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Original Article

Life cycle cost analysis and energy performance of President's office, Prince of Songkla University, Thailand

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Abstract

The importance of life cycle cost analysis for administration is to investigate the components and activities which are outstanding engagements making high operational cost. This involves energy efficiency and consumption reduction from occupants in building. The aim of this study is to evaluate the cost of operational performance in administrative buildings of Prince of Songkla University (PSU), Hatyai campus called President's office (PO). It has a 6,988 m^2 functional area including executive, administrative, and meeting operations. The highest cost of operation comes from electricity consumption estimated to be about 2,439,047 THB or 69,687 USD. To obtain the approximate energy performance of PO, energy audit was investigated. The primary operational energy was considered in four components;(1) Air-conditioning (AC) to cool the rooms, (2) Lighting to illuminate the rooms, (3) IT devices to process documents and database, and (4) auxiliary appliances to support administration. In particularly, AC system consumes the highest energy. Approximately 75% of the energy consumed in the building is attributed to administrative operations. This study also suggests some solutions that have been recorded to be effective in reducing the energy consumption of administrative building. The energy measures were divided into two different categories, reaching by internal and external factors. The most mutual recommendations were identified as lighting and air conditioning retrofits. Renewable energy is an environmental friendly solution but installation has been proved to cost higher than saving cost. Furthermore, there is still potential for improving energy performance not only by its physical characteristics but also by several significant factors such as occupant's behavioral change, and control of indoor environmental condition. The energy efficiency improvement requires holistic measures for sustainable energy building.

Keywords: administrative building, energy efficiency, energy performance, life cycle cost, operational energy

1. Introduction

Nowadays, the rapid and cost effective solutions for globalized energy and environment concerns were considered as the basis of energy plan and policies worldwide. With regards to Greenhouse Gas (GHG) emissions concern, energy consumption is often used to measure the environmental performance of buildings (Biswas *et al*., 2008). Actually, buildings contribute approximately 30% of total global greenhouse gas emission and consumes up to 40% of allenergy, primarily through the use of fossil fuels during their operational phase (The United Nations Environment Programme [UNEP], 2016). Therefore, it's essential to diminish energy consumption for development of energy efficiency including cost effectiveness of buildings. It's also recognized that by this meaning, a significant amount of energy saving can be converted to high building's performance which optimize energy expenses and reduce GHG emissions as well (Mangan & Oral, 2016).

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The improvement of energy efficiency levels in buildings plays an important role in solving the energy, economic, and environmental problems. Several studies have highlighted the importance of both embodied energy and operational energy use in buildings over their lifetime (Biswas *et al*., 2008). For old building, inefficient energy using traditionally will involve in greater energy consumption and extravagant utilization of natural resources with global impacts. Therefore, finding creative possible strategies and sustainable approaches to reduce the energy demand in administrative building is initiated (Akande *et al*., 2016).The main objective of this study was to evaluate life cycle costs and life cycle energy of building operations for developing energy efficiency.

2. Literature Review

2.1 LCA and LCCA approaches

A life-cycle assessment (LCA) is the tool to evaluate the environmental impact associated with all the stages of product's life or services. It was conducted to quantify the energy use in several industries, powerplants (Kannan *et al*., 2004), and buildings (Akande *et al*., 2016). As the conventional LCA, does not include any cost analysis which is a major criterion in decision making, the cost of product and process is estimated using a life cycle cost analysis (LCCA) (Kannan *et al*., 2004). LCCA is an economical technique to evaluate the total cost of owning and operating a facility over period of time. It is also a recognized tool to determine long term cost effectiveness of a project (Kannan *et al*., 2004). It can be performed on large and small buildings or on isolated building systems. LCC can be calculated in three stages; conceptual stage, acquisition stage, and in service stage. LCC considers all cost required for construction, operational, maintenance and end-of-life costs. It includes all associated costs such as delivery, installation, commissioning, insurance, energy and water use, replacement, maintenance, repair and end-of-life costs. LCC can be improved by adopting alternative modern techniques without much alteration in the building. LCC effectiveness can be calculated at various stages of entire span of the building. Financial benefits associated with energy use can also be calculated using LCC analysis (Kale *et al*., 2016). Life cycle assessment (LCA) for green building design has recently been developed around the understanding that there is a shortage of holistic environmental assessment tools in the building industry (Horne *et al*., 2009). The LCA brings benefit to the decision making process in that it can be used to review sustainability initiatives throughout the entire life cycle of the building, the design detailing, delivery and deconstruction phases (Biswas, 2014).

