Energy Efficiency in Academic Buildings Through Optimization and Operational Strategies

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ABSTRACT

Electricity consumption in commercial buildings needs serious and particular attention due to current situation of increased world fuel prices. This paper presents the potential savings in order to achieve energy efficiency in academic building through optimization and operational strategies. This study also helps to identify the energy savings gap within the building through energy saving measures and application of renewable technologies. There are three main components that have been selected as the subjects of investigation, i..e., the cooling equipment, lighting and electrical appliances. A number of existing analytical tools such as ASHRAE CLTD/CLF, lumen method, net present value and benefit cost ratio have been adopted during the course of conducting this research. The results showed that the usage of air-conditioning, lighting and electrical appliances can be reduced by 12%, 52% and 40%, respectively when all the energy saving measures were in place and implemented.

Keywords: *Energy efficiency, energy savings, air-conditioning*

1.0 INTRODUCTION

Throughout these current days, the number of commercial buildings had been increased and they contribute to the huge increase of energy demand [1]. The building-sector consumed about 40% of total global energy [2]. Heating, ventilation, and air-conditioning (HVAC) consumed the most energy, followed by lighting and electrical appliances [3].

Several researchers have introduced many possible ways to conserve the energy consumption in the buildings. One of the major energy conserving techniques in buildings is energy efficiency [1, 4]. Energy efficiency is defined as the goal to reduce the amount of energy required to provide required products and services [1]. Installing a proper insulation on the wall of a building is an example for lowering the energy consumption of a building for heating and cooling purposes. This kind of improvements can contribute many advantages in conserving the energy consumption and thus reducing the CO2 emissions and electrical bill significantly [4]. Energy efficiency is also proved to be cost-effective strategy for building's economy without extending the energy consumption.

Energy efficiency measures typically focused on energy audits and the implementation of energy-saving measures that are largely technical by nature and aimed at containing the effects of rising costs [5].

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Energy management is the key option to saving energy in an organization through energy efficiency. Much of the importance of energy saving stems from the global need to save energy-this global need affects energy prices, emissions targets, and legislation, all of which lead to several compelling reasons why we should save energy at our organization [6].

Energy efficiency measures are meant to reduce the amount of energy consumed while maintaining or improving the quality of services provided in the building [7]. The building or organization may also be keen to reduce its carbon footprint to promote a green and sustainable image [8, 9]. This study examines the energy savings gap within an academic building through energy saving measures and the application of renewable technologies. The usage of air-conditioning, lighting and electrical appliances can be reduced by 12.58%, 52.23% and 40%, respectively when all the energy saving measures were implemented.

2.0 METHODOLOGY

In this research, there are some specific methods that can be applied in successfully fulfilling the research objectives. This is duly described in the succeeding sections.

2.1 ASHRAE CLTD/CLF

The amount of cooling loads is a measure of how much energy is needed to be added or removed from a space by air-conditioning (AC) system to have an optimum level of comfort [10]. This method also helps to identify whether the size of the installed air-conditioning unit is suitable for a certain space. The results from this calculation may give a huge impact towards the operating energy efficiency, occupant comfort, indoor air quality and building durability [11]. Thus oversizing the AC will cause the overuse of energy, poor indoor air quality, bad building and equipment durability. Selecting and designing the AC system require a right-sizing procedure to meet the predicted heating and cooling loads of the building [12].

2.2 Cooling Load Estimation

i. External sensible loads

Heat gain from conduction through opaque walls:

$$\dot{Q}_{\text{wall}} = U \times A \times CLTD_{\text{corrected}} \tag{1}$$

where, U is the overall heat-transfer coefficient of wall W/(m^2°C), A is the area of exterior wall (m^2), $CLTD_{\text{corrected}}$ is the corrected cooling load temperature difference (°C).

$$CLTD_{\text{corrected}} = \left(CLTD_{\text{July,40N}} + LM - 1.2\right)K + (25.5 - t_{\text{RA}}) + \left(t_{\text{OA,dd}} - 29.4\right) \tag{2}$$

where, LM is the latitude-month correction, K is the color correction factor, t_{RA} is indoor air dry bulb temperature on design day in °C, $t_{OA,dd}$ is the outdoor air dry bulb temperature on design day in °C, $CLTD_{July,40N}$ is from Carrier handbook (indoor = 26.7°C) whereas LM is from ASHRAE handbook (indoor = 25.5°C).

