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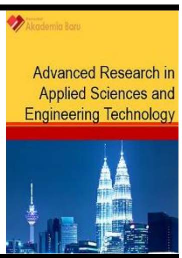

Comparative Study of Residential Lighting Technologies

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ABSTRACT

As the lighting load constituted amount of power in electricity system, improving of efficiency in lighting technology would make a beneficial to consumer, energy provider and environment. Consequently, majority of home lighting manufacturers were competing each other by improving and claiming their product as the best energy efficient lighting product. Knowledge or exposure regarding to lighting technology especially on energy efficiency, power quality and economy are an important issues to give awareness to user before buy or use the lighting product. Therefore in this research study, three types of lighting product such as energy saving incandescent lighting, compact fluorescent lighting (CFL) and solid state lighting (LED) were compared. Comparative parameters were collected from data provided by lighting manufacturer and experimental data conducted in laboratory using power quality meter and lux meter. Hence, these study discussed in term of economy, power and light quality and energy efficiency of the tested lighting product. At the end of this study, the best home lighting technology is determined successfully.

1. Introduction

Lighting technology was start developed in 1879 and since many revolutions were occurred until now [1]. Today, there are many types of lighting technology such as incandescent, halogen, fluorescent, and light emitting diode (LED) was developed. Besides that, each type has difference characteristic and performance [1]. Performance of each type can affect energy consumption of lighting system. Lighting system is produce more than 10% of energy consume in the world [2]. Due to the concern of global warming, all government in the world introduced energy saving system and implementing it on lighting system. According to this issue, developing more efficient lighting system is very important. So that as a user, knowledge and exposure due to lighting technology are important for making energy efficiency a successful work. Nowadays, there are many types of lighting technology were developed in the world. In addition, after energy efficiency system was introduce

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and enforce in entire world, many research was done in lighting technology to produce the most efficient lighting system. Majority of home lighting technology manufactures were competing each other by improving their product and claim it as a best energy efficient lighting product. Inline of it, the comparative study of home lighting technology can be used as a method to prove and verify the performance in term of economic issue, power quality, and energy efficiency. As a result, user will gain information and lead them to identify the factor of choosing the lighting product. Generally, this project purpose is to study about home lighting technology. Comparative study will be conducted to examine each type of home lighting technology performance. The specific objectives of this project are to determine various type of latest home lighting technology, to define the parameters for comparative study in home lighting technology and finally, to evaluate the best home lighting technology, based on the comparative parameters. The scope of this project is essential as a guideline in order to achieve the objective. Therefore, there are several scopes of project that need to be focus. The scopes of this project are by compare three types of home lighting technology with same lumen (340-400 lm), colour (warm white) and voltage (240Vac), the tested of home lighting technology are energy saving incandescent lamp, compact fluorescent lamp (CFL) ambient type and LED lamp, the comparative parameters for this study are initial cost, running cost, energy consumption, power factor, total harmonic distortion (THD) and illuminance (lux), the study was conducted at energy efficiency laboratory Faculty of Electrical Engineering (FKE) UTeM and lastly, comparative parameters data are taken using Fluke 43B and Meterman digital lux meter.

2. Performance of Difference Type of Lighting

2.1 Incandescent lamps

Incandescent lamp is type of lamp that cheap to buy, but quite expensive to run. This type of lamp is the least efficient form of electric lighting compare to others lamp with 95% of energy was emitted as heat and only around 5 % of energy converted to light. It has a shortest life compare to others lamps. Therefore, energy costs will depend to the quantity as many times as the cost of the lamp. The short life also makes more maintenance and replacement cost. This type of lamps emits 14-18 Lumens per watt [6]. Figure 1 represents the voltages and currents waveforms from incandescent lamp when applying the rated voltage. It produce unity power factor and it create no harmonic distortion [7].