2.2 Energy audit and energy measures

An energy audit (EA) is a process to monitor working problems, improve occupants comfort, and optimize energy use of existing buildings (Rahman, 2009; Sterling *et al*., 1994).Energy audits and monitoring energy use is indicated as the first step towards increasing energy efficiency within an organization. Several studies using energy auditing techniques to assess the energy performance of school buildings have been carried out. An energy audit was performed in commercial and educational buildings in Thailand, aiming at identifying energy conservation measures (ECMs) (Bernardo *et al*., 2016). In this initiative, several energy conservation opportunities were identified across electrical and mechanical systems, resulting in 52% of energy savings (Alajmi, 2012). In addition, it identifies the opportunities for energy conservation. It was also described as a key element for decision making in energy management (Tim & Jutidamrongphan, 2016).

The focus on reducing building operational energy use through the last decades has distinguished that buildings are becoming more energy efficient; therefore increasing the relevance of the environmental and economic impact of the other life-cycle stages is important (Oregi *et al*., 2017). LCA is well recognized as a valid framework to assess the potential impacts of building projects. With regards to this tool, previous research findings presented that the majority of operational cost evolves from internal energy consumption. The operational energy involves the energy utilized by the building's operations and use (air conditioning, heating and lighting, office and kitchen equipment) (Biswas, 2014). In developing countries, retrofitting existing buildings at the optimal level is also a priority. In this regard, there is remarkable possibility for using this opportunity to update the heating and cooling technologies used in buildings, as well as implementing low cost but effective passive solutions to improve energy efficiencies such as thermal mass and sunshades (United Nation Development Programme [UNDP], 2016).

2.3 Energy efficiency in Thailand

Energy is a major concern in Thailand, as continued economic development demands more consumption and production of electricity. Energy efficiency is the key to achieving energy security and reducing greenhouse gas emissions. The building sector has been identified as an area where significant savings can be made because energy demand and consumption in this sector is considered to be rapidly growing (UNDP, 2016).

Energy conservation in Thailand's Energy Efficiency Development Plan focuses on two approaches: (1) Economical use or reduced expendable use of energy, and (2) energy efficiency improvement such as reducing energy in doing the same activities, involving, among others, lighting, hot water production, cooling systems, transportation or running machines in the manufacturing process. Energy conservation plays a significant role in strengthening energy security, alleviating household expenditure, reducing production and services costs, reducing trade deficit and increasing the competitive edge, including reduction of pollution and greenhouse gases (GHG) which cause global warming and climate change. Therefore, energy conservation has been an important policy of the government, particularly since the enforcement of the Energy Conservation Promotion Act, B.E. 2535 (1992) (Energy Policy and Planning Office [EPPO], 2016). It also was frequently emphasized as the context of the energy efficiency development plan of Thailand 2015-2036 as strategies to achieve the target in compulsory measures by enforcement of energy conservation standards in designated factories and buildings (EPPO, 2015).

3. Research Design and Methods

The sequence of the research is as follows: an overview of life cycle assessment and energy efficiency is first clarified. Second, the method used for evaluating operational cost equipped with monitoring systems to investigate building performance analyzing the comparability between them is explained, followed by a brief presentation of the chosen energy audit systems. Thirdly, a section with the results of how the energy audits have been evaluated followed by a discussion of the findings and energy efficiency. Lastly, conclusions and policy implications are suggested.

