ENERGY EFFICIENT LIGHTING FOR BETTER ENVIRONMENT

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ABSTRACT: Global overall energy consumption is rising. Along with it, a relative contribution is lighting energy. While existing light sources are reaching their limit of performance, LED-based light sources are however offering the potential to meet energy saving targets with their improving performance. In most buildings, the dominant light source is the fluorescent lamp. Although it is energy efficient, the total energy consumed is still significant, especially more so for public institutional buildings in Malaysia. This research studied the application of linear LED replacement tubes as the alternative retrofitting energy efficient solution to the existing fluorescent tubes in the International Islamic University Malaysia Main Library. The study assessed the potential to reduce energy consumption and consequently, the electricity bill but without reducing the performance. The methodology adopted the data collection technique through physical walk-through audit and an observational survey of the existing lighting situation. Using the Lighting Power Density (LPD) calculation methods from ASHRAE and IESNA, a recommended light level and cost analysis were undertaken. With the LED retrofit, the recommended lighting levels were established, and an annual savings of 33% was predicted in one academic building, with a return on investment period of less than two years.

Keywords: energy efficient, LED lighting, light retrofitting

INTRODUCTION

Global lighting energy consumption is enormous, and the demand is rapidly increasing. Currently, more than 33 billion lamps operate worldwide, translating into 19% of the world's electricity consumption (de Almeida, et.al., 2013). With the skyrocketing electricity prices and mounting concerns about climate change have forced governments, policy makers and the global lighting markets to start to migrate and encourage consumers to energy efficient light sources, like LEDs. Historically, electrical light sources evolved from Edison's incandescent bulb to mercury vapor fluorescent lamp, metal halide up to high-pressure sodium lamps (Cole and Driscoll, 2014) and the latest addition are the light emitting diodes (LED). LED entered the market as a light source for general illumination in the early 2000s, but by 2006 it had improved and became competitive and popular in both residential and commercial applications. They are projected to dominate the light sources, thus rendering the traditional ones obsolete. Energy efficient LEDs are revolutionizing the energy sector of lighting with their extreme reliability and a much longer lifetime than all other light sources. As existing light sources approached their limit of performance, LEDs are offering the potential to meet energy saving targets with their rapidly improving performance. Upon this context, this article studied the applications of LEDs as a retrofitting solution to the existing fluorescent lighting system and assesses their potentials to reduce energy consumption and electricity cost with no adverse effects on performance. The study used the IIUM Main library as a case study.

AN OVERVIEW OF GLOBAL LIGHTING ENERGY CONSUMPTION

Lighting accounts for more than 19% (or almost one-fifth) of the overall world electricity production where artificial lighting ranks at the top among the end-uses dominating global electric utilities. This phenomena entails greenhouse gas (GHG) emissions of an equally vast scale of 1,900 million tons of CO_2 annually, equivalent to 70% of the emissions of the world's lighter passenger vehicles (OECD/IEA, 2006 & IEA, 2010). The amount of electricity used for lighting in buildings differs according to the type of buildings. In some buildings, it is the largest single category of energy consumption. In the US, for instance, lighting in commercial buildings is the leading energy consumer with 25%, ahead of space cooling (13%) (U.S DoE, 2011).

LIGHTING ENERGY of UNIVERSITY BUILDINGS

Globally, almost half of the global lighting electricity is consumed by the commercial sector/tertiary sector, where universities belong. This is estimated at 1,133TWh representing 43% of lighting consumption (DoE, 2011). The rest is distributed amongst the residential sector (with 811TWh or 31%); the industrial sector (with 490TWh or 18%,) and the outdoor stationary sector (with 218TWh or 8%). In institutional buildings, lighting energy consumption has an enormous impact on both financial and environmental interests. In the United States, the Department of Energy (DoE, 2011) notes that in a classic college or university, lighting represents 31% of the total energy use, making it the best targets for energy savings (E-Source Companies LLC, 2003). In another study by Mahlia, et.al (2011) it was observed that the lighting energy could consume up to 42% of the total energy supplied. However, as much as 30 to 50% of light energy plus 10 to 20% of cooling load can be saved after lighting retrofits. The increasing energy bills, environmental responsibility, financial constraints, aging infrastructures are all forcing institutions to re-examine and re-evaluate their energy consumption and other conservation demands. A recent study by (SchoolDude, 2013) shows that energy inefficient universities use up to three times more energy than energy efficient ones. Thus, as universities search for new financing mechanism, the next constant issue is adopting new energy efficient technologies that will save enormous amounts of money that could go toward improving educational programs and meeting other university needs.

