

Making a case for white light-emitting diodes in the Western Cape

R Solomon

Advanced Machines and Energy Systems Group, Department of Electrical Engineering, University of Cape Town

A B Sebitosi

Department of Electrical Engineering, University of Cape Town

Abstract

Within the context of the energy crisis in the Western Cape, the Provincial Government and Eskom (the South African power utility) embarked on a retrofit campaign to install 5 million compact fluorescent lamps (CFLs) in a desperate attempt to decrease the generation deficit. There is also increased pressure for investments in new generation capacity, with all options including the Pebble Bed Modular reactor (PBMR), the Open Cycle Gas Turbines (OCGT) as well as renewable resource technologies being proposed. Despite all these concerted efforts it is widely regarded that demand-side technologies, with education programs, subsidies and research funding, have greater scope for achieving success as they tackle the root cause rather than the symptom.

The light emitting diode (LED) is a new energy efficient option in the lighting sector that has in recent times been deployed extensively by the City of Cape Town's Transport Network Operations Department. The technology promises superior attributes that include a longer lifespan and higher energy conversion efficiencies, when compared to the traditional incandescents and fluorescents.

This paper details the achievements of the LED in its brief history in the local traffic and signals industry as well as its projected impact on the city traffic light department's future energy and maintenance budget. It is then proposed that these monochromatic signal LEDs, which is fast evolving into a white LED, holds the best promise in Cape Town as well as the Western Cape's energy future if adopted for general lighting in the domestic, commercial and industrial market.

Keywords: lighting emitting diode, white light, Cape Town, Western Cape, energy crisis, compact fluorescent lamps

Introduction

With rolling power blackouts, a rapidly growing economy and environmental politics is on the rise, the Government of the Western Cape and Eskom embarked on a retrofit campaign to install 5 million CFLs in an attempt to decrease the power generation deficit. There has also been increased pressure for investments in new generation capacity, with all options including the Pebble Bed Modular Reactor (PBMR), the Open Cycle Gas Turbines (OCGT) as well as renewable energy technologies being proposed. Despite all these concerted efforts it is quite evident given the post-crisis contingency plan that demand-side technologies along with education programs, subsidies and research funding, have greater scope for achieving success as they tackle the root cause rather than the symptom (Energy Efficiency, Eskom website; Western Cape Recovery Plan).

The light emitting diode (LED) is a new energy efficient option in the lighting sector. Whether from White LEDs or from a mixture of LED-based monochromatic sources, this technology promises superior attributes that include a longer lifespan and higher energy conversion efficiencies when compared to incandescents and fluorescents.

A simple example is the retrofitted LED lumen-equivalent traffic signals installed in Cape Town's Central Business District (CBD). The retrofit consumes 10.6% of the electricity when compared to the incandescent (i.e. 5.8W compared to the incandescents 55W alternative). The small scale of this 10-year long project is expected to yield savings on both electricity and maintenance costs in the region of R300 million over an operating period of 27 years.

For residential and commercial application, despite its high initial cost, there is scope for its

uptake in what the South African Bureau of Standards (SABS) Standard on Interior Lighting refers to as simple visual requirements and continuously lit for visual purposes. These are rated below 200lux. Once these markets have been achieved the domino effect of lower prices and higher flux LED-based alternatives shall manifest.

The white light emitting diode inherently possesses characteristics that make it energy efficient (Taguchi, 2006; Schubert, 2006). Other advantages include its usability, functionality and applicability making it a lighting technology unlike any other. However, for potential residential and commercial users, the case for an energy efficient technology uptake must be brought down to the level of rands and cents. The economics behind replacing common devices (such as incandescents) with new technology (WLEDs) seems to be comprehended via cost versus savings analogies. This is referred to as life cycle costing (LCC).

In light of the energy crisis the Western Cape experienced, the scope for demand-side technology is great. With the aim of increasing electricity security as a short and medium term goal, this paper contends that the crisis is cause for widespread implementation of WLEDs for general lighting applications.

In this regard, the City of Cape Town must be applauded for their great foresight in energy efficiency, as they have begun to search for more sustainable development options.