Database records for twelve months in fiscal year 2016 for each surveyed building and their investigations are compiled. Material flow analysis was provided for understanding operation and activities including life cycle cost evaluating. To obtain the approximate building's energy performance of the selected office, the main methodology was applied in appraisal, called energy audit including staff interviews. Energy auditing comprises of monitoring the energy consumption in majority of building. The user perception interview is suitable for describing the occupants' perceptions and experiences of the operational energy (Rohdin, 2011). As the main focus of this study is the sustainable administrative and development of operational energy performance, energy auditing was adopted to evaluate the performance of the internal electricity consumption. Electricity use of the buildings was monitored by both examining the electricity bill invoice gathered by building and ground subdivision and inspecting practical activities including observations. No instrument was used to measure the indoor temperature and humidity because of limited resources and more especially because it was not manifested in the objective of the study. To collect relevant and data, access to the selected building authorization was requested (Akande *et al*., 2016).

Life cycle cost was calculated as the sum of operational cost requirements for all functional units in building. The net life cycle cost is given from first determining the input–output-based material requirements of each unit. The input energy and materials was gotten from monthly invoice. The output waste and wastewater could be gained from generating rate multiplying the amount of staff by theirs generating coefficient and multiplying working days in year. This is then multiplied by the cost of material or treatment which is obtained by providing documents. Electricity cost was calculated from three parts; capacity, operating time, and cost of electricity per unit multiplies by exchange rate as given equation below:

Electricity cost (USD/year)

$$= \underbrace{W \times \frac{1}{1000} \times N}_{\text{Capacity}} \times \underbrace{H \times D}_{\text{Operating hr.}} \times \underbrace{3.96^{*} \times \frac{1}{35.0}^{*}}_{\text{Cost per unit}}$$

where W = power of appliance (Watt), N = no. of appliance, H = operation time (hr /day), D = Working day in a year(day/year), 3.96 = Electricity cost per unit (Fiscal year 2016) (Bht), 1/35.0 = Exchange rate (Fiscal year 2016) (USD/Bht) (Bank of Thailand [BOT], 2016).

This paper is structured in six sections. Section 2describes the relevant researches including life cycle assessment, energy efficiency with concise additional case studies of green building and its energy profile. Section 3describes the research design, method used and the quantification of life cycle cost, energy audits, and energy efficiency measure. Section 4 provides site background and the contribution of the study for sustainability. Section 5 reveals the results of the life cycle cost analysis and energy performance including breakdown of appliance system as well as their combination including discusses the findings. It also describes the investigated energy reduction measures to support the sustainability of the PO building prior to concluding in Section 6. Supplementary data complementing Section 5 and 6 are stated in Table 1 to 3 using electricity cost equation. The overall step in research structure was demonstrated in Figure 1.

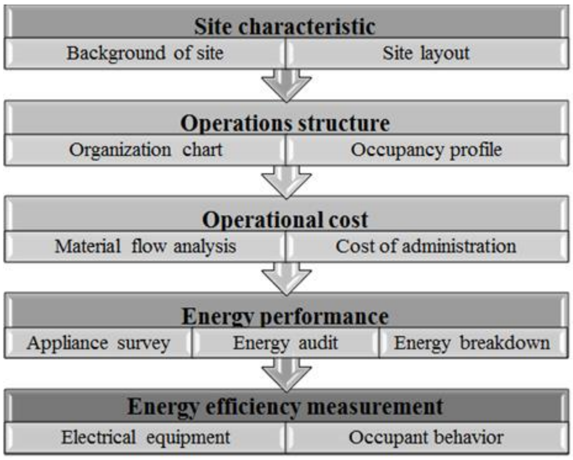


Figure 1. Overall research design and methodology

4. Background of Study Site

President's office (PO) is a management sector in Prince of Songkla University (PSU), Hat Yai campus, Thailand, which facilitate the administrative functions in the campus. It is located at the front part of the university as mentioned in the map of electrical bus route in PSU (Figure 2). PO is mainly in charge of planning, maintenance, meeting, and management of campus activities. PO was chosen for this study because it is a good representative of divergent operations in campus buildings. In addition, the selection of PO was initiated by research problem under sustainable university development. To be a green campus, PSU executive board has intentionally supported green policy to be sustainable academic management by themselves. Therefore, PO is a starting unit in inspiration for sustainability. Green campus campaign and information could be launched from university's website (http://green.psu.ac.th/index.php/th/).

