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Energy efficient lighting and energy management

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Abstract
Energy management and the application of energy consumption reduction methods is high on the priority list of South Africa's electrical supply utility, Eskom. One of Eskom's Demand Side Management (DSM) recovery plan steps was the establishment of a subsidy programme for energy auditing and energy efficient lighting. A need arose to implement new lighting designs and to improve existing lighting systems. These improved lighting systems are used as recommendations in Energy Audits to achieve lighting efficiency and energy consumption reduction. It also highlights and promotes cost effective designs and energy management. New and better lighting methods are developed and researched to increase returns, domestically and in industry. This also highlights the importance of energy consumption reduction. This paper also discusses an Energy Audit conducted at a school in Worcester by the Service Learning and Development (SLD) unit of the Cape Peninsula University of Technology, Electrical Engineering Department in Bellville. The SLD delivers a service to the community, to improve their standard of living and to provide training to electrical engineering students. The aim of the project was to recommend energy consumption reduction methods.

Keywords: lighting efficiency, energy audit, efficacy

Introduction

According to Capehart, energy management is the judicious and effective use of energy to maximise profits (minimise costs) and enhance competitive positions (Capehart et al 2003). Besides energy conservation, other means of energy consumption reduction can be done viz. load shedding, power factor correction, efficient lighting systems etc. The driving force in Energy Management is the development of new energy efficient technologies to reduce the combustion of fossil fuels and to provide standard energy services, viz. heating, lighting, air-conditioning and process equipment for industry.

The amount of energy dissipated in converting mechanical or chemical energy to electrical energy in the generation process must be kept in mind when designing an efficient lighting system. One British thermal unit (Btu) is the amount of energy used to increase the temperature of one pound of water by one degree Fahrenheit. One kWh of electrical energy is equivalent to 3412 Btu. One should be aware of the fact that the steam turbines and boilers used to generate electrical energy, dissipate more than 10 000 Btu of primary fuel to produce one kWh of electrical energy (Capehart et al 2003). This excludes losses due to inefficiencies when used by the end user.

In 1950 the total annual energy consumption in the USA was 16 million barrels of oil equivalent (MBOE) per day. Their imported crude oil amounted to $3 billion crude oil in 1970. In 2000 the figure increased to $119 million. In 2000 they consumed almost 50 MBOE. Worldwide more than 200 MBOE per day is consumed. Worldwide lighting dissipates about 30% to 70% of the total overall energy consumption (Capehart et al 2003). Proper lighting designs would reduce annual energy consumption.

Eskom recovery plans in South Africa

The emission of greenhouse gas is augmented by the fact that the South African government committed itself to make electrification available to informal settlements and rural areas. A further problem is that the electrical supply utility, Eskom cannot cope with the growing demand and it results in load shedding and outages. Conducting energy audits, retrofitting government and corporate buildings, designing and installing cost effective lighting systems, can increase capacity. Of the 45 million South

Africans in 2001, about 34 percent did not have access to electricity.

This is 1.3 times greater than the world average. In rural areas 51 percent of the households did not have access to electricity. This is more than twice the world average [NER]. About 77% of this country's primary energy source is provided by coal (Eskom). This leads to emission of greenhouse gases, causing global climate change [DME]. Despite coal being environmentally the least desirable fossil fuel, it will continue to be South Africa's most important resource in power generation. Eskom has developed indicators to quantify the amount of emissions produced by their generators. This is illustrated in Table I (Eskom 2006).

Table I: Environmental implications of using 1MW of power

Water usage	1 260 litres
Coal burnt	500 kg
Ash produced	139.78 kg
Ash emitted	0.31 kg
SO_2 emissions	7.91 kg
No_x emissions	3.61 kg
CO_2 emission	890 kg

Eskom tries to reduce these unwanted emissions at their power stations in compliance with the Constitution of the Republic of South Africa (Act 108 of 1996). This Act states that the people of South Africa have the right to a clean environment.

Closer to home, the Western Cape was severely hit by power outages and experienced load shedding since November 2005. It unexpectedly lasted for three months. Eskom was in a crisis and had to put a recovery plan in place for the Koeberg power station near Cape Town, to restore the electricity supply to the Western Cape [Anon]. Some of the following recovery plan steps were put in place by Eskom:

- During peak periods, the estimated 300 MW shortfall will be addressed through a Demand Side Management (DSM or energy efficiency) programme.
- 500 DSM teams will implement Efficient Light Programmes and provide information on the conservation of electricity in residential areas (geyser temperature adjustments, pool pump settings etc.)
- Eskom is busy engaging with potential independent power producers for assistance and has obtained an additional 80 MW at R115 million.
- A number of mobile generation plants have been procured, to supply an additional 100 MW for the winter peak period.
- A subsidy programme for energy efficient lighting.

