energy performance requirements, as well as the test methods associated for linear fluorescent lamps. The standard was co-issued by the Administration of Quality Supervision, Inspection and Quarantine (AQSIQ) and The Standardization Administration of the People's Republic of China (SAC).

The MEPS program covers linear fluorescent lamps for general purposes. The standard is applicable to two types of lamps under this scope:

- Cathode preheating lamp which equips with starter and works on AC frequency circuits.
- Cathode preheating lamp which works on high frequency circuits.

The MEPS classified lamps into three energy efficiency tiers, with Tier 1 being the most efficient and Tier 3 being the least efficient. Tier 3 is the minimum energy performance requirement, which must be met by all LFLs entering the market.

Table 11 details the energy efficiency tier requirements for different LFL products. Requirements for lamps with different color temperature also differed. The initials representing different color temperatures are defined in Table 12. In addition, all LFLs must satisfy the requirements for lumen maintenance and product life which were set in Double-capped fluorescent lamps - Performance specifications (GB/T 10682-2010).

The MEPS also specified that LFLs with Tier 2 efficiencies were regarded as energy efficient products.

Table 11: Energy efficiency tiers classification for linear fluorescent lamps (China: GB 19043-2013)

	Diameter (mm)	Rated power (W)	Additional Info	Initial luminous efficacy (lm/W)					
				RR, RZ			RL, RB, RN and RD		
				Tier 1	Tier 2	Tier 3	Tier 1	Tier 2	Tier 3
Cathode preheating lamp which equips with starter and works on AC frequency circuits	26	18		70	64	50	75	69	52
		30		75	69	53	80	73	57
		36		87	80	62	93	85	63
		58		84	77	59	90	82	62
Cathode preheating lamp which works on high frequency circuits	16	14	High luminous efficacy series	80	77	69	86	82	75
		21	High luminous efficacy series	84	81	75	90	86	83
		24	High lumen series	68	66	65	73	70	67
		28	High luminous efficacy series	87	83	77	93	89	82
		35	High luminous efficacy series	88	84	75	94	90	82
		39	High lumen series	74	71	69	79	75	71
		49	High lumen series	82	79	75	88	84	79
		54	High lumen series	77	73	67	82	78	72
		80	High lumen series	72	69	63	77	73	67
	26	16		81	75	66	87	80	75
		23		84	77	76	89	86	85
		32		97	89	78	104	95	84
		45		101	93	85	108	99	90

Table 12: Definition for color temperatures - China

	Color Temp. (K)
RR	6500
RZ	5000
RL	4000
RB	3500
RN	3000
RD	2700

2.3.2. Endorsement Label for Lamps

Linear fluorescent lamps were included in the endorsement labeling program, the CQC Energy Conservation Certification program implemented by China Quality Certification Centre.

Linear fluorescent lamps must meet all the requirements in "Energy Conservation Certification Rules for Double-Capped Fluorescent Lamps for General Lighting Service (CQC31-465132-2013)" in order to be endorsed for the CQC Energy Conservation Certification label (Figure 13).

Figure 13: CQC Energy conservation certification label (China)

The scope, test method, and evaluation of the CQC certification program are very similar to the mandatory MEPS program. Requirements for CQC certification are the same as the Tier 2 requirements set in the mandatory MEPS program.

2.3.3. MEPS for Ballasts

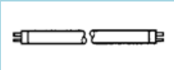
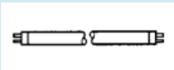
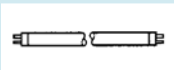
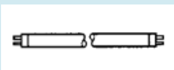
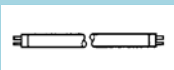
The MEPS for linear fluorescent lamps in China were first introduced in 1999 and revised in 2013. The standard - Minimum allowable values of energy efficiency and the energy efficiency grades of ballasts for tubular fluorescent lamps (GB 19043-2012) - defines energy efficiency tiers, energy efficient performance requirements, minimum energy performance requirements, as well as the test methods associated for ballasts. The standard was co-issued by Administration of Quality Supervision, Inspection and Quarantine (AQSIQ) and The Standardization Administration of the People's Republic of China (SAC).

Several international standards and regulations including Measurement method of total input power of ballast-lamp circuits (EN 50294) and EU regulations (EC) No. 245/2009 and (EU) No. 347/2010, were used as reference in the development of the Chinese standard.

This standard is applicable to Magnetic ballasts and electronic ballasts with rated power between 4W to 120W and works under 220V and 50Hz AC power supply.

The MEPS covers both electronic and magnetic ballasts but the requirements for energy efficiency tiers are different. The MEPS classified electronic ballasts without brightness control into three energy efficiency tiers, with Tier 1 being the most efficient and Tier 3 being the least efficient. Tier 3 is the minimum energy performance requirement, which must be met by all electronic ballasts entering the market. Table 13 details the energy efficiency tier requirements for electronic ballasts. Ballasts with brightness control should be tested at 100% of luminous output and in addition they must meet the maximum system input power requirement when tested at 25% luminous output, as specified in Table 15.

Table 13: Energy efficiency tiers classification for electronic ballasts without brightness control (China: GB 17896-2012)

Lamps information					Ballasts efficiency (%)		
Type and illustration		Nominal power (W)	International code	Rated power (W)	Tier 1	Tier 2	Tier 3
T8		15	FD-15-E-G13-26/450	13.5	87.8	84.4	75.0
T8		18	FD-18-E-G13-26/600	16	87.7	84.2	76.2
T8		30	FD-30-E-G13-26/900	24	82.1	77.4	72.7
T8		36	FD-36-E-G13-26/1200	32	91.4	88.9	84.2
T8		38	FD-38-E-G13-26/1050	32	87.7	84.2	80.0
T8		58	FD-58-E-G13-26/1500	50	93.0	90.9	84.7
T8		70	FD-70-E-G13-26/1800	60	90.9	88.2	83.3
T5		4	FD-4-E-G5-16/150	3.6	64.9	58.1	50.0
T5		6	FD-6-E-G5-16/225	5.4	71.3	65.1	58.1
T5		8	FD-8-E-G5-16/300	7.5	69.9	63.6	58.6
T5		13	FD-13-E-G5-16/525	12.8	84.2	80.0	75.3
T2		6	FDH-6-L/P-W4.3x8.5d-7/220	5	72.7	66.7	58.8
T2		8	FDH-8-L/P-W4.3x8.5d-7/320	7.8	76.5	70.9	65.0
T2		11	FDH-11-L/P-W4.3x8.5d-7/420	10.8	81.8	77.1	72.0
T2		13	FDH-13-L/P-W4.3x8.5d-7/520	13.3	84.7	80.6	76.0
T5-E		14	FDH-14-G5-L/P-16/550	13.7	84.7	80.6	72.1
T5-E		21	FDH-21-G5-L/P-16/850	20.7	89.3	86.3	79.6
T5-E		24	FDH-24-G5-L/P-16/550	22.5	89.6	86.5	80.4
T5-E		28	FDH-28-G5-L/P-16/1150	27.8	89.8	86.9	81.8
T5-E		35	FDH-35-G5-L/P-16/1450	34.7	91.5	89.0	82.6
T5-E		39	FDH-39-G5-L/P-16/850	38	91.0	88.4	82.6
T5-E		49	FDH-49-G5-L/P-16/1450	49.3	91.6	89.2	84.6
T5-E		54	FDH-54-G5-L/P-16/1150	53.8	92.0	89.7	85.4
T5-E		80	FDH-80-G5-L/P-16/1150	80	93.0	90.9	87.0
T8		16	FDH-16-L/P-G13-26/600	16	87.4	83.2	78.3
T8		23	FDH-23-L/P-G13-26/600	23	89.2	85.6	80.4
T8		32	FDH-32-L/P-G13-26/1200	32	90.5	87.3	82.0
T8		45	FDH-45-L/P-G13-26/1200	45	91.5	88.7	83.4

Note that MEPS covers ballasts used for tubular fluorescent lamps in various shapes (double-capped linear, single-capped linear, and circular etc.) but only ballasts related to linear fluorescent lamps are listed in these tables.

For Magnetic ballasts, the MEPS only set the minimum energy performance requirements, as shown in Table 14. The MEPS did not set tier classification for Magnetic ballasts.

For electronic ballasts without brightness control, Tier 2 efficiencies were regarded as energy efficient products. For electronic ballasts with brightness control, products tested at 100% of luminous output have to meet Tier 2 requirements in order to be regarded as energy efficient product. In addition, electronic ballasts with brightness control tested at 25% of luminous output must meet Tier 2 maximum requirement as set in Table 15.

Table 14: Minimum energy performance requirements for Magnetic ballasts without brightness control (China: GB 17896-2012)

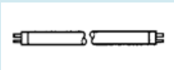
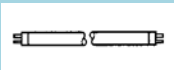
Lamps information					Ballasts efficiency (%)
Type and illustration		Nominal power (W)	International code	Rated power (W)	
T8		15	FD-15-E-G13-26/450	15	62.0
T8		18	FD-18-E-G13-26/600	18	65.8
T8		30	FD-30-E-G13-26/900	30	75.0
T8		36	FD-36-E-G13-26/1200	36	79.5
T8		38	FD-38-E-G13-26/1050	38.5	80.4
T8		58	FD-58-E-G13-26/1500	58	82.2
T8		70	FD-70-E-G13-26/1800	69.5	83.1
T5		4	FD-4-E-G5-16/150	4.5	37.2
T5		6	FD-6-E-G5-16/225	6	43.8
T5		8	FD-8-E-G5-16/300	7.1	42.7
T5		13	FD-13-E-G5-16/525	13	65.0

Table 15: Maximum system power input for ballasts with brightness-control tested at 25% luminous output (China: GB 17896-2012)

Energy efficiency tiers	System input power (P_{in})
Tier 1	$0.5P_{Lnom}/\eta_{b1}$
Tier 2	$0.5P_{Lnom}/\eta_{b2}$
Tier 3	$0.5P_{Lnom}/\eta_{b3}$
η_{b1}, η_{b2}, and η_{b3} refer to the efficiency of Tier 1, 2, and 3 ballasts in Table 13	

2.3.4. Labeling for Ballasts

Ballasts for linear fluorescent lamps were not included in the China Energy Labels programs, which is the mandatory labeling program associated with MEPS for selected products.

Ballasts for tubular fluorescent lamps were included in the endorsement labeling program, the CQC Energy Conservation Certification program implemented by China Quality Certification Centre.

Ballasts for tubular fluorescent lamps must meet all the requirements in Energy Conservation Certification Rules for Ballasts for Tubular Fluorescent Lamps (CQC31-461225-2012) in order to be endorsed for the CQC Energy Conservation Certification label (Figure 13).

2.3.5. Incentive policies

The "High efficiency lighting product promotion program" was one of the earliest and largest incentive program implemented to promote energy efficient products. The Ministry of Finance and the National Development and Reform Commission co-issued the "Interim measures for financial subsidy and fund management for the high efficiency lighting product promotion program" in 2007[11], marking the inception of the program.

The program covered high efficiency lighting products such as fluorescent lamps for general lighting purposes, tri-phosphor linear fluorescent lamps (T8 and T5), metal-halide lamps, high-pressure sodium lamps, LED lamps, as well as ballasts associated with these products. The program used an indirect approach to provide the subsidy. Lighting program companies were required to participate in a bidding process in order to be included in the subsidy program. The subsidy was granted to the bid-winning companies who would sell their products to the consumers at reduced prices. For bulk purchasers, the subsidy was 30% of the price for each product, and for residential consumers, the subsidy was 50% of the price for each product. The products manufactured by the bid-winning companies must meet the energy-saving requirements. A program label (Figure 14) was also required to be printed on the package of the subsidized products. By December 2011, the program had subsidized over 500 million units of efficient lighting products, resulting in 20 TWH electricity savings and 20 million tons of CO_2 reduction, cumulatively.

Figure 14: Label for high efficiency lighting product promotion program (China)

Efficient lighting products are also supported by the China's "Government procurement program for efficient products". This is a mandatory program for government procurements and is administered by both the Ministry of Finance and the National Reform and Development Commission. It covered a variety of products among which LFLs are included. MoF and NDRC co-issued and regularly updated the mandatory procurement list for efficient product, and the government was only allowed to purchase products from the list. The first procurement list was published in 2004. The 15th procurement list, which is also the newest and current list, was published in January 2014.

11 http://www.sdpc.gov.cn/hjbh/hjjsjyxsh/t20080508_210085.htm

2.3.6. Lamp Market

Discussions with Chinese lighting experts reveal that linear fluorescent lamps used in China are dominated by 4-foot (36W) lamps, and that the most common colour temperature of Chinese fluorescent lamps is 6500K. China is the world's largest manufacturer of lamps. Figure 15 graphs Chinese linear fluorescent lamp production over the period 2006-2010 (ACMR 2011). Production has increased by around 60% over this period. Note that more recent data was not available for China.

Figure 15: Production of linear fluorescent lamps in China (source: ACMR 2011)

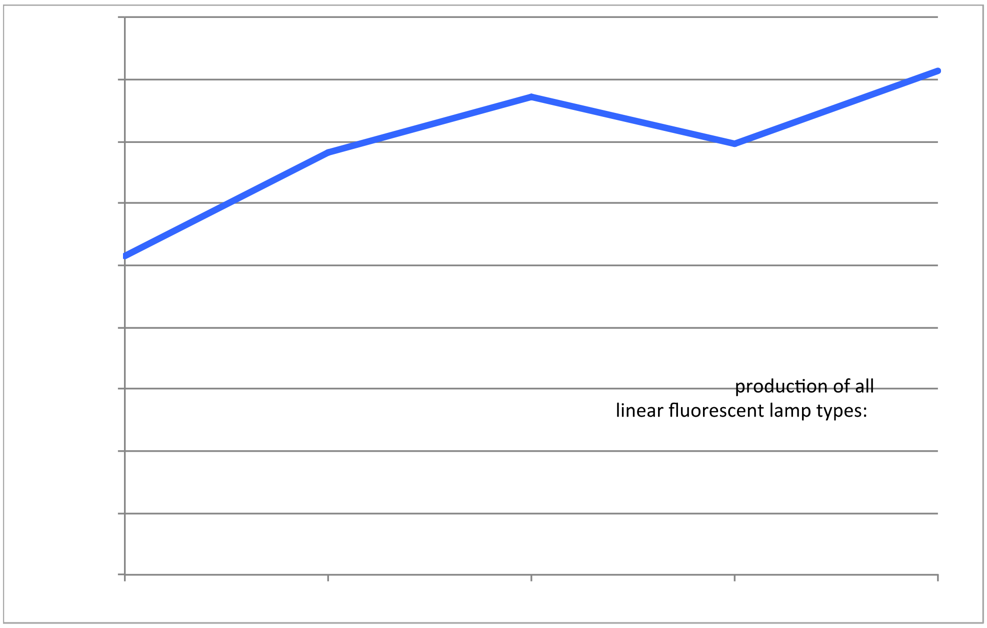
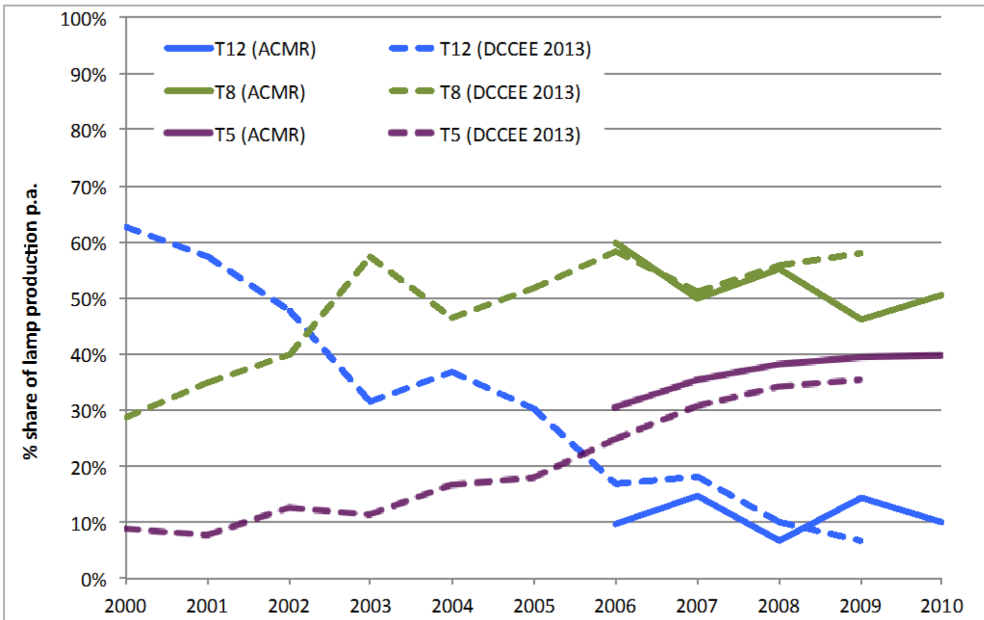


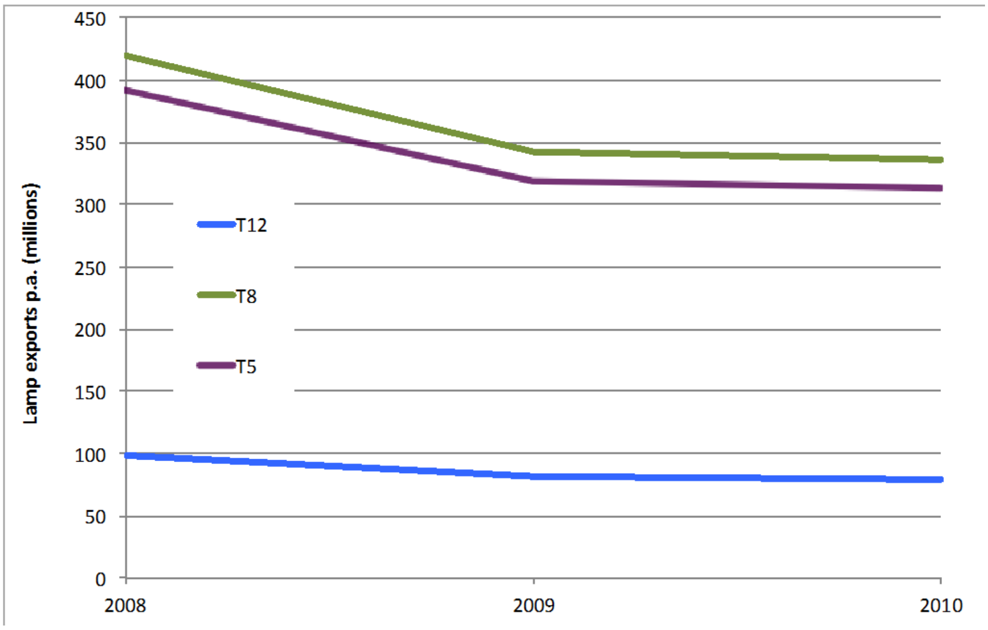
Figure 16 graphs the percentage share of fluorescent lamp production over the period 2007-2012, showing estimates from two sources (note it is possible that these originate from the same dataset). In this figure we can see significant reduction in the manufacture of T12 lamps, an early increase in T8 production which appears to stabilize, and significant increase in T5 production.

Figure 16: Percentage share of linear fluorescent lamp production in China (sources: ACMR 2011, DCCEE 2013)



The only available data for linear fluorescent lamp export from China was ACMR 2011, which graphed exports, by lamp type, over the period 2008-2010. These are shown in Figure 17

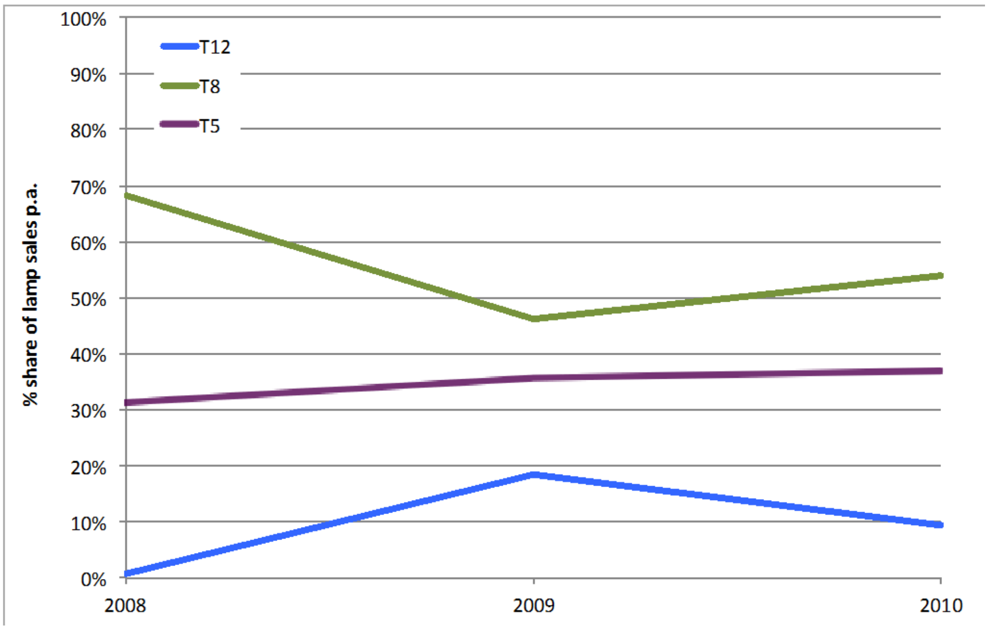
Figure 17: Chinese exports of linear fluorescent lamps, by type (source: ACMR 2011)



In Figure 17, exports of T5 very closely track those of T8, which may indicate that these data have been estimated (ACMR 2011 results are based on surveys of major Chinese lamp manufacturers).