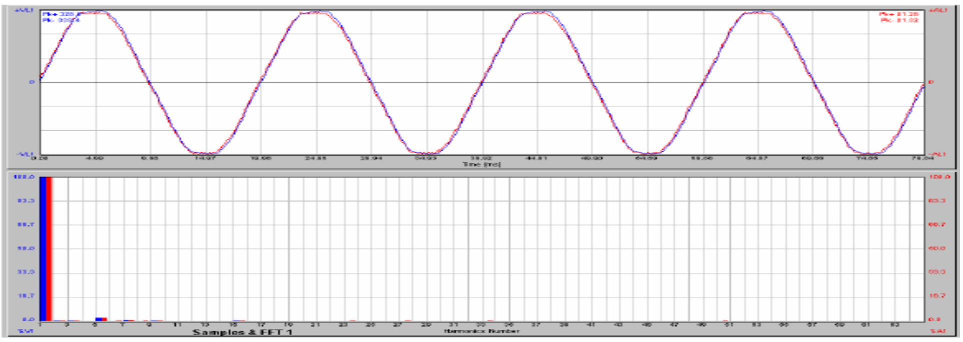


Fig. 1. Performance of incandescent lamp [7]

2.2 Compact Fluorescent Lamps (CFL)

Compact fluorescent lamp (CFL) have more efficiencies compare to incandescent lighting. It also is very easy to use. All type of CFL's has installed with electronic ballasts and starters to operate. This type of lamp is operating in same way like normal fluorescent lamp. The efficiency of CFL's is 5 times greater than incandescent lamp. It also has 8 times life span compare to standard incandescent lamp [6]. The lamp under-test emits 105 L/W at the rated voltage of 220 volts and rated active power of 28 watts [8]. CFL has a poor leading power factor, (0.599). Harmonic Distortion in current flow is large, nearly 103% [7] (Figure 2).

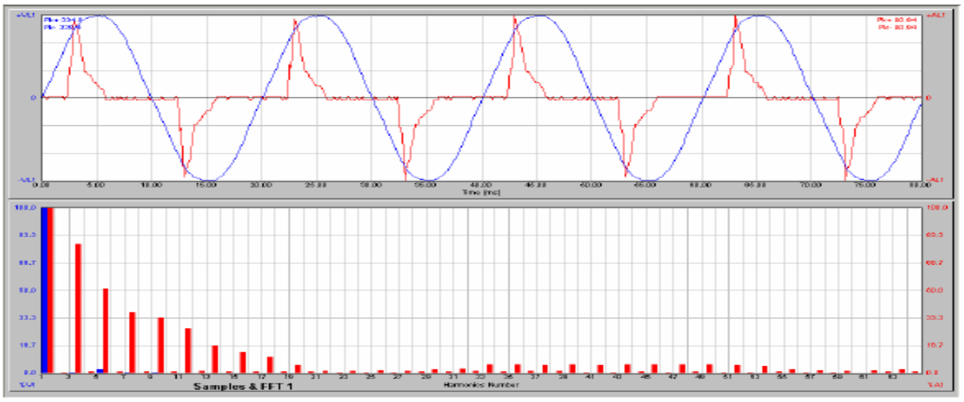


Fig. 2. Performances of CFLs [7]

2.3 Solid-state lighting (LED)

Light Emitting diodes (LED) have the latest lighting technology and the highest efficiency among the CFL and standard incandescent lamp. It has extremely long life compare to other lamp technology the rated lifetime at least 25,000 hours or 22 years based on use of 3 hours per day [7]. This type of lamp uses more less power, but same brightness with CFL and incandescent lamp. With only 3.3Watt, LED lamp produce very poor leading power factor, (0.05) and very low total harmonic distortion, 9.3% [5].

3. Criteria for Comparison of Lighting Technology

There are three type of lighting technology that will be compared each other in certain parameter. The criteria that are chosen mainly considered from user and electric power utility concern. User usually concern about quality, quantity, cost and lives span that given by the lamp [6]. There are some criteria that produce from customer and electric power system point of view [8] (Table 1).

Table 1
Criteria for lighting technology comparison

No.	Criteria	Description
1	Lamp cost	$Total\ lamp\ cost = initial\ cost + running\ cost$
2	Lighting harmonic	$THD = \frac{P_2 + P_3 + P_4 + \cdots + P_\infty}{P_1} = \frac{\sum_{n=2}^{\infty} P_n}{P_1}$ $HD = \frac{V_2^2 + V_3^2 + V_4^2 + \cdots + V_\infty^2}{V_1^2}$
3	Efficacy / Luminous Efficiency	$Efficacy = \frac{luminous\ flux/Lumen}{power\ consume/Watt}$
4	Power factor	$Power\ Factor\ , PF = \frac{Real\ Power\ (Watt)}{Apparent\ Power\ (VA)}$

4.Research Methodology

In this section, the methodology of the project will be discussed. To ensure that project is achieve objective and follow the schedule, a systematic procedure need to plan and done. This project is conducted by reviewing each part of the process through flowchart (Figure 3).