Incandescence versus fluorescence

In 1999, 21% of the USA electricity consumption was used for lighting. Ninety one percent of this electrical lighting technology used was conventional incandescence and fluorescence (Steigerwald et al 2002). Significant improvements in lighting efficiency will have a major impact on worldwide energy consumption reduction.

Incandescent light is broadband of which most lies outside the visible light spectrum. To be effective, the metal-filament of the lamp must be heated (to the incandescence temperature). Tungsten is used because it has a very high melting point; most filaments operate at temperatures in the region of 2 700 °C. Because of this, incandescence is very inefficient. At this high temperature the surface of the filament evaporates until it eventually fractures under its own weight. This reduces its lamp life. The incandescent bulb is very inefficient, since it dissipates about 90% of energy in the form of heat. This energy is in the invisible infrared part of the spectrum. The ambient temperature of a room with many installed incandescent lamps is much higher than under conditions where these lamps are switched off. This results in an increased use of air conditioning and an increase in energy consumption.

The second technology is fluorescence, where low pressure gas is excited rather than heated, resulting in narrowband atomic line emissions. This is re-emitted by fluorescent materials. The discharged light is narrowband in the visible light spectrum. Fluorescence is initiated by a discharge in mercury vapour, causing radiation in the ultraviolet region of the spectrum. Its efficiency is much higher than that of the incandescent lamp.

Table 2: Lamp specifications

Technology	*Incandescence*	*Fluorescence*
Efficacy (lm/W)	16	85
Lifetime (khr)	1	10
Input power (W/lamp)	75	40
Colour rendering index	95	75

Up to now fluorescence technology with its better efficacy, has provided remarkable energy savings. By replacing the incandescent lamps with fluorescent lamps or compact fluorescent lamps (CFLs), the ambient temperature of the room will be lowered, since the latter operate at a cooler temperature. This results in huge energy consumption reduction, firstly due to the higher efficacy of the CFLs, as can be seen in Table 2, and secondly due to the elimination of additional air conditioning (Kendall & Scholand 2001). A CFL has a lifetime much higher than that of an incandescent lamp. Lamp life is defined as the time at which 50% of the test samples have failed or the time it took the lamp to maintain 50% of its initial brightness.

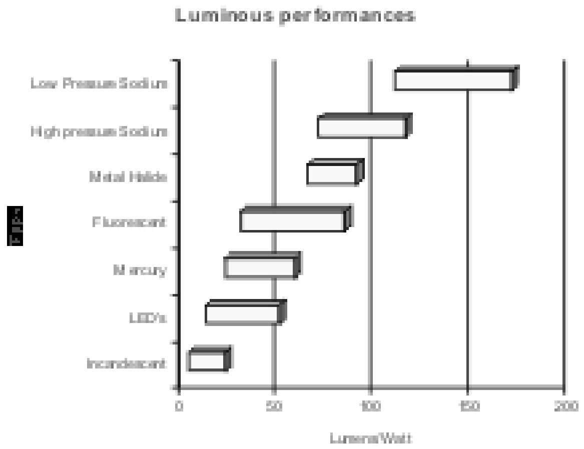

Figure I: Efficacy of various conventional and semi-conductor light sources

Figure I (Kendall & Scholand 2001) illustrates that a 100-watt typical incandescent lamp has an efficacy of 17.5 lumens per watt and produces 1750 lumens, whereas a 100W fluorescent lamp produces between 3000 and 9000 lumens depending on the colour type.

It shows that the efficacy of fluorescent lamps is 2 to 6 times better than that of incandescence. Solid-State or LED technology is another lighting technology that is vigorously being researched. Solid-State lamps will become available as a white light source, competing with incandescence and fluorescence, in the near future.

Lighting design

High lighting standards are important to illuminate a workspace effectively and the general surroundings sufficiently. A lighting load has a very poor load factor, as it is utilised over a very short period per day. This leads to the perception that its energy consumption has little impact on the maximum demand of a domestic, office or industrial installation.

The fluorescent tube, CFL and solid-state lamps are lighting technologies promoted to replace conventional incandescence. Energy efficient, cost effective lighting designs are being implemented worldwide. The first parameter to establish in a lighting design is the Standard maintained Illuminance (lx), according to the application or activity being performed, as listed in Table 3.

The next step of the design is to determine the lamps Efficacy, Luminous flux, Luminous intensity, Iluminance, Utilisation Factor and Maintenance Factor (MF) to calculate the number of lamps and its ratings. The design can then be verified by plotting the floor-plan with luminaire arrangements and isolux diagrams (Fritz 2004). The displayed pattern of illuminance lines on a plane as a series of illuminance contours forms an Isolux diagram as shown in Figure 2 (Prichard 1999).