$$\frac{1}{U} = R_{\text{T}} = R_{\text{o}} + \sum \frac{\Delta x}{k} + \sum \frac{1}{C} + R_{\text{i}} \tag{3}$$

where, R_T is the total thermal resistance (m$_2$°C)/W, R_o & R_i are combined heat transfer coefficients of convective and radiative at outside and inside of the wall (m^2°C)/W, C is the surface conductance W/(m^2°C), Δx is the thickness of a wall, k is the thermal conductivity of wall materials W/(m^2°C).

Heat gain from conduction through roofs:

$$\dot{Q}_{\text{roof}} = U \times A \times CLTD_{\text{corrected}} \tag{4}$$

$$CLTD_{\text{corrected}} = \left(CLTD_{\text{July,40N}} + LM - 1.2\right)K + (25.5 - t_{\text{RA}}) + \left(t_{\text{OA,dd}} - 29.4\right)f \tag{5}$$

where, f is correction factor for attic ventilation; f =1 no attic ventilation, f = 0.75 positive attic ventilation.

Conduction through glass windows:

$$\dot{Q} = U_{\text{glass}} \times A_{\text{glass}} \times \left(t_{\text{OA,dd}} - t_{\text{RA}}\right) \text{ [Watt]} \tag{6}$$

Heat gain through glass windows by solar radiation:

$$\dot{Q} = A_{\text{glass}}.SC.MSHGF.CLF \text{ [Watt]} \tag{7}$$

where, *SC* is the shading coefficient of glass window, *MSHGF* is maximum solar heat gain factor, *CLF* is the cooling load factor.

ii. Internal sensible loads

Heat gain from conduction through partitions/ceilings/floors:

$$\dot{Q} = U \times A \times \left(t_{\text{adj}} - t_{\text{RA}}\right) \text{ [Watt]} \tag{8}$$

Heat gain from lights

$$\dot{Q} = INPUT \times CLF \text{ [Watt]} \tag{9}$$

Heat gain from occupants:

$$CL_{\text{S}} = \text{(number of occupants)} \times \text{(sensible heat release per person)} \tag{10}$$

Heat gain from appliances:

$$CL_{\text{S}} = \text{sensible heat from equipment} \tag{11}$$

Heat gain from ventilation & infiltration air:

$$CL_{\text{S}} = 1.232 \times V\left(t_{\text{OA,dd}} - t_{\text{RA}}\right) \tag{12}$$

iii. External latent loads

Heat gain from occupants:

$$CL_{\text{L}} = \text{(number of occupants)} \times \text{(latent heat release per person)} \tag{13}$$

Heat gain from appliances:

$$CL_{\text{L}} = \text{latent heat from equipment} \tag{14}$$

Heat gain from ventilation and infiltration of air:

$$CL_{\mathrm{L}} = 3012 \times V\left(w_{\mathrm{OA,dd}} - w_{\mathrm{RA}}\right) \tag{15}$$

2.3 Lumen Method

Despite the scientific impression of the lumen method equations, there are inaccuracies and assumptions built into the method. Therefore, the lumen method should not typically be used as a standalone, final solution; it should be used as a tool in particularly uniform settings of lighting design if a simple, rough technique of illuminance quantification is desired [13]. Illumination can be calculated as:

$$I = L_{\mathrm{l}} C_{\mathrm{u}} L_{\mathrm{LF}} / A_{\mathrm{l}} \tag{16}$$

where, I is the illumination (lux, lumen/m^2), L_{l} is lumens per lamp (lumen), C_{u} is coefficients of utilization, L_{LF} =0.85 is light loss factor and A_{l} is area per lamp (m^2).

