Economic Analysis and Energy Consumption Approaches for Lighting Improvement of Government Building Facilities

Teguh Tri Lusijarto[1,] *, Ridwan Arief Subekti[1], Vita Susanti[1]
[1]*Research Centre for Electrical Power and Mechatronics, Indonesian Institute of Sciences*
Bandung, Indonesia
*tetri65@gmail.com

***Abstract*—This paper discusses the conversion of fluorescent tube lamp to LED tube lamp in terms of economic analysis point of view. This research was conducted for several brands of the lamp, namely Philips fluorescent tube, Goolite LED tube, and Philips LED tube. Each lamp brand totaling five pieces were tested in the workspace at Research Centre for Electrical Power and Mechatronics - Indonesian Institute of Sciences. The methodology of this research is to measure the lumen, voltage, current, and power factor of each type of lamp. Furthermore, an economic analysis of fluorescent and LED tube was carried out by comparing the amount of electricity cost toward the electricity cost savings. The variable of a lifetime, investment cost, and the amount of electric energy consumed are used as electricity saving variable. From the test results, it is obtained that a smaller electric power consumption about 50%, the light of LED tube lamps emit 17.36-33.84% brighter than fluorescent tube lamps. Regarding the cost, although the price of LED tube lamp is 4-6 times higher than fluorescent tube lamp, it gives 48.64-55.87% electricity cost savings. The electricity cost savings for LED tube lamp is due to 50-60% more energy efficient and 2-3 times longer lifetime compared to fluorescent tube lamp. It can be concluded that as a replacement of fluorescent tube lamp, the use of LED tube lamp for lighting in a government building is very profitable.**

Keywords—LED tube lamp; energy efficiency; electricity cost; power factor; lumen

I. INTRODUCTION

Population growth, increasing economy, depletion of fossil fuel reserves, increasing demand and excessive use of electrical energy are those of some factors that could lead to an energy crisis in Indonesia. The State Electricity Company (PLN), an Indonesian government-owned corporation intensifying the development of power plant to meet national electricity needs. At the end of 2015, the total installed capacity has reached 55,528.10 MW with an increase of 2,462.60 MW compare to previous year. The amount of the electricity used by PLN customers in 2015 was 202,845.82 GWh with an increase of 2.13% from the previous year. The largest users are the household customers group, which consumed 88,682.13 GWh or 43.7%. Industrial customer groups consumed 31.6%, business groups consumed 18.2%, and others (social, government buildings, road lighting) of 6.5% [1].

One effort that can be made to make energy savings is to energy conservation in business buildings, social, household, and government offices. Energy conservation, among others, by applying energy-efficient lamp such as a light-emitting diode (LED) for room lighting. The LED lamp is solid-state that serve as rectifying of electrical current. Its function produces light energy (photons) because the positive electron flow through it release the photon energy.

Currently, the development of usage of LED lamps is growing rapidly. Besides being used for room lighting in households and office buildings, LED lamps could also be applied to greenhouses [2], a headlamp for vehicles [3], [4], mining [5], Museum [6] and others.

Compared to other types of lamps such as incandescent lamps, compact fluorescent lamps (CFL), and fluorescent lamps, the LED lamps have more advantages such as lower electrical energy consumption, longer lifetime, and environment-friendly. Das *et al*. [7] conducted economic studies by comparing the use of LED lamp and high-pressure sodium (HPS) using HOMER software. From the research, it is found that the lighting efficiency of HPS lamp is 37.6%, while LED lamp reaches 73.2%.

Another advantage of using LED lamp is the lifetime longer than other types of lamps. CFLs can operate for about 5,000 hours while fluorescent lamp has better lifetime around 20,000 hours. Incandescent lamps are the most commonly damaged lamp with the lifetime only 1,000 to 2,000 hours. The longest lifetime of LED lamps is because these lamps use a light-emitting diode (LED) that produces light without being burned. In normal use, the LED lamp lifetime is about 30,000 to 50,000 hours [2], [8], [9].