With respect to the CFLs, despite its limitations, defects and environmental hazards; these have not been causes for the lack of penetration. Rather it has been the user perceptions. This paper does not wish to deter users from CFL technology, which has improved greatly, but to make those in the energy sector aware that even though it is by no means perfect, it has still found room for uptake.

Western Cape energy crisis - a background

At 75% of South Africa's peak load, residential consumers of electricity of every income sector are threatening the security of electricity networks. This sector has been the target of media campaigns to load shift and be more energy conservative, taking into account that they push utilities to invest in greater generation capacity. A number of reports on demand side issues relevant to this country and province directly state that efficiency on lighting will significantly reduce this peak (Acharya; Winkler et al, 2006; Nkomo, 2005).

Constraints in electricity supply to the Western Cape find their roots in the breakdown of two major functionaries, the transmission network to the Western Cape and half of Cape Town's only generation Unit, Koeberg. Peak power cannot be supplied because the available peaking units (Acacia,

Palmiet and Steenbras) are inadequate to substitute the loss of major supply. Consequently blackouts and load shedding (controlled and uncontrolled) have occurred since October 2005.

The short-term goal during this energy crisis is to save 400 MW at peak periods. With the increased use of heating loads, motor load, and the prolonged lighting loads because of the longer nights and weather conditions (poor visibility on roads, etc.), winter posed a great threat to this target.

Strategies were devised to best tackle this crisis. This DSM action is reactive as opposed to being pre-emptive. These costly interventions include purchasing 5 million CFLs from China for residential and commercial application, subsidised electric blankets, three-22 MW emergency Mobile Generation Plants (diesel-powered generators) and the refurbishment of gas generation plants at Athlone and Roggebaai (Western Cape Recovery Plan; Eberhard, 2006). These ad hoc measures are to cost an estimated 5 to 10 times more than Eskom's standard generation costs.

The City of Cape Town – bold and foresighted

Developments within the City of Cape Town, the most populous Municipality of the Western Cape, towards an environmentally sustainable and energy-conscious future are becoming evident to its residents. Examples of other successes are in the coming section. Responsible governance is an important aspect of politics that proves to its electorate that government goes beyond just delivering services. In this instance, the driving force behind the energy and climate change strategy, are those issues pertaining to foreign trade, investor perception and their economic prospects.¹ The role of energy efficiency is thus changing. To abate further energy crises may no longer be the primary goal of energy efficiency schemes as we know now that even well managed and well-maintained generation units face freak accidents.

Action strategies now look at economic incentives, social entrepreneurship and sustainable development. For example, the City of Cape Town's objectives to increase foreign investment, local productivity and conform to global initiatives to decrease CO₂ emissions are their objectives linked towards energy efficiency and renewable energy uptake.

Considering that 2 MW of electricity is being consumed by the traffic system and its present technology,² a bold strategy to retrofit 1 200 of the Metropolitan's Major traffic intersections' signals from incandescent bulbs to LEDs is one of the projects initiated by the City of Cape Town. This ten year pilot project which started early in this decade replaces 120 intersections per year with a full retrofit of each signal. A small step in the right direction



Figure 1: Projected cumulative savings of maintenance and electricity consumption over 27 years based on the use of the retrofitted LED traffic signals in Cape Town
Source: City of Cape Town (2006)

(given that Cape Town alone has 100 000 incandescents in its traffic lights), it is the local authority's way of reducing its high consumption of electricity that accounts for 41% of its energy mix (City of Cape Town, 2006).

It is estimated that the additive saving achieved on electricity and maintenance over the installation period of ten years could be in the order of R23.8 million (City of Cape Town, 2006)³ with the estimated CO₂ emissions being mitigated standing roughly at 39 000 tons. With a half-lifespan of approximately 15 years (based on how these intersections change between signals), the need for replacement and maintenance will be low.

The maintenance costs of having teams go out and replace incandescents, which have high failure rates, include staffing, vehicle fleet use and maintenance, and stock-piling replacement of incandescents. These are without considering compromised safety to road traffic users in the case of the often-abrupt bulb failures.

