

LED lighting as a substitute for the fluorescent tube

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Introduction

LED lighting is commonly used in bicycle lights, torches, traffic lights, garden lights and exit signs. As a light source LEDs offer many advantages:

- Lamp life is not reduced by frequent switching (for example - flashing bicycle lights)
- The light is highly directional. This means that much more use can be made of the available light when compared with most other light sources, where light is distributed in all directions.
- Very long life, typically in the vicinity of 30,000 to 50,000 hours
- Improving efficiency
- Immediate full brightness when switched on, making them appropriate for use with occupancy sensors.

Whilst LEDs were only available in colours such as green for many years (and hence their now widespread use in traffic lights) in recent years white LEDs have come onto the market.

LED lighting is not, however, yet widely used for commercial lighting with the exception of exit signs. Early adopters of technologies such as LED down lights have been frustrated by high prices, low light output, or early failure.

However, LED technology is set to improve. This paper reports on a trial of LED lighting as a fluorescent substitute undertaken by CarbonetiX with the support of the Victorian Government Sustainability Fund, managed by Sustainability Victoria, and the City of Frankston. It discusses the barriers to the uptake of LEDs, and identifies the trends that are likely to make LED lighting viable for widespread use as a fluorescent substitute by 2015. It also makes recommendations as to how building owners can achieve immediate energy savings with their fluorescent lighting.

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Fluorescent lighting and LEDs

Fluorescent lighting, specifically linear fluorescent tube lighting, is the most common form of commercial lighting in use. It is the main form of lighting in offices, supermarkets, schools, hospitals and many other buildings. Fluorescent lighting is efficient, reliable and affordable.



LED lights are now available as linear fluorescent substitutes, and are sold with the claim that they are more energy efficient than fluorescent. This article discusses

- A trial of these lights in a community centre.
- The barriers to uptake of LEDs as a fluorescent substitute.
- The trends in LED technology development that are overcoming these barriers and are likely to mean that LED lights will be widely substituting fluorescents by 2015.
- A suggested approach to LEDs by building owners and discussion of bridging strategies to reduce fluorescent energy consumption between now and 2015

The Solid State Lighting trial on which this report is based was undertaken by CarbonetiX in partnership with the Victorian Government Sustainability Fund, managed by Sustainability Victoria, and the City of Frankston.

The Solid State Lighting trial

The trial took place from October 2008 through to October 2009. It involved the following:

- A desktop evaluation of LED tubes.
- Testing the six best tubes
- Photometric testing of the best tube
- A changeover of lamps in the Mahogany Neighbourhood Centre in the City of Frankston from fluorescent to the best performing LED and monitoring of performance.

Desktop evaluation of LED tubes

The trial commenced with a desk-top evaluation of 1200mm long LED tubes for total brightness and luminous efficacy. We sought out specifications from LED suppliers from Australia and around the world and evaluated products from nineteen different manufacturers.

Testing the six best tubes

Lamps from those six manufacturers who appeared to have the best products on paper were then purchased for testing. These were then tested in a typical office light fitting (with iron core ballast) for light output and power consumption. Tube costs varied between \$50 and \$120.

For the LED tubes to work the starter in the light fitting has to be removed. Additionally some manufacturers require that the power factor correction capacitor and iron-core ballast be disconnected or bypassed. Note that LED tubes as a fluorescent substitute cannot be used on fittings with electronic ballasts without bypassing the ballasts. Some of the lamps tested required bypassing of the ballast, others didn't.

Performance levels varied widely, and a couple of the tubes additionally had poor light colour (too blue).

Photometric testing of the best tube

One lamp had clearly superior light output, and was then sent to a NATA certified laboratory for further testing. It was a 18 watt tube and proved to have an overall lighting efficacy of around 80 lumens per watt.

It is important to note that the colour of the selected lamp was good, somewhere in between a cool-white and daylight colour.



Lamp changeover and monitoring at the Mahogany Neighbourhood Centre

The Mahogany Neighbourhood Community Centre is located in the City of Frankston. It has an office that is staffed during normal business hours and provides meeting and training rooms to the community. The centre is generally in use seven days a week by community groups, and was nominated for the trial by Frankston City Council.



Prior to the lighting change over the Centre was illuminated with halo-phosphor tubes of indeterminate age in a range of fitting types. We estimated an overall system lighting efficacy of between 30 to 50 lumens per watt (which takes into account ballast energy losses and light losses in the light fitting). Due to the directional nature of the LED lamps, which means a minimal amount of light is “lost” in the fitting, it was determined that the existing fluorescent tubes could be replaced with the LEDs with little or no loss in light output.