If we subtract lamp exports from production, we should get a reasonable estimate of domestic lamp sales within China. This calculation was performed and Figure 18 shows the resultant sales split of lamps for 2008-2010. It is difficult to ascertain any trends from this figure.

Figure 18: Comparison of Chinese domestic lamp sales share from two data sources



No Chinese data was available to differentiate between triphosphor and halophosphate T8 lamp production or sales. However, from Testing undertaken for this study (Chapter 3) only 3 of the 8 models sampled were triphosphor. The 2013 Chinese MEPS for lamps (for 4-foot 6500K lamps - minimum efficacy 62 lm/W) will allow the use of halophosphate lamps.

2.3.7. Ballast Market

Data for the Chinese ballast market is very scarce. The only available data was for ballast export from China, and these were estimated by CALI (Chinese Lighting Industry Association) at 0.38 billion for 2010 and for 2011, and 0.32 billion for 2012. No breakdown by magnetic / electronic ballast type was available.

2.3.8. Notes on Market Data Sources and Assumptions

The primary source of useful data for China was the ACMR 2011 report. The data in this report is based on surveys of the major Chinese lamp manufacturers. Any conclusions drawn rely on the accuracy of this data.

2.3.9. Market Summary

The domestic linear fluorescent lighting market for China is summarised in Table 16, which uses a tick/cross system to indicate the progress of this market towards energy efficiency.

Table 16: Chinese domestic market summary

Lamps	**Most popular CCT**	**6500K**	
	Most popular length	4-foot	
	Most popular power	36W	
	Low-power retrofit lamps commonly available	Unknown	
	MEPS regulations in force	Yes	✔
	MEPS regulations mandate triphosphor	no	✗
	Market share halophosphate (and trend)	high	✗
	Market share T5 (and trend)	40% ↑	✔
	Market share T12 (and trend)	low	✔
Ballasts	MEPS regulations in force	yes	✔
	Market share electronic (and trend)	Unknown	

In China, halophosphate lamps remain popular, although T12 sales appear relatively low, and T5 sales are significant and growing. Little is known about the domestic market for ballasts in China, although a MEPS is in place for ballasts.

2.4. European Union

2.4.1. MEPS for Lamps

MEPS for linear fluorescent lamps in the EU are set out in Commission Regulation (EC) No 245/2009 which was amended by EC No 347/2010 in 2010. The regulation entered into force in April 2009 and is currently being reviewed. It sets requirements for linear and compact fluorescent lamps without integrated ballast, high intensity discharge lamps, and ballasts and luminaires able to operate such lamps. The requirements cover lamp efficacy and lamp performance characteristics.

Lamp efficacy requirements in the first stage (entered into force in 2009) are set for double-capped fluorescent lamps of 16 mm and 26 mm diameter (T5 and T8 lamps) as outlined in the table below.

Table 17: Rated minimum efficacy values for T8 and T5 lamps in the EU

T8 (26 mm Ø)		T5 (16 mm Ø) High Efficiency		T5 (16 mm Ø) High Output	
Nominal wattage (W)	Rated luminous efficacy (lm/W), 100 h initial value	Nominal wattage (W)	Rated luminous efficacy (lm/W), 100 h initial value	Nominal wattage (W)	Rated luminous efficacy (lm/W), 100 h initial value
15	63	14	86	24	73
18	75	21	90	39	79
25	76	28	93	49	88
30	80	35	94	54	82
36	93			80	77
38	87				
58	90				
70	89				

In the second stage (3 years after entry into force of the regulation - 2012), the requirements above are applicable to all double-capped fluorescent lamps of other diameters than those covered in the first stage (e.g. T12 lamps).

At a third stage (8 years after entry into force of the regulation - 2017) fluorescent lamps without integrated ballast shall be designed to operate with ballasts of energy efficiency class at least A2 according to Annex III.2.2 of the regulation.

Lamp performance requirements became active 1 year after entry into force of the regulation and apply to fluorescent lamps (covered in stage 1) without integrated ballast which shall have a color rendering index (Ra) of at least 80.

In the second stage, 3 years after entry into force of the regulation, fluorescent lamps without integrated ballast shall have a color rendering index (Ra) of at least 80 and at least the lamp lumen maintenance factors in Table 18.

Table 18: Lamp lumen maintenance factors for double-capped fluorescent lamps

Lamp lumen maintenance factor	Burning hours			
Lamp types	2000	4000	8000	16000
Double-Capped Fluorescent lamps operating on non-high frequency ballasts	0.95	0.92	0.90	
Double-Capped Fluorescent lamps on high frequency ballast with warm start	0.97	0.95	0.92	0.90

Fluorescent lamps without integrated ballast are also required to have at least the lamp survival factors in Table 19.

Table 19: Lamp survival factors for double-capped fluorescent lamps

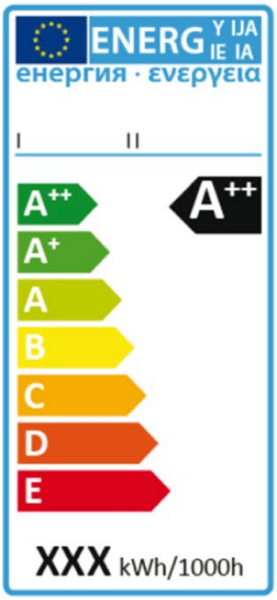
Lamp survival factor	Burning hours			
Lamp types	2000	4000	8000	16000
Double-Capped Fluorescent lamps operating on non-high frequency ballasts	0.99	0.97	0.90	
Double-Capped Fluorescent lamps on high frequency ballast with warm start	0.99	0.97	0.92	0.90

2.4.2. Labeling for Lamps

Comparative labeling is required in the European Union since September 2013 according to the Commission Delegated Regulation (EU) No 874/2012 of 12 July 2012 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of electrical lamps and luminaires[12]. Future revisions should take place no later than three years after its entry into force (no later than 2016). The lamp label is shown in Figure 19.

12 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32012R0874:EN:NOT

Figure 19: EU Lamp Label



The regulation applies to electrical lamps (such as filament lamps, fluorescent lamps, high-intensity discharge lamps and LED lamps and modules) and luminaires designed to operate such lamps. The label shall include information on the supplier's name and model, the energy efficiency class and the weighted energy consumption in kWh per 1000 hours.

The energy efficiency class is determined on the basis of their energy efficiency index (EEI), as per Table 20. The EEI is the rated power over the reference power (P_{rated}/P_{ref}). The rated power is corrected for models with external control gear and measured at their nominal input voltage. The reference power is calculated considering the useful luminous flux of the model.

Table 20: Energy Efficiency Classes for Lamps in the EU

Energy efficiency class	Energy efficiency index (EEI) for non-directional lamps
A++ (most efficient)	EEI ≤ 0,11
A+	0,11 < EEI ≤ 0,17
A	0,17 < EEI ≤ 0,24
B	0,24 < EEI ≤ 0,60
C	0,60 < EEI ≤ 0,80
D	0,80 < EEI ≤ 0,95
E (least efficient)	EEI > 0,95

2.4.3. MEPS for ballasts

MEPS for ballasts in the EU are included in regulation (EC) No 245/2009 which was amended by EC No 347/2010 in 2010. The scope covers all fluorescent lamp ballasts and the test procedure is contained in standard EN 50294.

The first stage requirements, one year after the Regulation came into force, are:

- The minimum energy efficiency index class shall be B2[13] for most common ballast types[14] and A1 for dimmable ballasts.
- (At the dimming position corresponding to 25 % of the lumen output of the operated lamp, the input power (Pin) of the lamp-ballast circuit shall not exceed: Pin < 50% * PLrated/ηballast, Where PLrated is the rated lamp power and ηballast is the minimum energy efficiency limit of the respective EEI class.)
- The power consumption of the fluorescent lamp ballasts shall not exceed 1.0 W when operated lamps do not emit any light in normal operating conditions and when other possible connected components (network connections, sensors etc.) are disconnected. If they cannot be disconnected, their power shall be measured and deducted from the result.

The second stage requirements, three years after the implementing measure comes into force are:

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

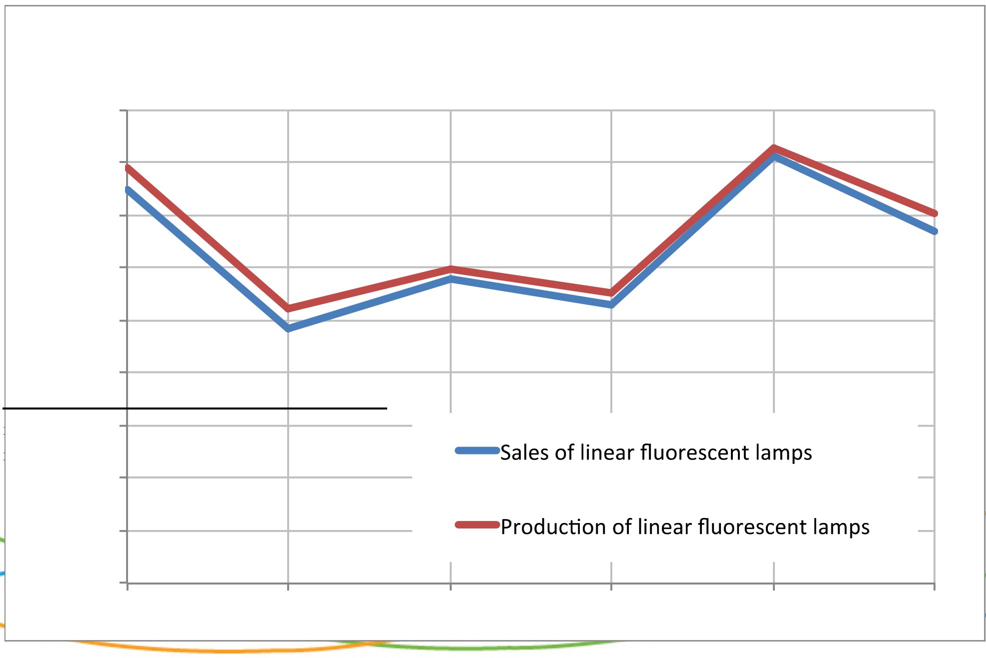
The third stage requirements, eight years after the Regulation comes into force are:

- Ballasts for fluorescent lamps without integrated ballast shall have the efficiency η ballast ≥ EBbFL where EBbFL is defined in Annex II.3.g of the regulation. (note that this will effectively mandate electronic ballasts).

2.4.4. Lamp Market

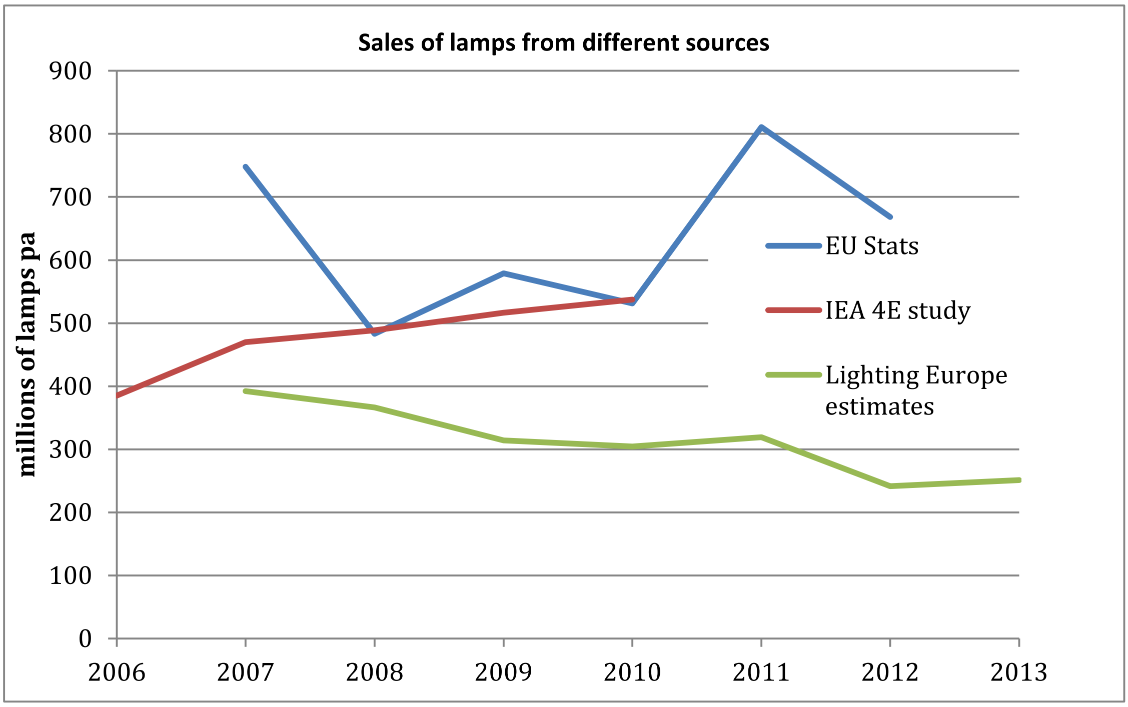
Like most 220/230V economies, linear fluorescent lamps in Europe are dominated by 4-foot, 36W lamps. Figure 20 graphs the official EU statistics for all linear fluorescent lamp sales and production over the period 2007-2012 (EU 2012a and EU 2012b).

Figure 20: sales and production of linear fluorescent lamps in the EU (source: EU 2012a and EU 2012b)



In Figure 20 we see sales very closely matching production, both of which are quite volatile. These observations lead us to question the accuracy of these statistics, which we understand rely on the 27 EU member country statistics bodies to submitting national reports, which are then aggregated. The EU statistics were compared with data used for the IEA 4E Benchmarking Study undertaken (IEA 4E 2011) as well as with data provided by Lighting Europe for the purpose of this study. These data sources are all graphed in Figure 21.

Figure 21: Linear fluorescent lamps sales in the EU (3 sources as listed in figure)



From the above figure above we can see that the EU statistics appear somewhat higher and more volatile than the other two sources of data with the Lighting Europe data in particular showing a gradual decline from 2007. It should be noted that whilst the IEA 4E mapping exercise was for residential lamps, the data for linear fluorescent lamps was for those used in all applications: commercial, industrial and residential. The report also includes the following notes about the data:

- Total fluorescent lamp sales values for lamps in 2006-7 considered robust, but of less reliability for 2008 onward.
- Breakdown of percentage sales by product type considered robust for 2009-2010, but of less reliability prior to this period.

For the market shares of T12, T8 and T5 lamps in the EU, estimates from three sources were sought and these are compared in Figure 22 and Figure 23, which graph estimated T5 and T12 lamp share respectively. Note in these figures that the UK Lighting Industry Association estimates are for the UK market only.

Figure 22: estimates of percentage share of T5 lamps in Europe / UK

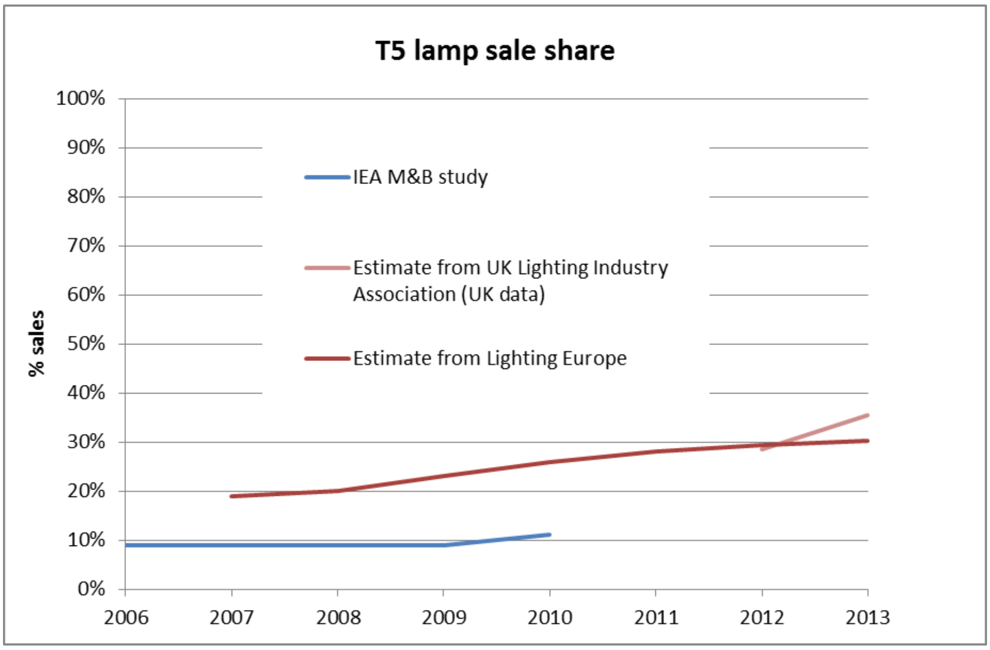
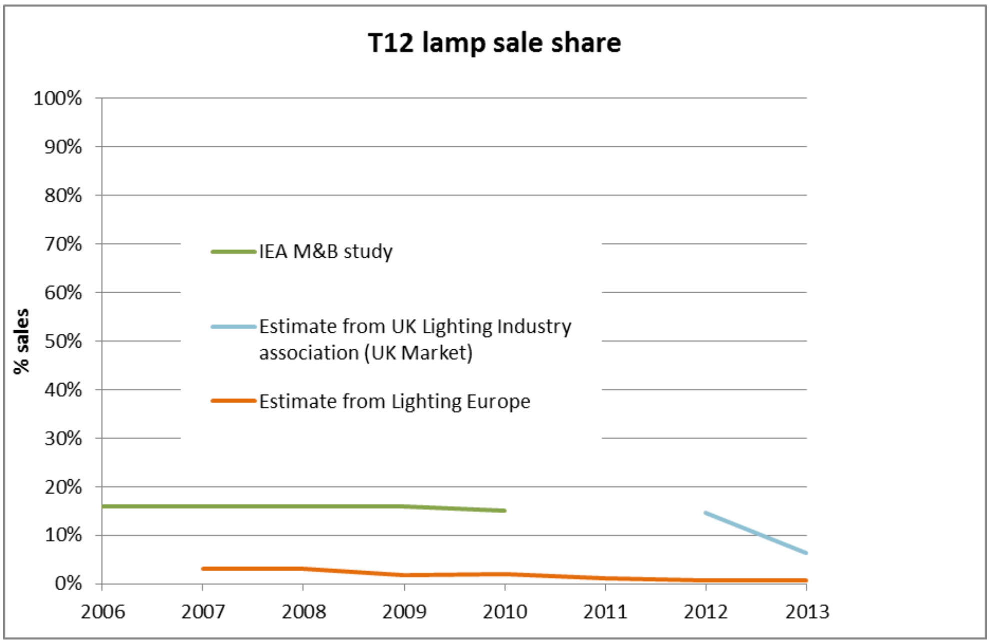


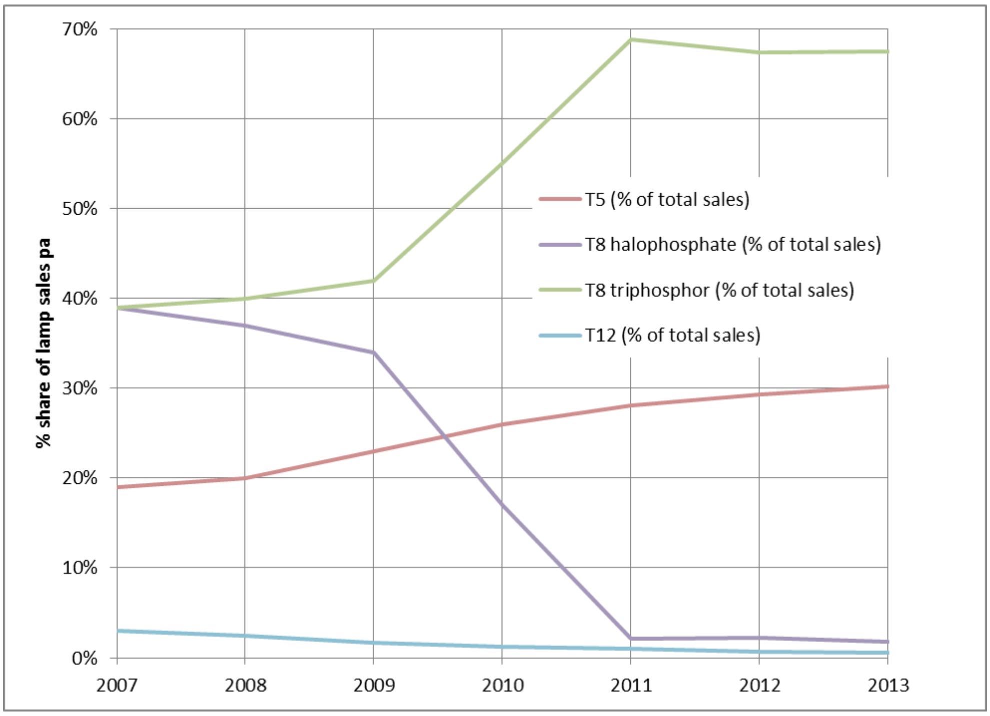
Figure 23: estimates of percentage share of T12 lamps in Europe / UK



In the above two figures, all estimates indicate declining T12 sales and increasing T5 sales, as is to be expected from general worldwide trends.