The silent emergence of the white LED in the Western Cape

Locally, the general impact of visible-spectrum LEDs has been a silent one. The device is so discrete that it has gone unnoticed over the last 5 years. Tucked under cabinet shelves, set into stairways and used for theatrical stage lighting, people have been enjoying the effect of colourful LED displays. Its ability to render a required luminance and ambience thus cannot be understated. LED technologies such as 5 mm through-hole, surface-mount and the new chip-on-board (COB) diodes have captured niche markets in Cape Town.

Signage and ambience enhancing illumination purposes for retail chains, fast-food outlets, bars, clubs and even emergency lighting are the preferred option for a host of reasons, including its novelty and energy efficiency. The detrimental impact of neon lighting (heat production and frequency of maintenance), the high power consumption of incandescents and the poor colour rendering of high intensity discharge lamps has positively steered commercial entities into an LED market where none of the abovementioned weaknesses, which are inherent to the named technologies, are carried through.

For this group of users, initial cost has not obstructed them from purchasing LEDs. It has been the perceived complexity. In addition, LEDs are not widely available in retrofit options for residential and commercial application. These are some of the barriers that exist for a potential market. Other problems include energy efficiency ignorance, poor energy usage habits and something that was never available before LEDs namely, highly satisfactory application-based lighting (Figure 2).

The discussion above proves that these lighting devices fulfil more than what they have been set out to achieve. With this in mind, lighting and drive technology (circuitry, programmable hardware and software) has progressed tremendously. The present-day lighting sector is vast and multi-faceted. There is need to catch on to this new technology. Estimates of all lighting loads in South Africa show that commercial entities use 35% of their energy on lighting and residential lighting accounts for almost 20% (Nortjie, 2006).

