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***Research paper***

# Life Cycle Analysis of Operational Energy in Office Projects Toward Sustainability Practices in the Malaysian Construction Industry

**Farzaneh Moayedi [1], Noor Amila Wan Abdullah Zawawi [1], Mohd Shahir Liew [2]**

*[1]Department of Civil & Environmental Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 32610 Tronoh, Perak, Malaysia*

*[2] Faculty of Geosciences and Petroleum Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 32610 Tronoh, Perak, Malaysia*

**Corresponding author E-mail: farzaneh.moayedi@gmail.com*

**Abstract**

Global warming mitigation is used as a requisite key to promote approaches and sustainable policies in developing countries that aim to minimize the level of carbon emission in built environment. In the past few years, energy demand has grown enormously in Malaysia. CO2 emission from energy consumption, mainly from electricity is a stark condemnation of commercial sector. Building operational energy particularly the thermal aspect, is the dominant factor that used to be highlighted and investigated due to the fact that it is the main proportion of operational energy consumption in buildings. The rate of energy dissipation in building components depends on design and environmental conditions. Accordingly, actions need to be taken in order to promote the quality of buildings in terms of heat exchanges, which can lead to a significant energy saving. Using of appropriate thermal insulation is effective way to diminish greenhouse gas emissions by reducing energy consumption. Therefore, the aim of the study is to investigate and determine the total amount of energy consumption from an office building. For reliability purposes, energy consumption from operation of baseline building was compared with the eco-friendly existing office building. Results show that, after implementation of sustainable solutions in the case study, operational energy consumption was successfully reduced to a grate extend.

***Keywords***: *Carbon footprint, Energy Consumption, Sustainable Development, Office Building, Operational Energy*

## 1. Introduction

Carbon dioxide ($CO_2$) is the most important gas among the Green House Gases (GHG), that is increasing in atmosphere due to human activities [1]. Construction industry have a broad impact on the environment and predominantly, buildings are the main contributor of emission due to high energy consumption [2]. Generally, construction industry is responsible for about 40% of total energy consumption and 38% of the $CO_2$ emission [3]. Malaysia accounts as one of the excessive $CO_2$ producers in the world [4]. In order to reduce the negative impact of this sector, sustainability needs to take place by reducing the use of operational energy. Building Information Modeling (BIM) can be used throughout the life cycle by providing integrated data and information which multiple designs can be simulated into one model. By stablishing BIM in early design phase, it is possible to measure and improve the sustainability [5]. Therefore, the main objective of the study is to investigate and determine the amount of annual lifecycle performance of the case study building in term of energy consumed and carbon emission during operation stage as compare to Baseline Building. This is done in order to identify the effectiveness of energy saving based on the service and facilities applied.

## 2. Research Background

Malaysia is depending excessively on energy with the recent rapid industrialization and development which lead to serious increase in GHG emission. Energy consumption and increase in construction material demand results in alarming concern with their negative impact on environment. Previous effort to reduce those impacts caused by the construction industry lead to, ‘Sustainable’ or ‘Green’ architecture which has become a global trend. Principles of sustainable design involve providing technically, economically, and socially pleasing, healthy environments, while minimizing environmental damage. Furthermore, sustainable and green architecture only focus on construction of eco-friendly environments [6]. Therefore, the fundamental approach toward sustainability should begin as early as design stage and it is essential to evaluate the building performance.

Energy conservation and sustainability have become vital topics, due to the fact that almost 50% of the energy consumed by buildings is wasted, and the total energy consumption by construction industry is forecasted to increase by 15.7% between 2013 and 2035 [7]. One of the approaches to be taken into consideration is operational energy estimation in early design phase, to ensure sustainability in buildings. Key components of energy conservation in buildings have been introduced through building regulations resulting in global carbon emission reduction. It has been estimated that

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energy efficiency technology has the potential to reduce carbon emission by 60%, which account for a billion tonnes of carbon and save conventional [8].

### 2.1 Energy Consumption in Building

Energy demand increased dramatically due to climatic conditions, choice of building envelope and building insulation. In term of building envelop; walls, roofs and glazing are the critical items required to be examined for thermal homeostasis. Consequently, selection of appropriate building envelope has direct influence on heat loss, heat gain, and air entering from outdoors which can result in reducing the energy consumption for heating and cooling of the building [9]. Adopting suitable simulation tools together with energy conservation strategies can be used for monitoring the performance of Heating, ventilation and air conditioning (HVAC) system for maximizing the energy saving by detection of abnormalities [10].

