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Energy Consumption Analysis and Potential Energy Savings of APublic Building In Nigeria

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ABSTRACT
Energy consumption in the building sector accounts for about 20% to 60% of total energy in different regions of the world. To palliate the effects associated with high energy demand, and greenhouse gas emissions; energy audits offers an effective approach to identifying energy wastages while proffering Energy Saving Opportunities (ESOs). In this study, the electricity consumption of the air-conditioning and lighting system for a Public Building were evaluated based on elements of the energy audit flow chart outlined in EN 16247-2. The data collected providedinformation on energy consumption and system characteristics. Data about the air conditioning loads through sub-metering systems and lighting load through site survey werecollected for analysis, comparison between utility meter and sub metering system, models to evaluate lighting energy demand based on EN 15193-1:2014. The energy saving opportunities for the building were analysed with suggestions on potential Energy Saving Opportunities put forward for energy reduction.

Keywords:*electricty consumption, energy audit, energy wastage,energy efficiency, energy saving opportunities*

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I. INTRODUCTION

The energy consumption in the building sector accounts for about 20% to 60% of total energy demand of building across different regions of the world (Ali *et al.,* 2021). To close the gap in energy demand, many countries generate more power mostly through non-renewable energy resources which emit greenhouse gases (Ali *et al.,* 2021; Javied*et al.,* 2015). To palliate the effect associated with high energy demand, energy management provides the possibility of combining creativity with a holistic approach to identifying opportunities to improve energy efficiency; thereby potentially realizing a considerable economic outcome(Finnegan *et al.*, 2015; Li *et al.*, 2017).

Energy Audit (EA), according to Li *et al.*, (2017) is defined as "a kind of scientific management method which is effective in building energy saving". Although, EA was primarily thought to be concerned with technical opportunities, the approach can be made more valuable by addressing issues of occupant awareness (Vesma, 2011). In this regard, the British Standards Institution (BSI)introduced a standard describing energy management system which identifies opportunities to improve energy efficiencyin buildings (EN 16247-2:2014). The process is intermittent in nature and assesses the building energy management system designed to cover all or some aspect of the building system; linked to local climatic conditions, energy use patterns, occupant behaviour, characteristics of building and activities; which can be monitored and investigated (Alajmi, 2012; EN 16247-2, 2014; Li *et al.*, 2017).

In developing countries, the demand for better thermal comfort and lighting are responsible for significant proportion of energy consumptions in buildings especially in commercial buildings (Assimakopoulos, *et al.,* 2017). Considering the aforementioned, many research works have implemented various standards and strategies, all significantly identifying or indicating improvement in energy performance of buildings.Alajmi, 2012 conducted an energy audit study of an educational building in a hot climate using the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard;the analysed energysavingspotentiallyoffers up to 52%energy reduction through non-retrofitting and retrofitting ESOs. Li *et al.,* (2017), investigated the energy consumption characteristics of a university campus;the results indicated high power consumption per capita which translates to low operating energy efficiency.In Ali *et al.,* (2021), a walk through energy audit was conducted of a research and development building, the energy consumption pattern was analysed; the results showedpotential significant annual energy savings through the replacement of existing lighting system with Light Emitting Diode (LED)type lights.

At this stage, analysing the energy consumption pattern of existing office buildings ideally facilitates site specific strategies to improve energy efficiency.In this paper, the energy consumption pattern is investigated and measured from a technical perspective. Upon analysis of the energy consumption pattern, areas of low operating efficiency are identified with some suggestions on potential energy opportunities put forward for energy reductionof the Public Building.

II. OVERVIEW OF THE AUDITED BUILDING

The audited building complexis a 4 storey building with gross floor area of 7,269.35m^{2}which was acquired, restructured and completed as a Research Institute in 2018. The building contains mainly offices, engineering laboratories, conference/seminar rooms, an ICT centre, library, day care centre and canteen. The offices are mostly open plan, partitioned, and accommodating a large number of staff and researchers. On average, 150 – 200 people use the building with irregular occupancy from 7am to 5pm, 5 days per week throughout the year excluding public holidays.