5. Results and Discussion

5.1 Site layout

President's office was separated into three connected buildings; building 1, building 2, and building 3 as illustrated in Figure 3. Both building 1 and 3 have three floors, building 2 has four floors. Totally, the three buildings are divided into 124 small parts. It has a 6,988 m^2 functional area including executive, administrative, and meeting operations.

Figure 2. President's office of Prince of Songkla University, Hatyai (SHC-PSU, 2012).

Figure 3. President's office layout.

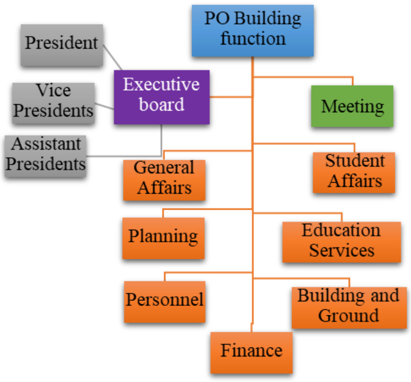


Figure 4. Functional chart of PO building.

5.2 Organization chart of PO building

The operational units in PO building can be separated based on its 3 function - executive, administration, and meeting. The executive board was divided into 3 levels: president, vice presidents, and assistant presidents. In PSU, Hat Yai campus, there is one president, eight vice presidents, and 16 assistant presidents. The administrative function was classified into seven units based on its responsibility as shown in Figure 4. Considerably, conventional meeting is another important function of PO building in moving campus forward by leading the university.

5.3 Occupancy profile

According to the individualities of the building and the difficulty of identifying sub-operational locations for each of them, general profiles have been designed depending on the functional units of the building, that the building was divided into three buildings: Building 1, 2, and 3. The function of administration in PO building was separated in seven divisions as aforementioned. Each division is responsible for campus management. According to this classification, Figure 5 illustrated the occupancy profiles of PO buildings which opens on weekdays (Monday to Friday), 8.30 to 16.30 hr. each day. The conventional usage of the buildings could be considered for three sections as 1) Fourteen executive rooms served for 25 executive committees related to daily use of 1-2 hours before and after meeting, 2) Seven administrative divisions which is major part of the building (regular usage 8 hrs per day, 5 days a week). The total amount of staff who worked in seven divisions of about 242 persons was measured for their operational activities (energy use and carbon footprint emission), and 3) Eight meeting rooms (daily use from 9 am to 4.30 pm). These operations are determined based on access control of workers, executive activities and meeting schedules. There are two meetings throughout the day from 2 hrs to 4 hrs. The occupancy profiles exemplified in Figure 5 are considered constant throughout the year due to the fact that during academic breaks, they still work and have meetings. However, it's closed on weekend and official holidays (16 days/year). Approximately, PO has 248 working days per year.

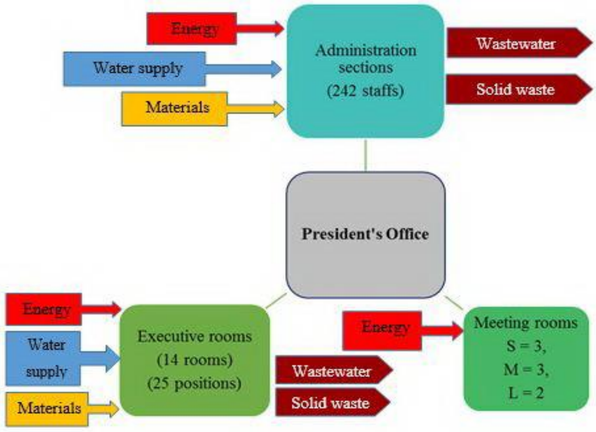
Figure 5. Organization structure of administrative functions in PO.

5.4 Operational cost

5.4.1 Material flow analysis (MFA)

To evaluate the operational cost of administration, material flow is a recognized quantitative procedure to measure material throughput for all economic activities including environmental burden it creates. MFA is used to identify and quantify the consumption of natural resources based on the mass balance principle (Frohling *et al*., 2013; Hoque *et al*., 2012), which could be used to evaluate energy consumption performances on industrial or sectoral levels (Sendra *et al*., 2007; Tanimoto *et al*., 2010). In this study, it accounts for all materials and energy used in services and consumption including administration (Figure 6). Generally, it is a method for evaluating the efficiency of using material resources. The throughput actually transformed into administration and management activities including documents then finally turned to the natural system in terms of waste and wastewater. The identification of wastes is necessary as the purpose of conducting an action plan to diminish the flow of materials and energy. Its methodology allows the monitoring of wastewater and solid waste that are typically accounted for in conventional life cycle analysis.

