Building life cycle analysis toward low carbon emission and energy efficiency

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Abstract. The Malaysian construction industry contributes as an empowerment to the Malaysian economic sector. Even though, the building and construction industry are the key sector for country development, but still they are among the biggest threat to the environment in form of greenhouse gases (GHGs) emissions. The problem of massive emission of carbon dioxide (CO2) from the burning of fossil fuels and their climatic impact has become major scientific and political issues. Buildings construction consume huge amount of natural resources and emitted million tons of carbon emission. In fact, Malaysia is one of the top 30 countries for carbon emission in the world. The energy demand in Malaysia has increased dramatically for the last few years. Commercial sector is also responsible for a great amount of CO2 emissions from the energy consumptions. Therefore, one way of reducing energy consumption could be facilitated to the reduction of CO2 emissions in this sector. Actions need to be taken in order to promote sustainable buildings in terms of carbon emission and energy consumption which can lead to significant energy saving in the built environment. Using appropriate thermal insulation can reduce and causes a reduction in greenhouse gas emissions by reducing energy consumption. This paper presents an absolute estimation and quantification of embodied and operational carbon emission and investigates the total amount of energy consumption. Results shows that after implementation of sustainable solutions in the case study, operational energy consumption and carbon emission were reduced to a grate extend.

1. Introduction
Carbon dioxide (CO2) is the most important of the greenhouse gases (GHGs) that are increasing in atmospheric concentration because of human activities [1]. This means that the atmosphere is trapping more heat that has to escape to space. This enhancement has linked the greenhouse effect to cause global warming. CO2 is the largest contributor to the greenhouse effect out of all the gases produced by human activities. The increase in CO2 has contributed about 70% of greenhouse effect to date [2].

The current concern about climate change and resource depletion issues is increasing around the world. Malaysia is considered as one of the highest CO2 producers in the world [10] and is ranked in the category of “in trouble” in terms of the ability to control CO2 in the climate change performance index (CCPI) [3]. According to the United Nations Development Programme (UNDP) report, Malaysia is ranked 26th in the list of countries that have the largest amount of carbon emission in the
world [4]. Additionally, over the period from 1990 to 2004, Malaysia’s emission growth was estimated at 221% which is considered the highest in the world [5]. However, Malaysia is playing an active role in reducing CO₂ emissions through national mitigation and intergovernmental mechanisms and promised to cut about 40% of the carbon emission by the year of 2020. The announcement was a response where it was projected that without any mitigation measures being taken by the country around 285.73 million tonnes of CO₂ will be released in 2020[14].

The construction sector has a significant negative impact on the environment and buildings are responsible for producing a large portion of CO₂ emissions arises from high energy consumption, where buildings have long life expectancy and require continuous consumption of natural resources for decades after construction [6-8]. The sector accounted for one-third of all energy use and similar proportion of GHGs emission [9-10]. In Malaysia, commercial buildings account for fifth of total domestic energy consumption [11]. Climate change mitigation from buildings construction or improvement in the building construction process will lead to sustainability benefits. The most effective decisions related to the sustainable design of a building are those that are made in the pre-construction and/or construction stages. In fact, decisions made after these stages lead to the inefficient and expensive process of retroactively modifying the design of the building to achieve a set of performance criteria [12]. In achieving green or sustainable building status, numerous rating systems have been created in the world to evaluate the buildings.

Environmental management system (EMS) is widely implemented with guided ISO series by many organizations due to its substantial advantages which enable constructions firms to improve its environmental performance and legislation, reputations and implement sustainability [13]. However, little attention is paid to the environmental impact of materials as finish product; this is one of the reasons that Life cycle analysis (LCA) of ISO 14040 is not implemented within the industries in Malaysia [14]. The ISO 14040 standards provide guidelines on the principles and conduct of LCA studies that provide an organization with information on how to reduce the overall environmental impact of its products and services. In order to realistically assess the performance of a building life cycle, accessibility to a comprehensive set of knowledge for a building’s form, materials, context, and technical systems is required. Therefore, the objective of the study are; first, to quantify and determine the total amount of annual lifecycle performance of the building in term of embodied, operational carbon emission and energy consumption.