Lighting Technologies

The three landmarks in lighting technology are the Incandescent lamps (ILs); the Fluorescent lamps (FLs); and the Solid State Lighting (SSL). They all experienced various improvements over 120 years, but LED-based light products, which began few decades ago as just indicators, are now poised to become the most efficient light source ever created. LED is a Solid State Lighting (SSL) that is lighting that uses semiconductors to convert electricity into light (de Almeida et.al, 2014). LED consists of a number of layered semiconductor materials where electricity is directly converted into light particles called Photons. This requires less energy input, leading to its efficacy gains. There are two main types of SSL technology: the inorganic semiconductor-based LED and the polymeric-based organic LED (OLED). Both technologies are currently the subject of active research worldwide (The National Academy of Sciences, 2013).

Haitz and Tsao (2011) predicted that the exponential development of cost per lumen (i.e. unit of useful light emitted) and the amount of light per package of LED lamps could reach 200 lm/W in 2020, overtaking the 100 lm/W in 2010 (de Almeida et.al., 2014). de Almeida et.al. further maintained that this would be the case if enough industrial and government commitment were utilized for research on LED-based lighting products. The mounting evolution due to LED's development is attributed to the successful production of white light-emitting diode (WLED). This shifted the bulk adoption of LED lighting from the niche markets of traffic lights, signage, and displays to architectural lighting (which has the highest global revenue of 45% in the light industry) and automotive industry.

LED-based lighting products for the building industry are available in two forms. The first, called LED linear replacement, consist of light bulbs or lamps that can replace, one-for-one, an existing lamp without modification to the original luminaire or fixture. Thus, they are shaped like a fluorescent lamp. The second is an integrated style LED retrofit kit that is not shaped like a fluorescent lamp. It is a purpose-built luminaire, which has either an integral LED light source or a LED module that can be removed. To be retrofit, these would require complete removal and replacement of the luminaire (The National Academy of Sciences, 2013)

Retrofitting Fluorescent lamps with LED Tubes

Lighting retrofit for an existing building is considered one of the most effective measures to reduce building energy consumption (Li, 2013). In the context of lighting products, Baynham and Stevens

(2014) explained that a retrofit is a product that is compatible with an existing system and which has an offering above and beyond what it replaces. Retrofitting presents an opportunity to take advantage of new technologies without incurring the need for full fitting replacement. In most cases, it involves a direct lamp replacement, requiring no rewiring or modification to the existing circuit. Through LED retrofitting projects, the US Department of Energy expected a potential energy savings of national electricity use by nearly half of its current total energy consumption by 2030 (U.S DoE, 2014). de Almeida et.al (2014) reported that the European Unions estimated 50% energy savings with progressive replacement of lamps with efficient LEDs in all sectors equating to a saving potential of 209TWh of energy, which translates into 77 million tons of CO_2.

Positively, as a result of various geographical, political, and cultural factors, LEDs made even more substantial progress in Asian countries. Mckinsey & Company (2012) reports that with Japan and China recording the highest penetrations, the value-based LED share in the regions' lighting market was over 10% in 2011. In Japan, for instance, lighting systems consumed 16% (the equivalent of 150.6TWh) of the total energy consumption. It is forecasted that if all incandescent and fluorescent lamps in Japan are to be replaced with LEDs, the overall energy consumption will be reduced by 9%, representing over 90TWh or 61% of the annual lighting electricity consumption. A simulation conducted by the Japan Electric Lamp Manufacturers Association found that the effect of this transition would be a reduction of 27 million tons of CO_2 annually (Center for Clean Air Policy, 2013; The Institute of Energy Economics Japan, 2011).

Previous Studies on Lighting Retrofitting

Many studies have been conducted regarding retrofitting conventional light sources with the rapidly progressive LED technology (Uddin, et.al, 2011; Chen & Chung, 2011 & Ryckaert, et.al, 2012). In Finland, Sarvaranta (2011) analyzed the impact of using total LED lighting on energy savings and CO_2 reduction between 2020 and 2050. The author estimated that household lighting energy consumption could be reduced by 80% (from 2.4 to 1.9TW/a) in 20 years and with the corresponding decrease in electricity cost. The Institute of Energy Economics Japan (2011) conducted a field trial in 2008 to examine the feasibility of installing LED lighting into communal areas of social housing (i.e. stairwells, corridors, and common rooms usually illuminated 24 hours a day). They measured the performance, energy saving potentials, and maintenance of light levels of over 4,250 LED lamps across 35 different sites. It was found that LED lightings can significantly reduce energy consumption, lower cost of maintenance, and improved lighting in social housing. In another study by Edirisinghe (2012) the power consumption of T8 LED lamp with a FL is compared to a unit area of a building space, the result indicated a reduction of 40% when LED lighting was used. The LED technology is witnessing a swift development as compared to other traditional light sources starting from the 1879 Edison's first incandescent bulb. It clearly portrayed LEDs as having the highest potential. LEDs as the current lighting 'breakthrough' are set to help considerably to reduce consumption of energy compared to existing conventional light sources. They are also predicted to improve light quality and reduce maintenance costs. With the evidences on the energy savings potential with LED retrofitting, this study undertook to retrofit a library building in a university. A library building is the most lit and with the longest duration of lighting in any institution.