Focusing on the administration sector, the largest constituent in PO buildings is the biggest material and energy user serving for 242 working staff. The occupancy profile of meeting and executive is not like that for administration, however, these casual users account for a significant proportion of total energy and material consumptions. This composite profile includes many types of work pattern rangingfrom routine officer, temporary members, and executive committees which are representative for four-year term.



S = 5-10 persons, M = 20-30 persons, L = 80 -100 persons

Figure 6. Material flows by function.

5.4.2 Cost of administration

Cost of each component was provided by source as presented in Figure 7. The cost of administration was gathered from three documents. Energy was investigated in terms of electricity cost as recorded in electricity bill monthly. Water supply was determined by water meter prior to concluded monthly invoice, and material and supplies were collected by annual issue of material from material disburse procurement. Entire materials and supplies cost was recorded in department disbursement account from each division. Electricity was charged from average rate in Fiscal year 2016 at 3.96 THB per unit (kWh). Water supply appraised for 29 THB per unit (m^3) and wastewater was estimated to be produced from 80% of water supply with the treatment cost 2 THB per unit (m^3) and the solid waste disposal will be charged before transport to waste gasification power plant at the rate of 319 THB per ton. An estimated value of about 1 kg per capita per day for solid waste generation coefficient has been used in calculating solid waste generation cost. Total cost of operation in PO building of about 80,670 USD (2.82 Mil THB) in 2016 was summed from each constituent. Annually, the highest cost of operation comes from electricity consumption estimated to be 2,439,047 THB or 69,687 USD (Exchange rate of Bank of Thailand in Fiscal year 2016 equaled to 35 THB per USD) equaled to 86% of total cost. Electricity consumption of the president's office has increased to 485,092, 574,020, and 574,560 unit (Watt) from 2013-2015 (Tim & Jutidamrongphan, 2016) and rising to 615,592 unit in 2016. This growing energy consumption results from routine activities in administrative divisions.

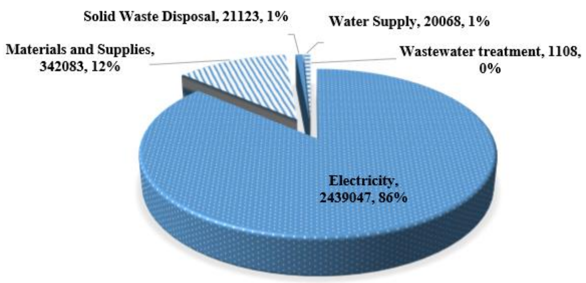


Figure 7. Cost of administration in PO building.

5.5 Energy performance

As aforementioned, the highest cost of operation resulted from electricity consumption. To evaluate energy reduction measurement, energy performance is required. The energy performance focused on the operational activities. Average operation hour were obtained from interview and observation. It also was assumed that 248 working days in administrative building is a regular operation time a year.

Operational Energy is the energy requirement of the building during its life. An energy audit program has been investigated from several operational activities e.g. financing, accounting, budgetary planning, reporting, documenting, meeting, academic supervision (guidance) as well as concrete objects such as databases and support services. The evaluation was held in fiscal year 2016. Although there will be a lot of detail planning to be carried out later, developing the significant energy audit plan at an early stage is required. In this study, the primary operational energy was considered in four energy systems: Air-conditioning (AC) to cool the rooms, lighting to light rooms, IT devices to process the documents, and database, and auxiliary appliances to support administration. By monitoring the four key components as the basic operators responsible for the specified tasks, the building supervisor can plan for the maintenance schedule.

