BIM-BASED ENERGY ANALYSIS OF CONVENTIONAL RESIDENTIAL BUILDINGS IN HOT-HUMID CLIMATE

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Abstract— As the campaign to raise international awareness towards saving the environment is growing, the need for studies to assess the building performances in terms of energy efficiency for Malaysia as a developing country is perceived more than ever. In line with the growing global trend toward energy efficiency in buildings, this paper makes attempt to estimate and analyse the performance of conventional buildings in terms of the associated dominant load; cooling load for the context of Malaysia through innovative workflow of Building Information Modelling (BIM). A double storey bungalow located in Kuala Lumpur was modelled in Revit Architecture and exported to Autodesk Ecotect Analysis, which both of them are the epitome of BIM tools, for energy analysis. The properties of the components including walls, roofs and windows were input into Ecotect and the simulations were run by varying the orientation and monthly climatic data. Total numbers of 48 simulations were conducted to calculate the monthly cooling load of the building for four orientations and 12 months. It was observed that throughout of the year, cooling loads are constantly required to maintain the comfort band however north orientation seems somewhat energy efficient rather than the others. The present study took a step towards more energy efficient buildings by providing succinct information regarding the performance of buildings in hot-humid climate and aimed at examining BIM-based building energy simulation.

Keywords— BIM,Cooling Load, Energy Efficient Buildings,Hot-humid Climate, Malaysia.

I. INTRODUCTION

Industrial sectors, including the building sector, started to recognize the impact of their activities on the environment in the 1990s. Significant changes were needed to mitigate the environmental impacts of building sector. The building sector had to focus on how buildings were designed, built and operated (Haapio&Viitaniemi, 2008). Green building has now become a flagship of sustainable development in Malaysia that takes the responsibility for balancing long-term economic, environmental and social health (Mohamad Kamar, Abd Hamid, Ghani, Egbu, &Arif, 2011). The Malaysian Green Building Index (GBI) has been developed recently by Association of Consulting Engineers Malaysia (ACEM) and PertubuhanArkitek Malaysia (PAM) and it offers an opportunity to create environmentally efficient buildings by using an integrated approach of design so that the negative impacts of building on the environment and occupants are reduced. The concept of sustainable development can be traced to the energy (especially fossil oil) crisis and the environment pollution concern in the 1970s (Xiaoping, Huimin, &Qiming, 2009).

Energy consumption is the main cause for greenhouse gas emissions worldwide. It is estimated that the construction sector accounts for about 30% of these emissions (Hejwowski&Weroński, 2002). The International Energy Agency predicts that the global energy demand will increase by more than 50% by 2030 if policies remain unchanged and more than 60% of this increase belongs to the developing countries. This will lead to a 52% increase in emissions of carbon dioxide (CO2), the main greenhouse gas (Nelson, Rakau, &Dörrenberg, 2010). With the growth in innovative construction methods, it has become imperative that design tools and novel estimation methods, to be provided, can give insights into the sustainability of a building at the design and construction stages, and help the project team to incorporate the notion of constructability with green building principles. Hence, this paper aims at estimating and analysing the energy consumption of conventional residential buildings in the hot and humid climate of Malaysia through Building Information Modelling (BIM).

II. LITERATURE REVIEW

Buildings have an enormous and continuously increasing impact on the environment, using about 40% of natural resources extracted in industrialized countries, consuming nearly 70% of electricity and 12% of potable water, and producing between 45 and 65% of the waste disposed in landfills (BanihashemiNamini, Ding, & Wang, 2015). Moreover, they are responsible for a large amount of harmful emissions, accounting for 30% of greenhouse gases, due to their operation, and an additional 18% caused indirectly by material exploitation and transportation (Yudelson, 2010). At the same time, the bad quality of indoor environments may cause health problems to employees in office buildings, thus, decreasing productivity.

In order to mitigate the impact of buildings along their life cycle, Green Building (GB) has emerged as a new building philosophy, encouraging the use of more environmentally friendly materials, the implementation of techniques to save resources and reduce waste consumption, and improvement of indoor environmental quality, among others (Yudelson, 2010). This would result in environmental, financial, economic, and social benefits.In line with the growing global trend in applying sustainability, Malaysia introduced its national sustainability assessment tool in 2010. Green Building Index (GBI) is Malaysia's industry recognized green rating tool for buildings to promote sustainability in the built environment. It is specifically developed for tropical climate, environmental and developmental context (Chua & Oh, 2011). The major objectives of GBI include Energy Efficiency, Indoor Environmental Quality, Sustainable Site Planning & Management, Material and Resources, Water Efficiency and Innovation in which energy efficiency along with material and resources comprise 32% of total marks in residential buildings in scale of 100. Moreover, commercial and residential buildings use about 13% of total energy consumption and 48% of electricity consumption (Chua & Oh, 2011). This shows the significance of energy usage of the conventional building construction and use of faster ways to enhance the efficiency in the building envelope.