The building has 2 main entrances on the South and West side of the building with the length of the structure oriented towards the South. The total area for fenestration is equal on the East and West of the building with shading devices. The South facing windows are fixed with very few projected windows as compared to the North of the building. The exterior and interior walling consist of hollow sandcrete blocks except for a few walling sections on the ground and first floor consisting of Compressed Stabilized Earth Blocks (CSEBs), The building roof is pitched with steel supportand having an atrium (total area of 206.20m^2) somewhat at the centre of the building with danpalonglazing material. The atrium allows daylight to illuminate the central areas of the building. However, the glazing material allows for an increasedheat gain.

Since the building is equipped with office equipment and devices, the office equipment power consumption accounts for significant proportion of the energy consumption of the building complex. Electricity is the major form of energy used by the building to power office equipment, air-conditioning, lighting, engineering laboratory equipment, elevators and water circulation pump. This electricity source is provided either by the utility company or 250kVA generator set installed as a backup energy source in the event of power failure from the utility company.

III. ENERGY AUDIT PROCESS

3.1 Scope of energy audit

In this study, the main objective is to apply the energy audit process for the Nigerian Building and Road Research Institute, Headquarters complex to reduce energy consumption. The scope of the energy audit is limited to elements of the energy audit process flow chart outlined in EN 16247-2: 2014 with limitation to auditing two technical systems; air conditioning system and lighting system in the building complex. Since this study has a research dimension, monitoring energy consumption and Energy Saving Opportunities reported in Vesma, (2011) will be used as a reference to improve data collection where necessary and Operation and Maintenance (O&M) activities.

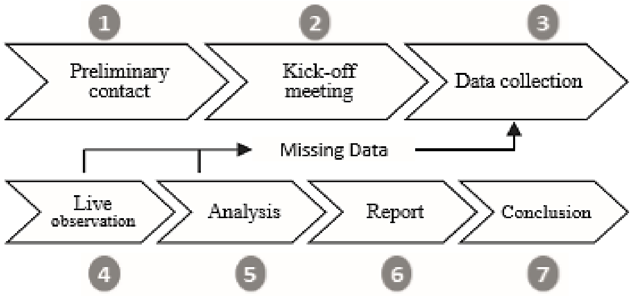

Figure 1: The energy audit process flow chart (Javied, *et al.*, 2015)

The parties involved in conducting the energy audit comprise of the project leader/members (research officers), operation and maintenance personnel (Electrical engineer/Electrician). Based on the available resource, the energy team defined the area to be audited and time frame in order to achieve the desired objective of the study.

3.2 Site survey and data collection

In this study, the electricity consumption applicable to air-conditioning and lighting system were evaluated by the energy audit team to identify ESOs for the building. The energy audit team inspected the building complex and observed energy consumption trends/patterns that deviate from desired objective.These deviationsindicated energy saving opportunities to be identified.

Firstly, the building complex has no historical data for comparison and the total electricity consumption is measured by only one meter installed at the energy outflow terminal from the incoming 500kVA transformer.

The meter was installed in November, 2018 and the building was occupied in January, 2019. To address this issue, the energy audit team installed Smappee Infinity energy management system to help identify, measure and evaluate the load contributors to the total building energy consumption. The installation of the energy management system was combined with a walk through energy audit to provide information on the installed load capacity and better understanding of energy use patterns

Based on the aforementioned, the information retrieved and relevant to this study is listed as follows;

a) Air conditioning/Lighting characteristics obtained from site survey
b) Total Building electricity consumption obtained from utility
c) Total Building electricity consumption obtained from electricity sub-metering system
d) Air conditioning electrical load obtained from electricity sub-metering system
e) Weather data; ambient temperature, relative humidity (RH) and wind speed, obtained from Nigerian Meteorological Office

Due to the COVID 19 pandemic which led to reduced occupancy, no significant correlation between occupancy rate and electricity consumption is drawn. However, parameters evaluated may suggest the influence of occupancy rate.

IV. RESULTS AND ANALYSIS

4.1 Analysis of electricity consumption

The recorded overall building electricity consumption for the audited period (September, 2019 to August, 2020) from utility and energy monitor is 109.425MWh and 99.405MWh respectively. A correlation between data collected from utility and energy monitor on an annual scale shows a 9.16% error margin. From a monthly time step shown in Figure 2, the error margin observed can be explained by two factors: i) energy monitor system failure(cloud data backup) and, ii) frequent power outage experienced. Also, data collected from the utility meter records only date reading is actually taken; omitting time.