In LED lamps, almost all electrical energy is converted into light; only a few energy is wasted and thus, the power used is more efficient. In general, LED tube lamp consist of tens to hundreds of light-emitting diodes (LED). It is different from fluorescent lamp where the working principle of the lamp illuminates the mercury gas in a tube that causing the incoming light source to become obstructed.

In general, LED lamps produce high heat. Therefore,it is required to have the construction of LED lamps with the good cooling system [10]. The LED lamp lifetime will increase if

heat management technique is designed effectively by controlling the temperature of the circuit board/base plate [11].

Other than that, LED lamps are more environment-friendly than other types of lamps. Fluorescent lamp and CFL produce mercury and phosphorus waste at the end of its life circle [12], [13]. In other research,it is found that the CO_2 generated by incandescent lamps is 206.97 kg/yr and CFL 53.81 kg/yr. Meanwhile, the LED lamp produces less CO_2 with approximately 22.77 kg/yr [14].

LED lamps are more comfortable for human eyes because the distribution of transmitted light is perpendicular to the source of light, in contrast to other types of lamps that are emitting the light spreads [15]. Furthermore, the lighting of the LED lamp can suppress visual fatigue more effectively than fluorescent lamp [16].

However, behind all those advantages of LED lamps as described above, there are some obstacles for people to use them because of the price is still higher than other types of lamps. In this paper, the economic analysis and energy consumption for lighting lamp in government buildings using LED tube lamp as a replacement for fluorescent tube lamp are discussed.

II. METHODOLOGY

In this research, the testing lamps were employed in one of the workrooms at Research Centre for Electrical Power and Mechatronics - Indonesian Institute of Sciences that serves as an of the test room. The room has a dimension of 8x4 meters and 2.83 meters in height, with the number of lamps used as many as five pieces.

This research is conducted by the following method:

1. The Measurement of lumen and electrical energy consumption for fluorescent tube lamp,
2. Installation and then the measurement of electrical energy consumption of LED tube lamp,
3. Efficiency calculation of the electrical energy consumption and economic analysis of LED tube lamp.

Further research methods will be described in more detail as contained below.

A. Testing Standard

The following standardization on testing and measurement are adopted in this study.

1. Indonesian National Standard (SNI)16-7062-2004 on measuring the intensity of lighting at work [17]. The SNI requirements and procedures for measuring are given as follow:

- The door of the room is by conditions in which the work is done.
- The lights in the room are turned on according to the working conditions.
- The lux meter is turned on and the sensor's cover is opened.
- The intensity measurement of local lighting/work desk in predetermined location is carried out.
- The measurement reading on the monitor screen is obtained after the value is stable.
- The measurement results are recorded on the working sheet.
- The lux meter is turned off after the completion of lighting intensity measurement.
- The measurement repetition is taken three times to obtain the average values.

2. Indonesian National Standard (SNI) 03-6575-2001 on the design of artificial lighting system procedure in buildings [18]. For workspaces in the office, the minimum level of illumination is measured 75 cm horizontally above the floor surface.

Due to test chamber condition that is not light-resistant, to obtain pure lumen of the lamp, the measurement is taken when the lamp's condition is on and off. The net lumens produced by the lamp can be calculated using this method.

B. Measurement of Lumen and Electrical Energy Consumption

In this research, LED tube lamps are considered to replace the fluorescent tube lamps. Philips and Goolite LED tube lamps are selected because they have similar casing and fitting dimensions with previous lumen specification (Philips fluorescent tube lamp) so that there is no need to change the existing electrical installation. Furthermore, both brands of LED tube lamp are available on the market.

The LED tube lamp used in this study has the same lumens as the previous fluorescent tube lamp, which ranges from 70-100 lumens/W [19]-[21]. Lumen measurement in the workspace was done by using Lutron Light Meter type LX-1008.