Every 36 watt tube (176 fluorescent tubes in total) was replaced with the best performing LED lamp in January 2009. Fortunately the best performing LED tube didn't require bypassing the ballast, which made the installation much easier.

Users of the facility were surveyed before and after the upgrade and noted either no change or an improvement in the quality of lighting. An illumination assessment showed that illumination levels after

the upgrade were around the same as before. Yet power consumption had dropped from over 40 watts per lamp down to 18 watts. As a result lighting power consumption has halved.



Nine months after they were installed a second evaluation was undertaken. Illumination levels were similar to when they were installed, and none of the lamps had failed. This would appear to bode well for the technology, however nine months of operation is not nearly long enough to establish whether or not the lamps will operate for 50,000 hours or not as claimed by the manufacturer.

The trial has established that LED fluorescent tubes can be used as a fluorescent substitute provided the lamp produces enough light. We only managed to find one tube that produced enough illumination.

The following barriers to update of the technology were also identified:

- High costs
- Uncertainty about lumen depreciation and lamp life
- Exaggerated performance claims from manufacturers

Barriers to the uptake of LEDs as a fluorescent substitute and trends overcoming these barriers

High costs

LED tubes purchased for the purpose of the trial ranged in price from \$50 to \$120 per tube. The best performing tube was in the higher end of this price range. This is expensive in relation to the \$5 paid for a good fluorescent tube.

Prices however are on a downward trend. "It should be possible to achieve about a 70% reduction in production costs for LED lighting by 2015", according to Paula Doe of SEMIⁱ, a global industry association serving the manufacturing supply chains for the microelectronic, display and photovoltaic industries.

Based on these projections by 2015 prices would be in the vicinity of \$20 to \$30 per tube. Assuming that energy use can be then halved by using LED tubes whilst providing similar illumination, the payback in energy savings is likely to be in the order of 3 years for a typical office, or lower once maintenance costs savings from longer lamp life are considered.

The installation cost of retrofitting a LED tube in a fluorescent fixture depends on the particular tube chosen. Some are designed for retrofit into an existing fitting that has an iron core ballast simply by removing the starter. This makes for low change over labour cost, no more than the cost of replacing a failed fluorescent tube with a new fluorescent tube.

However if the fitting has an electronic ballast, or the particular model of LED tube requires bypassing of the iron core ballast, the installation cost increases significantly, as this requires ballast bypass or removal. This could add in the vicinity of 50% to 100% to the changeover cost, which unfortunately will extend the payback.

Uncertainty about lumen depreciation and lamp life

Lumen depreciation is the loss of light that occurs from a lamp as it ages. For example a fluorescent tube will typically produce 15% to 20% less light at the end of its life.

LED manufacturers are claiming lamp lives in the order of 50,000 to 100,000 hours. 50,000 hours at continuous 24/7 operation represents nearly 6 years of operation. The technology is developing so quickly that it is impossible for a manufacturer to test a lamp and determine lifetime and lumen depreciation for this long before it is obsolescent.

The Illumination Engineering Society (USA) has developed two standards to aid in determining lamp life and light output. These are LM-80 Approved Method: Measuring Lumen Maintenance of LED Light Sources and LM-79 Approved Method: Electrical and Photometric Measurements of Solid State Lighting Products. Both these standards came out in 2008.

LM-80 provides a controlled method for undertaking a 6,000 hour test which then can be used to predict light performance out to 36,000 hours.

Based on this standard a “L70” life can be estimated. This is the number of hours of operation by which time light output has dropped to 70% of its original. In theory LEDs fail by becoming too dim, rather than actually stopping working. Lamp life is then stated in terms of its L70 life. For example a tube where the L70 life was estimated to be 65,000 hours would have a stated life of 65,000 hours. However, as confident predictions of lumen output can only be predicted to 36,000 hours using LM80 the L70 figure becomes a little meaningless if it is beyond 36,000 hours.

Unfortunately few manufacturers are providing data on lamp life in accordance with LM80. Philips is an exception, with a chart below for one of its LEDsⁱⁱ.