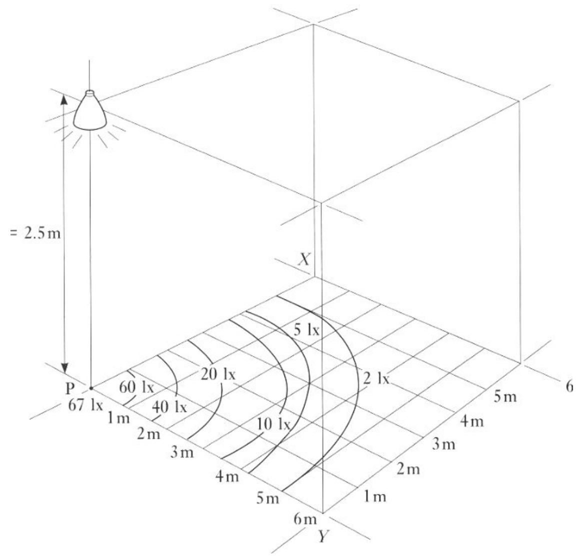

Figure 2: An Isolux diagram

Table 3: Standard Illuminance of various activities

Standard maintained illuminance (lx)	Activity	Location
50	Rarely used, visual tasks confined to movement	Cable tunnels, storage tanks, walkways
100	Occasionally used, visual tasks confined to movement	Corridors, changing rooms, bulk stores, auditoria
150	Occasionally used, visual tasks involves some risk to people, plant or product	Loading bays, medical stores, plant rooms
300	Continuously occupied, visual tasks easy	Libraries, lecture theatres
750	Continuously occupied, visual tasks difficult	Drawing office, meat inspection, chain stores
1500	Continuously occupied, visual tasks extremely difficult	Fine work and inspection, precision assembly

Types of lighting systems

Lighting technology is very dynamic, with new lamps being developed constantly. A lighting design can be one of the following three or a combination of them (Raissen 2000):

- General lighting replaces natural sunlight, when the sun sets. This is achieved by using an indirect light source, viz. wall mounted fittings, ceiling suspended luminaries and lamp stands. The primary light beam must shine upwards to be reflected by the ceiling, and the secondary one(s) beams directly downward. Indirect lighting systems result in an evenly distributed light output, with fewer shadows and less glare. Fluorescent, tungsten halogen or metal halide light sources are recommended for general lighting. Fluorescence is the most energy efficient, where metal halide is very expensive.

- Task lighting is purpose-designed and installed for specific tasks to be performed. These tasks vary from reading, writing, cooking, sewing, computing and TV watching. This design makes use of desk lamps, table lamps, study lamps and sunken ceiling or floor fixtures. Compact fluorescent and incandescent lamps are recommended. Task lighting can also be achieved by controlling general lighting by means of dimmers, enhanced by a desk lamp.

- Accent lighting accentuates or highlights objects. These objects can be anything from plants, pictures, statues, garden walkways or displayed retail merchandise. Variable low voltage light sources are recommended. Four ceiling mounted antiglare 50W, 12V metal halide down lighters per $12m^2$ will be adequate to illuminate displayed merchandise. The more expensive merchandise should be lit more than that of the cheaper ones. The customer's eye will be attracted to the brightest light level.

Energy audit of lighting systems

Energy Audits revealed that the most common mistakes leading to the waste of energy in a lighting design are as follows (Anderson 2003):

- Inefficient luminaires; when the lamp demands more power to produce the same illumination than necessary
- Over lighting; when the output illumination is more than necessary
- Excessive heat generation; when heat produced by artificial lighting needs to be offset by air conditioning
- Transmission loss; if luminaries are installed far from work surface, light intensity will be lost.

The following projects emphasize the significance of energy audits (Kreuger 2005):

Energy efficient streetlight network for Cape Town

In October 2005 a private company TFMC conducted an energy audit and has been awarded a contract to design, construct, operate and maintain an energy efficient streetlight network for the City of Cape Town. The invested capital would eventually exceed R60 million. The contract entails the removal of the existing inefficient luminaries that uses mercury vapour lamps. It will be replaced with new standardised luminaries, using energy efficient high-pressure sodium lamps. The agreement is open to an option to extend the contract to other areas. Besides the increased road safety factor, the financial benefits to the City of Cape Town, over the ten year contract period, will be millions of Rand. TFMC is already negotiating with other municipalities to promote the benefits of retrofitting existing public lighting networks.

FNB Bank City

Lemay Electrical concluded the retrofit of more than 18 000 luminaires at FNB Bank City, resulting in a saving of 2.2 MW. They replaced:

- 75W fluorescent tubes with 58W ECG lamps, which resulted in the same light output.
- 250w high bays fittings with 120W ECG lamps and reflectors, which resulted in the same light output.
- 25, 3x36W lamp fittings (average 500 lux) with 30, 2x28W lamp fittings (average 517 lux), resulting in a 52W saving per fitting.