Figure 24 shows the Lighting Europe estimates for EU sales share of T12, T5 as well as T8 halophosphate and T8 triphosphor lamps.

Figure 24: Estimated lamp sales shares in the EU (source: Lighting Europe estimates)

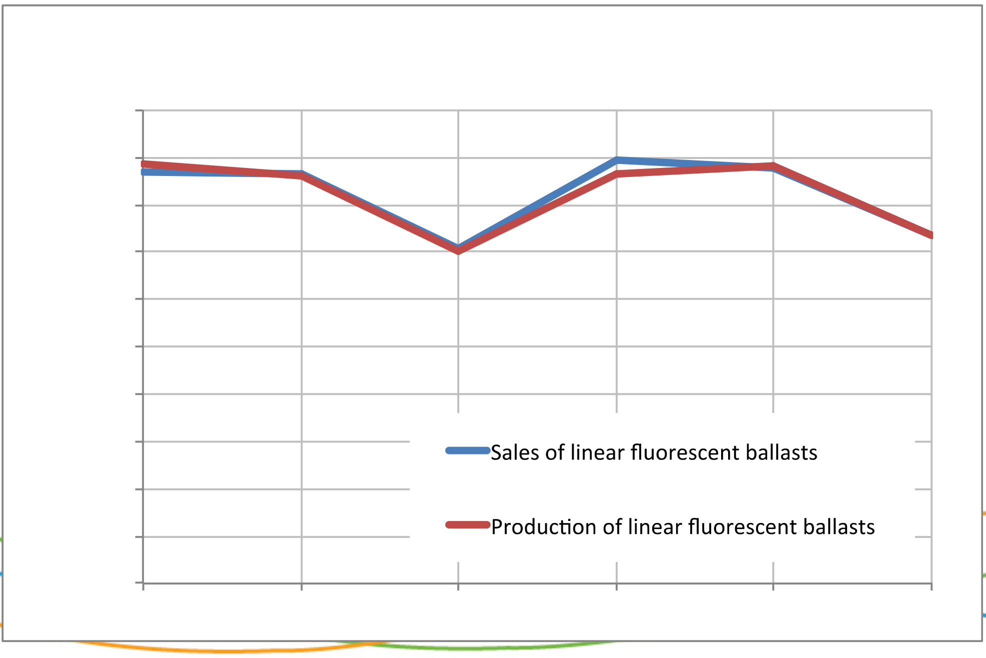


In Figure 24 we can see the share of T8 halophosphate lamps declining sharply from 2009, showing the effect of the introduction of MEPS that year, which effectively mandated triphosphor lamps. This trend appeared to stabilize in 2011.

2.4.5. Ballast Market

Depicted in Figure 25 are official EU statistics for all linear fluorescent ballast sales and production over the period 2007-2012 (EU 2012a and EU 2012b).

Figure 25: Sales and production of linear fluorescent ballasts in the EU (source: EU 2012a and EU 2012b)



In Figure 25 we see sales of ballasts very closely matching production, which lead us to question the accuracy of these statistics, as was the case for lamps (refer discussion in section 2.4.4). The volumes also appear to be very high - i.e. more ballasts sold than lamps. The EU statistics also show the split of electronic / magnetic ballast sales to be around 10% electronic over 2007-2012. As is the case with other developed economies, we would expect the market share of electronic ballasts to be significantly higher than this, particularly in recent years.

Thus, this data cannot be considered robust. Currently, no other estimates of the EU ballast market are available for use in this study.

2.4.6. Notes on Market Data Sources and Assumptions

Data on lamp and ballast production was taken from PRODCOM – the EU centrally held statistics on manufactured goods (EU 2012a). This gives the values for the EU as a whole (EU27 – up to end 2012 there were 27 member states) and for each Member State, by year and by product code for:

- Value (in Euros)
- Sold volume
- Unit value

"Sold volume" data (expressed in units sold) were used for the "production" values in this study (Figure 25).

EU27 trade since 1988 by CN8 (DS_016890) data was taken from EUROSTAT (EU 2012b). Data extracted was the value in Euros by product code exported to and imported from selected countries. 32 countries (out of a total of 284) that were expected to be those with the greatest trade volumes were chosen. These are listed in Appendix B along with more information on the data extraction. The values from each country were added to give total export and total import figures.

The volumes of exports and imports were calculated from the sales values using the unit sales value in Euros for each year from PRODOM. Sales within the EU were calculated using the following formula:

Sales in EU = production in EU + imports into EU – exports from EU.

Appendix B contains further information on the extraction of EU statistics. As noted previously, there is some doubt about the validity of the EU statistical data. Estimates from other sources we sought (industry associations) and these have been used to draw conclusions in this study.

2.4.7. Market Summary

The domestic linear fluorescent lighting market for the EU is summarised in Table 21, which uses a tick/cross system to indicate the progress of this market towards energy efficiency.

Table 21: EU domestic market summary

Lamps	**Most popular CCT**	**4100K**	
	Most popular length	4-foot	
	Most popular power	36W	
	Low-power retrofit lamps commonly available	Yes	✔
	MEPS regulations in force	yes	✔
	MEPS regulations mandate triphosphor	yes	✔
	Market share halophosphate (and trend)	2% ↓	✔
	Market share T5 (and trend)	30% ↑	✔
	Market share T12 (and trend)	1% ↓	✔
Ballasts	MEPS regulations in force	Yes	✔
	Market share electronic (and trend)	Unknown	

The EU MEPS for fluorescent lamps appears to have largely replaced T8 halophosphate lamps with triphosphor lamps. The market share of T5 lamps is increasing and T12 decreasing. No robust data was available to make any conclusions about the ballast market in the EU.

2.5. India

2.5.1. MEPS and Labeling for Lamps

India has a mandatory comparative labeling program for linear fluorescent lamps, The comparative labeling includes tiers ranging from 1 to 5 stars in order of ascending efficacy. The Bureau of Energy Efficiency (BEE) is the implementing agency for energy performance standards. The energy performance standard for LFLs was implemented in 2009. There is currently no defined timeline for revision of these standards, however these are likely to be revised when the review of the Indian standard for safety and performance for linear fluorescent lamps takes place at the Bureau of Indian Standards (BIS).

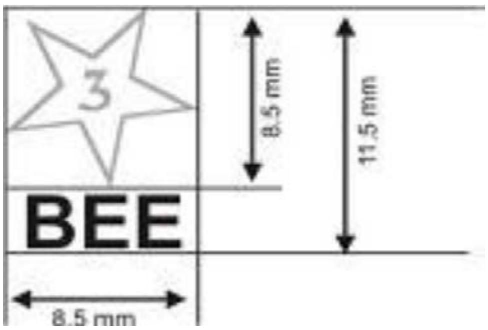
Energy performance standards for linear fluorescent lamps in India are listed in the Schedule for linear fluorescent lamps [15] and notified in regulation[16]. The scope, test method, parameters to be tested, and label design are referred to in the schedule.

The label is comparative and includes the following information:

- Lumen per watt after 100, 2000 and 3500 hours of use.
- Star rating of the product based on energy efficiency performance.

Figure 26: Sample Label for linear fluorescent lamps on the packaging sleeve - India

Figure 27: Sample Label on linear fluorescent lamps - India



The star marking as per the rating is required to be stamped on the lamp as shown in Figure 27.

The labeling program covers linear fluorescent lamps for General lighting service which covers 4 feet linear fluorescent lamps for wattages up to 40W and 6500K color temperature for halo-phosphates and 6500K, 4000K & 2700K for tri-phosphate category. The energy efficiency tiers for LFLs for various categories of star rating are shown in the table below.

15 http://220.156.189.29/Content/Files/Schedule2_TFL.pdf
16 http://220.156.189.29/Content/Files/TFLnoti.pdf

Table 22: Energy Efficiency Tier Classification for LFLs (India)

Star Rating	1	2	3	4	5
Lumens per Watt at 0100 hrs of use	<61	>=61 & <67	>=67 & <86	>=86 & <92	>=92
Lumens per Watt at 2000 hrs of use	<52	>=52 & <57	>=57 & <77	>=77 & <83	>=83
Lumens per Watt at 3500 hrs of use	<49	>=49 & <54	>=54 & <73	>=73 & <78	>=78

The products should conform to minimum requirements of standard IS 2418 (part I) and (part II) – 1977 to participate in BEE S&L Program.

As was reported by BEE, lamp labeling also functions effectively as a MEPS - that is, manufacturers are reluctant to produce lamps with a low star rating. Note however from Table 22 that the 1 star limit is expressed as a “less than” - i.e. all lamps lower than the stated efficacy are allowed to carry 1 star. This is contrary to most other labelling schemes, which require a “greater than” efficacy limit. Presumably, it is the 2 star limit which serves as the de facto MEPS - this is supported by testing that was undertaken - no lamps were sampled that were worse than 2 stars.

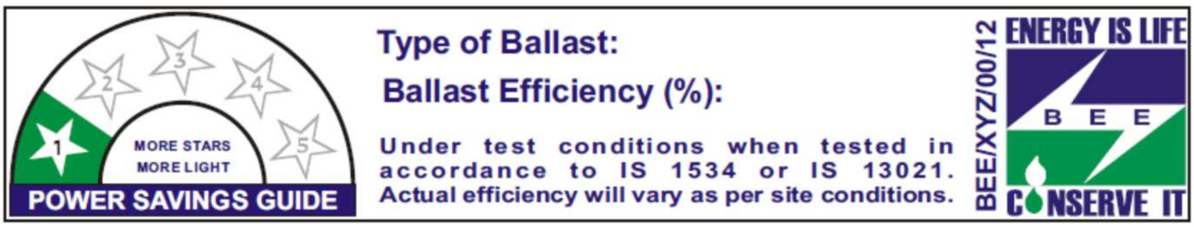
2.5.2. Labeling for Ballasts

India has comparative labeling program for Ballasts which is voluntary. Currently, no updates are scheduled for revision of energy performance standards of ballasts. Energy performance standards for ballasts in India are listed in the Schedule for Ballasts[17]. The scope, the test method, parameters to be tested, and label design are referred to in the schedule.

The label is comparative and shall include the following information:

- Type of ballast.
- Ballast efficiency percentage.
- Star rating of the product based on energy efficiency performance.

Figure 28: Sample Label for Ballast on the packaging (India)



The above design shall be printed on the packaging on the ballast.

Figure 29: Sample Label on the name plate of one star ballast

;/Schedule2_TFL.pdf

The above design is a sample for one star ballast and shall be printed on the name plate of ballast.

The labeling program covers magnetic ballasts and electronic ballasts for linear fluorescent lamps and single capped fluorescent lamps. It also includes built in ballasts where the ballast is inbuilt in the luminaire. The ballasts which are integral to the lamps are excluded from the program.

The energy efficiency tiers of ballasts for various categories of star rating are mentioned below:

Table 23: Energy Efficiency Tier Classification for ballasts

Star Rating	Category
1 Star	≥B1 and < A3
2 Star	≥A3 and < A2
3 Star	≥A2 and < A2 BAT
4 Star	≥A2 BAT and <A1
5 Star	= A1
Lumens per Watt at 3500 hrs of use	<49

Note the following:

- BAT = best available technology
- B1 = magnetic ballast
- A3, A2, A2 BAT = non dimmable electronic ballasts
- A1 = dimmable electronic ballasts

The detailed requirements for ballasts for fluorescent lamps are specified in Annexure-I of the schedule[18].

2.5.3. Lamp Market

Discussions with Indian lighting experts reveal that linear fluorescent lamps used in India are dominated by 4-foot (36W) lamps, and that the most common colour temperature of Indian linear fluorescent lamps is 6500K. No direct data was available to distinguish between halophosphate and triphosphor lamp sales in India, however, from lamp sampling conducted for the this study (Chapter 3) only 4 of the 10 models sampled were triphosphor.

Information regarding lamp production and sale in India is scarce. The only data source discovered for this study (BEE 2014) was provided by the Indian Bureau of Energy Efficiency (BEE), who administer the mandatory fluorescent lamp labeling scheme. The minimum efficacy limits for the scheme are as follows:

- India 1-star < 61 lm/W
- India 2-star ≥ 61 lm/W
- India 3-star ≥ 67 lm/W
- India 4-star ≥ 86 lm/W
- India 5-star ≥ 92 lm/W

BEE provide lamp sales data for 2012 and 2013. These are shown in Figure 30 (4-foot T8 lamps) and Figure 31 (4-foot T12 lamps).

18 http://220.156.189.29/Content/Files/Schedule-15ballast.pdf

Figure 30: Annual sales of 4-foot T8 lamps (source: BEE 2014)

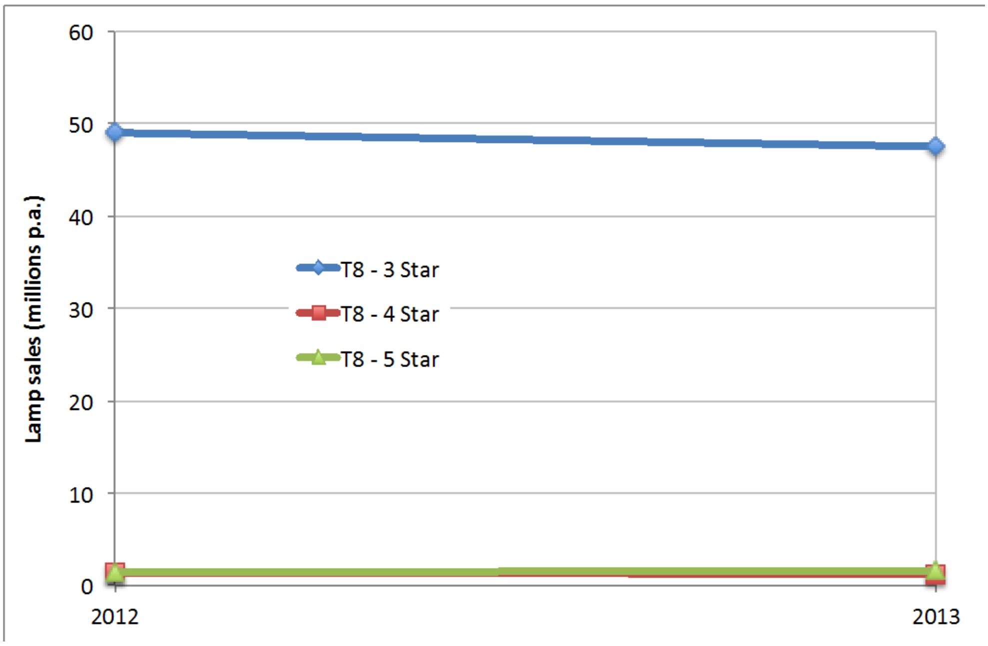
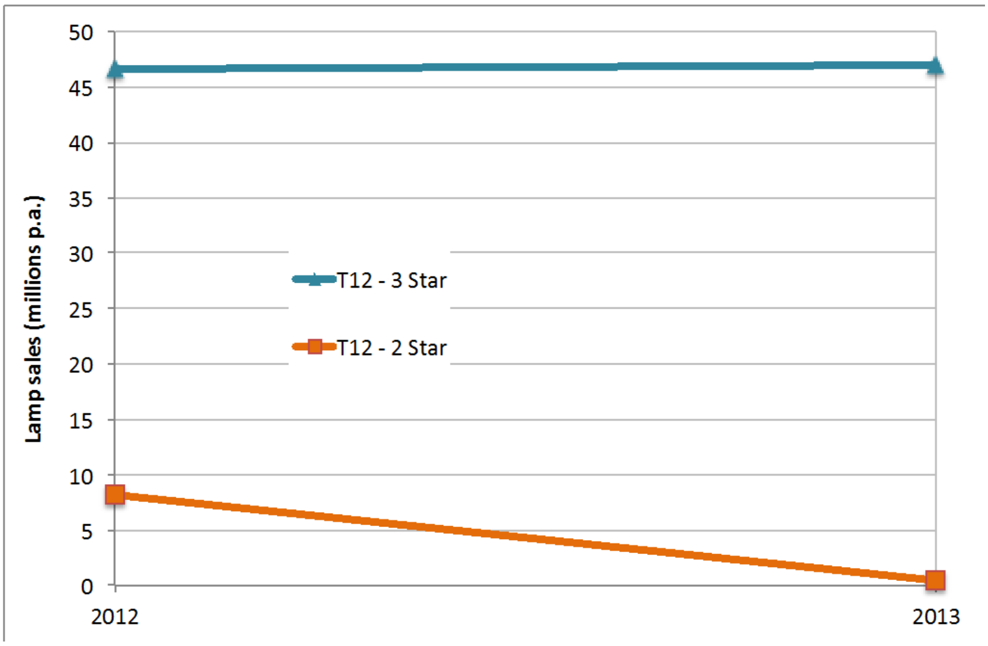


Figure 31: Annual sales of 4-foot T12 lamps (source: BEE 2014)



From the above figures it is difficult to draw many conclusions, other than the following:

- T12 and T8 lamp sales are almost equal, at around 50 million lamps per annum for each.
- The most popular lamps (sold in approximately equal numbers) are 3-star T8 lamps and 3-star T12 lamps.

- Sales of 2-star (T12) lamps declined significantly from 2012 to 2013, from around 8 million to around 0.5 million p.a.

The website of the Indian lighting industry association (ELCOMA) states that around 200 million fluorescent lamps are manufactured in India annual, with a growth rate of around 3% p.a.

2.5.4. Ballast Market

No data for the Indian ballast market was able to be secured for this study. Note that India does not currently have a MEPS for ballasts, but does have a voluntary labelling program for ballasts (refer section 2.5.2).

2.5.5. Market Summary

The domestic linear fluorescent lighting market for India is summarised in Table 24, which uses a tick/cross system to indicate the progress of this market towards energy efficiency.

Table 24: India domestic market summary

Lamps	**Most popular CCT**	**6500K**	
	Most popular length	4-foot	
	Most popular power	36W	
	Low-power retrofit lamps commonly available	Unknown	
	MEPS regulations in force	yes	✔
	MEPS regulations mandate triphosphor	no	✗
	Market share halophosphate (and trend)	high	✗
	Market share T5 (and trend)	Unknown	
	Market share T12 (and trend)	high	✗
Ballasts	MEPS regulations in force	no	✗
	Market share electronic (and trend)	Unknown	

India (effectively) has MEPS in place for linear fluorescent lamps, but not for ballasts, although mandatory labeling is in place for lamps and is voluntary for ballasts. T12 and halophosphate lamps remain popular. The market share of T5 lamps as well as electronic ballasts remains unknown.

2.6. United States

2.6.1. MEPS for Lamps

Energy standards for linear fluorescent lamps in the US are set by the Department of Energy (DOE) and are listed in the Code of Federal Regulations (CFR) Title 10 – Energy, Part 430 - Energy conservation program for consumer products[19]. The scope, the test method for measuring average lamp efficacy (LE), color rendering index (CRI), and correlated color temperature (CCT) of electric lamps are also referred to in the CFR.

The regulation applies to general service fluorescent lamps which should meet the requirements listed in Table 25 since 1995.

Table 25: DOE standards since 1995

Lamp Type	Nominal lamp wattage	Minimum CRI	Minimum average lamp efficacy (lm/W)
4-foot medium bipin	>35W	69	75
	≤35W	45	75
2-foot U-shaped	>35W	69	68
	≤35W	45	64
8-foot slimline	>65W	69	80
	≤65W	45	80
8-foot high output	>100W	69	80
	≤100W	45	80

In addition, general service fluorescent lamps manufactured after July 14, 2012, shall meet or exceed the lamp efficacy standards in Table 26.

19 http://www.ecfr.gov/cgi-bin/text-idx?SID=833a295c99e4190254009eae99aff072&node=10:3.0.1.4.18&rgn=div5#10:3.0.1.4.18.3.9.2

Table 26: Additional DOE standards effective July 14, 2012

Lamp Type	Correlated color temperature	Minimum average lamp efficacy (lm/W)
4-foot medium bipin (T8 – T12)	≤4,500K	89
	>4,500K and ≤7,000K	88
2-foot U-shaped (T8 – T12)	≤4,500K	84
	>4,500K and ≤7,000K	81
8-foot slimline (T8 – T12)	≤4,500K	97
	>4,500K and ≤7,000K	93
8-foot high output (T8 – T12)	≤4,500K	92
	>4,500K and ≤7,000K	88
4-foot miniature bipin standard output (T5)	≤4,500K	86
	>4,500K and ≤7,000K	81
4-foot miniature bipin high output (T5HO)	≤4,500K	76
	>4,500K and ≤7,000K	72

The DOE are currently developing new regulations for fluorescent lamps with the Notice of Proposed Rulemaking published in April 2014. Under the current timetable the regulations are expected to be adopted in December 2014 with the new regulations taking effect in December 2017.