2.4 Net Present Value and Benefit Cost Ratio

The difference between the present value of cash inflows and the present value of cash outflows over a certain period of time is called *Net Present Value (NPV)*. This method uses to determine the profitability of a certain project or investment [14]. The basics formula for the *Net Present Value* is:

$$NPV = \sum_{t=0}^{T} \frac{\mathrm{C_t}}{(1+r)^{\mathrm{t}}} - C_{\mathrm{o}} \tag{17}$$

where, Co is the Initial Investment, C_{t} is cash flow at year t, r(%) is the discount rate and T is total time (yr). Meanwhile, the Benefit Cost Ratio formula is simply:

$$BCR = \frac{\text{Program benefits}}{\text{Program Costs}} \tag{18}$$

3.0 RESULTS AND DISCUSSIONS

Air-conditioning is the most contributor to the energy consumption of the building. Table 1 is the comparison of data for the actual and the desired costs.

Table 1: Cost analysis of energy consumption from air-conditioning

Room No.	Total area of room (m^2)	Capacity (people)	Required cost (RM/month)	Ideal cost (RM/month)
C24 109-01	35.675	30	29410.02	25626.88
C24 113-01	71.35	60	49495.16	43139.02
Space office	71.35	7	63625.00	55645.15
Lecturer room Level 2	294.32	10	8418.86	7339.78
Professor Room Level 3	17.84	1	1180.88	1028.82
AP and Dr. Room Level 3	13.38	1	1160.52	1011.00
Tutor Staff Room Level 3	8.92	1	1109.62	967.35
Computer Lab	169.46	40	41575.12	36235.71
Computer Lab	169.46	10	11045.30	9629.01

From the table, it can be concluded that the more capacity of the room, the more energy is needed to cool the room to a desired temperature of 24°C [15]. Lighting is the second contributor to the energy consumption of the building. Table 2 shows the cost savings of the electricity consumption.

Table 2: Cost analysis of energy consumption from lighting

Room No.	Total area of room (m^2)	Capacity (people)	Actual cost per month (RM)	Required cost per month (RM)	Saved cost per month (RM)
C24 109-01	35.675	30	19.95	10.42	9.53
C24 113-01	71.35	60	73.30	20.18	53.12
Space office	71.35	7	24.432	20.18	4.26
Lecturer Room Level 2	294.32	10	131.12	86.00	45.12
Professor Room Level 3	17.84	1	16.29	5.04	11.24
AP and Dr. Room Level 3	13.38	1	8.14	3.78	4.36
Tutor Staff Room Level 3	8.92	1	8.144	2.52	5.62
Computer Lab	169.46	40	94.06	49.52	44.55

In terms of cost, all the rooms that are inspected exceed the required total cost due to the fact that the current lumen (lm) level exceeds the required standard lumen level (the International Standard is 250 lux or 250 lm/m^2). Note that the lumen is a measure of the total quantity of visible light emitted by a source. There are several aspects that lead to the excessive cost of lighting:

- The inefficient bulbs that consume high power but produce less lumen.
- Over lamp at certain area.
- High Light Loss Factors

To have an ideal power consumption, every time the electricity is not in use, it will automatically enters the sleep mode. Therefore, it is assumed that the amount of hours used in normal operation mode is six hours while for the operation in sleeping mode is set to two hours. Table 3 shows the total cost when using the sleep mode function for two hours.

Table 3: Cost analysis of energy consumption from electrical appliances

Electrical Appliances	Total normal cost for a month (RM)	Total ideal cost for a month (RM)	Total saved cost per month (RM)
Computers	7874	3742.8	4131.2
LCD Projectors	420	160.4	259.6
Personal Printers	384	150.7	233.3
Office Printers	60	23.5	36.5
Office Copiers	123	49.4	73.6

From Table 3, it can be deduced that when applying the sleeping mode, i.e., when not in use, it gives a significant impact on energy usage by the electrical appliances. This can be shown by the use of computers that have reduced of power consumption by 48%, LCD projectors by 38%, personal printers 39%, office printer by 39% and office copiers by 40%.