Since the diagnosis of our efficiency and lighting

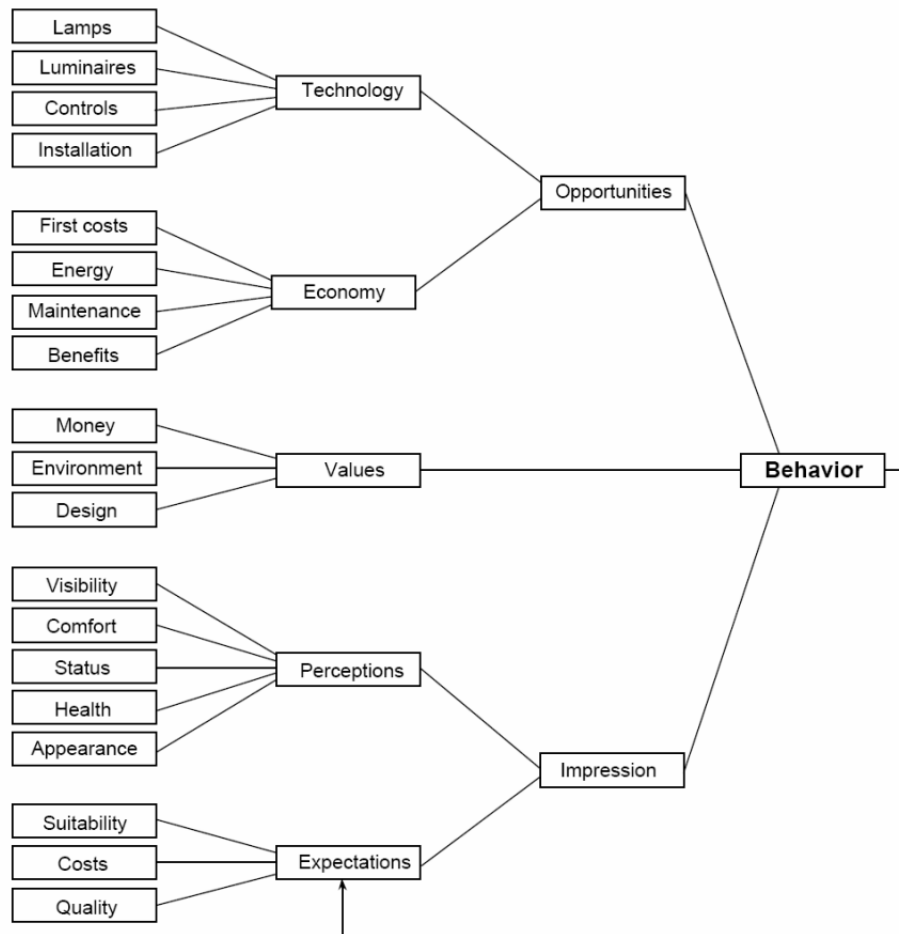


Figure 2: Path towards energy efficient lighting behaviour
 Source: Boyce (1997)

problem has reached full circle (Eberhard, 2005) the present climate is now conducive for the ingestion of White LEDs. As an advantage, the device fulfils the needs of the City's objectives.

The truth and problem with CFLs

The arguments against CFLs include their detrimental harmonic pollution of electrical networks, the heat generated at distribution components, the delayed response after switching and its objectionable colour rendered among others. They also contain mercury and yttrium, which have disposal problems for the environment. From a purely technical aspect, the efficiency of mercury vapour source fluorescents is limited to about 90 lm/W. This is due to one critical factor namely the loss of energy incurred when converting a 250nm UV photon to a photon of the visible spectrum (Schubert & Kim, 2005). Moreover, the technology of CFLs is not likely to improve given this fundamental limitation.

During the 1980's the CFL became a global acronym for energy efficiency. Academics in these sectors had many high hopes and expectations for its widespread uptake. Light, they claimed, just

light, had the potential to affect communities in such a way that poverty would be alleviated, education improved, industries built and pandemics would be a thing of the past. But what has stood in the way of this technology is poor user-perception. This issue and not the aforementioned technical or environmental factors have been responsible for the lack of penetration of this technology.

Again from a purely technical aspect while conversion efficiencies of incandescents stand at approximately 10%, a not so-often publicised fact is that CFLs only have conversion efficiencies in the region of 40%!

Given therefore that this technology has reached its peak, there is a great need to research alternate technologies that have the potential of bettering the efficiency when compared to CFLs. Nonetheless, it is likely to remain as one of the alternatives in the near to medium term of the general lighting market.

White light from LEDs

White LEDs for illumination is an entirely new frontier in the production of white light. Solid-state lighting (SSL) is the name for this dynamic area of research. The crude nature of solid-state devices, as

mentioned before, finds its foundations in quantum physics and lends itself to optics, photonics and electronics. This crudity refers to its bias characteristics, which produce light in a non-linear, but reliable and predictable fashion. Each LED reacts differently (in the order of milli and micro measurements) to the next requiring strict testing and binning (putting LEDs into chromaticity batches). The strictness of these procedures allow for users and designers to specify, on a very minute basis, any attribute including chromaticity, colour temperature, viewing angle and wattage to mention a few.

Today, LED-based solid-state lights producing white light may be achieved via several methods. Commercially viable options, as cited by OIDA⁴ are a blue LED with phosphor(s), a UV LED with several phosphors, and three or more LEDs of different colours (Schubert & Kim, 2005; Oida Technology Roadmap, 2001). The latest developments include a quantum dot coating on blue LEDs to produce a high colour temperature similar to incandescents. Two diodes of different wavelengths may also be used. This is known as the binary complementary method.

Four areas to consider when using WLEDs include:

- Digital or analog control
- Correct driving
- Light production
- Light requirement

So it can be said that colour rendering by synthetic white light sources and the driving mechanisms for them all play important aspects in the production of light. These factors are now taken into consideration when industry interacts with developers. This optoelectronics industry is large in developed countries around the world.

The correct driving (biasing) of LEDs is important since the estimated lifespan is likely to be achieved under these conditions and other environmental ones. Lifespan is important as a maintenance issue where LEDs need to surpass the output of any other device in multiples.

Light production mechanisms of chips are important. However, these factors can be said to combine together efficiently only if they are able to satisfy the user. This information points us once again to the suitability of light production mechanism for a task, hence, giving room for a host of LED-based lighting solutions.