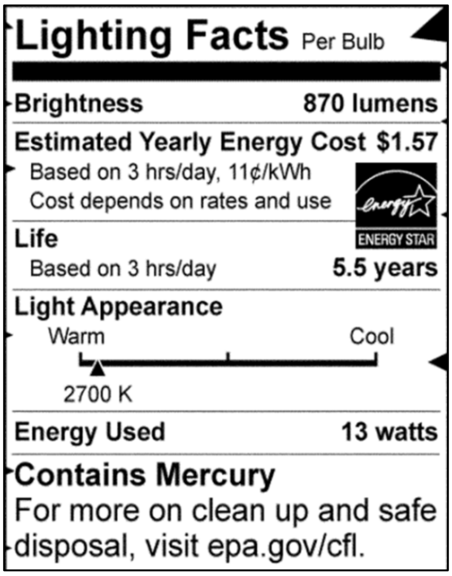
Note that at the time of writing of this report, an exemption from the current MEPS was in place, for certain manufacturers, which was granted from July 2012 until July 2014 (US DOE 2013). This exemption allows certain manufacturers to adhere to the previous MEPS (75 lm/W for4-foot T8 lamps) for 2 years. Manufacturers were required to apply for this exemption and it was granted to several successful applicants, including the major lamp manufacturers and the majority of the lamps tested for this study (Chapter 3).

2.6.2. Labeling for Lamps

Labeling requirements for lighting products in the US are described in the Code of Federal Regulations (CFR) Title 16: Commercial Practices, Part 305 — Energy and water use labeling for consumer products under the energy policy and conservation act ("energy labeling rule")[20].

20 http://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=167b0413204fe810e1112a68ced1cabe&n=16y1.0.1.3.29&r=PART&ty=HTML#16:1.0.1.3.29.0.16.14

Figure 32: Lighting Facts label for general service lamps



Fluorescent lamps ballasts and luminaires are covered and should be labeled to include information such as light output, estimated energy cost, life, correlated color temperature, and the wattage. An example of this information displayed using the Lighting Facts label is shown in Figure 32.

Linear fluorescent lamps in the US are not eligible to earn the ENERGY STAR, an endorsement label under the Environmental Protection Agency (EPA) voluntary program to identify and promote energy-efficient products.

2.6.3. MEPS for Ballasts

The previous regulation for ballasts for fluorescent lamps is as follows:

Scope:

- Ballasts that operate the following linear fluorescent lamp combinations:
    - One F40T12 lamp
    - Two F96T12 lamps
    - Two F40T12 lamps
    - Two F96T12/ES lamps
    - One F34T12 lamp
    - Two F96T12HO lamps
    - Two F34T12 lamps
    - Two F96T12HO/ES lamps
- Input voltage 120-277 Volts; 60 Hz

Energy Efficiency Metric:

- Ballast Efficacy Factor (BEF) = The ratio of the ballast factor, specified as a percentage, to the ballast input power in watts. Ballast efficacy factor is only meaningful when used to compare ballasts operating the same type and number of lamps. Also called the ballast efficiency factor.

The previous requirements are shown in Table 27.

Table 27: US ballast MEPS requirements (previous)

Application for operation of:	Ballast input voltage	Total nominal lamp watts	Ballast efficacy factor
One F40 T12 lamp	120/277	40	2.29
Two F40 T12 lamps	120/277	80	1.17
Two F96T12 lamps	120/277	150	0.63
Two F96T12HO lamps	120/277	220	0.39
One F34T12 lamp	120/277	34	2.61
Two F34T12 lamps	120/277	68	1.35
Two F96T12/ES lamps	120/277	120	0.77
Two F96T12HO/ES lamps	120/277	190	0.42

Commencing in November 2014 the new metric will be Ballast Luminous Efficiency (BLE) = ballast input power divided by the lamp arc power of a lamp-and-ballast system, as per the following table.

Table 28: US ballast MEPS requirements (commencing Nov 2014)

BLE = A/(1+B*average total lamp arc power ^ -C) where A, B, and C are as follows:

Description	A	B	C
Instant start and rapid start ballasts (not classified as residential) that are designed to operate **4-foot medium bi-pin lamps** **2-foot U-shaped lamps** **8-foot slimline lamps**	0.993	0.27	0.25
Programmed start ballasts (not classified as residential) that are designed to operate **4-foot medium bi-pin lamps** **2-foot U-shaped lamps** **4-foot miniature bi-pin standard output lamps** **4-foot miniature bi-pin high output lamps**	0.993	0.51	0.37
Instant start and rapid start ballasts (not classified as sign ballasts) that are designed to operate 8-foot high output lamps	0.993	0.38	0.25
Programmed start ballasts (not classified as sign ballasts) that are designed to operate 8-foot high output lamps	0.973	0.70	0.37
Instant start and rapid start residential ballasts that operate **4-foot medium bi-pin lamps** **2-foot U-shaped lamps** **8-foot slimline lamps**	0.993	0.41	0.25

Description	A	B	C
Programmed start residential ballasts that are designed to operate **4-foot medium bi-pin lamps** **2-foot U-shaped lamps**	0.973	0.71	0.37

Other Requirements:

- PF > 0.9 for commercial; PF > 0.5 for residential

Test Procedure:

- Based on: ANSI C82.2
- Samples: 4
- Aging: per ANSI C82.2
- Ambient temp: per ANSI C82.2
- Ambient relative humidity: per ANSI C82.2
- Voltage and frequency: ANSI C82.2
- Methodology: per ANSI C82.2
- Key equipment: per ANSI C82.2
- Tolerances: ANSI C82.2
- Calculations/algorithms/assumptions: ANSI C82.2

2.6.4. Lamp Market

Linear fluorescent lamps in the USA are dominated by 4-foot (32W) lamps, which represent around 90% of all (regulated) linear fluorescent lamp sales (US DOE 2014). Lower power 4-foot (25W) lamps have recently become available, designed to directly replace 32W lamps. One such model was tested for this study (Chapter 3) - it exhibited an efficacy[21] of almost 100 lm/W. The most popular colour temperature of US linear fluorescent lamps is 4100k (US DOE 2014).

Figure 33 graphs US linear fluorescent lamp sales over the period 2007-2012. Sales have been slightly volatile, but have remained within a ±7% band over this period.

[21] Tested with magnetic reference ballast

Figure 33: Sales of linear fluorescent lamps in USA (source: US DOE 2014)

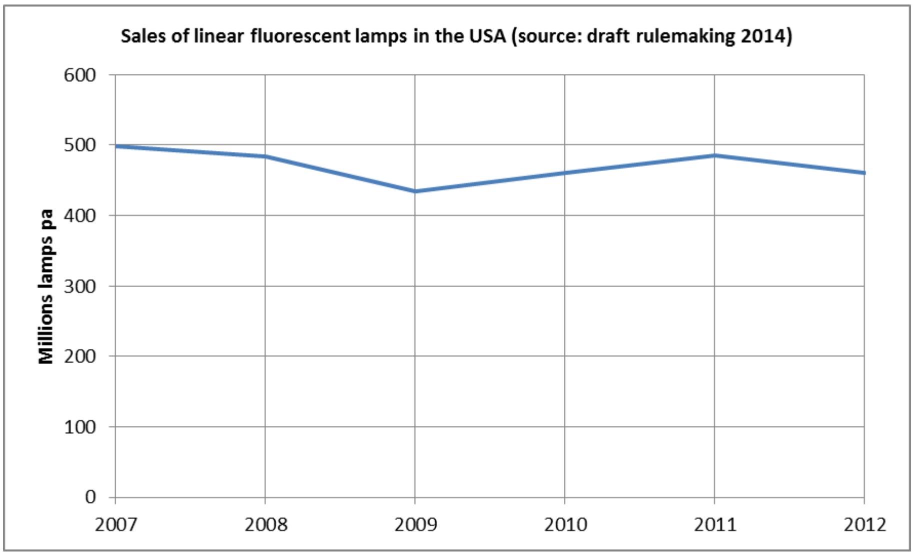
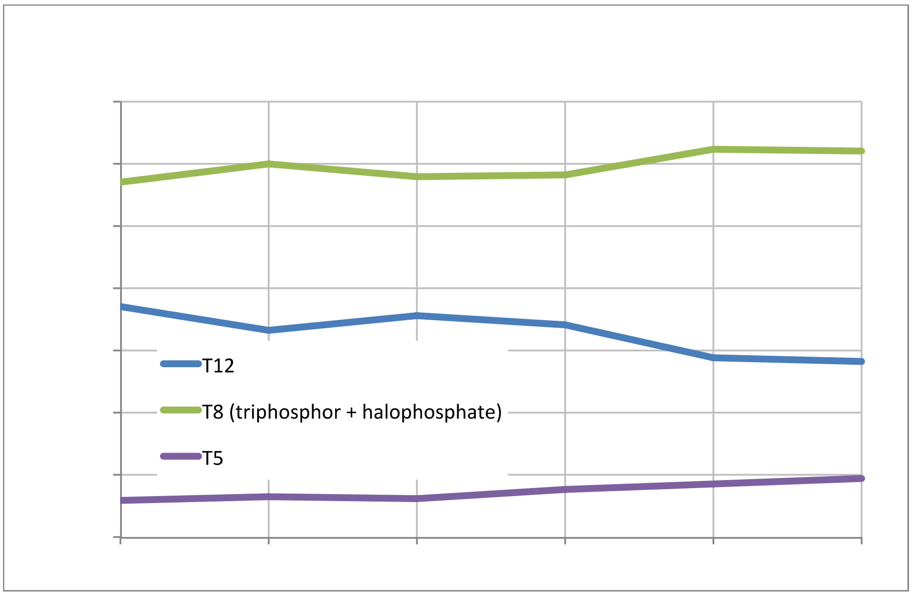


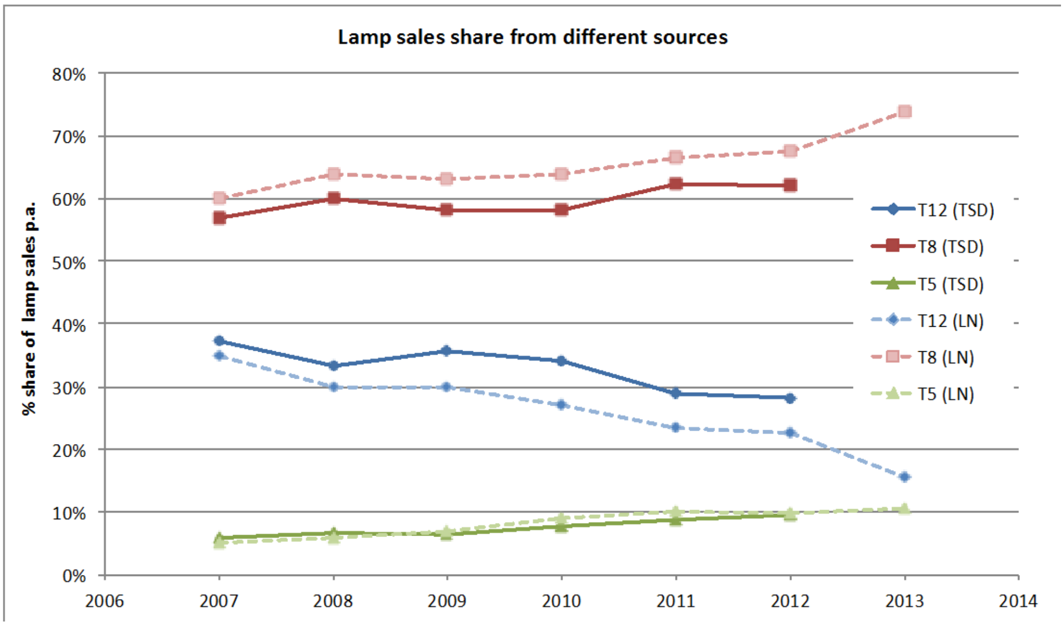
Figure 34 graphs the percentage share of fluorescent lamp types over the period 2007-2012. From this figure we can see a declining trend in T12 lamps, in favour of T8 and T5 lamps.

Figure 34: Percentage share of linear fluorescent lamp sales in USA (source: US DOE 2014)



The lamp sales data used in Figure 34 were taken from the Notice of Proposed Rulemaking Technical Support Document for General Service Fluorescent Lamps and Incandescent Reflector Lamps (US DOE 2014). These data were compared to those in recent on-line publications (Light Now 2013/14) which are based on data sourced from National Electrical Manufacturers Association (NEMA). The comparison is shown in Figure 35 which reveals reasonable agreement in trends and reasonable agreement in absolute terms between the two sources (TSD = technical support document, LN = Light Now). Note however that it is thought that both of these originate from the same source (NEMA).

Figure 35: Comparison of US lamp sales share from two data sources



No US data was available to differentiate between triphosphor and halophosphate T8 lamp sales. Lamp sampling conducted for this study revealed that halophosphate lamps remain available (2 of the 8 lamps sampled were halophosphate). The current US MEPS for lamps (for 4-foot lamps - minimum efficacy 88-89 lm/W depending on colour temperature) effectively mandates triphosphor lamps.

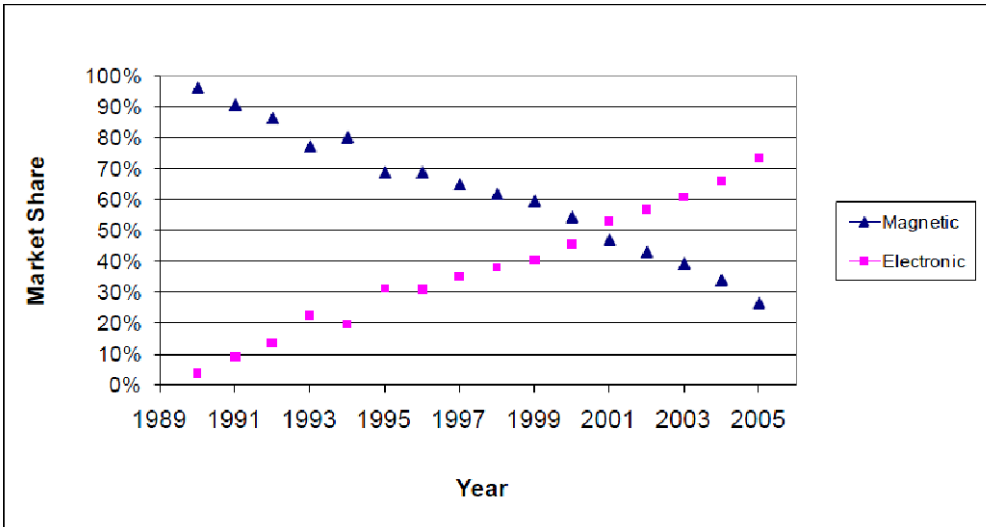
Note that an exemption from current MEPS was granted from July 2012 until July 2014 (refer section 2.6.1). This exemption allows certain manufacturers to adhere to the previous MEPS (minimum 75 lm/W for 4-foot lamps) for a limited period.

The current California Energy Commission (CEC) product registration database (CEC 2014) includes a listing of the colour rendering index (CRI) of the listed lamps. If a CRI of 80 or greater is taken as an indicator that the lamp is triphosphor (an industry rule of thumb) then around 60% of T12 and T8 lamps listed on the database are triphosphor. Note that the Californian MEPS regulations also still allow halophosphate lamps - e.g. minimum efficacy for 4-foot lamps is still 75 lm/W.

2.6.5. Ballast Market

Recent data for the types of ballasts sold in the US (magnetic vs electronic) was not readily available. However Figure 36 charts estimates the electronic/magnetic market share of ballasts in the US from 1989 to 2005. From this figure we can see that the US appears to have enthusiastically embraced electronic ballasts for many years.

Figure 36: US ballast market share, by technology type (source: US DOE 2011)



Supporting this conclusion is the current California Energy Commission product registration database (CEC 2014) which lists 86% of registered ballasts as being electronic.

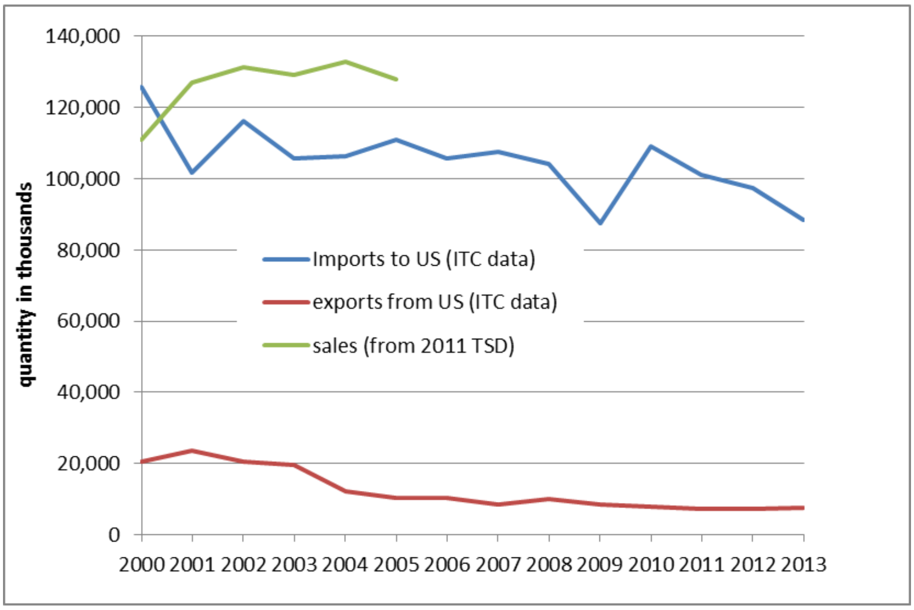
The US Final Rule Technical Support Document for Fluorescent Lamp Ballasts (US DOE 2011) states that the majority of 4-foot T12 ballasts were magnetic whereas most (about 97% of T8 sales in 2005) for 4-foot T8 ballasts were electronic. If we assume that T12 are all magnetic and T8 and T5 are all electronic, then using the latest lamp sales data in the 2013 draft rulemaking (US DOE 2013) electronic ballasts had a market share in 2012 of just under 80%.

Overall, taking into account the trends in market share shown in Figure 36, the lamps sales data and the CEC data it is estimated that electronically-ballasted luminaires ballasts now represent an estimated 80-90% of fluorescent luminaire sales in the USA.

Both electronic and magnetic ballasts are manufactured in the US. The USITC Interactive Tariff and Trade DataWeb have import and export data for ballasts but does not distinguish between magnetic and electronic[22]. These data are shown in Figure 37. The data to 2005 suggests that a high proportion of US ballasts are imported.

[22] The product code used was HTS – 8504100000, described as 'BALLASTS FOR DISCHARGE LAMPS OR TUBES'

Figure 37: US Import, export and sales figures for ballasts



2.6.6. Notes on Market Data Sources and Assumptions

The assumptions used for the analysis of lamps and ballasts in this study, and assumptions required in order to apply the findings of this study to the entire US market, are as follows:

- The lamps types covered by US Federal Regulations represent the majority of lamps sold in the US marketplace (note that regulations cover 4-foot and 8-foot double-capped linear fluorescent lamps).
- Sales by NEMA members (on which the US DOE data are based) represent 90% of US shipments (note that this is the assumption applied by US DOE in developing their datasets).

The lamp data used in this report, and the ballast data to 2005, are thought to be robust – they are based on the US Federal Rulemaking process which is stringent and subject to significant stakeholder review. The only remaining areas of uncertainty are:

- The lack of recent robust data for the ballast market means that we can only be indicative about the current situation. However the signs are that the increasing trend to electronic ballasts has continued.
- It is not possible to be quantitative about the market share of halophosphate vs triphosphor lamps.

The US market for linear fluorescent lamps and ballasts is summarised in the following section.

2.6.7. Market Summary

The linear fluorescent lighting market for the US is summarised in Table 29, which uses a tick/cross system to indicate the progress of this market towards energy efficiency.

Table 29: US domestic market summary

Lamps	**Most popular CCT**	**4100K**	
	Most popular length	4-foot	
	Most popular power	32W	
	Low-power retrofit lamps commonly available	yes	✔
	MEPS regulations in force	yes	✔
	MEPS regulations mandate triphosphor	yes	✔
	Market share halophosphate (and trend)	medium	✗
	Market share T5 (and trend)	10% ↑	✔
	Market share T12 (and trend)	30% ↓	✗
Ballasts	MEPS regulations in force	yes	✔
	Market share electronic (and trend)	80-90% ↑	✔

Even though the US has MEPS for fluorescent lamps that should mandate T8 triphosphor lamps, halophosphate lamps continue to be available, due to an exemption granted until July 2014. The market share of T5 lamps is increasing and T12 lamps decreasing (although remaining significant). The US ballast market is an exceptional performer, having moved almost entirely to electronic ballasts.

3. Lamp Testing

3.1. Methodology

3.1.1. Research and Information Gathering

The initial task undertaken for the testing component of this study was to collect, categorize and review relevant sources of information, on the MEPS and test procedures applicable to the target economies. The types of documents collected included:

- Legislation and regulations for MEPS and labeling of linear fluorescent components.
- Standards used to describe or facilitate MEPS and labeling, such as test methods, performance standards and any other standards where MEPS/labeling limits or algorithms might be held.
- Manufacturers' product performance claims.
- Other useful documents, such as reports or studies which examine similar issues to those being analyzed in the study.