At the building level, when the envelope parameters are designed with the purpose of calculating the energy performance, the size and capacity of mechanical equipment can be reduced and, consequently, the electrical power distribution system may also be reduced. However, the accurate estimation of the building envelope will not necessarily lead to an exemplary high energy performance due to the fact that the energy consumption is strongly influenced by the building's system and components. The quest for analysing energy performance requires a coherent application of parameters which together deliver the performance of the whole building's systems. It is therefore necessary to apply an integrated approach to the process of building design and evaluating performances (Radhi, 2008). In general, the factors influencing the total building energy performance can be divided into seven categories:

- Climate (e.g., outdoor air temperature, solar radiation, wind velocity, etc.),
- Building-related characteristics (e.g., type, area, orientation, etc.)
- User-related characteristics, except for social and economic factors (e.g., user presence, etc.),
- Building services systems and operation (e.g., space cooling/ heating, hot water supplying, etc.),
- Building occupants' behaviour and activities,
- Social and economic factors (e.g., degree of education, energy cost, etc.), and
- Indoor environmental quality required (Z. Yu, B. C. Fung, F. Haghighat, H. Yoshino, & E. Morofsky, 2011).

In this paper, monthly cooling loads are used as the basis of comparison. It should be noted that these are cooling loads, not energy loads. These loads determine how much cooling is required to maintain spaces in a building within the thermal comfort band. However, energy consumption depends on the efficiency of the devices used for cooling or heating those spaces and apparently, for the same load, different devices with different efficiencies result in different energy consumptions. Therefore, using cooling load as the basis of comparison shows a more realistic view in terms of the impacts on buildings. Additionally, some works studied the performance of buildings by using a simple box representing a room or a house. However, the complex interconnections of the zones within a building (e.g. adjacency to warmer or cooler zones such as kitchen or staircase) and the impacts of inter-zonal gains and losses on total loads cannot be studied by using a simple box (Banihashemi, Golizadeh, Reza Hosseini, &Shakouri). Consequently, the role that the different components play in augmenting or reducing loads due to those inter-zonal losses or gains are ignored and this leads to unrealistic energy performance results.As the campaign to raise international awareness towards saving the environment is growing, the need for studies to assess the building performances in terms of energy efficiency for Malaysia as a developing country is perceived more than ever. In line with the growing global trend toward energy efficiency in buildings, this paper makes attempt to estimate and analyse the performance of conventional buildings in terms of the associated dominant load; cooling load for the context of Malaysia.

III. RESEARCH METHODOLOGY

Performing a full scale simulation including climatic data, building type and properties, if applicable, could greatly provide accurate results (provided the simulation model is correct) but it also requires a lot of input data, which are not generally available, and experienced users. This paper uses the full scale method for estimating the performance of buildings in the context of Malaysia and in order to overcome the relevant drawbacks, it incorporates reasonable scopes to obviate the users from too many runs of simulations and limit the number of input data to those which can be accessed easily by the users. This model is based on the assumption that different components have direct impacts on the cooling loads of buildings, which consequently affects the energy loss and consumption. To limit the scope of this

study, the following criteria were taken into consideration:

- The simulated case should represent a typical residential building type; a conventional bungalow with common materials used in its envelope in Malaysia.
- The cooling load is just considered as it is the dominant load for the climatic conditions of country.

The case study (Fig. 1) is a double storey bungalow located in Kuala Lumpur. It was modelled in Revit Architecture and exported to Autodesk Ecotect Analysis, which both of them are the epitome of BIM tools, for energy analysis. A conventional 25cm brick wall with a layer of cement mortar and granite stone on the exterior surface and a layer of plaster on the interior side of the wall was used as a benchmark. The outer surface of the roof is covered by 10cm layer of asphalt which is a common material for covering the roof. Then, Monthly space cooling loads were calculated for each alternative. Table I shows the list of components used and their specifications. It is hypothesized that material used in the external shell has a direct impact on monthly load of the building. Among various factors influencing residential building energy consumption, occupant behaviour plays an essential role and is difficult to investigate analytically due to its complicated characteristics (Z. Yu, B. C. M. Fung, F. Haghighat, H. Yoshino, & E. Morofsky, 2011). Management of hours of operation of HVAC is a crucial key in saving energy. The zones must be cooled only when they are occupied. Hence, to simplify the simulation, it was taken for granted that the cooling system in the building becomes active when the inside temperature goes higher than the predefined comfort band. Additionally, it was assumed that residents use mechanical cooling systems for bed rooms and living room and natural ventilation for the rest of the zones. Also, people use the bedrooms only for resting and spend other times in the living room. For energy simulation, each room in the building was defined as a zone which each zone had its own thermal properties. The thermostat was set between 18-26 oC to provide thermal comfort for the occupants. Table 2 indicates the user profile of the zones in the building.