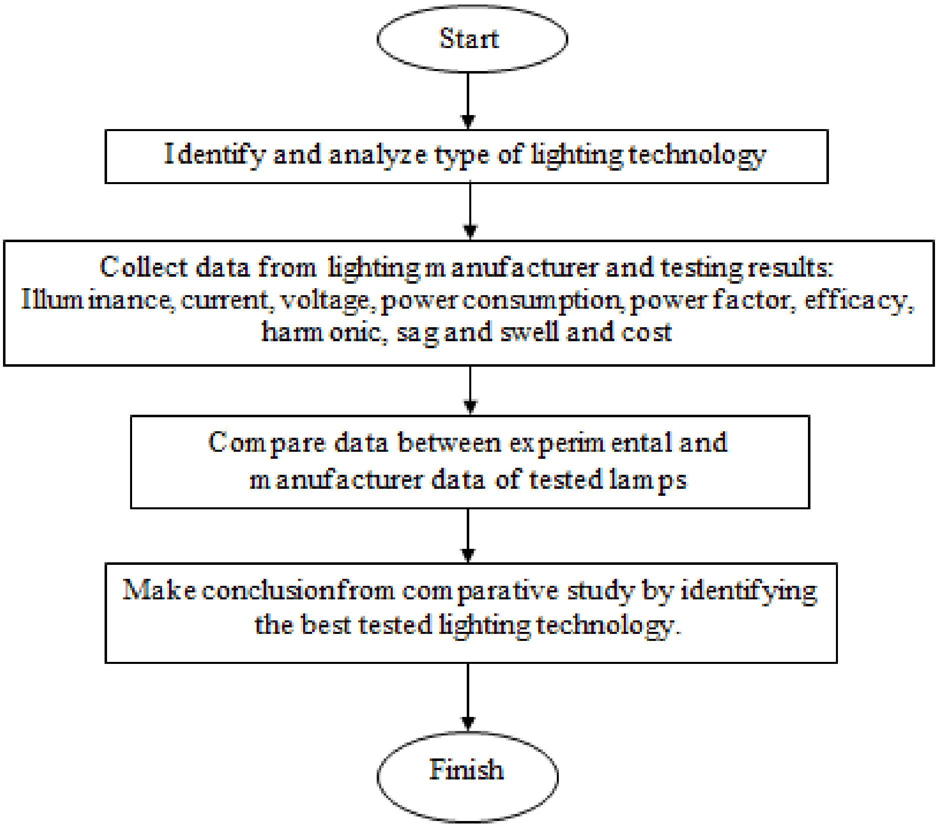


Fig. 3. Research flowchart

5.Identify and Analyze Type of Lighting Technology

In this part, types of lighting technology that will be testing are chosen. Three type of lighting technology that will be tested and compare are Energy Saver Incandescent lighting, Compact Fluorescent lighting and Solid State Light Emitting Diodes (LED) lighting.While choose these three type of lamp, several criteria and aspect of this lamp are fixed to make testing be more accurate and persist. The criteria and aspect that fixed such as colour rending (warm white), lumen (340-400lm), and rating voltage (240Vac).

5.1 Observation from the Experiment

After choosing and identify type of lighting, data from lighting manufacture were collected and then experiment and testing each type of lighting technology are conducted. The parameter that were tested are current, energy consumption, power factor, kilowatt-hours meter reading and illuminance (lux). Before conducted the testing, all the preparation from testing room, apparatus and measurement device need to be positioned correctly. This is to ensure the output data are validate and accurate. The tested time is 1day (24 hour) per session. But there are three type of lighting technology was tested and it make three week to finish all experiment. The data was recorded in power quality meter by using data log function provided in fluke meter. Then, the stored data were transferred to a PC by using Fluke View software.