2. Methodology
In this study, the need for adopting case studies as one of this research strategies arises out of the desire to determine the total amount of embodied operational carbon emission from buildings. Furthermore, the system boundary was specified to construction and operation stages, which includes the manufacturing and transportation of building materials to the construction site, construction equipment and energy consumptions during building operation. Therefore, in order to successfully complete the model, inventory data that are relevant to the most important building materials were included. Inventory analysis is the second stage of LCA where the carbon emission from quantified materials was calculated. It includes the calculation procedures (total mass, transportation emissions and calculations of materials emissions) for embodied carbon emission from basic materials as well as complex materials.

The amount of carbon emission for each material was extracted from the bill of quantities, which is a document used in tendering in the construction industry in which materials, parts and labors (including costs) are itemized. For embodied carbon emission, the calculation was achieved through the utilization of Inventory of Carbon & Energy (ICE V2.0) which is the latest carbon inventory database for carbon conversion rates. Then, the conversions to tonnes are the density value, where it can relate the volume and weight of each material.

It is strongly suggested to include embodied carbon emission from transportation in LCA. Therefore, the distance between the suppliers of building materials and the location of case study was estimated and most of building materials sources were located around 20km to 250km radius, therefore
the calculation of embodied carbon emission from transportation of building materials is varying from one material to another.

In order to quantify the annual operational energy consumption it was compulsory to provide the necessary drawing plans and materials specifications of the case study building. Some basic and necessary assumptions for energy modeling were established such as energy model inputs for materials and internal gains. Using of 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 the used materials in construction, the annual operational energy from baseline building calculated. Then, alternative changes (sustainable solutions) which were applied in the case study were identified and stablished to evaluate their effects on annual operational energy consumption. Since, HVAC system specifically air conditioning in buildings consume massive amount of energy, the total operational energy consumption of baseline building was calculated based on the dynamic energy model simulation and manual calculations. Alternative changes on cooling system and design of case study building were considered and examined to evaluate the effects on reducing the building’s annual operational energy use.

3. Results and Discussion
The description of substructure, superstructure and finishes of buildings envelope including structural elements such as (foundations, columns, beams, slabs and staircase) and materials used for these elements are concrete and steel reinforcement, non-structural elements (walls, plastering, painting) and its components such as brick/block masonry, mortar and paint. The flooring system consisted of cement screed, various types of tiles, vinyl and carpets, while other building elements such as metal and non-metal works, doors and windows which consist of aluminum, mild steel, wood and glass were included in calculation of embodied carbon emission. From the results obtained in Figure 1, the carbon emission was classified into seven major construction elements. The result shows that the concrete contributed to the highest level of carbon emission with the amount of 2.68 million kgCO\textsubscript{2} which represents 30.69%, followed by steel (1.77 million kgCO\textsubscript{2}) with 20.43%, mortar (1.52 million kgCO\textsubscript{2}) with 17.61%.

Figure 1. Contribution of building components.

Internal and external finishes were further elaborated individually by materials for detailed analysis and discussions. These finishes including the following:

- Internal and external floor finishes; Comprising of the following materials; cement and sand screeds, various types of tiles, marble and granite slabs, paints, and, vinyl and carpet tiles.
- Internal and external wall finishes (paints, plaster and cement skim coat, tiles, aluminum panels and glass panels).
Internal and external ceiling finishes; ceiling boards/tiles (plaster boards, gypsum boards, mineral fiber boards, cement boards), paints and skim coats.

It can be seen that in Figure 2, the highest quantity of carbon emission was observed from homogenous and ceramic tiles which have embodied emission of 47.36% adding of porcelain tiles (2.72%) would have a total of 50.08%. In addition, aluminum works such as in cladding, ceilings have 28.34% and Granite slabs have a great contribution of carbon emission and represents 18.93%. While paint works contributed for about 2.34%. The lowest carbon emission was observed from gypsum and calcium silicate boards which are 3.41%.