The fluorescent lamp MEPS requirements for the target economies were derived from these documents and the efficacy aspects of these requirements are summarised in the following sections.

3.1.2. Lamp Sampling

Linear fluorescent lamps were purchased from several retail locations in each of China, Europe (United Kingdom), India and the USA. A wide variety of retail outlets were sampled, including large hardware stores, small hardware stores, trade-supply stores, lighting specialist stores and on-line suppliers.

Lamp choice was limited to 4-foot T8 lamps (which is globally the most popular linear fluorescent lamp type) targeting the most popular color temperature and lamp power for each of the four economies, as follows:

- China = 36W, 6500K
- India = 36W, 6500K (some other color temperatures were purchased for comparative purposes)
- Europe (UK) = 36W, 4000K
- USA = 32W, 4100K.

As many different lamp brands and models were sampled as possible (within budget constraints) ranging from lower-cost, lesser known brands to higher-cost, well known brands. Around 12 samples of each model were purchased and shipped to laboratories which were accredited to conduct linear fluorescent lamp testing. The detailed lamp sampling methodology is outlined in Appendix C.

3.1.3. Lamp Efficacy Test Procedure

The test procedures for lamp efficacy in the ten economies were assessed in order to identify any differences in test methods that may influence the test results, performance claims or MEPS/labeling metrics from each of those economies. The relevant test procedure for each economy is listed in Table 30 along with the equivalent mirror test procedure with which the country's procedure is harmonized.

Table 30: Lamp efficacy test procedures

Country	Test Procedure	Basis of Test Procedure
Australia	AS/NZS 4782.1	IEC 60081
Canada	IES LM-9	IES LM-9
China	GB/T 10682	IEC 60081
Europe	EN60081	IEC 60081
India	IS2418	IEC 60081
Japan	JIS C 7801	IEC 60081
Korea	KSC 7601	IEC 60081
Thailand	TIS 236-2548	IEC 60081
USA	10 CFR 430.32	IES LM-9
Mexico	IES LM-9	IES LM-9

As indicated in Table 30, the test procedures for these economies are equivalent to either the Illuminating Engineering Society of North America (IES) procedure LM-9 or the International Electrotechnical Commission (IEC) method contained in IEC 60081. Thus it is only these two procedures that are relevant to this study. The key aspects of each of these test procedures are summarized in Table 31.

Table 31: Comparison of lamp efficacy test procedures

Test Aspect	IES LM-9	IEC 60081
Initial lamp aging time	100 hours	100 hours
Ambient temperature	24-26 °C	24-26 °C
Relative humidity	Not specified	Max 65%
Air movement	< 4 m/min	Not specified
Stabilization time	~15 minutes	15 minutes
Reference ballast	As required by IEC lamp data sheet	As required by IEC lamp data sheet*, otherwise default inductive
Circuit voltage	Rated voltage of reference ballast	Rated voltage of reference ballast
Integration equipment	Typically integrating sphere	Typically integrating sphere

*IEC lamp data sheet contains technical information for standard lamp types, including testing requirements

After detailed scrutiny of the test procedures, including discussions with international testing experts and lighting professionals from the target economies, it was concluded that there were no substantive differences between LM-9 and IEC 60081 that were likely to result in any material differences between test results. Given this, the IES and IEC test methods, on which all the test methods of the ten target economies are based, are essentially harmonized. Thus it is expected that lamp test results from all ten economies are comparable, without the need for any further adjustment or normalization.

Lamp samples from each of the four economies were shipped to three laboratories. The locations of these laboratories, and the test procedures used, are shown in Table 32.

Table 32: Test laboratories and test procedures

Lamp Samples from Country	Location of Test Laboratory	Test Procedure
China	China	IEC 60081
India	India	IEC 60081
UK	India	IEC 60081
USA	USA	IES LM-9

All lamps were seasoned for 100 hours prior to testing, as is required by the IES and IEC test procedures or relevant country regulations. All lamps were tested using an inductive (magnetic) reference ballast which operated the test lamp at mains frequency. Operation of lamps at high frequency will improve lamp efficacy by around 10% compared to operation at mains frequency (US Federal Register 2011).

During testing the correlated color temperature (CCT) and color rendering index (CRI) of the lamps were also measured in accordance with the relevant International Commission on Illumination (CIE) test procedure. Four samples of each lamp model were tested.

The following section presents the results of lamp testing.

3.2. Analysis of Lamp Test Results

3.2.1. Tested Lamps

Table 33 lists the key details of all the lamp models tested (4 samples of each model were tested). Rated performance claims are presented, where they were available. Note that rated information was not available for several lamp models, particularly where those models represent lesser known brands (e.g. with limited information printed on packaging or available online).

Due to the variety of outlets where lamps were purchased (e.g. low cost on-line vendors versus high cost small specialty stores) the stated lamp cost ($/lamp), whilst still useful in differentiating inexpensive from expensive lamps, should be treated with caution. Note also that very high lamp prices (considered outliers) are not presented.

Table 33: Details of tested lamps (where available from packaging and catalogues)

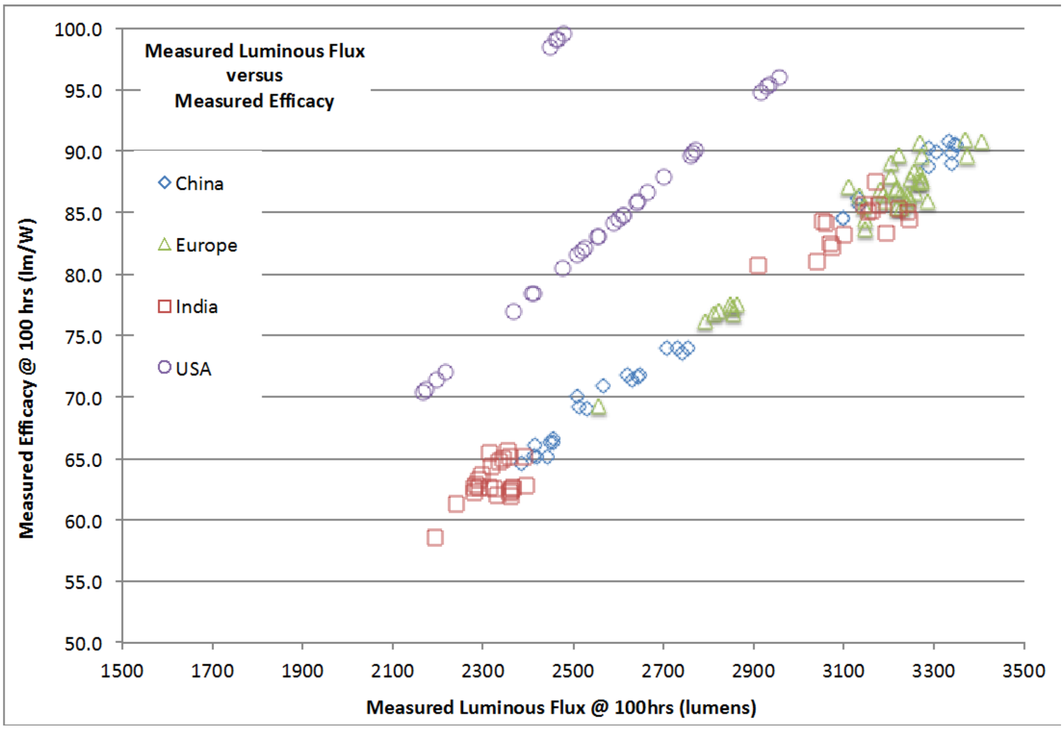
Model ID	Origin	$/lamp (USD)	Rated Power (W)	Rated CCT (K)	Rated Life (hrs)	Rated CRI	Phosphor Type	Rated Flux (lm)	Rated Efficacy (lm/W)	Claimed Energy Rating
CH01	China	$2.36	36	6500	12000	75	halophosphate	2500	69.4	
CH02	China	$3.93	36	6500		80	triphosphor	3200	88.9	
CH03	China	$2.83	36	6500	15000	80	triphosphor	3070	85.3	
CH04	China	$1.18	36	6500	13000	70	halophosphate	2500	69.4	
CH06	China	$1.34	36	6500	15000	80	triphosphor	3024	84.0	
CH07	China	$0.71	36	6500			halophosphate			
CH09	China	$0.63	36	6500	12000	70	halophosphate	2500	69.4	
CH10	China	$0.63	36	6500			halophosphate			
IN01	India	$1.28	36	4000			triphosphor	3250	90.3	5
IN02	India	$0.89	36	6500	15000		halophosphate	2450	68.1	3
IN03	India	$1.58	36	2700			triphosphor	3250	90.3	5
IN04	India	$0.59	36	6500	5000		halophosphate	2425	67.4	3
IN05	India	$0.63	36	6500	15000		halophosphate	2500	69.4	3
IN06	India	$0.72	36	6500	5000		halophosphate	2500	69.4	3
IN07	India	$1.80	36	4000	18000	80	triphosphor	3350	93.1	5
IN08	India	$0.53	36	2700	15000	80	triphosphor	3250	90.3	5
IN09	India	$1.39	36	6500	13000	70	halophosphate	2450	68.1	3
IN10	India	$0.51	36	6500	5000		halophosphate	2450	68.1	3
UK01	UK	$4.15	36	4000	15000	80	triphosphor	3350	93.1	A
UK02	UK	$4.15	36	4000	20000	80	triphosphor	3350	93.1	A
UK03	UK	$4.15	36	4000	20000	80	triphosphor	3370	93.6	A
UK04	UK	$4.15	36	4000	15000	80	triphosphor	3350	93.1	A
UK05	UK		36	4000	10000		triphosphor	3200	88.9	A
UK06	UK	$2.34	36	4000	15000	80	triphosphor	3350	93.1	A
UK07	UK		36	4000	15000	80	triphosphor	3350	93.1	A
UK08	UK		36	4000	15000	90	triphosphor	2800	77.8	A
UK09	UK	$3.73	36	4000	16000	80	triphosphor			A
UK11	UK		36	4000		80	triphosphor	3350	93.1	A
US01	USA	$2.68	32	3500	30000	78	triphosphor	2800	87.5	
US04	USA	$4.30	25	4100	32000	82	triphosphor	2400	96.0	
US05	USA	$2.43	32	4100	20000	73		2850	89.1	

Model ID	Origin	$/lamp (USD)	Rated Power (W)	Rated CCT (K)	Rated Life (hrs)	Rated CRI	Phosphor Type	Rated Flux (lm)	Rated Efficacy (lm/W)	Claimed Energy Rating
US06	USA	$3.75	32	4100	15000	78	triphosphor	2500	78.1	
US07	USA	$2.50	32	4100	20000	75	triphosphor	2800	87.5	
US08	USA	$2.39	32	4100						
US09	USA	$3.99	32	4100	20000	78	triphosphor	2600	81.3	
US10	USA	$2.06	32	4100	24000	80	triphosphor	3150	98.4	

3.2.2. Results

Test results were collected from each of the three laboratories and mated with other information such as rated lamp values and lamp cost, etc. Figure 38 graphs the measured lamp luminous flux, versus measured efficacy, for all 144 lamp samples tested.

Figure 38: Measured luminous flux versus measured efficacy (result for each single lamp sample)



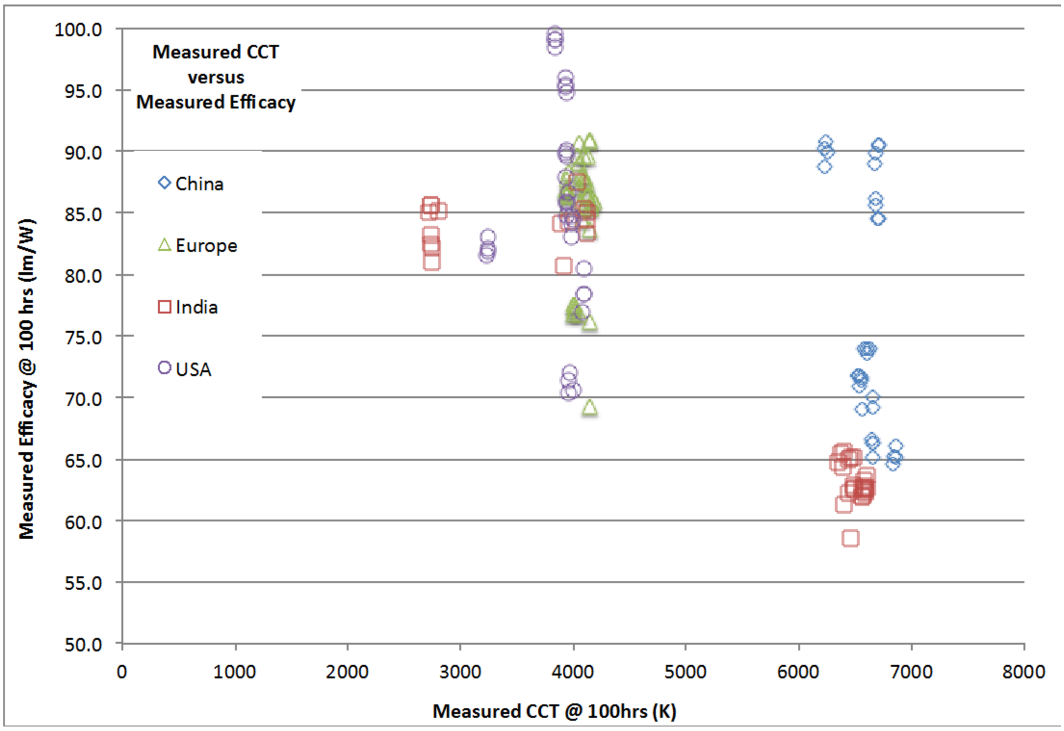
In Figure 38 we can see the Chinese, Indian and European lamps (36W) grouped along a line with a slope of 1/36W, and the 32W US lamps similarly grouped. Note that as lamp wattages are fixed, increases in light output will trend linearly with increases in efficacy.

The upper USA lamp values are for a high performance 25W lamp model which is designed to replace a 32W lamp. This lamp exhibited the highest efficacy (almost 100 lm/W) of the study. This is approaching twice the efficacy of the poorest lamp sample, which measured 58.6 lm/W.

From Figure 38 we can deduce that there is a very wide spread of lamp efficacy , with luminous flux ranging from around 2150 to around 3450 lm and efficacies from 58 to 100 lm/W.

Figure 39 graphs the measured correlated color temperature (CCT) of each sample, against its efficacy.

Figure 39: CCT versus efficacy (raw results for each lamp sample)



The test result dataset (albeit from a small sample size) supported the known relationship between color temperature and efficacy – lamps with higher color temperatures were less efficient. The Indian lamps illustrate this point well - Indian lamps of three color temperatures were sampled, rather than a single color temperature as occurred for the other three economies. The 6500K Indian lamps were significantly less efficient than the 2700K and 4000K lamps.

Figure 40 graphs the measured color rendering index (CRI) versus efficacy.

Figure 40: CRI versus efficacy (raw results for each lamp sample)

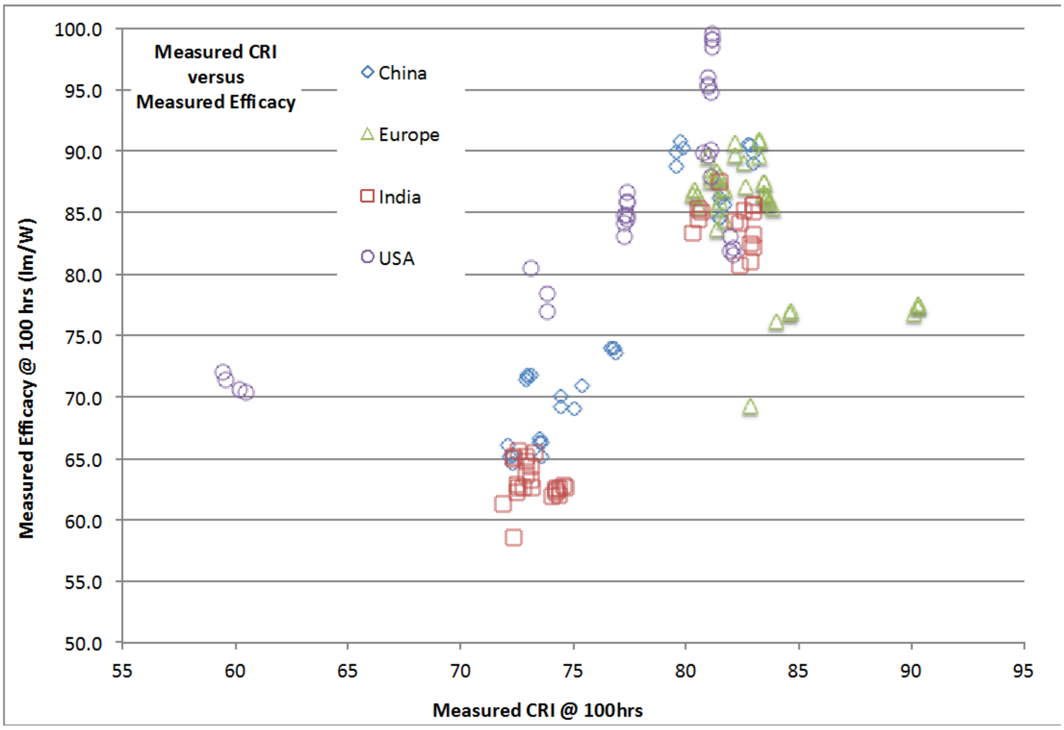


Figure 40 appears to show two interesting phenomena with respect to the relationship between CRI and efficacy.

Firstly, the "low cost" lamps are essentially commodity products with price as their key selling point. Manufacturers use as little of the costly phosphors as possible to get the desired lamp performance. The poor phosphors result in lamps with poor CRI and poor efficacy.

Secondly, "high cost" lamps value performance over first cost - manufacturers may be investing in quality triphosphors but making subtle design changes that result in performance trade-offs. For example, they may sacrifice some efficacy in order to achieve a very high CRI – it is possible that this is the case for the European lamps.

Also appearing in Figure 40 is one US lamp with very poor CRI and efficacy. This is a low-cost, low-recognition brand of lamp purchased from a local hardware store.

3.3. Comparison of Test Results with MEPS and Labeling Requirements

For each of the four economies sampled, the test results, rated values and MEPS/labeling efficacy requirements are compared in this section. Note the following for the graphs appearing in this section:

- The plotted "measured efficacy" is the average (mean) measured efficacy of the 4 samples tested, for each particular lamp model.
- The plotted "rated efficacy" is the rated efficacy of each lamp model. These data points are generally close to the measured efficacy values. Note that one apparent data point may actually represent a number of lamp models that have the same rated values.

These data are presented for each country in the following sub-sections.

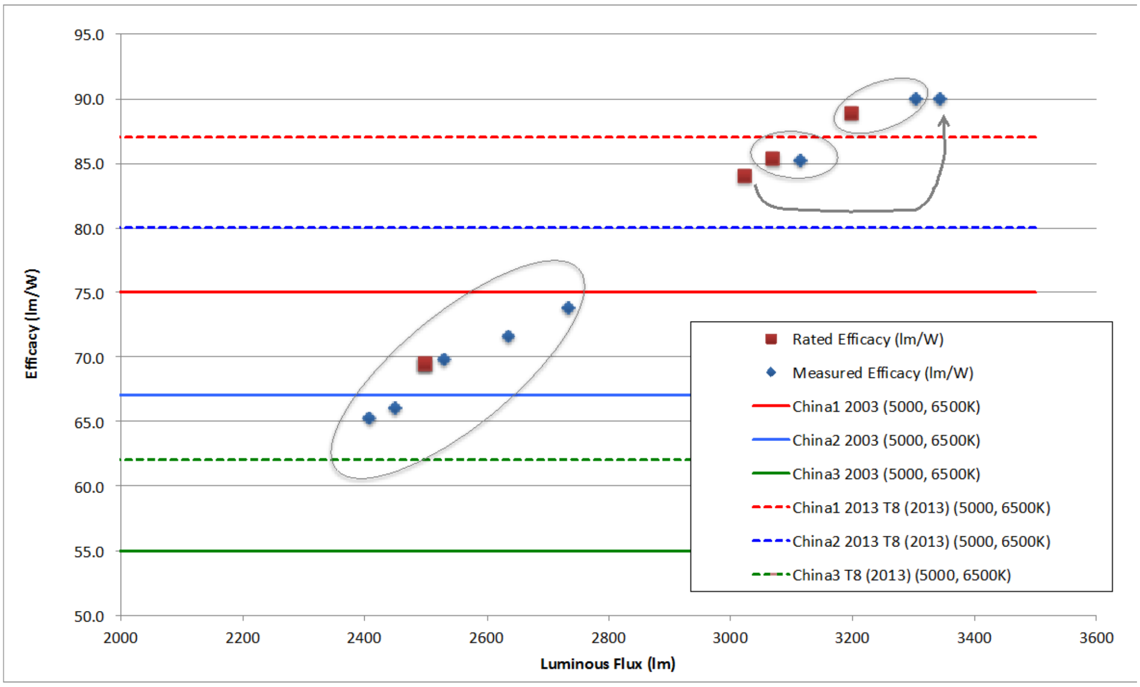
3.3.1. China

Figure 41 shows results for the lamps purchased in China. China has a three-tier system of lamp efficacy requirements, which can be expressed (approximately) as follows:

- Tier 3 = MEPS
- Tier 2 = "recommended"
- Tier 1 = "target".