4.0 CONCLUSION

As a conclusion, the study has shown the energy saving in academic buildings through the proposed energy efficiency and operational strategies. The huge amount of energy used in academic building is cooling system, followed by lighting and electrical appliances. By turning off the air-conditioning when not in use (i.e., during lunch hour, for one hour), considering the standard temperature of 24°C for indoor thermal comfort (thermostat set point) and use proper insulation level for the wall (204.88-mm concrete block-Perlite filled insulation) gives a significant potential saving in terms of the building economics. In order to have energy efficient building, few standards must be followed such as Malaysia Standard, International Standard and ASHRAE Standard. There is a need to revise the benefits in terms of the life cycle of the bulb and cost saved by using LED instead of CFL bulbs. By applying the sleep mode (when not in use) for electrical appliances gives a huge amount of electricity savings, thus correspondingly reducing the electricity consumptions for the building. There are many potential saving measures that can be implemented in order to achieve an energy efficient building. The usage of R410A instead R22 as the refrigerant may contribute to reducing the amount of environmental pollution. Other renewable sources (solar, wind, etc.) need to be considered as well for an energy efficient building. The usage of air-conditioning, lighting and electrical appliances has been shown to be reduced by 12.58%, 52.23% and 40% respectively when all the energy saving measures were implemented. Therefore, the building needs to follow the recommended operating procedures to have a better energy efficient building.

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REFERENCES

1. Sukri A., Yusri M., Abdullah H., Rahman H.A., Majid M.S. and Bandi, M. 2012. Energy Efficiency Measurements in a Malaysian Public University. *2012 IEEE International Conference on Power and Energy (PECon)*, Kota Kinabalu, Malaysia.
2. Hassan J.S., Zin R.M., Majid M.Z., Balubaid S. and Hainin M.R., 2014. Building Energy Consumption in Malaysia: An Overview, *Jurnal Teknologi*, 70(7): 33-38.
3. Berarfi U., 2015. Building Energy Consumption in US, EU and BRIC Countries. *Procedia Engineering*, 118: 128-136.
4. Sorrell S., 2015. Reducing Energy Demand: A Review of Issues, Challenges and Approaches, *Renewable and Sustainable Energy Reviews*, 47: 74-82.
5. Gul, M. S. and Patidar, S. Understanding The energy consumption and occupancy of a multi-purpose academic building. *Energy and Buildings*, 2015. 87: 155-165.
6. Eaton R., Johnson M., 2015. *A Study on Energy Efficiency in Enterprises: Energy Audits and Energy Management Systems Implementation of National Minimum Criteria for Energy Audits, In Line with Annex VI of The Energy Efficiency Directive*, Ricardo Energy & Environment
7. Javied T., Rackow T. and Franke J., 2015. Implementing Energy Management System to Increase Energy Efficiency in Manufacturing Companies, *Procedia CIRP*, 26: 156-161.
8. Bhati A., Hansen M. and Chan C.M., 2017. Energy conservation through smart homes in a smart city: A lesson for Singapore households. *Energy Policy*, 104(December 2016): 230-239.

9. Boydak O., 2017. Commercial Buildings Energy Consumption Survey (CBECS) and Its Comparison with Turkey Applications, *Journal of Clean Energy Technologies*, 5(1): 69-72.
10. Spitler J. D., 2010. Load Calculation Applications Manual, *ASHRAE Journal*, 2: 349.
11. Burdick A., 2011. Strategy Guideline: Accurate Heating and Cooling Load Calculations, *U. S. Department of Energy*, Washington DC.
12. Recommended Light Levels (Illuminance) for Outdoor and Indoor Venues, National Optical Astronomy Observatory, https://www.noao.edu/education, 2011.
13. Malaysian Standards, MS 1597-2-40:2017, 2005. *Household and similar electrical appliances -Safety - Part 2-40: Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers*, Second revision, IEC 60335-2-40:2013, MOD.
14. Mahlia T.M., Ng H.M., Olofsson T., Andriyana A. and Hasanuddin I., 2012. Energy and Cost Savings of Optimal Thickness for Selected Insulation Materials and Air Gaps for Building Wall in Tropical Climate, *Energy Education Science and Technology Part A: Energy Science and Research*, 29(1): 649-662.
15. Walraven D., Laenen B. and D'haeseleer W., 2015. Economic System Optimization of Air-cooled Organic Rankine Cycles Powered by Low-temperature Geothermal Heat Sources, *Energy*, 80: 104–113.