A. Equipment and Tools

In this testing, the main equipment that used is Fluke power quality analyzer. This power quality analyzer is used to measure power consumption, harmonic, voltage, current and power factor. Another tool is light meter or lux meter. Lux meter is used to measure the illuminance of the tested lighting technology.

a b c d

Fig. 4. List of equipment used in this research (a: Fluke 43B Single Phase Quality Analyzer, b: Phoenix Single Phase Electronic kWh meter, c: Meterman Digital Light meter & d: AC/DC Current Clamp)

B. Lighting Power Station

Experiment were conducted and tested in lighting power station that was design and built to make experiment be more systematic (Figure 5 and 6).

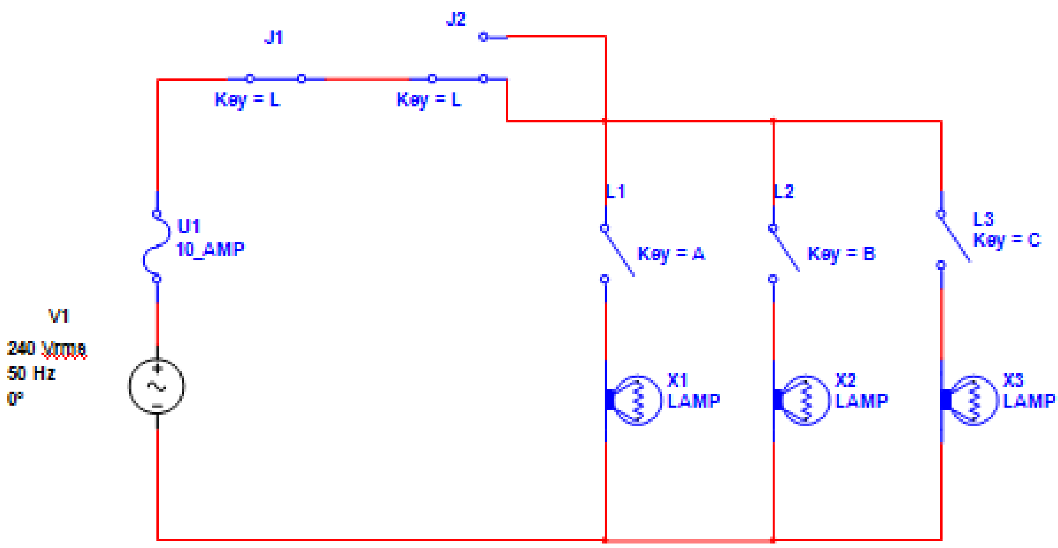


Fig. 5. Circuit of Lighting Power Station

Fig. 6. Lighting Power Stations

C. Experiment Room

Experiment was held in testing room to make data measured was accurate. This testing room for this study is located at energy efficiency laboratory Faculty of Electrical Engineering (FKE) UTeM (Figure 7 and 8).

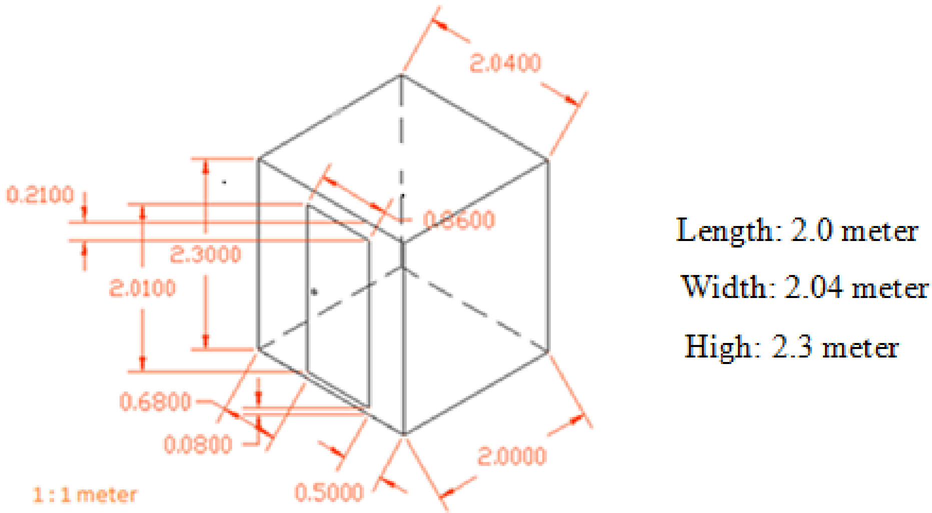


Fig. 7. Schematic diagram of testing room

Fig. 8. Side and front view of testing room

C. Determination of Illuminance Measurement Points

Based on the room index, the minimum number of illuminance measurement points were determine using room index (RI) and number of points for measuring illuminance is based on Table 2.