Ecotect provides a range of thermal performance analysis options. At its core is the Chartered Institute of Building Services Engineers (CIBSE) Admittance Method used to determine internal temperatures and heat loads. This thermal algorithm is very flexible and has no restrictions on building geometry or the number of thermal zones that can be simultaneously analysed (Handbook, 2001). In order to determine the performance of buildings accurately, considering a plethora of variables such as building types and their orientations, climatic data of the location in which the buildings are used, users' profiles such as operation schedules and types of their activities are essential (ASHRAE Handbook—Fundamentals, 2009). Therefore in this work, five year weather data (2005-2010) of Kuala Lumpur which include monthly average dry bulb temperature, monthly average percent humidity, monthly average wind speed, monthly average direct solar radiation and monthly average diffuse solar radiation were obtained from Malaysian Metrological Organization. Table 3 shows monthly mean values of climatic data for the selected cities. As for the physical properties of buildings, variables like U-factor of external walls, roof and windows along with building orientation and climatic data constituted the parameters considered to be used in the calculation of cooling loads in the residential building model. In order to measure the cooling loads, the properties of the components such as walls, roofs and windows were input into Ecotect and the simulations were run by varying the orientation and monthly climatic data. In the end, total numbers of 48 simulations were conducted to calculate the monthly cooling load of the building for four orientations and 12 months.

Table 1: The Physical Properties of Building's Envelope

Components	Layer Name	Width (mm)	Density (Kg/m^3)	Specific Heat (J/Kg.K)	Conductivity (W/m.K)	U Value ($W/m^2.K$)
Wall	Granite	10	2880	840	3.49	1.88
	Cement Mortar	10	1650	920	0.72	
	Brick	220	2000	836.8	0.71	
	Plaster	10	1250	1088	0.43	
Roof	Asphalt	10	2300	1700	1.2	2.56
	Screed	25	950	656.9	0.209	
	Concrete Slab	150	2300	656.9	0.753	
	Air-gap	600	1.3	1004	5.56	
	Gypsum	12	2320	1088	1.29	
Windows	Double Glazed Aluminum Frame	30	0.38	0.4	0.107	2.214

Table 2: The Building Occupancy Profile

Zone	Area (m^2)	Volume (m^3)	Occupancy	Activity	HVAC System	Comfort Band
Living Room	18	51.09	4	Sedentary	Mixed-Mode System	18-26 °C
Kitchen	6	17.78	4	Cooking	Natural Ventilation	NA
Bathroom	5	13.11	1	Sedentary	None	NA
Toilet	3	9.83	1	Sedentary	None	NA
Bedroom	10	28.16	2	Sedentary	Mixed-Mode System	18-26 °C

Table 3: The Climatic Data

Month	Dry bulb Temperature	% humidity	Wind Speed m/s	Direct Solar Radiation Wh/m²	Diffuse Solar Radiation Wh/m²
Jan	26	60	1.3	1216	1120
Feb	27	60	2.6	2353	1465
Mar	27	58	2.8	1817	2259
Apr	27	63	2.7	2096	2959
May	27	66	2.1	2961	3350
Jun	27	63	2.4	4615	3167
Jul	27	63	3.4	5828	2844
Aug	27	62	3.4	5888	2276
Sep	26	64	2.4	4983	1993
Oct	26	65	2.1	2386	1806
Nov	26	66	2.5	1422	1242
Dec	26	61	1.7	564	998