Figure 2 describes the monthly percentage error margin plotted thus allowing a total overview of the obtained result. The chart shows the magnitude in percentage error; when utility data is compared to energy monitor (Red down bar – positive value and White up bar – negative value). July, 2020 is the only month where the electricity consumption value from energy monitor exceeds the monthly electricity consumption value from utility. The deviation does not establish a pattern that explains nonconformity of July, 2020 in comparison to other months.

It can be seen that February, 2020 has a peak value while March and April, 2020 records no data from utility and energy monitor due to; i) disconnection of the building complex from the grid, ii) total lockdown due to the pandemic. From May, 2020 the building was reconnected back to the grid. However, the building was partially occupied due to the partial lockdown put in place.

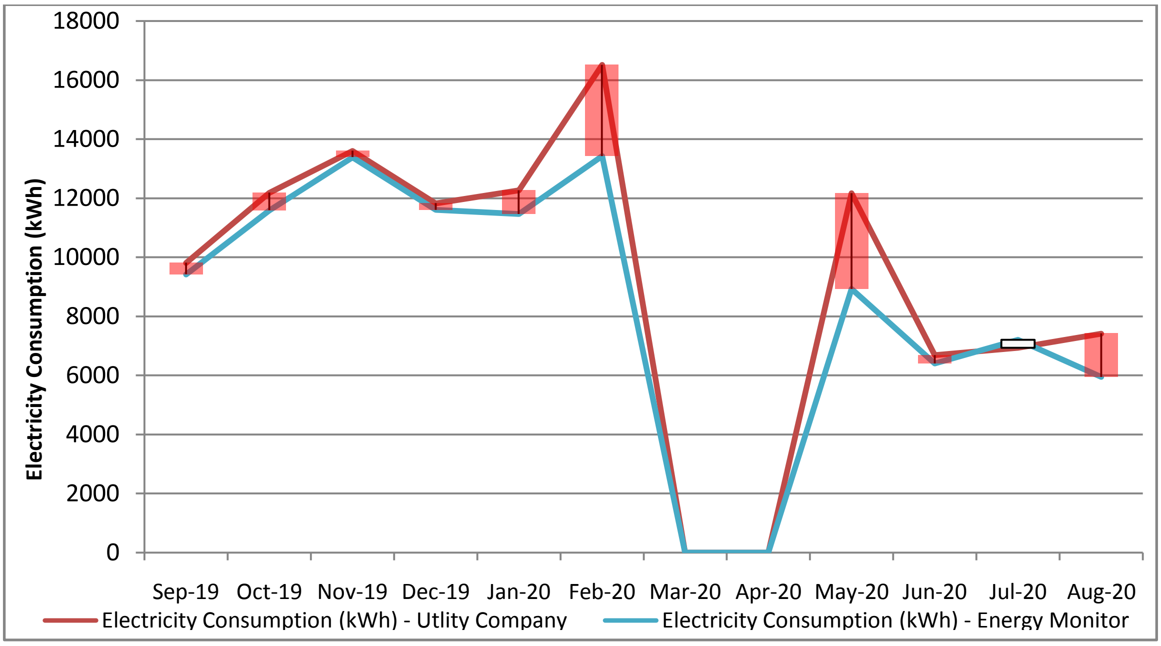

Figure 2: Monthly Electricity Consumption as function of monthly difference - Sept; 2019 to Aug; 2020

4.2 Electricity consumption by air – conditioning and potential energy savings

From site survey, the largest rated component is air – conditioning. Therefore, electricity sub-metering system installed provided the contribution of the air conditioning load to the overall electrical usage of the building complex. The air-conditioning system consists of multiple split air conditioning systems independently controlled by occupants in offices, construction laboratories, conference/seminar rooms, library and so on. There are a total of 109 units with total installed rated power capacity of 200.64kW

The monthly electricity consumption profile of air condition over the entire audit period is shown in Figure 3. The average monthly proportion of electricity consumption of air conditioning equipment is 52.19%. It can be seen that the consumption exhibited seasonal trends; dry season (October – April) having higher air conditioning electricity consumption compared to the wet season (April – October). It is evident that the largest opportunity for energy saving in the building complex is to significantly reduce the air condition load. The seasonal trends do not have significant opportunities for energy savings as such, data was considered on daily time step.