AC system in PO building was surveyed. The total number of AC in each section was summed up in Table 1. AC is the greatest section of energy use in PO building for cooling room. Operation time of each section is differentiated. AC provided for administration (8-9 hrs/d), meeting function (6-7 hrs/d), and executive room (2-3 hrs/d) was estimated for energy consumption calculation. The lighting system in operation is depicted in Table 2. The major of light in PO building is T5 that changed from T8 bulb since 2013. This could reduce energy from 36 W to 28 W for bulb type 1,198 mm and reduced from 18 W to 14 W for small bulb type (588 mm). The electricity used for IT device and auxiliary appliance was monitored. Table 3 presented information of appliance usage in administration operation. IT device shows the significant ratio of energy consumption cost of about 399,588.71 Bht/yr with regards to routine staff’s operation.

Table 1. AC system monitoring in PO building.

AC size (BTU)	Capacity (kW)	No. of AC			Consumption (Unit/day)	Cost (THB/yr)
		Meeting	Administration	Executive		
9,000	0.77	1			3.08	3,031.08
12,000	1.03		1	1	6.68	6,567.35
12,500	1.07		2	1	12.32	12,103.28
18,000	1.54	1	4	4	46.27	45,466.24
20,000	1.71	1	4	2	46.27	45,466.24
24,000	2.06	3	1	3	44.22	43,445.52
25,000	2.14	5	3	3	84.62	83,144.28
28,000	2.40		2		23.99	23,575.09
30,000	2.57	2	4		71.98	70,725.26
33,000	2.83			1	4.24	4,167.74
36,000	3.08	7	5	8	200.51	197,020.38
37,000	3.17	1	2		44.39	43,613.91
40,000	3.43			1	5.14	5,051.80
48,000	4.11	8	12	6	415.42	408,185.81
60,000	5.14		24		616.97	606,216.56
130,000	11.14	1			44.56	43,782.31

Table 2. Lighting system in PO building.

Lighting - Bulb type	Capacity (W)	No. of lamp	Cost (THB/yr)
T5 1198 mm Ft 1*28 W	28	100	21,998.59
T5 1198 mm Ft 3 * 28 W	28	1359	298,960.87
T5 588.7 mm Ft 1 * 14 W	14	43	4,729.70
Compact-Fluorescent bulb 9 W	9	111	7,848.78
T5 1198 mm Ft 2 * 28 W	28	442	97,233.78
T5 588.7 mm Ft 3 * 14 W	14	63	6,929.56
T5 1198 mm Ft 2 * 28 W	28	442	97,233.78
T5 588.7 mm Ft 2 * 14 W	14	8	879.94
T8 Ft 2 * 18 W Surrounding	18	16	2,262.71
LED bulb 12 W	12	29	2,734.11
T8 588.7 mm Ft 2 * 18 W	18	8	1,131.36
Ceiling bulb 32 W	32	2	502.82

Table 3. IT device and auxiliary appliance in PO operation.

Appliance Type	Appliance	No. of Appliances	Capacity (W)	Operation time (hr/d)	Cost (THB/yr)
IT device	Computer - Desktop	235	200	8	369,262.08
	Computer - Laptop	24	65	4	6,128.18
	Printer	72	40	8	22,627.12
	Scanner	10	20	8	1,571.33
Auxiliary appliances	Photocopier	3	1100	6	19,445.18
	Projector	5	210	0.5	515.59
	Fax machine	10	10	8	3,468.96
	Telephone	104	10	24	36,077.18
	Microwave oven	6	800	0.5	2,356.99
	Refrigerator	12	125	24	52,034.40
	Pot	12	700	8	65,995.78
	Fan	39	75	0.5	1,436.29
	Television	10	90	0.2	176.77
	Blower	38	30	8	8,956.57
	Rice cooker	1	600	0.2	117.85

Total electricity consumption ratio was summarized and used as index to describe overall energy use. Figure 8 indicates that air conditioning (AC) system accounts for 3/5 of the total operating energy of a PO building. Meanwhile, lighting equipment require one-fifths of the operating energy and IT equipment demands tend to require about 14%. Finally, auxiliary demands completed the energy profile, requiring only 6% of the total operational energy. According to the highest electricity cost of PO is paying for AC system. Therefore, reducing electrical cost on AC will greatly impact on cost of operation.