![Figure 2. Embodied carbon emission of building finishes.](image)

Figure 2, shows the embodied carbon emission from materials transportation. As can be seen that the transportation of brickworks has the highest carbon emission equivalents (14,461.25kgCO₂e) among others, followed by concrete (13,031.31kgCO₂e), steel (9,483.21kgCO₂e), framework (6,795.98kgCO₂e), mortar (5,324.25kgCO₂e) building finishes (3,119.87kgCO₂e), glass (634.95kgCO₂e) and timber (73.24kgCO₂e) respectively. It was observed that the contribution of transportation to the total carbon emission is less than 2% of overall emissions.

![Figure 3. Carbon emission from materials transportation.](image)

The building elements were further analyzed in order to understand the nature of its carbon emission and associated building’s GFA. As shown in Figure 4, it was observed that concrete has the highest carbon emission per square meter among other elements with (110.24kgCO₂e/m²), while steel...
ranked the second for carbon emission per square meter, which have (72.75 kg CO$_2$/m$^2$), mortar has carbon emission per meter square of (62.71 kg CO$_2$/m$^2$). While brick and block works have embodied emission of (47.91 kg CO$_2$/m$^2$), finishes have (46.19 kg CO$_2$/m$^2$), timber (9.50 kg CO$_2$/m$^2$) and glass (6.82 kg CO$_2$/m$^2$) were the lowest in carbon emission per square meter.

![Figure 4](image)

**Figure 4.** Contribution of carbon emission per (GFA) m$^2$.

### 3.1 Operational Emission & Energy Consumption

Table 1 and Table 2 show various essential input data that were considered for calculating the operational energy consumption. All specifications of building components were simulated and calculated to determine the total amount of operational energy consumption. The energy consumption was determined based on the baseline design, including materials specifications and services of the building.

| Room Conditions | Cooling | Set point | 24 °C |
|-----------------|---------|-----------|-------|
| Humidity Control | Min. % Saturation | 55% | |
| | Max. % Saturation | 65% | |
| | Min. Flow Rate | 0.00 l/(s·m$^2$) | |
| System outside air supply | Add. Free Cooling Capacity | 0.00 AC/h | |
| | Variation Profile | off continuously | |

| Energy Modeling Inputs (Internal Gains). |
|-----------------------------------------|
| **Room Conditions** | **Fluorescent Lighting** | **Internal Gains** |
| | | |
| **Cooling** | **Set point** | **24 °C** |
| Humidity Control | Min. % Saturation | 55% |
| | Max. % Saturation | 65% |
| | Min. Flow Rate | 0.00 l/(s·m$^2$) |
| System outside air supply | Add. Free Cooling Capacity | 0.00 AC/h |
| | Variation Profile | off continuously |
| | **Max Sensible Gain** | 5.00 W/m$^2$ |
| | **Max Power Consumption** | 5.00 W/m$^2$ |
| | **Radiant Fraction** | 0.45 |
| **Fuel** | **Electricity** | |
| People | Max Sensible Gain | 73.27 W/P |
| | Max Latent Gain | 58.61 W/P |
| | Occupant Density | 5.00 m$^2$/person |
| Machinery | Max Sensible Gain | 11.00 W/m$^2$ |
| | Max Latent Gain | 0.00 W/m$^2$ |
| | **Max Power Consumption** | 11.00 W/m$^2$ |
| | **Radiant Fraction** | 0.22 |
| | **Fuel** | **Electricity** |
### Table 2. Energy Modeling Inputs (Materials).

| Category | Material       | Conductivity (W/(m.k)) | Density (kg/m³) | U-Value (W/m²K) | Total R-Value (m²K/W) |
|----------|----------------|------------------------|-----------------|-----------------|---------------------|
| Wall     | Brickwork      | 0.7700                 | 1700.0          | 2.6107          | 0.2130              |
|          | Plaster        | 0.5700                 | 1300.0          |                 |                     |
| Windows  | 6mm Glazing    | 2.8600                 | -               | 5.7638          | 0.1735              |
|          | Screed         | 1.1500                 | 1800.0          |                 |                     |
| Roof     | Insulation     | 0.0290                 | 1400.0          | 0.4939          | 1.8546              |
|          | Material       |                        |                 |                 |                     |
|          | Cast Concrete  | 2.3000                 | 1000.0          |                 |                     |

Centralized chiller plant was used as the cooling system for the building with room temperature set-point at 24°C (Baseline Building). Additional sustainable solutions were installed in the existing building which assumed to have less amount of energy consumption as compared to baseline building. Calculation was conducted to determine the amount of cooling energy required to keep the temperature of the building at 24°C.