In addition to lumen measurements, there are also measurements of basic electrical parameters on each lamp using a Fluke (Power Quality Analyzer Meter) type 43B. Electrical parameters measured include voltage, current, and power factor. This measurement performed on each lamp consisting of: (1) 5 pieces of Philips fluorescent tube lamps (type: Master TL-D Super 80/36 W); (2) 5 pieces of Goolite LED tube lamp (type: LED-tube-GLT-T8-L120-18 W); and (3) 5 pieces of Philips led tube lamp (type: EcoFit LEDtube T8 LED 16 W).

Base on the electrical parameters obtained by measurement, the apparent power and real power of each lamp can be calculated using Equations (1) and (2).

$$S = V \times I \tag{1}$$

where S is the apparent power (VA), V is the voltage (V), and I is the current (A) [17].

$$P = V \times I \times \cos \varphi \tag{2}$$

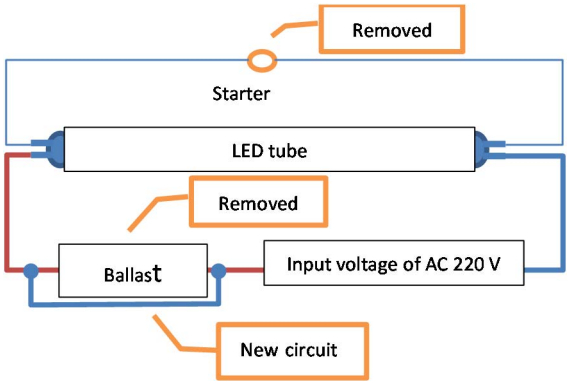


Fig. 1. Conversion of fluorescent tube lamp to LED tube lamp Circuit.

where P is the real power (W) and cos φ is the power factor [22].

C. Installation of LED Tube Lamp

The first step is to install LED tube lamp by changing the existing fluorescent tube lamp circuit. In LED tube lamp circuit, the ballast and starter are not used as in fluorescent tube lamp circuit. Furthermore, a new connection between the terminal LED tube lamp with an electric current source is established. The conversion process of the lamp circuit is given in Fig. 1.

D. Efficiency Calculation of Electricity Energy Consumption and Economic Analysis

Economic techno-analysis conducted in this research is to compare the calculation cost of fluorescent tube lamp replacement into LED tube lamp, and also calculate the amount of electricity cost savings. Therefore, in the calculation of economic techno-analysis, there are two main cost components, i.e.: (1) the cost of the lamp, and (2) the cost of electricity usage. Both components are calculated for the period of 1 year (per year).

In the analysis, we use the following assumptions:

1. The duration of lamp usage = 10 hours/day
2. The number of working days = 2 working days/month, 240 working days/year,
3. PLN's electricity price for government building = 1,352 IDR/kWh [23].

Based on the lamp specification, units of the lamp period is in hours. From the lamp period, then we calculate the lamp period factor (*f*) using Equation (3).

$$\mathrm{f} = \frac{\mathrm{Day}}{\mathrm{Life}} \tag{3}$$

where the lamp period factor"*f*" is a coefficient of numbers without units that used to calculate the lamp cost per year. "*Day*" is the day number of lamp usage in a year, while "*Life*" is the lamp period of days. By multiplying the lamp period factor (*f*) with the price of the lamp ($Price_{lamp}$), it yields the cost of the lamp ($Cost_{lamp}$) per year as the following equation,

$$Cost_{lamp} = f \times Price_{lamp} \tag{4}$$

The cost of electrical energy to be paid to PLN ($Cost_{energy}$) depends on the amount of electricity usage. The amount of energy consumption per year (*E*) (in units of kWh) is calculated using Equation (5). By multiplying the energy consumption and the purchase price of electricity from PLN (Priceenergy) in Equation (6), resulting in an electrical energy cost per year. By adding the cost of lamps ($Cost_{lamp}$) per year and the cost of electrical energy ($Cost_{energy}$) per year, the total cost of electricity ($\mathrm{Cost_{total}}$) per year can also be obtained (see Equation (7)).