Making a case for the white LED as the future in general lighting

Energy efficiency and the impact it will have on electrical networks, the directionality of the device in producing light, and light trespass and glare may now be tamed with LEDs. Its rural applicability is also high on the priority list for research. Sebitosi and Pillay (2003) succinctly illustrate how this high-



Figure 3: An example of the available retrofits for domestic and commercial use. An MR16 halogen lamp with white LEDs inside

Source: www.wattmanledlamp.com

ly advanced technology should affect rural communities. To date, many projects can claim to this success.⁵ But it is the life cycle costing (LCC) that has given the World a most unbelievable realisation. The longevity of this device will decrease our dependence on fossil fuels. A key prospect that cannot be overemphasized! Market penetration will eventually decrease lamp costs which stand at approximately \$2-3 for about 60-80 lumens (Narendran, personal communication) thus, only a major effort to penetrate the general lighting market will lead to more rural successes.

Under these circumstances, the lower capital investment alternatives have been exposing Capetonians to the multi-functionality of WLEDs. Flashlights, headlights (strapped onto a person's head), novel reading lamps (one WLED that clips onto a book) and festive strip-lighting are some of these lighting devices that have seen its way onto the shelves. Innovative alternatives are an ingenious method of capturing interest.

For low-income households and state-subsidised housing, the need for energy efficiency is great. Residents in these segments have been the base target of many programs, which include solar water heaters (SWHs), CFLs and insulating materials for ceilings.

With the advances made in switch-mode power supplies, digital power electronics have been employed for their energy efficiency. Digital control is thus preferred to analog because of the flexibility that it possesses.

An initiative into solid-state lighting in 2003 was the formation of the Lumina Alliance whose aim was to raise the case for a national initiative in semiconductor lighting. An extension of the Alliance was the South African Lighting Engineering Centre (SALEC) (Matei, 2005). Although the aims of both organizations were noble and noteworthy, the efforts to make a success of the industry collaboration were 'pathetic' and 'recently forgotten' (Matei, 2005).⁷

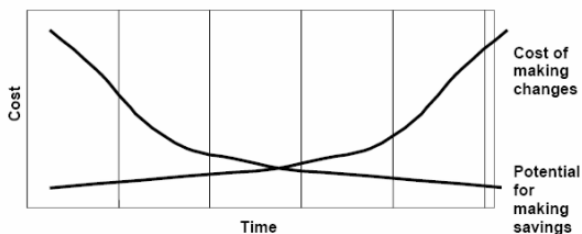
Life cycle costing

Life cycle costing (LCC) is an economic and financial tool used to achieve better-projected outcomes from the use of technology (New South Wales Treasury, 2004). It is a way for consumers to become aware of the costs beyond initial purchasing costs. The environmental impact of the use of the technology may also be quantified via the use of LCC. It is also a way to compare systems with different:

- Initial installation cost
- Operation cost (energy, relamping, maintenance etc.)
- Operational lifetimes

Figure 4: Potential savings and cost relationship

Source: New South Wales Treasury (2004)



Good quality, high flux-maintenance WLEDs, when operated correctly show us that through its long life spans, can be used continuously for a number of years.⁶ The financial rebate, due to longer maintenance periods and lower electricity consumption is cause for a concerted effort to develop

an industry from these devices. This becomes evident with the figure in Table 2.

A simple comparison between incandescent, fluorescent and LED technologies, based on a specific environment (household kitchen) and cost is illustrated below in table format. It shows, given the lifetime information of Table 2, that the LED outstrips the others but not in initial cost.

An example shall illustrate cost, energy consumption and required energy for the kitchen environment. Data from Tables 1 and 2 are drawn from. A base period of 50 000 hours (in excess of 5 years when operating continuously) is considered. Total cost is that of initial and replacement cost, and not energy cost. This is a cost incurred despite technology type.