$$Room\ Index.RI = \frac{L \times W}{H_m \times (L+W)} \tag{1}$$

where:
L = Length
W = Width
Hm = Height of the luminaires above the plane of measurement

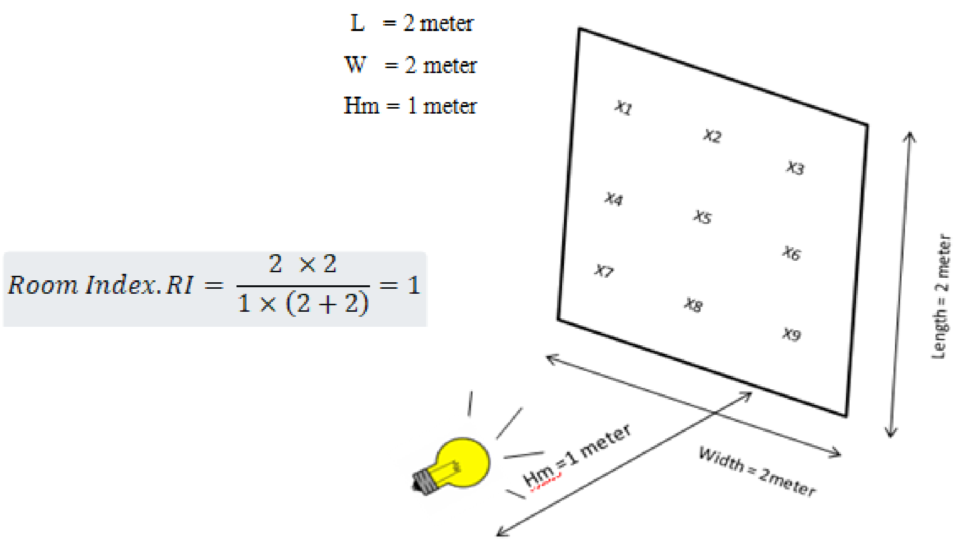


Fig. 9. Illuminance test setup

Table 2
Number of points for measuring illuminance

Room Index	Minimum number of measurement points	
	For ± 5% accuracy	For ± 10% accuracy
R1 < 1	8	4
1 < R1 < 2	18	9
2 < RI < 3	32	16
RI < 3	50	25

6. Results and Discussions

This section contains two types of collective data, first is data that provide by lamp manufacturer in the lighting box and catalogue, and secondly is data that collected from experiment in laboratories. The data was collected from three types of lighting technologies such as energy saving incandescent lighting, compact fluorescent lighting, and solid state lighting (LED).The parameters collected in this study are current, voltage, power consumption, power factor, total harmonic distortion, cost and percentage of energy saving. After that, both sources of data will be compared and make a data comparison between each type of lighting technology.

6.1 Data Provided by Lighting Manufacturer

All data was collected from lamp box that provide by manufacturer. Another source of this data comes from online catalogue in manufacture website and lighting template. Usually, data that provided from manufacturer are correct and precise. But not all of lighting manufacturer have high technologies and establish company, so sometimes there have an incorrect data provided by them and experiment must be held to prove that data weather it is true or not. Data that provided by manufacturer was tabulated in Table 3.