Energy efficient ECG luminaires are designed in Europe and use triphospher lamps with reflectors, which reduce energy consumption significantly.

The case of Nuwe Hoop School in Worcester energy audit

The Electrical Engineering Department, Cape Peninsula University of Technology, in Bellville, has established a Service Learning and Development (SLD) unit. The SLD unit delivers a service to the community, to improve their standard of living and to provide training to the students registered at the institution. The author headed the unit. The unit members are students and lecturers, and the unit was established in collaboration with government organizations, and private companies in the industry.

The SLD unit performs certain functions to the above mentioned role players, on a contract basis. As an incentive, the students and community members were provided with the necessary training and compensated with decent remunerations. The first project contracted to the SLD unit was in collaboration with the electrical supply utility (Eskom) and a company called Innovative Energy Projects. The SLD unit was to compile an Energy Audit at the 'Nuwe Hoop' Centre for the Deaf in Worcester, approximately 100 km from the university.

Figure 3 shows the SLD unit student members in front of the Nuwe Hoop School. This centre has three schools and three hostels that cater for pre-primary, junior and senior learners with impaired hearing. There was also a laundry and kitchen on the premises; its electrical appliances made a great contribution to the energy consumption of the centre.

Figure 3: The SLD unit student members at the entrance to the Nuwe Hoop School

The biggest problems encountered while conducting the audit were:

- unavailability of lighting plans, floor plans or updated floor plans
- unmarked room numbers
- the inaccessibility of certain areas
- fused lamps
- new installations in progress
- manpower shortage (unavailability of students)

After the energy audit was conducted, the following energy consumption reduction methods were recommended:

- approximately 800 incandescent lamps were to be replaced by energy efficient CFLs,
- 200 T8 fluorescent tubes, and
- 800 T12 fluorescent tubes be replaced by triphosphor lamps.

This would reduce the energy consumption of the interior lighting of the complex from 31 MWh to 12.5 MWh, for a unity power factor. At a cost of 52,17c/kWh, this is a massive saving per month. After the energy audit these recommendations were to be implemented by Innovative Energy Projects and community members.

Conclusion

This project highlights the importance of energy efficient, cost effective electrical lighting installations. The standard of living of the community has been improved as follows:

- Most of the incandescent lamps were darkened as the tungsten was deposited on the lamp walls. With the retrofit the learners productivity is increased, due to the proper lighting levels.
- The learners can benefit from the electricity bill and the savings if the now available funds are utilized elsewhere at school.
- The unemployed that assisted with the lamp retrofits and cleaning of lamp covers, earned wages for their input.

Glossary of terms

CFL: a compact fluorescent lamp. The integral one has the lamp and control gear built-in into a single unit. This fits into an existing light socket. In the modular unit the lamp and control gear is separate, with a dedicated lamp holder.

CRI (colour rendering index): a quantitative measure of the accuracy of colour rendering is the colour-rendering index (CRI). This measure is based on comparing the colours rendered by a LED's light source to the colours rendered by a 'perfect' reference light source. As the maximum luminous efficacy decreases, the maximum CRI increases, as the wavelengths move further to the extremes of the visible spectrum.

ECG luminaire: A luminaire designed in Europe that uses triphospher lamps with reflectors.

Efficacy (η) [lumen/watt or lm/W]: The efficiency of a light source by converting the electrical input power to light or the luminous flux to power intake ratio of a lamp.

Efficiency: A measure of the useful light output in lumens against the total amount of lumens generated by the light source.

Energy efficiency: The wise use of energy or electricity to save resources and money.

Iluminance or Illumination (E) [lux or lx or lm/m^2]: The luminous flux density at a point on a surface or $E = \Phi \div A$.

Lamp life: the time at which 50% of the test samples have failed or the time it took the lamp to maintain 50% of its initial brightness.

Load factor: ratio of the average power to the maximum demand over a certain period.

Luminaire: an apparatus (support, circuit auxiliaries and protection) that distributes, filters or transform light form a lamp/s. It excludes the lamp/s. Circuit auxiliaries are the components needed to operate the light source directly from the mains supply.

Luminous flux (Φ) [lumen or lm]: Light energy / waves radiated (received) by a source (surface).

Luminous intensity or candle power (I) [Candela or lm/sr]: Solid angular flux density of a source in a specified direction.

Maintenance factor (MF): Illuminance deterioration is caused by the lamp lumen maintenance factor (LLMF), luminaire maintenance factor (LMF) and room surface maintenance factor (RSMF). Thus MF =LMF*LMF*RSMF.

Utilisation factor (UF): A measure of the efficiency of installation or percentage of flux that reaches the work plane.

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