If WLED Type C is operated for that period of time at a total cost of \$1 206 under the kitchen environment; 6 MWh is the amount of energy used. For the 18W CFL listed in Table 2, 3.7 MWh of energy is used at a total cost of \$1940. For the 75 W halogen lamp, 15 MWh of energy is used costing the consumer \$5 300. It must be noted that the halogen lamps' initial cost is 14 times cheaper than the most expensive LED!

With reference to Figure 2, cost finds relevance in four of the five base criteria for choice in efficient lighting technology and behaviour. Technology does not have that cost component while it can be argued that the 'status' of perception of new or different technology be considered a cost variable.

Table 1: Comparison of light output, electrical input, efficacy and lifetime of the most ubiquitous lighting technologies available on the market

Source: Steele (2006)

Source	Light output (lm)	Electrical input (W)	Luminous efficacy (lm/W)	Lifetime (h)
High-power white LEDs	60-135	1.2-2.6	50-70	50 000
Halogen lamp (two pin)	950	50	19	2 000
Incandescent (screw type)	890	60	14.8	1 000
Fluorescent T12	2800	32	87.5	20 000
Compact fluorescents (CFL)	900	15	60	10 000

Table 2: Comparison of lamp type, illuminance, power required for implementation within a specific lit environment and cost

Source: Narendran et al. (2007)

Source	Lamp type (lx)	Average horizontal illuminance (W)	Power per kitchen (\$)	Initial cost
Incandescent	75W Halogen	157	300	212
CFL	18W	156	74	388
WLED	Type A	161	168	2 952
	Type B	167	200	2 384
	Type C	151	120	1 206

Conclusion

The aim of this paper is not to overawe the reader with fantastical statistics and data about WLEDs and its successes but rather to demonstrate, in a structured and sequential fashion the impact that LED technology is having and the prospects that SSL-LEDs may have when applied to the stated lighting environments, in particular, domestic and commercial spaces.

The feasible revolution will be the change in habit of energy use with a fundamental understanding of the visual needs of users of light. Governmental policy is a major driver that can assist in this matter. This is a responsibility that governments and local authorities must recognize and act upon.

Lower energy-consumption technology and energy consumers will then promote the use of renewable energy sources and a decentralized energy evolution will then occur.

A number of points to consider in the case for WLEDs in the Western Cape:

- If there are rural successes for ambient and task illumination, and the needs of rural lighting is no different from suburban lighting, why is there not any penetration in these residential environments?
- Targeting the ambient and task settings, because the lux requirements are lower and the task requirement for lamps are closer than normal respectively, is the first step.
- Mixing light sources is important.
- Because South African research groups are not going to get funding for physical and chemical research into LED chip structure, and that we are bound to be gross importers of LED technology, research into the user perception and adaptability of various users is important if we desire to penetrate the lighting market.
- Local government should consider implementing more LED installation projects.
- Local government should increase peoples' awareness about the options and energy efficiency of LEDs and other energy efficient technologies.
- There is a need to develop as many high quality lamps and retrofit options for the required task-based illuminance levels.

Notes

1. The authors do not necessarily believe that economically driven mechanisms to reduce emissions is a viable route for energy efficiency implementation strategies. A more sustainable approach, based on consumer behaviour and environmental awareness, is necessary to achieve this goal.

2. Information directly from the City of Cape Town's Transport Network Operations Department.
3. Half-life of LEDs is the time it takes to reach half of its maximum lux level. These may vary based on the degradation rate of the device.
4. OIDA is the Optoelectronics Industry Development Association in the USA. Their sole purpose is to bring together people from American institutions in the relevant fields to 'identify the technologies required to exploit market opportunities.'
5. The Light Up The World (LUTW) Foundation are pioneers in social entrepreneurship using WLEDs on solar photovoltaic systems. They document the technical and social benefits of their work very well. They may be searched at the website address: www.lutw.org
6. Depending on the chip structure and lens coating this value may vary between 2 and 5 years.
7. This information through personal communication between Stelian Matei and the author. It comes out of the Matei (2005) articles, but it is not known whether the articles were published. It was received via personal communication channels.
8. Chips or dies are the light-giving semiconductors embedded within an LED typically housed in a structure able to runaway heat.

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