Approximately 75% of the energy consumed in buildings is attributed to administrative operations (Figure 9) followed by meetings and executive function is the smallest part of total energy consumption. The findings show the impact of focusing on fundamental areas of administration (i.e. finance, educational service, personnel, etc.) to minimize the energy required to operate them. It means that the potential for energy saving is huge including appliance retrofit and operation time reduction. Occupant behavior changing is alternative in sustainable energy consumption. The challenges of implementing changes in operational energy performance improvement of PO buildings are addressed in the recommendations that could bring about energy efficient results.

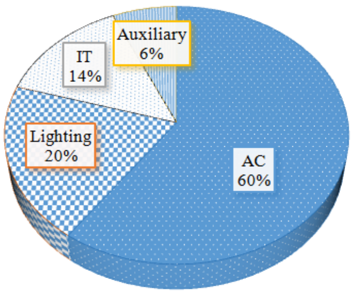


Figure 8. Annual electricity consumption ratio.

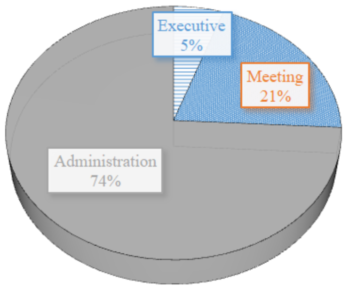


Figure 9. Energy use by function.

5.6 Energy efficiency measures

Energy breakdown represented that three-quarters of energy use are administrative operations. Therefore, steps to save energy in the building are significantly deliberated on among stakeholders. University executives, representatives of building, and ground subdivision, and administrative staffs play a crucial role in energy performance development for PO building.

The suggested measures were divided into two different categories, reaching by internal and external factors (Figure 10). The most mutual recommendations were identified as lighting and air conditioning retrofits. They could get grant support from the outsource fund in efficient appliances installation. The most cost-effective solution is not always the most environmentally sound choice. For instance, renewable energy implication might consume very little energy but cost more to install than it saves in energy cost. However, renewable energy installation was planned for renovating PO building as smart building in the future. Furthermore, there is still potential for improving energy performance not only influenced by its physical characteristics but also by many other factors such as occupant's behavioral change, and control of indoor environmental conditions.

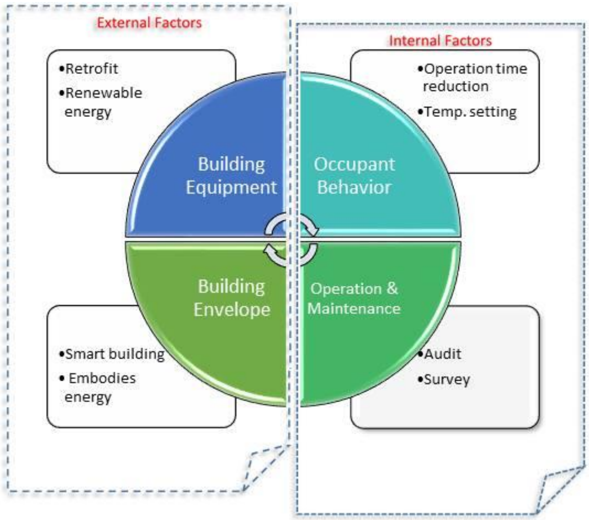


Figure 10. Energy efficiency measures for PO operations.

6. Conclusions

In this study, a life cycle cost has been evaluated to obtain the cost effective measurement. After the essential data required for the cost assessment had been gathered and after monitoring the appliance operation, the energy breakdown was calculated using the excel datasheet, and the annual energy consumption of the building was estimated. The primary operational energy was considered in four components: Air-conditioning (AC), lighting, IT devices, and auxiliary appliances. The findings presented that energy consumption was a major cost in operation of PO building. In particularly, AC is the major component in energy consumption. Approximately 75% of the energy consumed in buildings is attributed to administrative operations. The study also suggested some solutions that have been recorded to be effective in reducing the energy consumption of administrative building. The potentials to improve energy performance in PO building is considered both external and internal factors. In fact, this study showed that considering conventional practices including advance technologies, can be an effective strategy.

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