These tiers are graphed in Figure 41, both for previous (adopted in 2003) and new (2013) values.

Figure 41: Comparison of MEPS, rated and measured efficacy (Chinese lamps)



Note in the above figure that related rated and measured values are grouped by gray lines and ovals.

As can be seen in Figure 41, the Chinese rated and measured lamp values compared relatively well. All of the test lamps also meet the 2013 tier 3 (MEPS) requirements.

3.3.2. Europe

Figure 42 graphs measured and rated values for the UK-sourced lamps, alongside the European MEPS requirement (Regulation 245/2009 - Ecodesign Requirements for Fluorescent Lamps without Integrated Ballast).

Figure 42: Comparison of MEPS, rated and measured efficacy (European lamps)

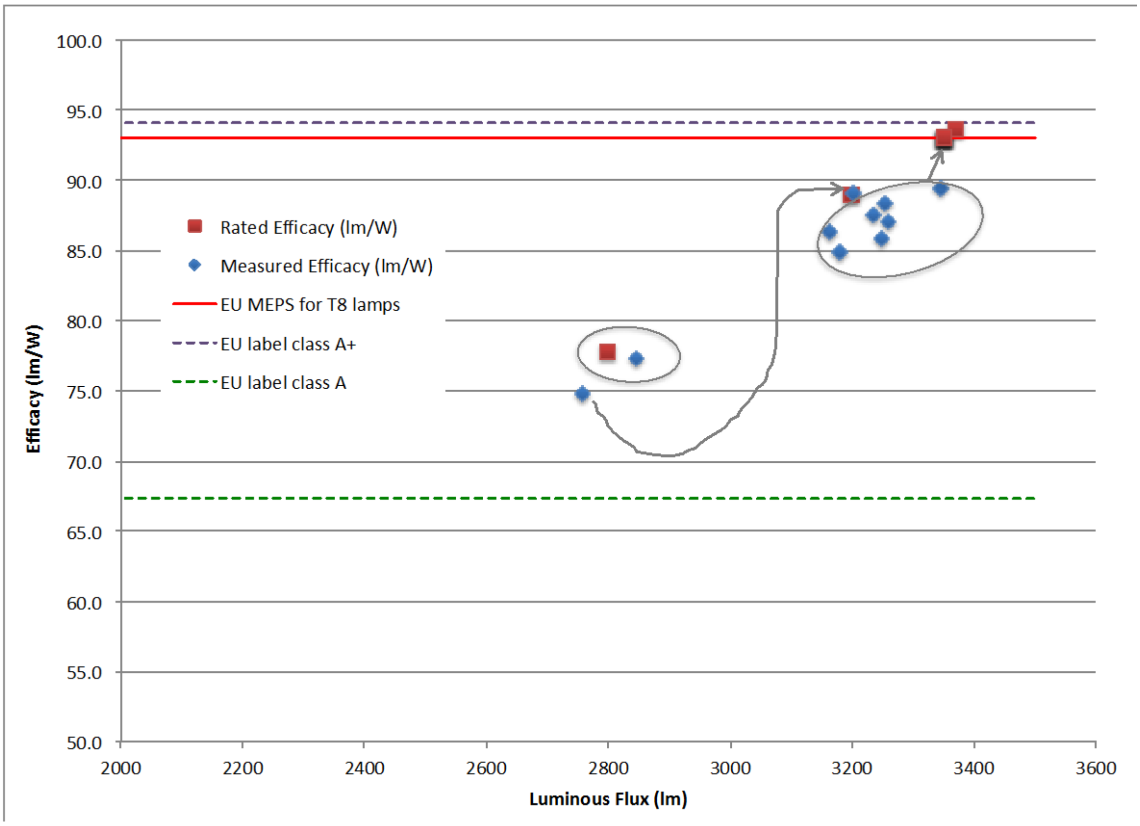


Figure 42 shows that most of the lamps tested claim efficacies that would meet MEPS (note that the upper two data points represent 7 lamps with the same or similar claimed efficacies). The remaining two lamps did not have rated values which met MEPS.

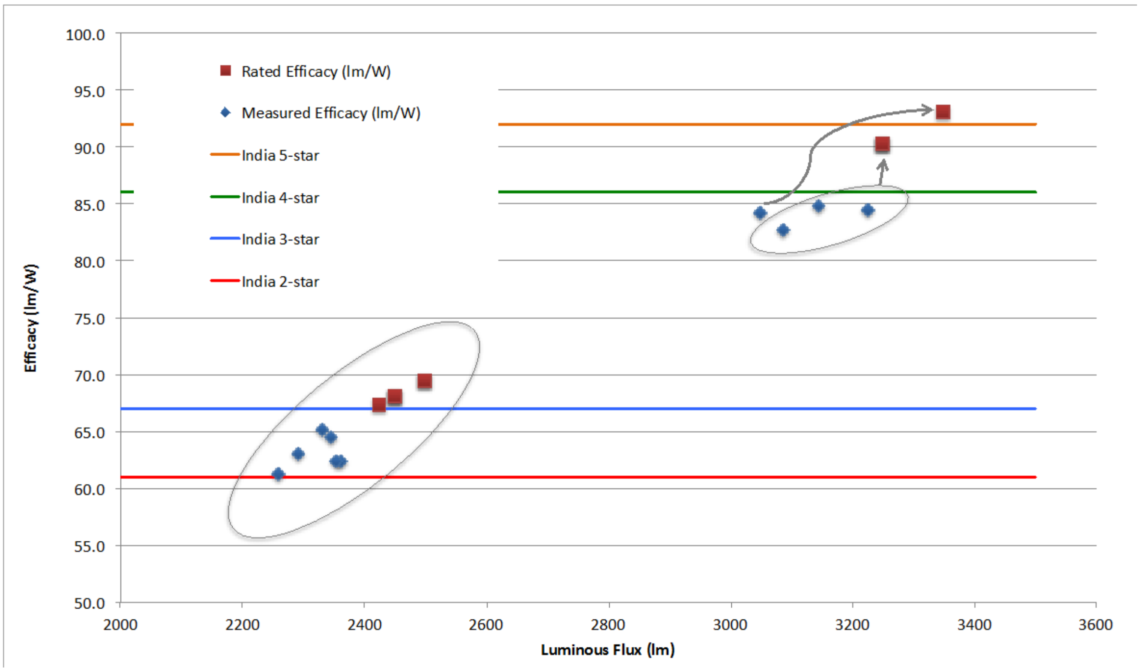
Note in the above figure that related rated and measured values are grouped by gray lines and ovals. With the exception of one particular lamp, measured values were slightly lower than rated values, although it should be noted that European MEPS are couched in terms of rated values, and the appropriate IEC lamp performance standard (IEC 60081) allows an 8% difference between the rated and measured luminous flux, and a 5% difference between rated and measured lamp power. Allowing for an 8% reduction in luminous flux has the effect of lowering the effective efficacy requirement (i.e. when assessed from the viewpoint of actual measured performance) from 93 to 85.6 lm/W. Many of the tested lamp models passed this effective limit, although two lamp models failed significantly (efficacies of 75-77 lm/W). Two models very slightly failed this effective limit.

Also graphed on Figure 42 are the efficacy requirements for class A and class A+ of the European energy label for lamps. All tested lamps claimed to be class A and all lamps met the efficacy requirement for class A. Note that the class A labeling level is below MEPS because the labeling regime applies to a very wide range of lamps – from incandescent lamps to LEDs. Note also that, like MEPS, the requirements for the European energy label for lamps is described in terms of rated lamp values.

3.3.3. India

Figure 43 graphs the rated and tested values for Indian lamps. India does not have an official minimum MEPS requirement for lamps, but does have a mandatory lamp labeling regime. The minimum efficacy limits for 2 star to 5 star labels are shown in the figure. All lamps below the 2-star limit (61 lm/W) are considered 1 star (i.e. there is no 1-star minimum limit).

Figure 43: Comparison of star rating bands, rated and measured efficacy (Indian lamps)



In Figure 43 we can see a clear grouping of halophosphate (lower left) and triphosphor (upper right) Indian lamps. It would also appear that the star ratings were established to accommodate the (possibly rated) values of halophosphate versus triphosphor lamps – i.e. 2-3 star and 4-5 star respectively.

The halophosphate lamps were rated 3 star but tested to be 2 star only (for 100 hour tests only). The triphosphor lamps were rated 5 star but tested as 3 star (very close to 4 star). Note that the Indian star rating system does require ratings to be based on measured values rather than rated values (i.e. no tolerance allowed - rated values allow a difference between the rated value and the actual performance of the lamp). This is supported by the following words from the regulation:

> *However, no tolerances shall be applicable on declared performance values on the label.*
>
> *The measured values will be converted to star ratings for each point i.e. at 100 hours, 2000 hours, 3500 Hours and the average of the 3 ratings will be taken. This will be rounded of (<0.5 to lower level and =>0.5 to higher level) to the nearest integer which will be the star rating for the product.*

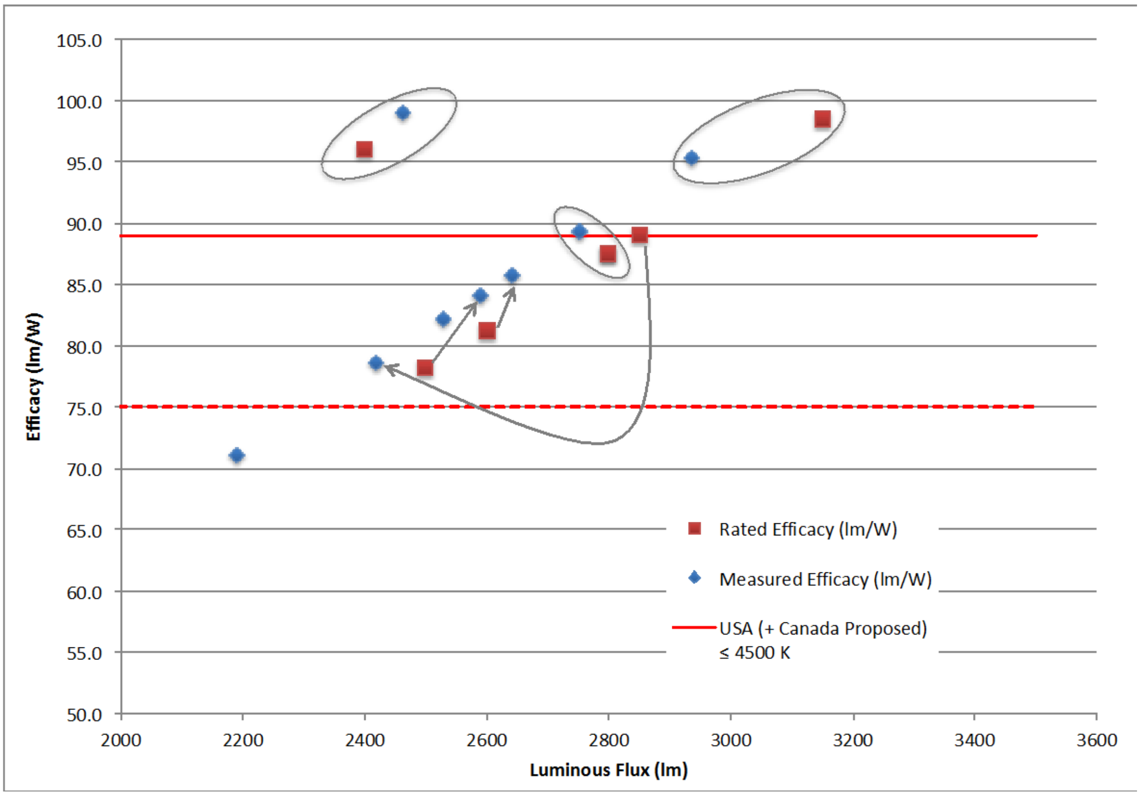
Thus it seems possible that lamps might have 2000 and 3500 hour measurements that improve the average, and allow what appear to be 2 star lamps to achieve a rating of 3 stars. Without testing at 2000 and 3500 hours this cannot be clarified.

In Figure 43 we can also see that measured values were somewhat lower than rated values (related rated and measured values are grouped by gray lines and ovals). The IEC standard 60081 (on which the Indian lamp standard is based) allows an 8% difference between the rated and measured luminous flux, and a 5% difference between rated and measured lamp power. All but one lamp model was within the permissible 8% flux tolerance (its flux was 9% lower than rated). As can be seen from the figure above, with the exception of one model, the rated efficacy values did meet the claimed star rating (5 star triphosphor lamps at top right and 3 star halophosphate lamps at bottom left).

3.3.4. USA

Figure 44 graphs measured and rated efficacies for the US-sourced lamps.

Figure 44: Comparison of MEPS, rated and measured efficacy (US lamps)



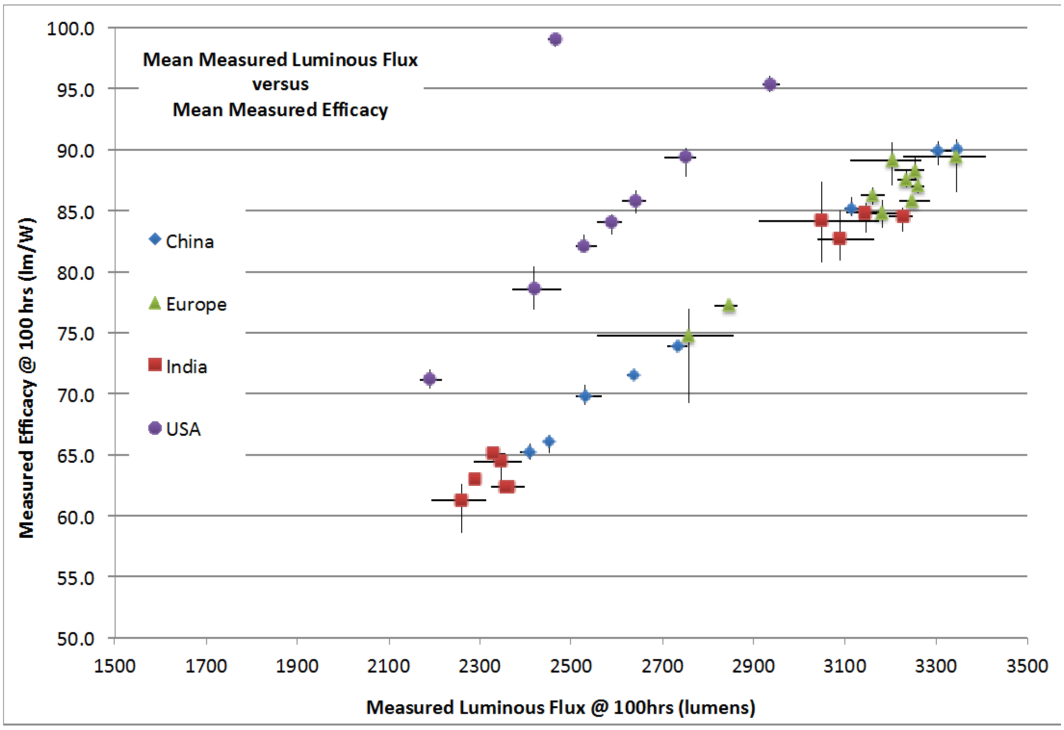
Note that related rated and measured values are grouped by gray lines and ovals.

From Figure 44 it appears that many of the tested lamps are below the current MEPS requirement, although this can be explained by an exemption from current MEPS, for certain manufacturers, which was granted from July 2012 until July 2014 (US DOE 2013). This exemption allows certain manufacturers to adhere to the previous MEPS (75 lm/W) for 2 years. Manufacturers were required to apply for this exemption and it was granted to several successful applicants, including the major lamp manufacturers and the majority of the lamps tested for this study. We note that one model (the previously discussed "low-cost" model that had low efficacy and low CRI) also appears to fail to meet the previous MEPS standard.

3.4. Comparison of Results Between Economies

Figure 45 graphs the average (mean) flux and efficacy results for each lamp model tested. The error bars in this figure represent the variation between samples of the same model (4 samples of each model were tested).

Figure 45: Luminous flux versus efficacy (mean results for each model)



From Figure 45 the following conclusions were drawn:

The lamps tested exhibit a very broad range of efficacy, from around 60 to 100 lm/W. Lamp light output (luminous flux) also varies from 2150 to 3400 lm.

There is a clear distinction between halophosphate and triphosphor lamps (also examined in section 3.5). This is particularly evident for the Indian lamps, which are heavily polarized between halophosphate (~65 lm/W) and triphosphor (~85 lm/W).

The USA and Europe have generally higher lamp efficacies, which is to be expected given the higher MEPS requirements in these economies.

Of the lamps tested (noting the small sample size) Europe had the most efficient. The tested USA lamps (again a small sample size) were less efficient, due presumably to the MEPS exemptions which have been granted to several USA lamp suppliers (discussed in section 2.2).

3.5. Other Comparisons

Figure 46 graphs rated and mean measured efficacy for all lamp models tested. In most cases, measured values were typically within 8% of rated values. This is a common occurrence for lamps – e.g. the IEC performance standard 60081 allows an 8% tolerance between rated and measured light output.

Figure 46: Rated versus mean measured efficacy

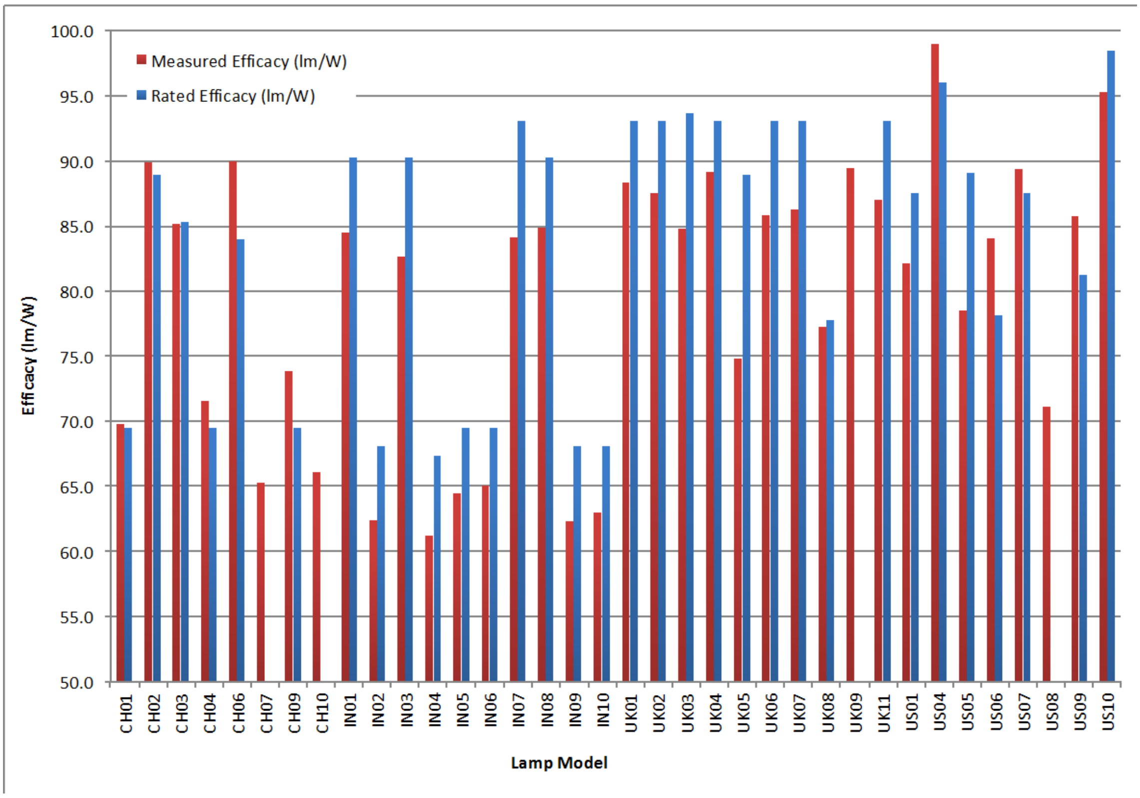
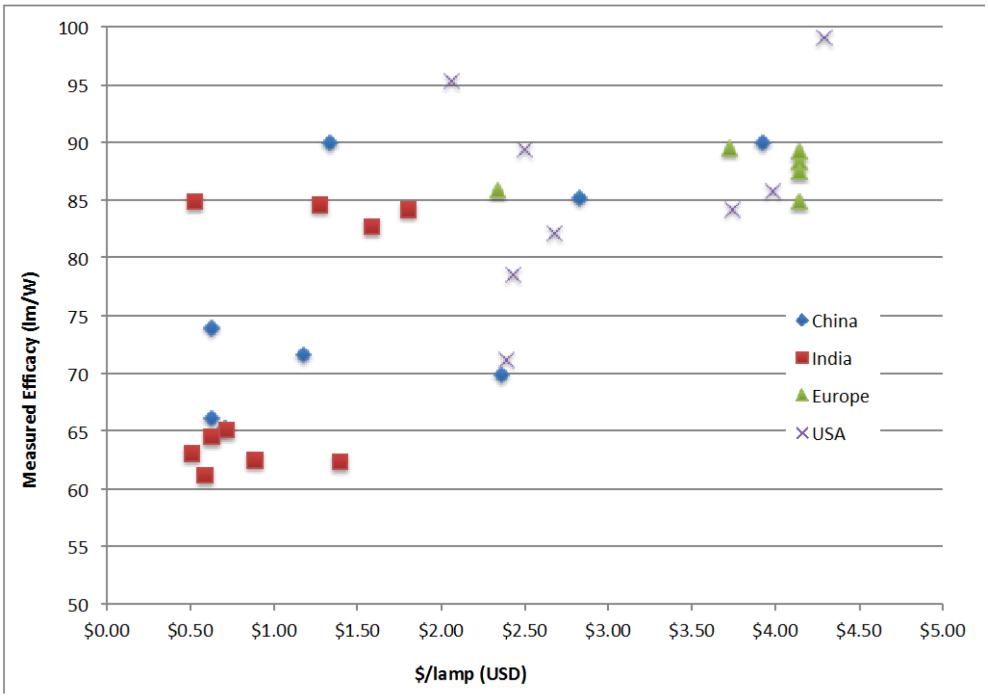


Figure 47 graphs the cost per lamp versus efficacy.