$$E = \frac{P}{1000} \times Hour \times Day \tag{5}$$

$$\mathrm{Cost_{energy}} = \mathrm{E} \times \mathrm{Price_{energy}} \tag{6}$$

$$\mathrm{Cost_{total}} = \mathrm{Cost_{lamp}} + \mathrm{Cost_{energy}} \tag{7}$$

The notation used in the economic analysis of lamp usage is listed in Table I.

III. Result and Discussion

A. Illumination Level

In this study, the test is performed on Philips fluorescent tube lamp 36 W [19], Goolite LED tube lamp 18 W [21], and Philips LED tube lamp 16 W[20]. The lumen measurements are conducted on each workbench under the lamp. The distance between the workbench and the lamp is about 1.08 meters. The results of lumen testing are shown in Table II and Fig. 2.

TABLE I. List of Parameters that Used in Calculation

Notation	Explanation	Units
f	Lamp period factor	-
Day	Number of days of the lamp usage in a year	day
Life	Lamp period	day
$Cost_{lamp}$	Cost of the lamp	IDR
$Price_{lamp}$	Price of the lamp	IDR
E	Electrical energy	kWh
P	Electrical Power	W
Hour	Duration of the lamp usage	h (hour)
$Cost_{energy}$	Cost of electrical energy	IDR
$Price_{energy}$	Purchase price of the electricity from PLN	IDR/kWh
$Cost_{total}$	Total cost of the electricity	IDR

TABLE II. Illumination Level of Fluorescent Tube Lamps (FTL) and LED Tube Lamps

Point of measurement	Lumen (Lux)		
	5 FTL	*5 LED Goolite*	*5 LED Philips*
Workbench 1	90.10	121.75	101.10
Workbench 2	166.60	228.74	192.08
Workbench 3	140.00	180.73	174.41
Average	**132.23**	**177.07**	**155.85**

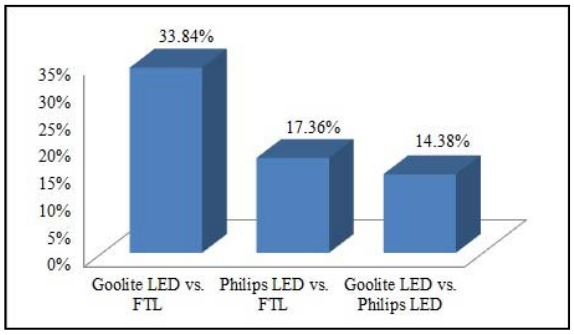


Fig. 2. Lumen increase of LED tube lamp (in percent).

From Table II and Fig. 2, it can be seen that the illumination level of Goolite LED tube lamp is 33.84% higher than FTL (fluorescent tube lamp), while Philips LED tube lamp is 17.36% brighter than fluorescent tube lamp.Generally, with lower electrical power, both brands of LED tube lamps are brighter than fluorescent tube lamp because the light out of the LED tube lamp will be directly emitted without media intermediaries, which is different from fluorescent tube lamp where the light produced must pass through the media intermediaries of mercury gas in the tube. Comparison of lumen specifications per watt of LED tube lamp is higher than the fluorescent tube lamp [19]-[21].Based on the comparison of both brands of the LED lamp, the Goolite 14.38% brighter than Philips. It's due to the power of Goolite lamp higher than Philips with 18 W and 16 W, respectively.

The LED lumen quality is now better when compared to the early generation of LED lamp. In 2008, the US Department of Energy (DoE) had launched commercial LED lamps designed to replace incandescent lamps and CFLs. The result obtained that the LED lumen is still low on average about 31 lumens/W[24]. Similarly, Sangwan et al.[25] said that the lumen per watt of LED lamps is lower than the fluorescent tube lamps and CFLs. It probably because of the low quality of LED lamps when it first produced. Also, LED lamps quality depends on manufacturers.