Figure 4 depicts the daily electricity consumption profile of air conditioning electricity consumption to the total electricity consumption. From the electricity consumption trend, consumption increases from the beginning of the week (Sunday), peaks on Monday and then decreases. There is slight increase from Thursday to Friday which may be an effect resulting from failure to switch off some air conditioning unit.

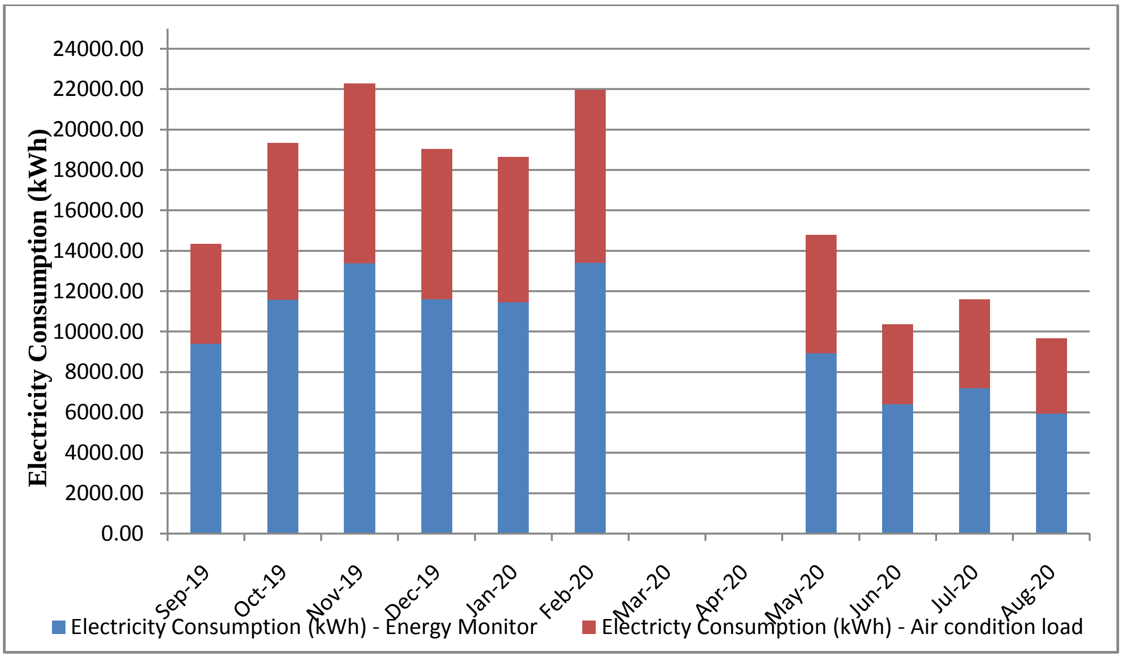

Figure 3: Monthly proportion of air condition electricity consumption

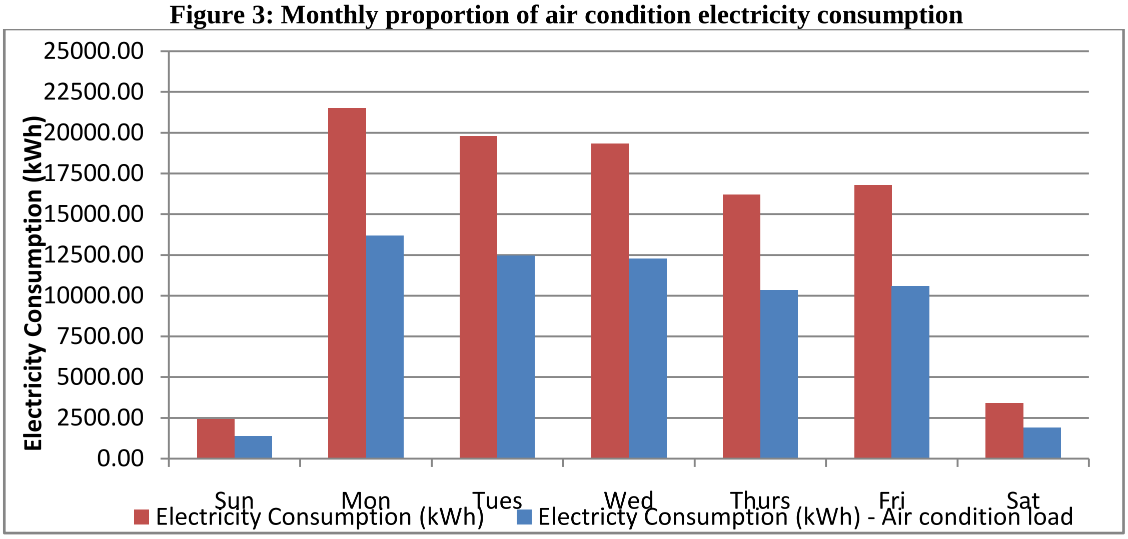

Figure 4: Daily electricity consumption profile of total electricity consumption to air conditioning electricity consumption

Figure 4 shows that 5.23% (3273.34kW) of the annual electricity consumption associated with air conditioning is on during off days (Saturday and Sunday), which means some staff/researchers left their air conditioning unit on when leaving office on the last day of a working week (Friday). Also, there is a slight increase in air conditioning electricity consumption on Saturday compared to Sunday, probably due to the fact that some staff works on Saturday.

On the potential energy saving aspect, the air conditioning systems were installed in 2018 and fall within the standard life cycle of air conditioning which is between 15 and 20 years. As a result, the air conditioning units do not require upgrade. However, majority of the air conditioning systems require periodic maintenance to optimize performance. Although, split unit offer some advantages compared to centralized unit, the unavailability of PIR sensory systems or programmable thermostat that allow auto power off in cases of low usage or cooling empty spaces have caused excessive energy consumption. Also, control systems independently controlled are predominately set to 16^0C by occupants irrespective of external monthly average temperature and relative humidity recorded between 24.4^0C & 29.8^0C and 22.09% & 90.03% within the audited period. Based on the research institute's location within the tropics, temperature should be evaluated to preset temperature set points to maintain internal thermal quality at 90 percent acceptability while reducing energy consumption.