Table 3
Tabulated Data from Lighting Manufacturer of Energy Saving Incandescent Lighting, CFL and LED lighting

Lighting type / Parameter	Energy saving Incandescent Lighting	CFL Lighting	Solid State Lighting (LED)
Initial cost(RM)	RM 4.90	RM 14.32	RM 20.00
Power consumption (Watt)	28W	8W	7W
Voltage (V)	240V	100-240V	240V
Frequency (Hz)	50Hz	50-60Hz	50Hz
Luminous flux /Lumen (Lm)	340Lm	400Lm	350Lm
Efficacy(Lm/Watt)	12.14 Lm/W	50 Lm/W	50 Lm/W
Life Span (Hour)	2000H	6000H	25000H
Energy saving (%)	30%	80%	80%

From Table 3, shows that energy saving incandescent Lighting is the lowest in initial cost but have higher power consumption, meanwhile, LED lighting has the lowest in term of power consumption but higher in initial cost. Besides that CFL lighting has a highest luminous flux compare to others lighting technologies. Then, efficacy of CFL and LED lighting is same and high. Furthermore, LED lighting have a superior value in life span parameter, it shows LED lighting can withstand for a very long time compare to others.

6.2 Experimental Data from Tested Lighting Technologies

This data was collected from experiment and laboratories testing that were held in Energy Efficiency Laboratory in Faculty Electrical Engineering. This experiment was conducted to measure data such as illuminance, power consumption, total harmonic distortion and cost. The apparatus and tools that use are lighting power station, Fluke 43B single phase power quality analyzer, Meterman lux meter, kilowatt hour meter and laptop to transfer data that was save and recorded from flux meter.

A. Illuminance

Illuminance is the quantity of light falling on a unit area of surface. This experiment is conducted in a specified room using Meterman lux meter. Nine reading points has determined based on room index value (RI). Average of lux value was determined using equation below and data was tabulated in Table 4.

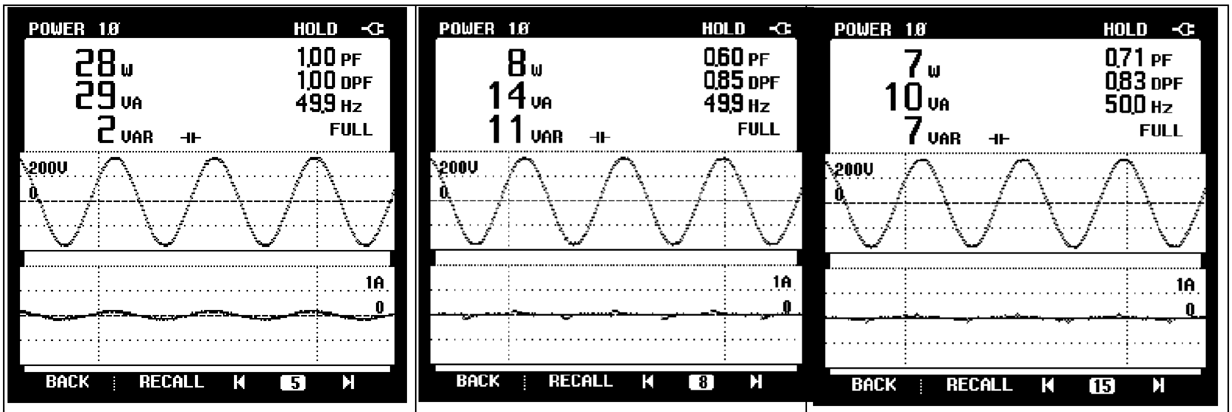
Table 4
Tabulated Data of Illuminance for Energy Saving Incandescent Lighting, CFL Lighting and Solid State Lighting (LED)

Energy Saving Incandescent Lighting		CFL Lighting		Solid State Lighting (LED)	
Points X_n	Illuminance (Lx)	Points X_n	Illuminance (Lx)	Points X_n	Illuminance (Lx)
X_1	34.6	X_1	28.0	X_1	29.5
X_2	37.2	X_2	29.5	X_2	34.5
X_3	33.5	X_3	24.1	X_3	27.3
X_4	40.0	X_4	33.3	X_4	40.6
X_5	40.3	X_5	40.0	X_5	60.6
X_6	36.1	X_6	29.6	X_6	37.8
X_7	29.6	X_7	24.3	X_7	25.6
X_8	30.3	X_8	27.2	X_8	30.6
X_9	26.5	X_9	22.2	X_9	24.1
Average = **34.23** Lx		Average = **28.69** Lx		Average = **34.53** Lx	

According to Table 4, average of illuminance for solid state lighting has a highest illuminance and CFL lighting has lowest value of illuminance. Highest value of illuminance should be okay because more high illuminance more quantity light falling in certain area.