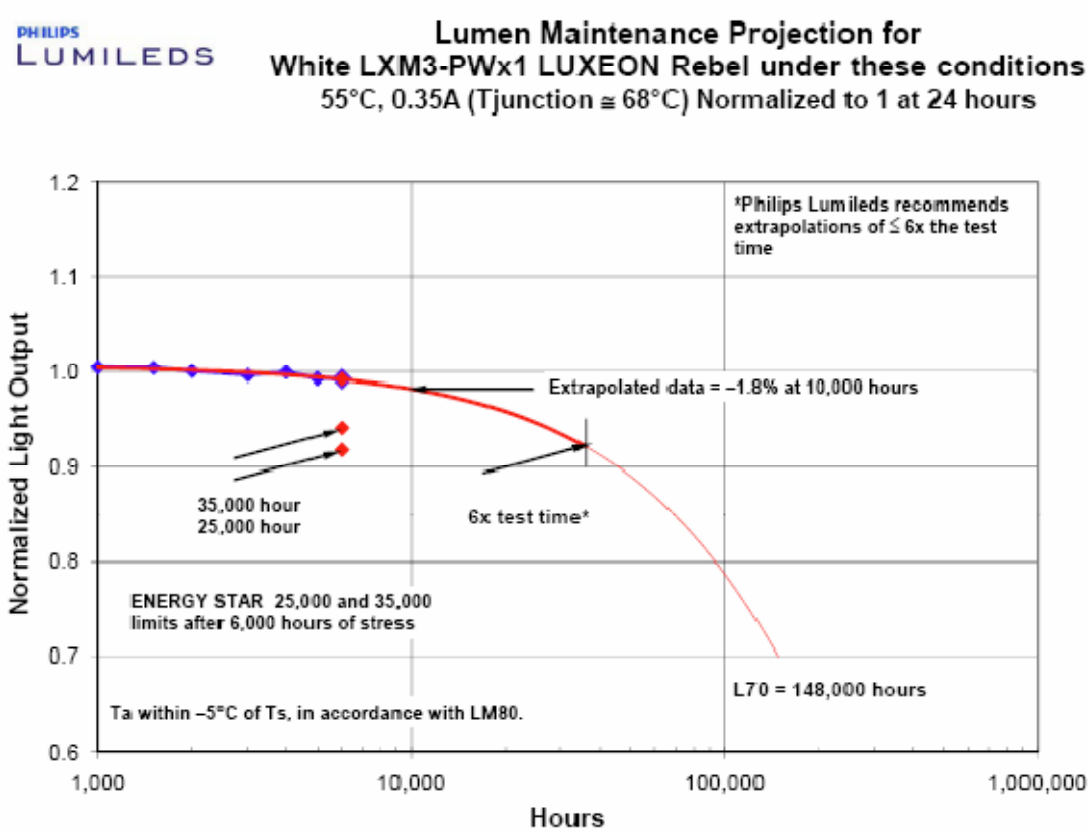


Figure 1 - Sample lumen depreciation chart

Further complicating the issue of lamp life are factors related to the mounting of the LED and heat dissipation and its power supply. LED Lamp life depends on three factorsⁱⁱⁱ:

1. Current (ie amps). High current reduces life
2. Surface temperature. High temperature reduces life
3. Air temperature surrounding the LED. High temperature reduces life

A lamp may well fail prematurely because of:

- A poor quality power supply that delivers excess current
- A poorly designed fitting that doesn't dissipate heat from the surface and back of the LED module
- A poorly designed fitting that traps air allowing it to heat up to high temperatures around the module.

In testing a variety of LEDs we have had a number of early failures (light stops working), and these are likely to be due to one of the three issues listed above.

Based on LM80 we believe that the only way to have surety about lamp life is to ask for a test report to LM80, and for prudence to assume that the life will only be 36,000 hours if the L70 life is longer than 36,000 hours.

Exaggerated performance claims

None of the six lamps we tested in our trial produced the amount of light their manufacturers claimed.

The best performing one in our trial was tested by a NATA certified laboratory and found to produce less than 80% of the light the manufacturer claimed.

Just as some manufacturers have, in our experience with LED failures, made exaggerated claims about lamp life, many are making exaggerated claims about light performance.

This is a barrier in two ways:

- Credibility is reduced
- The lamp may not be bright enough for the application

In our trial we only found one tube that was bright enough to be confidently used as a retrofit for an old installation using halo-phosphor tubes.

The only way to have some assurance that the light will perform as claimed is to ask the manufacturer to provide a test report in accordance with LM-79, and then to qualify whether this standard applies to the LED module, or the entire lamp or fixture. In the case that it applies to the module only, multiply the LM-79 figure by around 75%, and ask further questions about the design of the overall lamp and its power supply to seek assurance that it won't be subject to excess current or temperature.

The 75% multiplier^{iv} allows for a range of inefficiencies that are not measured by LM-79, such as losses in the power supply, thermal losses (the lamp may be operating at a higher temperature) and losses in the fixture.