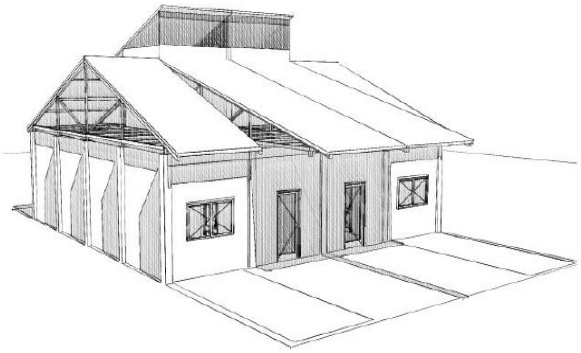


Fig.1. The Modelled Case in BIM

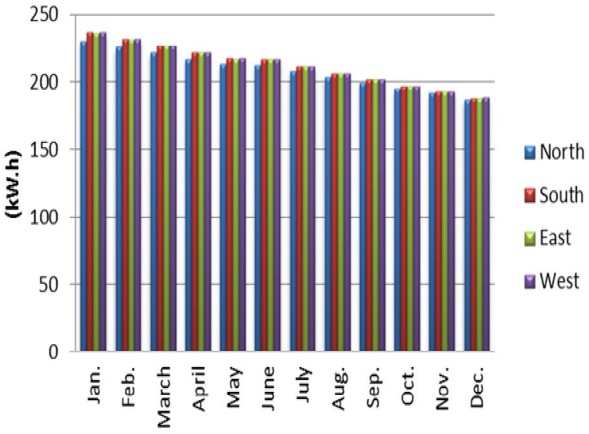


Fig.2. Monthly Cooling Load Depicted for Four Orientations

IV. ANALYSIS AND DISCUSSION

Kuala Lumpur is the capital city of Malaysia with hot-humid climate. As a holistic view on Figure 2, it is indicated that the plotted graph experiences a gradual decrease from January to December. This decrease amounts to 50 units and is almost with the same acceleration for the whole orientations; North, East, South and West in spite of a sudden drop between the first and second 6 months period. The positive values of cooling loads testify that throughout of a year, there is a requirement for cooling loads up to certain degrees. The relatively high solar radiation and ambient temperature give rise to a high sol-air temperature. The high sol-air temperature will then increase the temperature difference between external state and internal state. This drives more heat to flow into the building space and as a result, higher air condition cooling power is required.

Cooling load is the rate at which energy is removed at the cooling coil that serves one or more conditioned spaces in any central air conditioning system (Handbook, 2001). The total building cooling load consists of sensible and latent loads; the former includes the heat transferred through the building envelope such as walls, roof, floor, windows, doors etc and the latter encompasses the heat generated by occupants, equipment, and lights. The sensible load affects the dry bulb temperature, while the latent load affects the moisture content of the conditioned space. Malaysia is a tropical country, hence, ambient temperature doesn't fluctuate wildly, but since the building is more exposed to solar radiation, sensible loads play a major role in heating the internal zones. As a result, to minimize the flow of heat into an air conditioned building, proper measures such as enough insulation for the walls should be provided. Higher thermal conductivity of an insulation material means lower thermal resistance; therefore in order to get an optimum thermal insulation, thicker thickness is required to be used. One of the interesting analogies drawn from the Figure2 lies in the behaviour of the building in North orientation against the rest. It can be seen that the cooling loads estimated in North orientation have around 10 per cent gap with that of other orientations however, as the time goes by, this gap becomes closer and in December, it completely sealed.

CONCLUSION

An energy efficient building design entails considering a plethora of factors. In this competitive market, being able to perform a precise analysis and accurate estimation is considered as an advantage. With respect to project appraisal and the impact of sustainable criteria such as occupant comfort and cooling loads of the building on the design, BIM can aid the design team to collect the vital information from the model to analyse and select the most beneficial alternative in the early stages of the design. In this research, an efficient workflow of BIM based sustainability analysis including Revit and Ecotect software was applied to model a bungalow representing a conventional residential building in hot-humid climate of Malaysia and simulate its energy performance based on the variables such as thermal conductivity of walls, roof and windows, climatic conditions and orientation. It was observed that throughout of the year, cooling loads are constantly required to maintain the comfort band however north orientation seems somewhat energy efficient rather than the others.

Each research faces some challenges and limitations in its development process and this study is not an exception of this rule. Generally, in doing an energy simulation based study, researchers when are to investigate the effects of a specific component on the energy consumption of a building, keep other parameters fixed and just focus on the relationship between the variable and its target. Therefore, this paper did not consider the effects of other variables such as ventilation and infiltration as well as shading while the interaction of these components may affect the results of this study. The present study took a step towards more energy efficient buildings by providing succinct information regarding the performance of buildings and aimed at examining BIM based

building energy simulation. It is recommended to further research in analysing more components and variables and assessing the possible impacts of any inconsistency in the final energy outputs.

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