Office buildings are among the quickest growing development within the construction industry. Office development consume considerable amount of energy (70-300 kW h/m$^2$) which is proven to be higher than consumption in residential sector by 10-20 times. HVAC system in buildings utilize almost 40% of total energy in commercial sector by providing comfortable and healthy environment for the occupants. One of the main factor which requires special attention for evaluation of HVAC's energy demand is the occupancy. Since, there is strong correlation between comfortable indoor temperature by occupant and outdoor temperature, it is crucial to determine the relationship between the occupants and HVAC system in order to minimize the energy consumption while not sacrificing occupant's comfortability [11].

## 3. Method of Research

HVAC systems specifically air conditioning consumes massive amount of energy. The total operational energy consumption of baseline building was calculated based on the dynamic energy model simulation and manual calculations. Malaysia is a tropical country therefore, for simulation and calculation of annual operational energy consumption heating load was not count.

In order to quantify the annual operational energy consumption, it was necessary to investigate drawing plans and materials specifications of the case study. Some basic and necessary assumptions for energy modeling was established, such as Energy Model Inputs for materials and internal gains. Using the Integrated Environmental Solutions software (IES) as a part of Building Information Modeling (BIM), by establishing some additional assumptions such as activity, type of system and environmental temperature range for comfort of the building as well as U-Value for materials in construction, the annual operational energy from baseline building was calculated. Then, alternative changes (sustainable solutions) which was applied in the case study, was identified to evaluate the effects on annual operational energy consumption.

### 3.1 Case Study

The selected case study for the research is an office building (research and development) which is constructed in three blocks. The total gross floor area for offices is 15,000 m$^2$ over 4 upper floors located in Universiti Teknologi PETRONAS campus, Perak, Malaysia. The building is designed to meet the required environmental and sustainability performance criteria and achieved Green Building certification status under Green Building Index Malaysia (GBI).

## 4. Results and discussion

### 4.1 Annual Energy Consumption

Annual amount of energy consumption from the baseline building during its operation stage is shown in Table 1. The operation of building assumed to be the typical operational hours in Malaysia (8 AM- 5PM).

**Table 1.** Annual Energy Consumption in Operating Hours

| Description | Energy consumption (MWh) |
|---|---|
| Chiller Plant | 1,731 |
| Air distribution (FCU & AHU) | 255 |
| Artificial lighting | 237 |
| Lifts | 17.2 |
| Fans | 868 |
| Receptacle Load- Plug Loads | 1,236 |
| Heat recovery wheel | 0 |
| Receptacle Load | 5 |
| **TOTAL ENERGY CONSUMPTIO (kWh)** | **4,349** |

Final result shows that the primary contributor of energy consumption are chiller plant (1,731), load plug (1,236) and fans (868), while total amount of energy consumed is 4,349 kWh. As expected chiller plan was the main contributor in term of energy consumption.

### 4.2 Modifications

The case study building was designed to have less amount of energy consumption as compared to baseline building. The reduction was achieved by necessary modifications
which was implemented in the building during its design stage. Major model inputs and modifications are presented in Table 2. First sustainable solution that was implemented in the case study building is heat recovery wheel. In this system latent heat from the exhaust air passes through the wheel and provide air with lower temperature. Consequently, heat recovery wheel was successfully installed in every floor in order to reduce the total energy consumption. Second sustainable solution was installation of façade which work as a thermal insulating that can have significant impacts on the cooling system and electrical demand. Façade can also help in preventing solar radiation reaching into the building. Figure 1 and Figure 2 provide the simulation of building before and after considering the external shading device. Once all modification related to HVAC and other elements was applied, annual energy consumption of the building base on 24-hour operation was calculated. Table 3 present the annual energy consumption from different elements of the building. The results show that the total energy consumption for the baseline building is (7,777 kWh), which was reduced to (5,536 kWh) after implementation of modifications. A comparison between the final results of energy consumption in baseline building and eco-friendly existing building shows that the implemented modification had significant ramification on reduction of energy use. The estimated total energy saving compared to the baseline is approximately 31.31 percentage.

60 g/cm$^3$ density
70 g/cm$^3$ density
80 g/cm$^3$ density

**Table 2.** Major Model Inputs & Implemented Modifications

| Details | Existing Building | Baseline Building |
|---|---|---|
| Facade | Provided external shading device; Estimated OTTV 44W/m² | Not provided; Estimated OTTV 50W/m² |
| Heat Recovery wheel | Provided at each floor level | Not provided |
| Total supply Air flow rate & power | Proposed AHU/FCU flow rate & power | Auto sized required supply air flow rate & power estimated based on the baseline efficiency of 0.6W/m³/s (if power <4kW) & 1.5W/m³/s (if power >4kW) |
| Chiller | District cooling | Same District cooling |
| Lighting | Actual lighting design | Maximum lighting power limit as per MS1525 |