Exaggerated claims are a significant barrier to the wide uptake of LEDs as a lighting source.

Manufacturers need to start using the LM80 and LM79 standards to provide some assurance that their

claims are valid. Additional reassurance should also be provided by a manufacturer warranty that guarantees a minimum life for the lamp as a whole, and does not just rely on estimates of module life.



Fortunately there is a move towards certification. In the USA the EPA Energy Star program now has Energy Star standards for commercial Solid State lighting^v (which advanced to version 1.1 in December 2008). At present this standard only applies to complete lighting fixtures, and does not apply to products for retrofit in existing fittings. It does not yet extend to LED tubes as a fluorescent substitute.

The Energy Star standard for LED lighting fixtures currently covers:

- Shelf-mounted display and task lights
- Portable desk lamps
- Recessed down lights
- Outdoor step lights
- Outdoor pathway lights

To be eligible a luminaire must:

- Be tested in accordance with nominated standards, including LM-79, LM-80 and ANSI C78.377 (which is a colour standard).
- Meet certain colour requirements
- Have a three year warranty
- Maintain at least 70% of initial luminance (ie L70) for at least 25,000 hours for residential indoor and 35,000 for residential outdoor.
- Have a minimal luminaire efficacy of 24 to 45 lumens per watt depending on application

From October 2011 (or perhaps earlier, depending on technological advancement) a higher "category B" standard will be available requiring a luminaire efficacy in excess of 70 lumens/watt.

The development of these standards gives confidence that eventually LED tubes as a fluorescent substitute will be subject to the Energy Star standard, particularly once LED efficacy becomes clearly superior to fluorescent.

LED light output is increasing

Notwithstanding exaggerated performance claims, lamp luminous efficacy is improving.

Our experience in testing LEDs over the last two years has shown a great improvement in LED efficacy over that time.

CREE, a major manufacturer, recently claimed it has achieved 110 lumens per watt of white light^{vi}.

Driving improved performance is the US Department of Energy's "L" prize, for the first manufacturer to produce a solid state light that produces in excess of 150 lumens per watt.

So by how much can LEDs improve? Kevin Willmorth, of SSL interactive, and an active critic of exaggerated performance claims states^{vii} that "The DOE and NIST have established that the maximum [theoretical?] efficacy of solid state sources is 230 lumens per watt at the die level." Willmorth says that this translates into a practical theoretical maximum of around 167 lumens/watt for a luminaire of neutral colour, based on the theoretical 230 lumens/watt at the die level.

At current rates of improvement it is reasonable to assume that an efficacy of 150 lumen per watt will be achieved before 2015, and that lamps are then commonly available with an overall efficacy of say at least 120 lumens per watt.

As LEDs are highly directional all -or almost all- of the light provided is useful. This compares very favourably with a fluorescent tube which throws light in all directions, and relies on the lighting fixture to reflect much of the light to where it is needed. High performance fluorescent lamps achieve around 100 lumens per watt, and in a high performance light fitting this results in around 80 useful lumens per watt. In a light fitting of moderate performance only around 70 useful lumens per watt is produced. For a moderate performing fluorescent tube (80 lumens per watt) in a moderately good fitting only around 56 useful lumens per watt are produced.

So by 2015 LED tubes should be available that typically produce between 50% and 100% or perhaps more useful lumens per watt than existing MEPS compliant tri-phosphor. This would mean that an 18 or 20 watt LED could be confidently used to substitute a 36 watt T8 with no loss of light output, or a 14 watt LED as a 28 watt T5 substitute.

LEDs are likely to be viable for widespread use as a fluorescent substitute by 2015

As discussed above:

- Costs are coming down, with a 70% cost reduction predicted by 2015. This is likely to provide a payback of less than 3 years for the retrofit of existing fluorescent fittings that have iron-core ballasts.
- The industry is in the process of developing certification and standards, which are likely to apply to LEDs as a fluorescent substitute before 2015. By 2015 it is likely that LEDs as a fluorescent substitute will be available that have Energy Star certification; and
- Luminous efficacy is improving such that by 2015 we can expect lamps to be performing at 120 lumens per watt or higher.

This will make LEDs a superior choice to fluorescent lighting, which has improved little over the last five years and is unlikely to improve significantly by 2015. In 2015 LED tubes are therefore likely to be widely available from electrical wholesalers and retailers. We may also see LED fixtures available to the same dimensions as fluorescent fixtures (eg 1200 x 300mm).

We may even see new high performance buildings with smart LED based lighting systems, such that illumination levels in any part of the building can be easily adjusted to suit the task and the occupancy of the space. For example providing 320 lux to your workspace when you are there, but then dimming down or switching off when you are not in your workspace.