B. Power Consumptions

Power consumptions are consisting of three main of power such as active power, reactive power and apparent power. Active power measure in Watt is portioning of real electrical power and utility cost charge are based on Watt [11]. Apparent power (VA) is product of rms voltage again current which relate to the effective load by current carrying conductors [11]. Reactive power (VAR) is reactive component of apparent power that cause by a phase shift between AC current and voltage in capacitor and inductor [11]. Other than that, power factor are the ratio of real power to apparent power it is not have more than value of one. Power consumption and power factor are indicated in Figure 10.



Energy saving Incandescent Lighting	CFL Lighting	Solid State Lighting (LED)

Fig. 10. Graphical illustration of power consumption and power factor for Energy Saving Incandescent Lighting, CFL Lighting and Solid State Lighting (LED)

According to Figure 10, the highest power factor is energy saving incandescent lighting which value is 0.965 that is near to unity value of power factor. The secondly value of power factor is LED lighting and the lowest is CFL lighting. Higher power factor is better to electrical power system because lower power factor will produce higher value of current that will increase energy lost. Besides that, LED lighting use lower active power and it make it as lowest lighting power consumption.

C. Total Current Harmonic Distortion

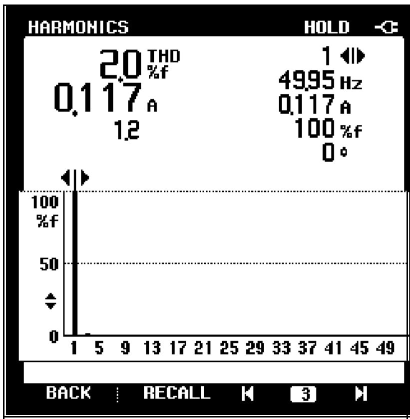
Total current harmonic distortion (THDi) is the ratio of the sum of the current of all harmonic components to the power of the fundamental frequency. It is the one of problem that always exists in electrical equipments [7]. Graphical data of THDi of energy saving incandescent lighting, CFL lighting and solid state lighting (LED) are shown in Figure 11.

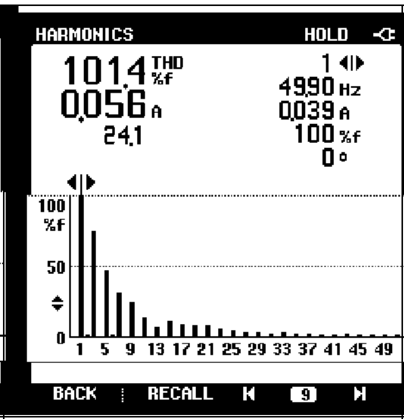
According to Figure 11, THDi of three of lighting technologies is difference. THDi of CFL lighting is higher compare to other, in power system point of view, the lighting system with lower percentage of THD will be better because it will produce less harmonic current distortion in power systems.

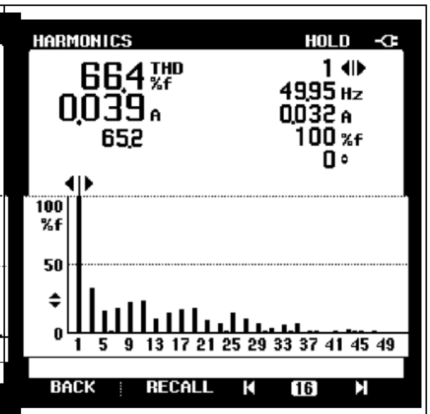
D. Cost

From customer point of view, cost of lighting product over the life span is very important. There are two main types of cost that very important to be considered when choosing lighting products. Firstly is initial cost and secondly is running cost. Initial cost are the cost that provided by manufacturer and it is the price that customer must pay to buy a certain lighting product and it will change based on current market price. Running cost is cost that use to operate in certain time.

Running cost was measured using kilowatt-hour meter and it price are depends on kilowatt-hour use and current tariff of electricity bill. The cost of tested lighting product was indicated in table below.