Figure 47: Lamp price versus measured efficacy (all 4 tested economies)



In Figure 47 there is a visible relationship between cost and efficacy. Note that 3 outliers were removed from this graph (UK lamps purchased from a local hardware store at very high cost). Due to the variety of outlets where lamps were purchased (e.g. low cost on-line vendors versus high cost small specialty stores) the stated lamp cost ($/lamp), whilst still useful in differentiating inexpensive from expensive lamps, should be treated with caution.

Figure 48 graphs the cost per lamp versus CRI. A price versus color quality relationship is apparent here, which is to be expected. Again, this should be used with caution and the correlation is less clear than is apparent in the price-efficacy relationship.

Figure 48: Lamp price versus measured CRI (4 tested economies)

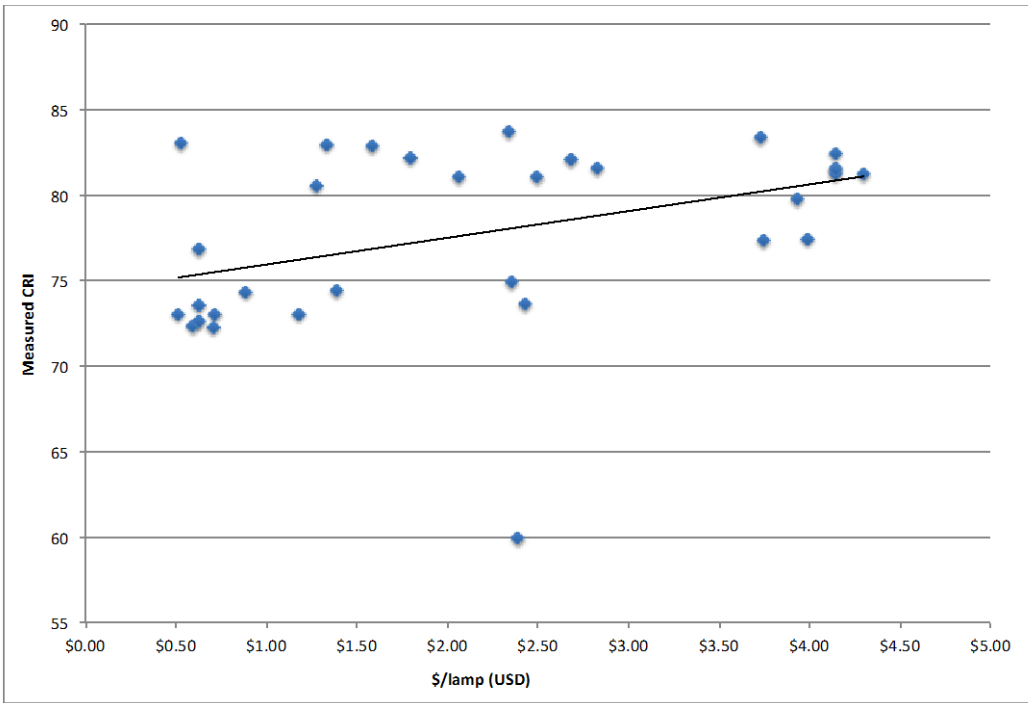


Figure 49 compares efficacy with CRI. We can see here that more efficient lamps generally have better color rendering properties, which is to be expected - these attributes are a function of lamp quality and presence of triphosphor coatings.

Figure 49: Measured efficacy versus measured CRI (4 tested economies)

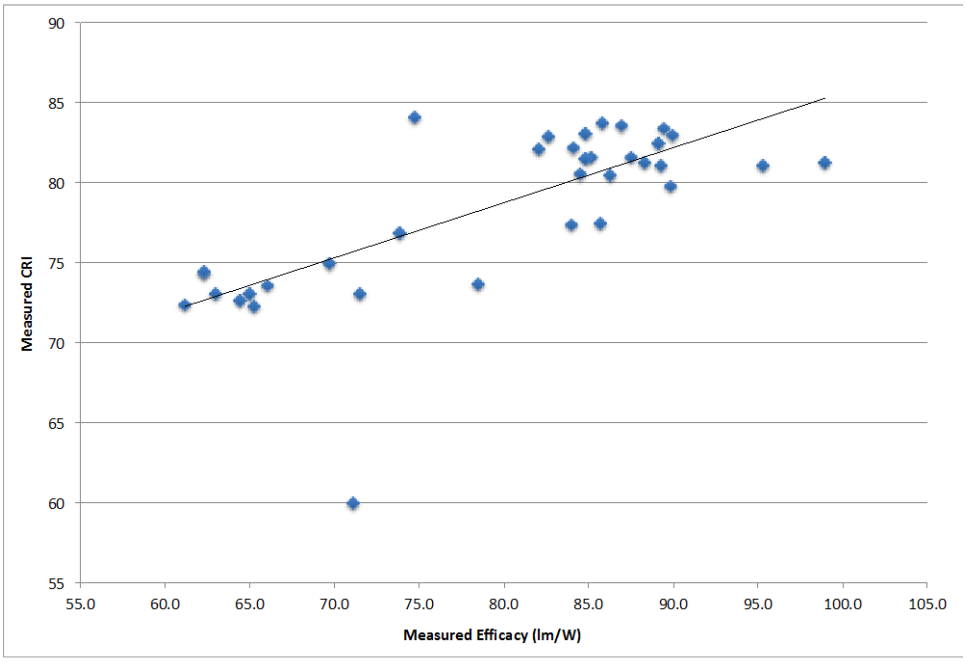
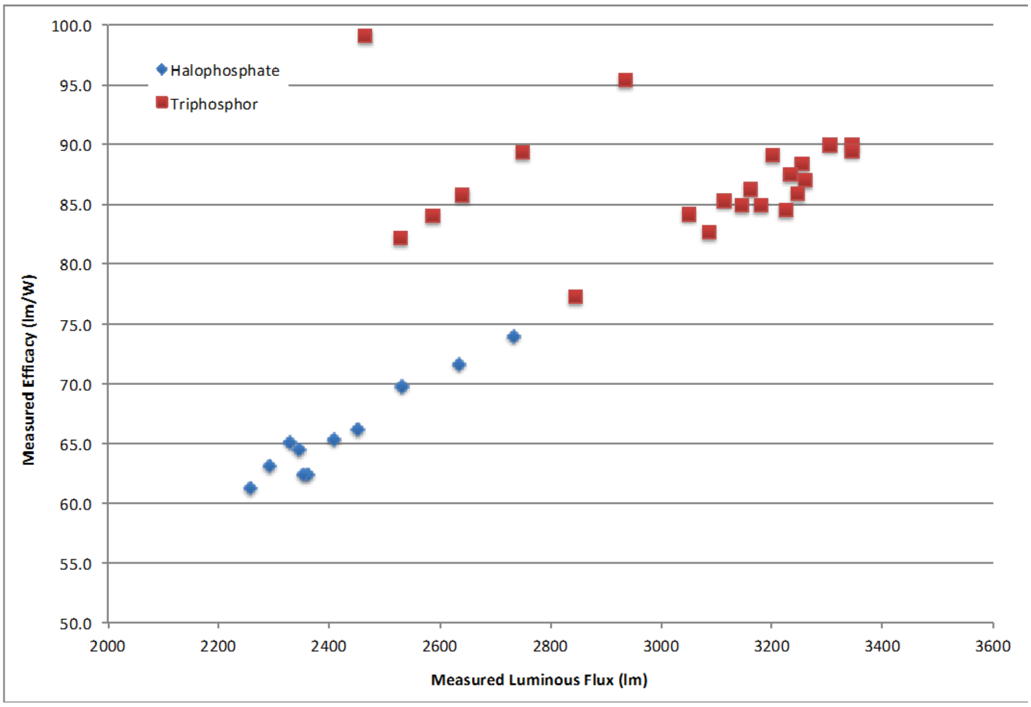


Figure 50 plots light output and efficacy, by apparent lamp phosphor type. The phosphor type was determined from lamp code – a "7" lamp code (meaning CRI of 70+) is generally understood by the lighting industry to be a halophosphate lamp and this was used to determine phosphor type.

Figure 50: Efficacy of halophosphate and triphosphor lamps



As expected, Figure 50 shows triphosphor lamps typically measuring 80+ lm/W whereas the halophosphate lamps were less than 75 lm/W.

3.6. Ballasts and Luminaires

Whilst this study is focused primarily on the energy performance of linear fluorescent lamps, it is important to note that lamps are a part of a lighting system – the performance of the ballast and luminaire into which lamp or lamps are installed have a significant impact on the efficiency of the system. For this reason, ballast and luminaire efficiency are briefly examined in this section. An illustrative example is also provided, based on test results, of how lamp, ballast and luminaire efficiency each contribute to the overall system efficiency.

3.6.1. Ballasts

Fluorescent lamps require a ballast in order to operate. The ballast is wired in series with the lamp(s) and serves control lamp starting and to limit the electrical current supplied to the lamp(s) during operation. Traditionally ballasts were similar in construction to transformers – comprised of copper windings and an iron core. Electronic ballasts have now become significantly more common, and the international fluorescent ballast market is currently in transition from the less efficient magnetic (wire-wound) ballasts to significantly more efficient electronic units.

Electronic ballasts operate fluorescent lamps at high frequency (typically 20kHz or higher) whilst magnetic ballasts operate lamps at mains frequency (50/60 Hz). At a given power, fluorescent lamps produce 10% more light when operated at high frequency (US Federal Register 2011). In addition, electronic ballasts have significantly lower heat losses (approximately 2W for electronic and 8W for magnetic). Electronic ballasts can also incorporate other power saving features, such as cathode cut-off circuits which eliminate cathode power use after start-up.

Some economies, such as the USA, have already experienced a market shift to electronic ballasts, which now dominate new ballast shipments. Concerted efforts by regulators, energy efficiency organisations and utilities within the USA have helped to accelerate this market shift. MEPS and labeling schemes for ballasts also vary widely across economies.

There are also a variety of metrics used to describe ballast efficiency. The USA is currently transitioning from using MEPS that rely on a photometry-based metric (ballast efficacy rating or BEF) to one that is purely based on the electrical efficiency of the ballast (ballast luminous efficiency or BLE). The BLE is the ratio of total lamp arc power that the ballast delivers to the total input power that the ballast draws. For example, an ideal ballast (i.e. no ballast losses) would convert all of its input power into lamp arc power and thus would have a BLE of 1.0. Ballast BLEs can range from as low as 0.75 for inefficient ballasts to more than 0.9 for efficient systems.

3.6.2. Luminaires

The luminaire houses the lamps and ballasts and distributes the lamp's light. Luminaire design has a significant impact on the efficiency of a fluorescent lighting system, although quantifying and regulating luminaire efficiency can be difficult. This is in part due to the fact that luminaires have many different applications and often are designed with goals that extend beyond those entirely related to efficiency (e.g. aesthetic design, glare mitigation, etc.). This wide variety of applications and design objectives leads directly to a wide range of luminaire efficiencies - best described as the fraction of total light produced which exits the luminaire.

For example, a luminaire that places a light source relatively deep in a reflector cavity (e.g. recessed downlight) in order to control glare and direct light towards a target area, may have a luminaire efficiency of less than 50%. Meanwhile, a luminaire that has only limited glare mitigation and light directing optics (e.g. direct-indirect pendant) can achieve luminaire efficiencies of 90% or more.

Being mindful of these issues, regulators worldwide have been reluctant to develop MEPS for luminaires. The USA and the EU have taken some steps in recent years to investigate standards (MEPS or labeling) that could be used to try to encourage the use of higher optical efficiency designs and/or the expanded use of lighting controls systems. However, the regulatory mechanism that has been most widely used to promote luminaire efficiency has been building standards. Under mandatory buildings standards, building designers are required to meet maximum power density limits for lighting. This encourages designers to select efficient luminaires but allows them the flexibility to specify luminaires that are appropriate to the application and to other design goals such as aesthetics.

However luminaire MEPS are still considered to be a useful regulatory mechanism for buildings or refurbishments which are not effectively captured by building standards. Luminaires MEPS may also be particularly appropriate for luminaire types that have minimal aesthetic considerations and where efficiency is a key driver (e.g. recessed troffers, high bay lighting, etc.).

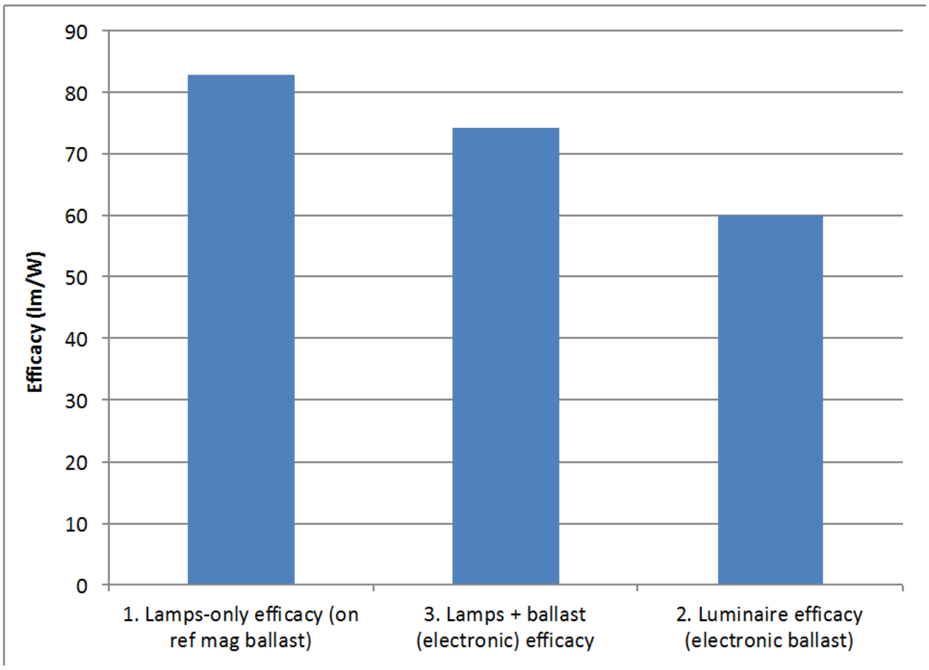
3.6.3. Illustrative Example of System Efficiency

In order to help illustrate the effect of ballast and luminaire losses on the efficiency of fluorescent lighting systems, a number of tests were conducted as part of this study. These tests used two of the USA linear fluorescent lamps that were tested previously (as discussed in section 3 of this report). These two lamps were then operated in a twin-lamp luminaire. Tests that were conducted as part of this illustrative example included:

- Lamps on a magnetic reference ballast: this is the test performed for all lamps, as described in section 3 of this report. This yields a lamp-only efficacy characterization (i.e. independent of any ballast losses) for the two lamps.
- Lamps in a luminaire: these same two lamps were operated in a twin-lamp lensed "wrap-around" luminaire which included a single electronic ballast able to operate two lamps. This yielded luminaire net light output, luminaire power input and luminaire efficacy of a "real-world" luminaire (low cost luminaire purchased directly off the shelf).
- Lamps on an electronic ballast: The electronic ballast was then removed from the above luminaire and used to operate the two lamps in an integrating sphere (lamps widely spaced to minimize light reabsorption). This generated a lamp + ballast characterization (lumen output, power input, efficacy) of these two lamps on a particular ballast (as opposed to on a reference ballast, as in #1).
- Ballast Luminous Efficiency (BLE): A measurement of the BLE (described in section 4.1) of the electronic ballast was also conducted.

Figure 51 yields the results of the first three tests described above. Efficacy drops from 82.5 lm/W for the lamps-only test (magnetic reference ballast) to 74.0 lm/W (lamp/ballast system efficacy) when tested on the electronic ballast and finally down to 59.9 lm/W when placed in the luminaire (lamp/ballast/luminaire system efficacy).

Figure 51: Efficacy measurements for lamps-only, on electronic ballast, in luminaire



Note that the luminaire is a lensed "wrap-around" (surface-mount) luminaire, which may be more or less efficient than a recessed luminaire typically found in an office application (recessed mount).

A second, related exercise was conducted as follows:

- Measure each individual component:
    - Bare lamp efficacy.
    - Ballast BLE.
    - Luminaire light output ratio (LOR) – the ratio of light emitted from the luminaire, to the light emitted from the light source(s).
    - Combine these measurements, using theoretical equations, to calculate a "theoretical luminaire efficacy".
    - Measure luminaire efficacy (system as a whole, in integrating sphere) = "measured luminaire efficacy".
    - Compare "theoretical luminaire efficacy" with "measured luminaire efficacy".

The theoretical equations used to combine the individual component measurements were as follows:

BLE = lamp power ÷ ballast power

Lamp efficacy = lamp lumens ÷ lamp power

Luminaire lumens = lamp lumens x luminaire LOR

Luminaire efficacy = luminaire lumens ÷ ballast power

Rearranging these equations we get:

Theoretical luminaire efficacy = BLE x lamp efficacy x LOR

The measured values for each of the right hand terms in this equation are presented in Table 34 along with calculation of the result for this equation, and the result when the entire luminaire system was measured in the integrating sphere.

Table 34: Results of theoretical versus measured luminaire efficacy

Measured BLE (electronic ballast)	0.861
Measured lamp efficacy (on magnetic reference ballast)	82.55 lm/W
Increase above lamp efficacy by 10% in order to estimate the impact of using an electronic ballast (i.e. as supplied with luminaire)	90.80 lm/W
Measured luminaire LOR	0.76
Theoretical luminaire efficacy = 0.861 x 90.80 x 0.76	59.4 lm/W
Measured luminaire efficacy (system as a whole, in integrating sphere)	59.9 lm/W

The theoretical and measured values for luminaire efficacy agreed very closely, suggesting that this kind of theoretical “sum-of-the-parts” analysis can be used effectively to estimated total system performance.

Note that as markets shift further toward electronic ballasts, there is likely to be a need to update test procedures so that high frequency reference ballasts are used. High frequency reference ballasts are already specified by some test procedures for lamp types which only operated on electronic ballasts (e.g. T5 lamps). These changes would eliminate the need for the correction factor for frequency used above, and would result in the BLE being a more intuitively obvious metric for determining ballast efficiency.

4. Conclusions and Recommendations

4.1. Conclusions from Policy and Market Mapping

Table 35 summarizes the relative performance of linear fluorescent lamp and ballast policies and markets in the economies analysed for this study (noting that there are limitations on the accuracy of some data used in the analysis - as discussed in the dedicated report section for each economy). A tick/cross system was used in order to create a visual indication of how economies are performing with regard to the relative efficiencies of linear fluorescent lamps and ballasts in those economies. It is accepted that each of these economies is subject to a different set of economic and social circumstances, some of which may make it easier or harder to adopt efficient technologies or effective policies. No judgment is made of any economy - the purpose of this report is simply to point out various aspects of linear fluorescent markets in the target economies.

In Australia, MEPS has effectively removed halophosphate and T12 lamps from the market. The market share of T5 lamps is significant and increasing, and the luminaire/ballast market is now dominated by electronic units.

Canada's MEPS does not currently mandate triphosphor lamps, although Canada has proposed a new MEPS which will harmonize with the USA (see below). Halophosphate T8 and T12 lamps appear to have remained popular in Canada. Sales of T5 lamps are increasing. Similar to the US, the Canadian ballast/luminaire market is a good performer, appearing to have moved considerably towards electronic ballasts.

In China, halophosphate lamps remain popular, although T12 lamp sales appear relatively low. T5 sales are significant and growing. Little is known about the domestic market for ballasts in China, although a MEPS is in place for ballasts.

In the European Union, MEPS has resulted in halophosphate lamps largely being replaced by triphosphor lamps. The market share of T5 lamps is increasing and T12 is decreasing. No robust data was available to make any conclusions about the ballast market in the EU.

India (effectively) has MEPS in place for linear fluorescent lamps (via a mandatory lamp labelling regime) but not for ballasts, which does however have a voluntary label. T12 and halophosphate lamps remain popular. The market share of T5 lamps and electronic ballasts is unknown.

The US has MEPS for fluorescent lamps that should mandate T8 triphosphor lamps, however halophosphate lamps continue to be available due to a MEPS exemption granted until July 2014. The market share of T5 lamps is increasing and T12 lamps decreasing (although these remain significant). The US ballast/luminaire market is an exceptional performer, having moved almost entirely to electronic ballasts.