Lastly, changing the direction of flow of air conditioning unit in most open offices will significantly reduce the number of system in use without compromising occupant comfort.

4.3 Electricity consumption of building lighting system and potential energy savings

From survey, the indoor lighting system of the building are predominately recessed LED ceiling luminaires of 18W and 30W independently controlled by occupants in offices, construction laboratories, conference/seminar rooms, library, corridor, toilets and so on. The colour appearance of the artificial light is categorized as cool with correlation colour temperature of 6400k. The control mechanism manually switches on/off group of luminaires using one gang, one way switches.

The total number of lighting system installed is summarized in Table 1 with total installed rated capacity of 21.648kW inclusive of the outdoor lighting system along the perimeter with E27 lighting fitting having 18W Compact Fluorescent Lamp (CFL) installed.

Table 1: Summary of detailed survey of indoor and outdoor lighting systems

Lighting System (LS)	**Installed Power, (W) and Number**		
Location	**Load (W)**	**Nos.**	**Total Load (W)**
Ground floor LS (Reception, within offices and laboratory spaces)	30	121	3630
	18	5	90
First floor LS (within open office spaces)	30	114	3420
Second floor LS (within open offices, seminar room and laboratory spaces)	30	116	3480
Third floor LS (within open offices and seminar room spaces)	30	114	3420
Fourth floor light (within office spaces)	30	112	3360
Corridor/Staircase LS for all floors	18	143	2574
Toilet LS on all floors	18	41	738
LS within the atrium	18	16	288
LS outside the Building complex	18	36	648
TOTAL (W)			**21648**

The assessment of the installed power for lighting system in the building was conducted in line with EN 15193-1:2014 to calculate the Lighting Energy Numeric Indicator (LENI). The result of LENI obtained are analysed with a proposed energy reduction intervention for indoor lighting systems. The proposed intervention for the indoor lighting system is from the view point of ease of implementation, and reduced cost in implementation by maintaining existing lighting system with introduction of Passive Infra-Red (PIR) and natural lighting sensor for open offices, laboratories, corridors/staircase and toilet.