Energy saving Incandescent Lighting	CFL Lighting	Solid State Lighting (LED)

Fig. 11. Graphical illustration of total current harmonic distortion for Energy Saving Incandescent Lighting, CFL Lighting and Solid State Lighting (LED)

According to Table 5, the lowest price for initial cost is energy saving incandescent lighting followed by CFL lighting and lastly is LED lighting. It show a huge difference between the highest and lowest price for tested lighting technologies, it because more high technology applied for lighting product make production price also high. But for running cost per month, it showed cost for LED lighting is the lowest and cheaper compare to others type of lighting technology. So, for the lighting product cost, more lower is better according to customer's point of view.

Table 5
Calculation of cost for Energy Saving Incandescent Lighting, CFL Lighting and Solid State Lighting (LED)

Lighting Type	Cost Calculations
Energy Saving Incandescent Lighting	Initial cost of one bulb = **RM 4.90** Kilowatt hour meter reading (24h) = 0.22 kWh TNB tariff = RM 0.218/ kWh Assume eight hour per day use, in 30 day equal to 240 hours: Kilowatt-hour use = 0.72 x 10 = 7.2 kWh Running Cost per month = 7.2 kWh x 0.218 = **RM 1.57**
CFL Lighting	Initial cost of one bulb = **RM 14.32** Kilowatt hour meter reading (24h) = 0.22 kWh TNB tariff = RM 0.218/ kWh Assume eight hour per day use, in 30 day equal to 240 hours: Kilowatt-hour use = 0.22 x 10 = 2.2 kWh Running Cost per month = 2.2 kWh x 0.218 = **RM 0.48**
Solid State Lighting (LED)	Initial cost of one bulb = **RM 20.00** Kilowatt hour meter reading (24h) = 0.18 kWh TNB tariff = RM 0.218/ kWh Assume eight hour per day use, in 30 day equal to 240 hours: Kilowatt-hour use = 0.18 x 10 = 1.8 kWh Running Cost per month = 1.8kWh x 0.218 = **RM 0.39**

7. Conclusion

As a conclusions, comparative study of home lighting technologies are conducted by considering the concern of consumers to lighting product quality as well for electric utility concern. It is important for domestic user to know about the latest lighting technology and the actual performance of each type of lighting technologies. There are three type of latest home lighting technology that use energy saving energy system such as energy saving incandescent lighting, CFL lighting, and LED lighting and each type of lighting have a difference performance. The parameters that have been tested and compared are current, power consumption, power factor, harmonic, initial cost, running cost, and illuminance. All the parameter can be dividing in three sections like economy, power quality and light quality. From each section, it shows the performance of each type of home lighting technology. According to data analysis that include in Table 6, for overall score, it showed LED lighting technology (Score = 25) is the best lighting product compare to other lighting technology. Although LED lighting is a bit costly, it produces high performance in power quality, lighting quality and economy section.

Table 6
Performance of Tested Lighting Technology

	Lighting type / Parameter	 Energy Saving Incandescent Lighting		 CFL Lighting		 LED Lighting	
		Value	Rating	Value	Rating	Value	Rating
Power Quality	Energy Consumption(Watt)	28Watt	**1**	8Watt	**2**	7Watt	**3**
	Power Factor	0.965	**3**	0.6	**1**	0.71	**2**
	THDI (%)	2.0%	**3**	101.4%	**1**	66.4%	**2**
	Score	**7**		**4**		**7**	
Lighting Quality	Illumminance (lux)	34.23 lux	**2**	28.69 lux	**2**	34.35 lux	**3**
	Luminous flux /Lumen(Lm)	340Lm	**1**	400Lm	**3**	350Lm	**2**
	Efficacy(Lm/Watt)	12.14	**1**	50	**3**	50	**3**
	Score	**4**		**8**		**8**	
Economy	Initial Cost (RM)	RM 4.90	**3**	RM 14.32	**2**	RM 20.00	**1**
	Running Cost (RM)	RM 1.57	**1**	RM 0.48	**2**	RM 0.39	**3**
	Life Span (Hour)	2000H	**1**	6000H	**2**	25000H	**3**
	Energy saving (%)	30%	**1**	80%	**3**	80%	**3**
	Score	**6**		**9**		**10**	
	Total Score (Higher the better)	**17**		**21**		**25**	

Rating Score Table

Rating	Worse	Moderate	Best
Score	1	2	3

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