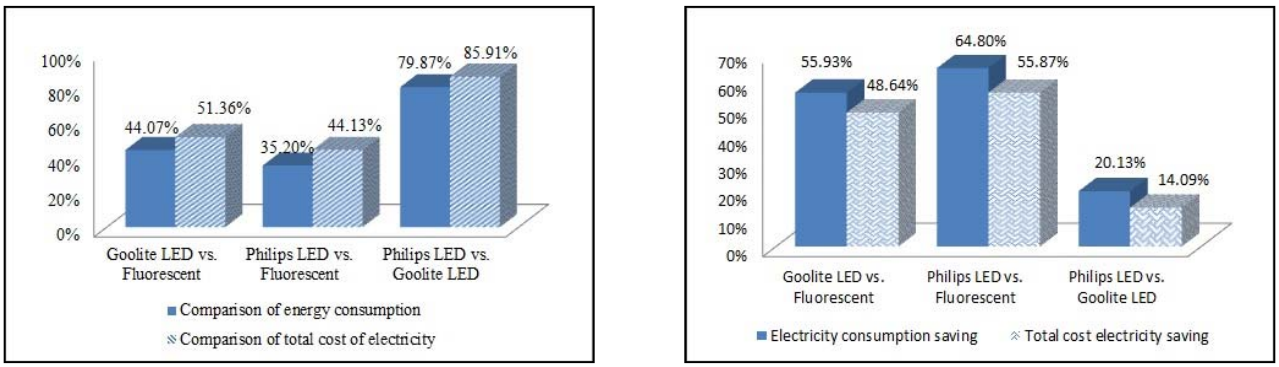
The LED lamps produced today is better quality than earlier. The result of the test in the laboratory, it is obtained that lumen of LED lamps reach 200/W[9]. Aman et al.[26], has conducted research on the performance of several types of lamps, such as incandescent, fluorescent, and CFL;the lumen/W of LED lamp is 37% higher than a fluorescent lamp. In other studies,it showed that lumen/W of LED lamp is better than other types of lamps. Khorasanizadeh et al. [14] revealed that lumen/W of incandescent is 12 lumens/W, CFL 70 lumens/W, and LED lamps 100 lumens/W.

B. Power Consumption

In this study, all sample lamps were measured using basic electrical parameters. The calculation of the amount of apparent power (*S*) and real power (*P*), Equation (1) and (2)are used respectively. The result of basic electrical parameters measurement and calculation of power consumption of the three types of lamps are shown in Table III. As shown in Table III, when compared to the three types of lamps, it is seen that the fluorescent tube lamp has the most apparent power (VA) and real power (W). According to data specifications, the fluorescent tube lamp has the greatest power, and thus, it requires the greatest current as well,while Goolite LED tube lamp required smallest electric current, and so the apparent power is also small.