**Table 3.** Annual Operational Energy of Building

| Description | Energy consumption (MWh) Baseline Building | Energy consumption (MWh) Existing Building |
|---|---|---|
| Chiller Plant | 3,665 | 1,801 |
| Air distribution (FCU & AHU) | 482 | 798 |
| Artificial lighting | 306 | 295 |
| Lifts | 17.2 | 17.2 |
| Fans | 1,581 | 873 |
| Receptacle Load- Plug Loads | 1,721 | 1,721 |
| Heat recovery wheel | 0 | 25 |
| Receptacle Load (Sanitary pumps and other misc. loads) | 5 | 5 |
| **TOTAL ENERGY CONSUMPTION (kWh)** | **7,777** | **5,536** |

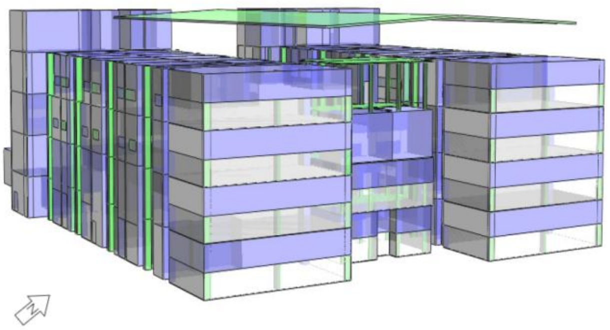

**Figure1.** Baseline Building No external shading device

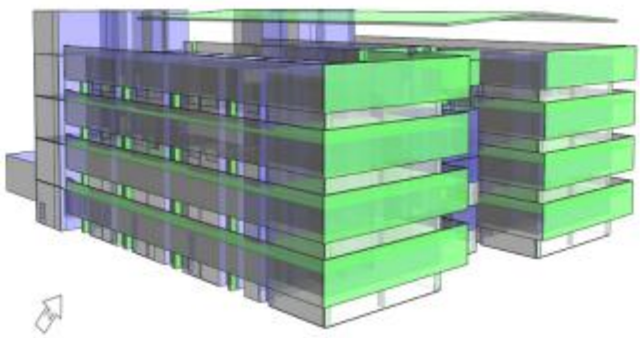

**Figure 2.** Energy Model (Existing Building)

### 4.3 Energy Simulation of chiller plant

According to results, chiller plant is the main source of energy consumption. In the building, annual estimation of energy consumption was based on 24 hour operation, Figure 3 present the peak hour of chiller plant operation for both baseline and eco-friendly existing building. In consideration of building type (research development), specific rooms were under operation on daily basis for

24hour. After all, the maximum usage of chiller plant fall under the working hour schedule (8AM-5PM).

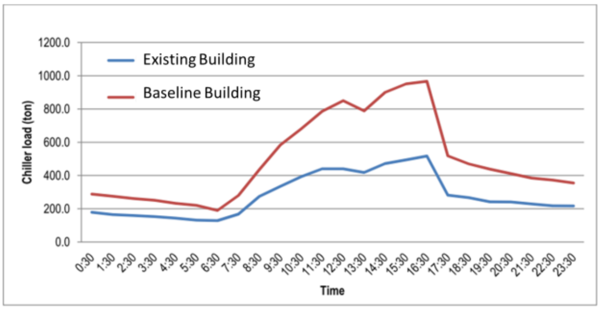


**Figure 3**. Peak Hour Chiller Load

### 4.4 $CO_{2\text{-}e}$ Emission

$CO_2$ emission was calculated according to the total energy consumption of the building and with the aid of carbon inventory for conversion of energy use to carbon equivalent ($CO_{2\text{-}e}$) emission. It was found that the total $CO_{2\text{-}e}$ emission from the baseline building is 5,253.52 kg$CO_{2\text{-}e}$ and the emission is successfully reduced to 3,739.68 kg$CO_{2\text{-}e}$ from the existing building. In total, 1,513.84 kg$CO_{2\text{-}e}$ was saved by effectuating the proposed changes.

## 5. Conclusion

Based on the simulation and calculations which was accomplished, it was found that the annual amount of operational energy consumption from baseline building is 7,777 kWh. The results of the study indicated that, with the use of alternative sustainable solutions, it is possible to reduce the energy consumption up to 31.31%. Thus, they have a remarkable capacity in reducing the required energy in building. It was evident that the annual amount of the building's energy consumption is reduced up to 5,536 kWh by replacing the baseline design with alternative sustainable design solutions such as façade, lighting system and heat recovery wheel. In order to achieve sustainability and reduce the negative impact on environment it is essential for decision makers and other professional parties involved in construction and design, to adopt and perform appropriate method for building investigation and simulation during the early phase of design. The results of the study can be useful to architects and building designers as they use BIM concept to develop more energy efficient buildings in the future with the goal of achieving sustainable development for the society.

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