Suggested approach to building owners/managers wishing to improve the energy efficiency of their fluorescent lighting now.

Every building owner/manager should be considering a future whereby they switch from fluorescent tubes to LEDs by around 2015. In practical terms this means that any lighting upgrades undertaken now should have a payback of less than five years.

Where lights are in use for long periods (eg 24/7) and access is difficult we recommend the use of LEDs now, provided you can get a good supplier warranty given the current high price of LEDs. Additionally where expensive elevated working equipment is required for the change over, you have to be very sure that the LEDs will go the distance. If the manufacturer cannot supply test data to LM80 you should also undertake a trial to ensure that illumination levels are adequate, bearing in mind the likely 30% loss of light output over the life of the tube.

It is significantly more expensive to fit a LED tube into a fixture using an electronic ballast, as this requires bypassing the ballast, unless LED manufacturers can make a tube that can be retrofitted to an electronic ballast. So some caution should be exercised if choosing to upgrade to an electronic ballast now if planning to move to LEDs in around five years time.

In the meantime, while waiting for LED technology to improve, building owners and managers should explore other options to reduce their fluorescent lighting energy use that have a fast payback and will provide both financial and environmental savings.

In many existing buildings there are three factors that result in energy wastage from fluorescent light fittings that can be easily overcome now with a quick return on investment:

- **Over illumination** - The space may be over-illuminated with respect to lighting standards. It may be possible to delamp – that is remove excess tubes – to save energy – whilst still providing standard compliant illumination.
- **Low performance fluorescent tubes** - Some buildings may still have older halo-phosphor tubes in use that are producing less than 70 lumens per watt. MEPS for fluorescent lighting means that only tubes with more than 80 lumens per watt can now be purchased, but this is still much lower than the 100 lumens per watt now available from very high performance tubes. Upgrading to higher performance tubes – that use no more power but produce more light – may enable delamping.
- **Low performance light fixtures** - The use of opal diffusers, for example, can reduce light output by over 30% in comparison with a prismatic diffuser. Most fittings are painted white on the inside, which has fair reflectivity. However with age the gloss white dulls and reflectivity is reduced. This means that less of the light coming from the rear or sides of a fluorescent lamp is reflected into the space below.

Wastage can be reduced and large energy savings can be achieved by reducing the number of tubes in the building by:

- upgrading to high performance T8 tubes of 100 lumens/watt
- fitting mirror-like reflectors in the light fittings to reflect light going upwards and sideways downwards and thus make it useful
- refitting opaque diffusers with prismatic diffusers if appropriate
- then undertaking an illumination assessment using a lux meter and delamping so that the space is not over-illuminated.

A combination of these four measures could mean that in each double fitting one tube is permanently removed, halving power usage. Typically the payback including installation is around two years. Reflectors, which are made of aluminium, have a low embodied energy in relation to the savings achieved and can be recycled if switching to LEDs in the future (as LED lighting is highly directional reflectors are no longer needed).



Alternatively the use of a T5 adaptor could be used now, with each T8 36 watt tube replaced with a 28 watt T5 adaptor. A T5 adaptor is a fitting and tube that enables a 28 watt T5 tube to be installed in a 36 watt T8 lamp holder. Unfortunately T5 adaptors have complicated electronics and with exaggerated claims by several suppliers there is a credibility issue. Additionally the savings may not be as high as delamping T8 tubes as described above.

Voltage reduction is another technology that can be used on banks of lights that are not frequently used with iron-core ballasts and is well suited to car parks. Voltage reduction units may need to be bypassed when eventually moving to LED tubes.

Building owners will save money and greenhouse gas emissions by installing these technologies now, as well as generating a positive return on investment. Then in around 2015 they are likely to be able to save even more by upgrading to LEDs in around 2015.

ⁱ Supply chain maps a path to bringing down the cost of LED lighting <http://www.ledsmagazine.com/magazine/pdf/0912>

ⁱⁱ <http://www.philipslumileds.com/pdfs/DR06.pdf>

ⁱⁱⁱ Jianzhong Jiao, LED Lighting Life Prediction, http://www.ledjournal.com/eprints/Osram_oct09.html

^{iv} See <http://solidstatelighting.wordpress.com/performance-standards/>

^v http://www.energystar.gov/ia/partners/product_specs/program_reqs/SSL_prog_req_V1.1.pdf

vi <http://www.ledsmagazine.com/magazine/pdf/0912>

vii <http://solidstatelighting.wordpress.com/performance-standards/>