TABLE III. MEASUREMENT RESULT AND CALCULATION OF POWER CONSUMPTION

Types of Lamp	Voltage (V)	Current (A)	Power Factor	Apparent Power	Real Power
Fluorescent tube 1 – 36W	205.10	0.33	0.59	67.68	39.93
Fluorescent tube 2 – 36W	205.00	0.33	0.59	67.65	39.91
Fluorescent tube 3 – 36W	205.10	0.33	0.59	67.68	39.93
Fluorescent tube 4 – 36W	205.00	0.33	0.59	67.65	39.91
Fluorescent tube 5 – 36W	205.30	0.33	0.58	67.75	39.29
Average	***205.10***	***0.33***	***0.59***	***67.68***	***39.80***
Goolite LED tube 1 – 18W	206.00	0.09	0.94	18.54	17.43
Goolite LED tube 2 – 18W	206.00	0.09	0.95	18.54	17.61
Goolite LED tube 3 – 18W	206.00	0.09	0.96	18.54	17.80
Goolite LED tube 4 – 18W	206.00	0.09	0.94	18.54	17.43
Goolite LED tube 5 – 18W	206.00	0.09	0.94	18.54	17.43
Average	***206.00***	***0.09***	***0.95***	***18.54***	***17.54***
Philips LED tube 1 – 16W	206.40	0.11	0.61	22.70	13.85
Philips LED tube 2 – 16W	206.30	0.11	0.62	22.69	14.07
Philips LED tube 3 – 16W	206.70	0.11	0.61	22.74	13.87
Philips LED tube 4 – 16W	207.10	0.11	0.62	22.78	14.12
Philips LED tube 5 – 16W	207.20	0.11	0.62	22.79	14.13
Average	***206.74***	***0.11***	***0.62***	***22.74***	***14.01***



(a) (b)

Fig. 3. Comparison of economic value for fluorescent tube lamps and LED tube lamps: (a) energy consumption; (b) electricity saving

Based on test results from the three types of lamps, fluorescent tube lamp has the smallest power factor (*cos φ*) with 0.59, while for Philips LED tube, the lamp power factor is 0.69. Low power factor in fluorescent is due to the tube lamp which contains of inductive materials and thus resulting in low working factor. It is different when compared to Goolite LED tube lamp, where the Goolite LED tube lamp has the best power factor about 0.95. The quality of the lamp is better if the power factor is high.

C. The Economic Analysis of LED Tube Lamp

In the techno-economic analysis, we assume the lamp usage per day and the number of working days in one year as discussed in section II. It is indispensable to calculate the approximate lamp period in a year.From the lamp product specification, the lamp period of Goolite LED tube lamp is the longest with 50,000 hours [21] followed by Philips LED tube lamp with 30,000 hours [20], and the fluorescent tube lamp with 13,000 hours[19]. To obtained the real lamp period, some sample of the lamps is needed to be tested. But to simplify the economic calculation, we use the lamp period data from data specification of the respective lamp. Furthermore, by using equation (3) and (4), we obtain the value of lamp period factor (*f*) and cost of the lamp ($Cost_{lamp}$). While the amount of electric energy consumption per year (*E*) and the cost of electrical energy ($Cost_{energy}$) are calculated using Equation (5) and (6), respectively.The total cost of electricity ($Cost_{total}$) that spend in a year is calculated using equation (7).The comparison of techno-economic analysis of the various types of lamps as shown in Table IV and Fig. 3.

From Table IV, it can be seen that the highest cost of the lamp per year ($Cost_{lamp}$) is Philips LED tube lamp with about IDR 15,600. Fluorescent tube lamp is the lowest cost of the lamp per year with around IDR 9,231. It is because the price of LED tube lamp at present is still very high compared to fluorescent tube lamp. It is due to the number of LED tube lamp users are still not much as fluorescent lamp tube lamp users so that the production of LED tube lamp is less than fluorescent tube lamp.Regarding electricity consumption per