Annual amount of energy consumption from the baseline building during its operation stage is shown in Figure 5. In this calculation the operation of building assumed to be the typical operation hours in Malaysia (8AM-5PM). The final result shows that the total amount of energy consumption is 4,344kWh. Expectedly chiller plan was the main contributor in term of energy consumption.
Figure 5. Annual energy consumption in operating hours.

The case study building was designed in such way to have less amount of energy consumption as compare to baseline building. Subsequently CO2e emission would be reduced, which leads to environmental friendly practice. In order to achieve these reductions necessary modifications were implemented in the building during its design stage. The following sections show the results of design modification:

1) HVAC Modifications
One of the sustainable solutions that were implemented in the case study building was heat recovery wheel. As the airstreams pass through the energy recovery wheel, the rotation of the wheel facilitates the transfer of energy from the higher energy airstream to the lower energy airstream. This means that the exhaust air precools the supply air. Also the systems use energy recovery wheels to reheat supply air after it was cooled down which is an effective means of humidity control.

Considering the case study building is located in Malaysia which has tropical climate with high temperatures and high humidity throughout the year, the system is the best solution in order to reduce the energy consumption by dependency on chiller. The total amount of energy transferred by the wheel is a function of the effectiveness of the wheel, the airflow volumes of the airstreams and the difference in energy levels between the airstreams. Therefore, heat recovery wheel was installed in every floor to reduce the total energy consumption as compared to the baseline building.

2) Overall Modifications
Once all modification related to HVAC and other elements, annual energy consumption of the building base on 24 hour operation were calculated. Figure 6 shows the annual energy consumption from different elements of the building. Based on the results, the total energy consumption for the baseline building is estimated to be 7,777 kWh, which this amount was reduced to 5,536 kWh after implementation of modification as shown in Figure 7. After careful analysis and comparison between the final results of energy consumption in baseline building and existing building, it is clear that implemented modification had significant ramification on reduction of energy use. The estimated total energy saving compare to the baseline is approximately 31.31 Percentage.
In addition, the carbon emission was calculated in accordance with the total energy consumption of the building and with the aid of carbon inventory for conversion of energy use to CO$_2$-e emission. It was found that the total CO$_2$-e emission from the baseline building was 5,253.52kgCO$_2$-e and the emission was successfully reduced to 3,739.68kgCO$_2$-e from the existing building. In total about 1,513.84kgCO$_2$-e were saved by effectuating the proposed changes as shown in Figure 8.

According to results, chiller plant was identified as the main source of energy consumption. Since, the annual estimation of energy consumption was based on 24 hour operation, Figure 8 present the peak hour of chiller plant operation for both baseline and existing building. In consideration of case study building type (research development), specific rooms are under operation on daily basis for 24 hour. After all, the maximum usage of chiller plant fall under the working hour schedule (8AM-5PM).

Figure 7. Comparison of Energy consumption and carbon emission.
4. Conclusion

The building sector is responsible for a significant energy demand globally which results in GHGs emissions along with the depletion of energy resources. Therefore it is critical that energy demand within the built environment is addressed to avoid further degradation of the natural environment. In Malaysia, the government has set a voluntary target to reduce 40% carbon emission intensity by 2020. This achieving might be distorted, unless the economy substantially shifts to the use of low carbon technology to produce the goods and services and inforce and introduce sustainable solutions. This study intended to determine the total carbon emission and energy consumption of non-residential building. Based on the simulation and calculations, it was found that the annual amount of operational energy consumption from baseline building was ascertained to be 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 by 31.31%. Thus, they could have a significant, beneficial role in reducing the building’s operational energy requirements. It was apparent that the annual amount of the building’s energy could be reduced up to 5,532 kW h by replacing the baseline design with alternative sustainable solutions such as façade, lighting system and heat recovery wheel. Building simulation and investigating the performance of the building virtually in the pre-construction and/or even during the construction stage will help decision makers, designers, engineers, and architects to select specifications with the least detrimental impact to the environment.

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