Table 35: Summary of policy and market mapping for 6 economies

		Australia		Canada		China		Europe		India		USA	
Lamps	Most popular CCT	4100K		4100K		6500K		4100K		6500K		4100K	
	Most popular length	4-foot		4-foot		4-foot		4-foot		4-foot		4-foot	
	Most popular power	36W		32W		36W		36W		36W		32W	
	Low-power retrofit lamps commonly available	no	✗	yes	✔	U		yes	✔	U		yes	✔
	MEPS regulations in force	yes	✔	yes	✔	yes	✔	yes	✔	yes	✔	yes	✔
	MEPS regulations mandate triphosphor	yes	✔	no	✗	no	✗	yes	✔	no	✗	yes	✔
	Market share halophosphate (and trend)	0%	✔	high	✗	high	✗	2% ↓	✔	high	✗	medium	✗
	Market share T5 (and trend)	40% ↑	✔	5% ↑	✔	40% ↑	✔	30% ↑	✔	U		10% ↑	✔
	Market share T12 (and trend)	0%	✔	high	✗	low	✔	1% ↓	✔	high	✗	30% ↓	✗
Ballasts	MEPS regulations in force	yes	✔	yes	✔	yes	✔	yes	✔	no	✗	yes	✔
	Market share electronic (and trend)	80% ↑	✔	high ↑	✔	U		U		U		80-90% ↑	✔

Note U = unknown

From Table 35 the following observations are made regarding linear fluorescent lamp and ballast policies and markets in Australia, Canada, China, Europe, India and the USA:

- All six economies have some form of MEPS in place for linear fluorescent lamps, noting that India's MEPS is effectively created by the mandatory star rating system for lamps.
- MEPS for lamps in Australia, Europe and the USA should mandate triphosphor lamps, although halophosphate lamps continue to be available in the USA (due to an exemption granted until July 2014).
- Halophosphate lamps also remain popular in Canada, China and India.
- The market share of T5 lamps is significant and growing in all economies (India unknown).
- All economies have MEPS in place for linear fluorescent ballasts, with the exception of India which has voluntary comparative labeling.
- Electronic ballasts now dominate in Australia, Canada and the USA (other economies currently unknown).

Figure 52 graphs the minimum linear fluorescent lamp efficacy requirements for ten economies (Japan, Korea, Mexico and Thailand have been added). Some simplifications have been applied in order to graph the requirements within a single figure. For example, Australian MEPS requirements are described in terms of lamp length, rather than lamp power, which is the case for most other economies. Lamp lengths were therefore converted to lamp power (using the rated power values of typical T8 lamp lengths e.g. 4-foot = 36W) in order to graph the Australian requirements alongside other economies. This may lead to some confusion, particularly in the case of T5 lamps. In case of any doubt, the regulations and standards for each economy should be consulted for further detail of the various MEPS requirements.

Figure 52: MEPS requirements for 10 economies (simplified)

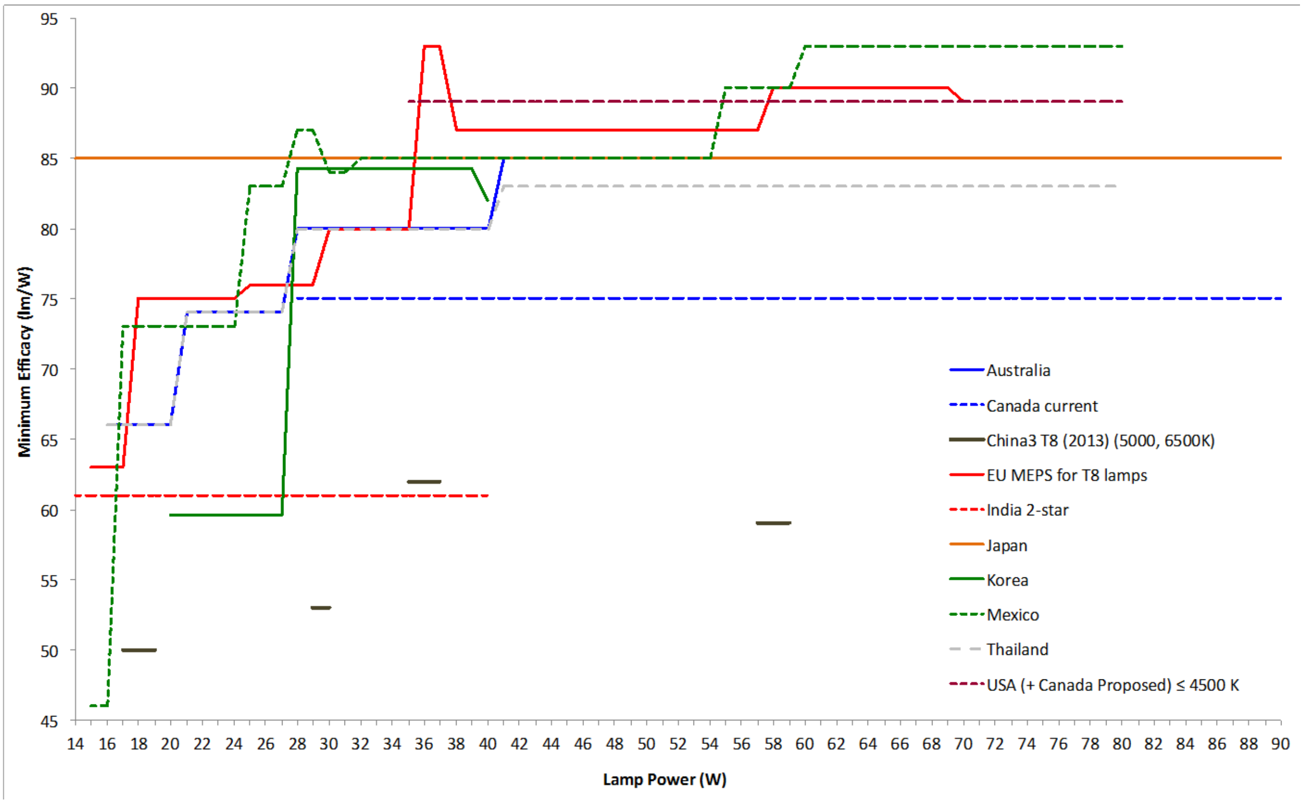


Table 36 lists the MEPS efficacy requirements for each economy, as applies to 4-foot T8 lamps only.

Table 36: MEPS efficacy requirements for 4-foot T8 lamps

Country	Requirement (lm/W)
Europe	93
USA (+ Canada Proposed) ≤ 4500K	89
Japan	85
Mexico	85
Korea	84.3
Australia	80
Thailand	83
Canada (current)	75
China3 (2013) (5000, 6500K)	62
India 2-star	61

From Figure 52 and Table 36 we can roughly group the MEPS requirements for these ten economies into 2 categories:

- High MEPS: MEPS for Australia, Europe, Japan, Korea, Mexico and USA, which require efficacies of 80+ lm/W for 4-foot lamps. Note that Canada currently requires efficacy of 75 lm/W for 4-foot lamps, however Canada has proposed a new MEPS which will harmonize with the USA.
- Low MEPS: countries such as India (note that India has labeling only - no official MEPS program for linear fluorescent lamps exists although labeling acts as a quasi-MEPS) and China, which have relatively low requirements for lamps.

The "high" MEPS requirements (80+ lm/W) will mandate triphosphor lamps, whereas the other MEPS requirements (75 lm/W and lower) will allow halophosphate lamps. Refer section 1.6.1 for a discussion of lamp phosphor types.

4.2. Conclusions from Lamp Testing

The ten economies studied (Australia, Canada, China, Europe, India, Japan, Korea, Mexico, Thailand and the USA) have well harmonized test procedures for linear fluorescent lamps. Thus lamp metrics from these economies can be compared directly, without any need for adjustment or normalization.

For ballasts, differing approaches are taken by various economies regarding test procedures and associated metrics. The USA is currently transitioning from photometry-based metrics to simplified metrics which are based solely on the electrical efficiency of the ballast.

A small sample of 4-foot linear fluorescent lamps sourced from China, Europe, India and the USA were tested and found to exhibit a very wide spread of efficacy, with luminous flux ranging from around 2150 to 3450 lm and efficacies from 58 to 100 lm/W. It is thought that the MEPS requirements in these countries have had a significant effect on lamp efficacy, particularly where MEPS requirements are more stringent.

The tested US and European lamps had generally higher lamp efficacies, which is to be expected given the higher MEPS requirements in these economies.

All tested Chinese-sourced lamps met the 2013 tier 3 (MEPS) requirements, noting that the Chinese requirements are relatively low.

The tested European lamps were amongst the most efficient of all lamps tested. Most tested lamps claimed efficacies that would meet MEPS (European MEPS is expressed in terms of rated values). All tested lamps claimed to be class A (European lamp label) and all lamps met the rated efficacy requirement for class A.

The tested Indian lamps were clearly grouped into halophosphate and triphosphor lamps. The tested lamps (after 100 hours ageing) did typically not meet their claimed energy label ratings (rating system expressed in terms of measured values). Note however that it is possible that these lamps might have 2000 and 3500 hour measurements that improve the average, and allow what appear to be 2 star lamps to achieve a rating of 3 stars. This is permissible in the Indian regulation. However without testing at 2000 and 3500 hours this cannot be clarified.

Many of the tested US lamps were significantly below the current MEPS requirement, which can be explained by a two-year exemption from current MEPS for certain manufacturers.

Generally, measured lamp luminous flux and efficacy were up to 10% lower than the corresponding rated values claimed by manufacturers.

There is a clear efficacy distinction between halophosphate and triphosphor lamps - halophosphate 60-75 lm/W and triphosphor 80-100 lm/W.

The tested lamps (albeit small sample size) supported the known relationship between color temperature and efficacy – tested lamps with higher color temperatures were less efficient.

There is a slight correlation between CRI and efficacy, which is to be expected (i.e. higher quality lamps exhibit both higher efficacy and color rendering properties). However, the tested European lamps showed a contrasting correlation - the lamps with very high CRI exhibit lower efficacies - it is possible that these products have sacrificed some efficacy for better CRI.

Higher priced lamps are generally more efficient with higher CRI.

Testing conducted using a single set of linear fluorescent lamps, ballast and luminaire revealed that the equation: *luminaire efficacy = BLE x lamp efficacy x LOR* can be used to accurately predict net absolute luminaire efficacy.

4.3. Discussion and Recommendations

Linear Fluorescent Lamps

It is clear from the work undertaken for this study, that efforts to achieve a complete transition to triphosphor lamps and electronic ballasts, would be well spent. However this should also be viewed in the context of the increasing popularity of LED linear lamps and luminaires in commercial lighting systems, which should not be ignored. A technology neutral approach could be taken in order to ensure the optimum performance of all linear-style lighting.

For linear fluorescent lamps, a two-tier harmonization effort could be implemented, that allows countries to choose from either a single "high" MEPS limit (mandates triphosphor lamps) or a single "low" MEPS limit which allows either halophosphate or triphosphor lamps. This would allow countries to decide which MEPS best suits their circumstances with respect to issues such as lamp cost and supply of phosphors. The "low" MEPS should also result in some countries increasing their current MEPS requirements, in order to ensure that even halophosphate lamps are relatively efficient (e.g. 75 lm/W rather than 55 lm/W). Countries could also adopt a two-tier system to ensure that both halophosphate and triphosphor lamps meet appropriate efficacy requirements. Countries with no MEPS should also be encouraged to introduce MEPS.

Also worthy of consideration are initiatives that seek to encourage lower power lamps where technically feasible. E.g. in the US 25W lamps are commonly available to replace 32W lamps. Promoting this style of lamp, together with an appropriate minimum efficacy requirement, would ensure that MEPS leads <u>directly</u> to reductions in energy usage, rather than simply increasing lamp light output (which relies on fewer lamps being fitted in order to reduce energy consumption).

The European Union and India both have mandatory comparative energy rating labels for linear fluorescent lamps. Labeling for lamps could also be considered, e.g. as a "bolt on" to a MEPS regime. Note however that the wide spread of efficacy between incandescent lamps and fluorescent / LED lamps means that much thought should be invested in the issue of lamp labelling.

Linear Fluorescent Ballasts

Amongst the economies studied, there are a variety of MEPS regimes for ballasts involving differing ballast efficiency metrics. In addition, the international fluorescent ballast market has been in transition for some time, from less efficient magnetic (wire-wound) ballasts to significantly more efficient electronic units (including dimmable and programmable ballasts). A global harmonization effort could be considered, to align ballast test procedures, efficiency metrics and MEPS.

Similar to the lamp halophosphate / triphosphor lamp issue, a two-tier magnetic / electronic ballast MEPS could be considered - with countries able to choose to mandate electronic-only ballasts if desired. A global effort to eliminate magnetic ballasts from the world marketplace could be also be adopted. Countries without ballast MEPS should also be encouraged to introduce MEPS. As ballasts are not typically an off-the-shelf item, labeling is not considered a high priority – efforts are better spent improving MEPS for ballasts. This is an important issue as efficient ballasts lead <u>directly</u> to power savings, which as discussed above is not the case for lamps.

Linear Fluorescent Luminaires

Luminaire design has a significant impact on the efficiency of a fluorescent lighting system, although quantifying and regulating luminaire efficiency can be difficult. Regulators worldwide have been reluctant to develop MEPS for luminaires. One constraint is absence of an agreed international luminaire standard to deal with photometric and electrical characteristics (noting that the method of photometry does exist). Luminaire MEPS may however still be considered a useful regulatory mechanism for buildings or refurbishments which are not effectively captured by building standards, and for luminaires that have minimal aesthetic considerations and where efficiency is a key driver (e.g. recessed troffers, high bay lighting, etc.). Given the intricacies associated with luminaire MEPS, these are considered a secondary priority, behind MEPS for lamps and ballasts.

References

ABS 2013, Lamp import data purchased from the Australian Bureau of Statistics, 2013.

ACMR 2011, China CFLs and DFLs Market Survey - Research Report, All China Marketing Research Co., Ltd., August 2011.

BEE 2014, lamp sales data provided from the lamp labeling scheme, Indian Bureau of Energy Efficiency, 2014.

CEC 2014, California Energy Commission (CEC) Product Registration Database, accessed on 28 February 2014, www.appliances.energy.ca.gov

DCCEE 2013, A Policy Makers Guide to Mercury in Compact Fluorescent Lamps, Department of Climate Change and Energy Efficiency (Australia), http://www.energyrating.gov.au/resources/program-publications/?viewPublicationID=2441

EU 2012a, PRODCOM, http://epp.eurostat.ec.europa.eu/portal/page/portal/prodcom/introduction

EU 2012b EUROSTAT, http://epp.eurostat.ec.europa.eu/portal/page/portal/international_trade/data/database

IEA 2006, Light's Labour's Lost - Policies for Energy-efficient Lighting, International Energy Agency, 2006.

IEA 4E 2011, Benchmarking Report - Impact of 'Phase-Out' Regulations on Lighting Markets, International Energy Agency, July 2011, http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=5

Light Now 2013/14, Light Now Blogs by Craig DiLouie , based on data from National Electrical Manufacturers Association (NEMA), www.lightnowblog.com/2013/10/t5-fluorescent-lamp-shipments-see-sustained-growth/, www.lightnowblog.com/2014/02/linear-fluorescent-lamp-shipments-retreat-during-third-quarter-of-2013/

NRCAN 2014, Archive data supplied by Natural Resources Canada (NRCAN) from product registration database, http://oee.nrcan.gc.ca/pml-lmp/index.cfm?action=app.welcome-bienvenue

US DOE 2011, US Final Rule Technical Support Document for Fluorescent Lamp Ballasts, www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/62

US DOE 2012, Information Page for General Service Fluorescent Lamps, www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/70#waiver

US DOE 2013, Information Page for General Service Fluorescent Lamps, http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/70

US DOE 2014, Notice of Proposed Rulemaking for General Service Fluorescent Lamps and Incandescent Reflector Lamps, US Department of Energy, 2014, http://www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0006-0045

US Federal Register 2011, Federal Register/Vol. 76, No. 86/Wednesday, May 4, 2011/Rules and Regulations, page 25213. Available from http://www.gpo.gov/fdsys/pkg/FR-2011-05-04/pdf/FR-2011-05-04.pdf

Appendix A: LED Resources

The following are useful resources when examining linear LED lamps as replacements for linear fluorescent lamps:

International Energy Agency – 4E SSL program

ssl.iea-4e.org/task-1-quality-assurance

US Department of Energy - solid state lighting page:

www1.eere.energy.gov/buildings/ssl/index.html

US Department of Energy – Caliper testing program:

www1.eere.energy.gov/buildings/ssl/caliper.html

Lighting Facts label:

www.lightingfacts.com

DesignLights Consortium:

www.designlights.org

Energy Star:

www.energystar.gov/index.cfm?c=ssl.pr_commercial

Lighting Research Center:

www.lrc.rpi.edu/programs/solidstate/index.asp

Appendix B: Further Detail on EU Statistics

EU statistics background

There are two PRODCOM codes for LFLS:

- 27401510 - Fluorescent hot cathode discharge lamps, with double ended cap (excluding ultraviolet lamps)
- 27401530 - Fluorescent hot cathode discharge lamps (excluding ultraviolet lamps, with double ended cap)

It is not clear what the difference is between these two classifications. (This issue was found by the contractors undertaking the Preparatory Study for Ecodesign regulation for tertiary lamps – although the codes themselves have been changed since then). The unit value for the two product codes is significantly different over the period (that for 27401530 is higher). This may include U shaped lamps.

There is a single CN8 (EUROSTAT) product code for LFLs: CN8 code 85393110 described as DISCHARGE LAMPS, FLUORESCENT, HOT CATHODE, WITH DOUBLE ENDED CAP. As for the PRODCOM categories this may include U shaped lamps.

There are two PRODCOM codes for lamp ballasts but these seem to align in a straightforward way with the type of ballast:

- 27115013 - Inductors for discharge lamps or tubes(magnetic ballasts)
- 27115015 - Ballasts for discharge lamps or tubes (excluding inductors) (electronic ballasts)

However it should be noted that these are not ballasts for specifically linear fluorescent lamps – presumably they include those for U shaped lamps and for other forms of discharge lamp.

CN8 (EUROSTAT) product codes for ballasts are:

- CN8 code 85041020 - BALLASTS FOR DISCHARGE LAMPS OR TUBES (EXCL. INDUCTORS, WHETHER OR NOT CONNECTED WITH A CAPACITOR)
- CN8 code 85041080 - INDUCTORS, WHETHER OR NOT CONNECTED WITH A CAPACITOR

PRODCOM categories may also include ballasts other than LFLs.

Countries whose trade included in Eurostat statistics:

- Argentina
- Australia
- Brazil
- Cambodia (ex Kampuchea)
- Canada
- China (People's Republic of)
- Colombia
- Costa Rica
- Egypt
- Ghana
- Iceland
- India
- Indonesia (ID+TP from 77,excl. TP -> 2001)
- Iran, Islamic Republic of
- Iraq
- Israel (Gaza and Jericho->1994)
- Japan
- Korea, republic of (South Korea)
- Malaysia
- Mexico

- Morocco
- New Zealand
- Nigeria
- Pakistan
- Philippines
- Russian federation (Russia)
- Switzerland (incl. Li->1994)
- Taiwan
- Thailand
- Turkey
- United States
- Venezuel

Appendix C: Instructions for Lamp Sampling Agents

Stores where lamps are purchased are as follows:

- Lamps shall be purchased at a minimum of 2 stores in each country.
- Stores chosen should carry a wide range of linear fluorescent models.
- Stores may include:
    - Retail store (e.g. large hardware store) and/or
    - Trade-supply store (e.g. electrical wholesaler) and/or
    - Lighting specialist store.
    - Only if required, on-line supplier. Note this is only if required to increase the range of available brands—however, it is likely that lower quality lamps may not be available online—thus online suppliers to be used only if the required range cannot be purchased in stores.

The type of lamp to be sampled is as follows:

- Lamp type: T8.
- Lamp length: 1200mm (4 foot).
- Lamp power:
    - India = 36W
    - China = 36W
    - Europe = 36W
    - USA = 32W
- Color temp: purchase the highest selling color temp (for linear fluorescent) for that country—ask the store assistant if required. Note only one color temp to be chosen for each country:
    - India = 6500K
    - China = 6500K
    - Europe = 4100K
    - USA = 4100K

Priorities in selecting lamps (in approximate priority order):

- Purchase as many different lamp brands as possible.
- Purchase 10-15 different lamp models in total.
    - This will probably be 1 or 2 models per brand—for example, 5 brands consisting of 2 differing models in each brand (low quality and high quality).
    - A brand may have more than one model available—e.g. a "high-performance" and a "budget" model.
- Purchase a wide range of low-quality to high-quality brands/models.
- Purchase as many different lamp brands as possible.
- Purchase the highest selling brands/models.
    - If in doubt, assume high quality = high price.

  - Note that this requirement is the lowest priority and only applies if the other priorities have been exhausted—for example, if there is a very wide range of brands available, then we would select the most popular brands.

The number of samples purchased of each model is as follows:

- For each model, please purchase ~12 samples (1 sample = 1 single tube).
- If 12 samples are not available, purchase as many as possible.