TABLE IV. ECONOMIC ANALYSIS OF FLUORESCENT TUBE LAMP AND LED TUBE LAMP

Parameters	Notation	Units	Types of Lamp		
			Fluorescent	***Goolite LED***	***Philips LED***
Real Power	*P*	W	39.80	17.54	14.01
Lamp period (10 hours/day)	*Life*	Hour	13,000	50,000	30,000
		Day	1,300	5,000	3,000
Lamp period factor per year (20 days per month)	*f*		0.18	0.05	0.08
Price of the lamp	$Price_{lamp}$	IDR	50,000	295,000	195,000
Cost of the lamp per year	$Cost_{lamp}$	IDR	9,231	14,160	15,600
Electrical energy consumption per year	*E*	kWh	95.51	42.09	33.62
Purchase price of electricity from PLN	$Price_{energy}$	IDR/kWh	1,352	1,352	1,352
Cost of electrical energy	$Cost_{energy}$	IDR	129,135	56,910	45,455
Total cost of electricity	$\boldsymbol{Cost_{total}}$	***IDR***	***138,366***	***71,070***	***61,055***
Number of fluorescent in workspace at 20 building		pcs	385		
Total cost of all workspace light at 20 building		IDR/year	53,270,923	27,361,961	23,506,343
Comparison of electricity cost saving for fluorescent and Philips LED tube lamps		IDR/year	29,764,580		
Comparison of electricity cost saving for fluorescent and Goolite LED tube lamps		IDR/year	25,908,963		

year, Philips LED tube lamp is the smallest consumption (33.62 kWh) and more efficient than Goolite LED tube lamp (42.09 kWh), while the most extravagant of the electricity consumption is fluorescent tube lamp (95.51 kWh).

By calculating the cost of lamps per year ($Cost_{lamp}$) and the cost of electric energy per year ($Cost_{energy}$), the total cost of electricity ($Cost_{total}$) of Philips LED tube lamp is the most economical lamp that is IDR 61,055. Goolite LED tube lamp occupies the second place with IDR 71,070, while the fluorescent tube lamp has the highest total electricity cost per year with IDR 138,366.

By multiplying the total electricity cost by some fluorescent tube lamps used in the workspace at 20 building of Research Centre for Electrical Power and Mechatronics (Table IV), the entire workspace of electricity cost can be calculated. The lamp used in the present is a type of fluorescent tube lamp with electricity cost per year reaching IDR 53,270,923. If the Philips LED tube lamp is used instead of the existing lamp, there will be an annual saving of IDR 29,764,580. When compared to both of LED tube lamp that is Goolite and Philips, the total cost of electricity Philips is more efficient with 14,09% (Fig. 3). The largest savings for the total electricity cost if Philips LED tube lamp is used to replace the fluorescent tube lamp, the obtained savings will be at 55.87%, while Goolite LED tube lamp is more efficient with 48.64% when compared to fluorescent tube lamp.

From the economic analysis, it can be concluded that the user of the LED lamp will save the total cost of electricity for a year.The energy-saving gained when using the LED lamp as a replacement the fluorescent lamp is in line with what is expressed by Khorasanizadeh *et al.* [14]. In his research, the comparison of energy consumption per year (kWh/yr) between LED lamp, CFL, and incandescent described. Based on the study, it is found that LED lamps is 55% more energy-efficient than CFLs. However, the higher price of LED lamps causes the first investment cost is also more expensive. But in the long run, the used ofLED lamps is very economical because LED lamps are more energy-efficient [14], [27].

IV. Conclusion

The economic analysis and energy consumption on the use of a fluorescent tube and LED tube lamps in government buildings have been discussed in this paper. From the lumen test result for Philips fluorescent tube lamp, Goolite LED tube, and Philips LED tube lamp, it is concluded that Goolite LED tube lamp has the brightest lamp followed by Philips LED tube lamp, while the lowest lumen test is Philips fluorescent tube lamp. Goolite LED tube lamp is 14.38% brighter than the Philips fluorescent tube lamp. From the measurement of basic electrical parameters,it is known that the highest electric current is fluorescent tube lamp, while Goolite tube lamp requires only small current with best power factor close to 1 (0.95). From the economic analysis of these three lamps, it can be concluded that the Philips LED tube lamp is the most economical because it requires the lowest of the total cost for electrical energy, and the uneconomical lamp is the fluorescent tube lamp. Although the LED tube lamps are more expensive than the others lamps these lamps have more energy-efficient and longer lamp period, so from the calculation of one year, the LED tube lamp also more economical. Overall, the use of LED tube lamps for lighting in a government building is profitable because of the efficiency in annual electricity cost.

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