Using the calculation model to evaluate the lighting energy demand, the evaluation of LENI was conducted in accordance to EN 15193-1:2014. The total estimated energy required for lighting for a period in a room is described in Equation 1;

$$W_t = W_{L,t} + W_{p,t} \ [kWh/ts] \qquad \text{Equation (1)}$$

Where $W_{L,t}$ is the estimated lighting requiredexpressed in Equation 2

$$W_{L,t} = \sum\{(P_n \ x \ F_c) \ x \ F_o \ [(t_D \ x \ F_D) \ + \ t_N]\}/1000 \ [kWh/t_s] \qquad \text{Equation (2)}$$

With; *P_n = installed load (kW), F_c = reducing factor due to use of daylight control (<1), F_o = reducing factor due to use of present based control (<1), t_D = annual hours of use by day (h), F_D = reducing factor due to use of constant lighting maintenance control (<1), t_N = annual hours of use by night (h)*

and$W_{P,t}$ is the estimated standby energy required during non-lighting period to provide charging energy emergency lighting

$W_{P,t} = \sum\{(P_{pc}\ x\ [t_s - (t_D\ + t_N)]) + (P_{em}\, x\ t_e)\}/1000\ [kWh/t_s]$ Equation (3)

For the audited building, $W_{P,t} = 0$

Therefore, equation 1 becomes,

$W_t = W_{L,t}\ [kWh/ts]$ Equation (4)

The LENI for the building is therefore calculated based on equation 5

$LENI = W/S\ [kWh/(m^2\ \ x\ year)]$ Equation (5)

Where W (kWh/year) is the total annual electrical energy used for lighting and S (m^2) is the net floor area

In Table 2, the results obtained from the calculation are reported. It can be seen that the existing building LS with total, 3000 working hours per year has LENI of 15.48 kWh/m^2year shown in Table 2

Table 2: Result of LENI evaluation for the existing lighting system and proposed energy saving intervention

Parameters	Existing LS	Energy Saving Intervention
$P_n\,(kW)$	20.88	20.88
F_c	1	1
F_o	1	0.9
t_D (hours)	2585	2585
F_D	1	0.9
t_N (hours)	415	415
$W_{L,t}$ (kWh)	62640	51518.27
$S\ (m^2)$	4045.53	4045.53
$LENI\ [kWh/(m^2\ \ x\ year)]$	**15.48**	**12.73**

The introduction of control systems in order to exploit the contribution of occupancy activities and natural light allows an overall reduction of 17.76% with Electrical Energy Savings (EES) of 11,122MWh/year.

From survey, the following were observed which will further reduce indoor lighting energy consumption where necessary;

a) On the use of LED luminaires, the efficiency of each the existing LED luminaires results in half the lighting efficiency. The other half relates to positioning the luminaire in ways that maximizes the output lumens. The existing luminaires can be rearranged or positioned optimally to meet operational need. By so doing, reducing the amount of recessed LED lighting system in use.

b) Some lighting switches control luminaires in more than one office space. The installation error result in low operating efficiencies and can be addressed by isolating control mechanism between office spaces.

V. CONCLUSION

This study reports on the energy consumption pattern of air conditioning and lighting load for the research institute within a one year time scale. The main findings of the study include;

1) The overall building electricity consumption for the audited period (September, 2019 to August, 2020) from utility and energy monitor is 109.425MWh and 99.405MWh respectively; This represents a 9.16% error margin associated with system failure (cloud data backup) and, frequent power outage experienced

2) Air conditioning is the major factor in power consumption with monthly average energy consumption at 52.19% of the total building electricity consumption.

3) 5.23% (3273.34kW) of the annual electricity consumption associated with air conditioning is during off days (Saturday and Sunday). This offers an opportunity of energy savings by installing PIR sensory system to automatically switch off air conditioning unit in unoccupied spaces.

4) Air condition temperature should be evaluated to preset temperature set points to maintain internal thermal comfort quality at 90 percent acceptability.

5) Also, a change in the direction of flow of air conditioning unit in most open offices will significantly reduce the number of system in use without compromising occupant comfort.

6) Total installed capacity of building lighting system is 21.648kW. Introduction of control systems offer a 17.76% reduction with electrical energy savings of 11,122MWh/year.

7) Re-arranging and repositioning lighting system to meet operational need may further reduce the number of recessed LED lighting system in use.

8) Lastly, installation of sub-metering systems at each floor will provide detailed analysis of energy consumption of various systems. As such, energy saving opportunities proffered will be more precise and effective.

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