The Case Study: International Islamic University Malaysia (IIUM) Main Library

The case study for this study is the IIUM Library at Gombak Campus, Kuala Lumpur. It was first established in 1983 with a small seating capacity. After three years, the library was added to five stories with the fifth level serving as a storage facility and not accessible to all. The library has a floor area of approximately 25,000 sqm, consisting of conducive environment with a seating capacity of over 2,000 users, 73 carrel rooms, 10 research rooms, 8 discussion rooms, 4 computer labs, 4 audio-visual viewing rooms, an auditorium and a multi-purpose room. The majority of the lighting technology employed at the IIUM Library building is fluorescent-based 36W T8 technology lamps with electronic ballast (93%). The lamps specifications are shown in Table 1.

Table 4: Specifications of the existing lamps in IIUM & the proposed LED lamps

Brand	**Existing T8 FLs**	**Proposed T8 LED**
	Philips Lifemax	**Philips InstantFit**
Type/color	T8 Linear Fluorescent bulb/Cool Daylight	Linear LED T8 (replacement)
Product Title	TL-D Standard 36W/54-765 ISL	14.5T8/48-4000IF 10/1
Lamp wattage	36W	14.5W
Lamp efficacy	72 lm/W	103lm/W
Lumen output	2600lm	1,500lm
Color temperature	6200K cool daylight	3000K - 5000K
Lifespan	13,000 hours	50,000 hours
Ballast Loss/Wattage	Electronic/8W	-
Hours of use per day	14 hours	14 hours
Days of use per week	7 days in a week	7 days in a week

Analyzing the Efficiency of the Existing Light

To appraise the energy efficiency of the existing lighting system, the Illuminating Engineering Society of North America (IESNA) Handbook, American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) Standard 90.1 and Malaysian Standard (MS 1525:2014) will be used as reference guide. They provide the codes and legislation used for designing and installing lighting systems in building. They also set the maximum allowable Lighting Power Density (LPD) in W per m^2 (or W/ft^2) and the average maximum illumination levels in Lux (lx) required. The energy used per square meter, called Lighting Power Density (LPD) is first calculated. It is a screening measure that indicates whether a space offers the opportunity for energy savings or not. LPD is found by dividing the total wattage (W) of the fluorescent tubes in a particular area by the floor area (m^2/ft^2). Next is to note the average illumination levels at task point of the different locations of the selected spaces using a handheld Lux Meter. Comparing the calculated and recommended LPD for the selected spaces (Table 2), it is clear that the existing lighting is not effective in terms of energy efficiency. It is so because, while most of the measured average illumination levels fall below or within the range of the recommended lux levels, the LPDs did not conform to the approved standards. In all spaces, it is higher than the recommended intensities. This confirmed the basis for the integration of the latest energy efficient lighting technology that will have effective LPDs, thereby reduce energy consumption, save energy and provide optimum performance.

Table 5: Comparing Measured & Recommended Lux Levels and LPD

Floor	**Space**	**Measured Lux (lx)**	**Recommended. Lux (lx)**	**Calculated LPD (W/m²)**	**Recommended. LPD (W/m²)**
1st Floor	Reading & Bookshelves	403	300 – 500	17.8	13
	Photocopy	182	100	12.5	5
2nd Floor	OPAC	412	300 – 500	22.5	13
	Leisure study	403	150	17.1	6
	CS Division	309	300	26.8	11
3rd Floor	Reading & Bookshelves	490	300 – 500	21.1	13
	Thesis collection	321	300 – 500	18.0	13
4th Floor	Reading & Bookshelves	401	300 – 500	47.4	13
	Meeting room	215	300	23.3	14

Lighting Energy Audit

To conduct an extensive lighting energy audit, the first step is to assess the existing lighting setting in terms of energy consumption by the type of light bulbs. The calculation of the energy consumption is based on the real measurement of the wattage input consumed by all existing fluorescent tubes in the library. Thus, the lighting system total power, overall energy consumption, and total energy cost of existing fluorescent lamps were found using the procedures employed in U.S. Department of Energy, (2010) and are tabulated in Table 3.

Equation 1: Total power (kW) consumed for lighting in the library;

$$Existing\ lamp\ wattage\ (W) \times Number\ of\ lamps$$

Equation 2: Total energy (kWh/year) consumed by existing lighting annually:

$$Total\ power\ consumed\ by\ luminaire\ (W) \times Hrs\ of\ use\ per\ day \times Day\ of\ use\ per\ week \times Weeks\ of\ use\ per\ year$$

Equation 3: Total energy cost (RM) annually for operation of the existing light in the library:

$$Total\ energy\ consumed\ (kW\ per\ yr) \times energy\ cost\ (sen\ per\ kWh)$$

Equation 4: Total energy savings: The energy saving (ES) will be the difference between the energy consumption (EC) of existing fluorescent lighting ($EC_{existing}$) and that of the retrofitting linear LED lighting ($EC_{retrofitting}$) system. The following relation will be employ:

$$ES = EC_{existing} - EC_{retrofitting}$$

Table 6: Number of FLs and Overall Lighting Power Consumption in the Library

Floor/Space	**Fluorescent type**	
	36W 4ft	**18W 2ft**
1st Floor	2,018	265
2nd Floor	1,283	102
3rd Floor	1,899	104
4th Floor	2,361	133
Total No.	**7, 561**	**604**
Total Power Consumed (kW)	**272, 196**	**10, 872**
	283.07	
Total power plus Ballast power (kW)	**348.388**	
Total energy consumption (kWh)	**1,775, 385.248 per year**	
Total energy cost (RM)	**RM 648, 015. 616 per year**	

The preceding calculations indicate the cost spent on lighting energy consumption for the overall 8,165 fluorescent tubes currently used at the IIUM Library building which is approximately RM650,000 annually. Recent electricity bill obtained from Development Division shows that the entire university (Gombak Campus only) is paying RM26,820,000 on electricity per year.

Comparing the Existing FL with the Proposed LED Lighting Systems

According to Owano (2014), Philips is one of the world's largest manufacturers of light bulbs and innovators in LED lighting and the InstantFit LED T8 is the world's first LED replacement tube that requires no rewiring. Hence, for this study, the LED T8 lamp model was chosen, as the proposed retrofit option is the Philips InstantFit LED Lamp. It is considered to have an ideal energy saving choice for existing linear fluorescent fixtures. Table 4 shows that retrofitting existing fluorescent tubes with InstantFit linear LED tube will actually reduce energy consumption and subsequent electricity bill of IIUM.

Table 7: Cost Comparison between Existing FLs & Proposed LED Light

	Existing Light: FL tube	**Proposed alternative: LED tube**
No. of Lamps required	7,561	7,561
Price (RM) per unit	4.5	88.00
Lifespan (hours)	13,000	50,000
Power Consumed per fixture (W)	44	14.5
Total Power Consumed (kW)	332.684	109.64
Total Energy Consumption (kWh) per annum	1,695,174.21	558,697.41
Energy Cost (RM)	618,738.59	203,924.56
Energy Savings (RM) annually	**414,814.03**	

For this particular study, 14.5W Philips InstantFit Linear LED tube was chosen as the proposed candidate. Although the cost is 17 times higher than existing FLs, it consumes three times less wattage and has almost four times longer lifespan. Thus, with the current electric utility rate of RM 0.365, if the existing fluorescent lamps at the IIUM Library are replaced with the proposed LED light, 1.14 million kWh of energy will be saved annually. This translates to an approximate sum of RM 415,000 saved, annually. The energy consumption for lighting is only 0.76% of the total energy cost of the campus, as against 2.5% of the current consumption for lighting.

Simple Payback Period (spp)

The simple payback period (SPP) was determined using the following relations (Zakaria, 2014), as follows: $SPP = CI/(AEC_{old} - AEC_{new})$; where CI (Cost of Investment, including installation cost) is RM778,783.00, assuming installation cost is RM10 per lamp. The difference in AEC (annual energy consumption) value is RM414, 814.03.
Thus, SPP = $778,783/(414,814.03)$
SPP = 1.88 years

CONCLUSION

The calculation of the lighting energy for the existing and the proposed InstantFit LED tube was undertaken based on the 14 hours per day and seven days per week operation usage. Table 4, shown previously, summarizes the calculated amount and value of energy savings to be generated when the existing lights are retrofitted with energy efficient InstantFit LED lights. The return on investment period, was found to be less than 2 years (22 months) when calculated in simple terms of comparing the total cost of the InstantFit LED fittings against the energy they save. This illustrates that the LED lighting will return its original investment cost in less than two years, far less than the approximate lifetime of the InstantFit LED retrofit. The financial value of these savings is approximately RM415, 000 annually, with an energy savings of 1.14 million kWh per annum by the new LED lighting. This result illustrates the efficiency and effectiveness of LED lighting as an energy saving measure.

With anticipated falling prices of LEDs, the technology will soon save billions in energy and maintenance cost across the globe. LED-based lights are thus, the answer to producing real and significant energy savings and actually reduce electricity bill at IIUM. Implementing this study will provide tremendous financial benefits that will quickly affect the lighting energy efficiency value of IIUM, in particular, and confirm its commitment towards becoming a more sustainable university worldwide.

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