THE IMPACT OF BUILDING ORIENTATION ON ENERGY USE: A CASE STUDY IN BUNG HATTA UNIVERSITY, INDONESIA

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Abstract

Many studies show that buildings are responsible for more than 40% of world carbon emissions. In warm and humid climates such as West Sumatra, CO_2 emissions predominantly come from the use of energy to provide cooling, lighting, to power appliances and electrical equipment. Nowadays, the number of buildings that use glass and glazing system in their façade tends to increase. As a result, the buildings are prone to solar heat gains if not properly oriented. This study aims to investigate energy use of a building in Padang City, West Sumatra, Indonesia with respect to different orientations by conducting building energy analyses. The outcomes showed that the optimized direction was when the building faces South-South West and the worst orientation was when the building faces East. It was estimated that the electricity use of the building were 64% for HVAC, 18% for lighting and 18% for miscellaneous equipment. The LCCA of the existing building was USD 872,995.29 for 30 year. However, this cost could be reduced by almost 2% if the building was oriented on the South-South West direction. The difference of the LCCA between the best and the worst building orientations, SSW and East, respectively, reached up to 4%.

Keywords: *energy; sustainable; green, orientation; building*

1.0 INTRODUCTION

Modernization across the globe comes with a major consequence: fast development of buildings and infrastructures all over the world. In most practice, the buildings are built with little concern of their impact to environments with many excuses related to speed, economics and efficiency (Adiwoso, Prasetyoadi, & Perdana, 2010). In addition, the rapid growth of population results in an increased of living quarters. As a consequence, a great number of buildings are built particularly in urban areas, which nearly reached 53% in 2014 (United Nation, 2014).

Boake (2009) stated that buildings are responsible for about 40%-70% of world CO2 emissions. The CO2 emissions is responsible to greenhouse effect that has contributed to climate change. The CO2 emissions are closely related to the use of energy in many sectors including transportation, industry, commercial and households.

In Indonesia, it is reported that the household sector contributed to more than 33% of the nationwide final energy consumption from 2000 to 2013 (PUSDATIN ESDM, 2014) and it is expected that this number will grow continually in the future (Surahman, Kubota, & Higashi, 2015). The energy consumption in Indonesia has increased by 7% per year (Ministry of Energy and Mineral Resources of Indonesia (MEMR), 2010). The increased is quite significant compared with the average world's energy consumption of 2.6% per year (Setiawan *et al.*, 2015).

In hot and humid climate like Indonesia, the CO2 emissions predominantly come from the use of energy to provide cooling, lighting as well as to power appliances and electrical equipment. According to the Indonesian Ministry of Energy and Mineral resources, energy conservation potential for household and commercial buildings ranges from 10%-30% per annum. Therefore, energy-saving strategies have to be implemented for more sustainable buildings.

According to USGBC (2016), a sustainable or green building is a holistic concept to make a positive impact on natural environment toward the entire life cycle of buildings. Building energy consumption depends on many factors including the number of occupants, building orientation, the number of appliances used, air conditioner performance, window/opening materials, shading as well as the materials of roof and walls (Setiawan *et al*., 2015). Setiawan *et al.* (2015) performed a study on energy consumption of residential houses in Indonesia. The study focused on the effect of building envelope design such as roof construction, glazing and sun-shading system on building energy consumption. The results showed that the most significant impacts were contributed by window shading, glazing and roof type, respectively.

Nowadays, the number of buildings that use glass and glazing system in their façade tends to increase significantly. As a result, the buildings are prone to solar heat gains if not properly oriented, particularly in hot and humid climate like Indonesia. As a consequence, the buildings require more energy to provide active cooling. Therefore, this study aims to provide an insight regarding the importance of building orientations to provide passive thermal and visual comfort for the buildings as an effort to reduce building energy consumption. The optimized orientation of a building at a case study along with their energy performance and financial consequences are also presented in this article. The wind ventilations as a means of passive cooling are also investigated.

2.0 METHODOLOGY

The methodology used in this study is described in the following section:

2.1 Analytical Tools

To achieve the aim of this study, building energy analyses were performed. Autodesk Revit conceptual building performance analysis tools were used in this study. Revit's Building Energy Analysis is a cloud-based energy simulation service powered by Green Building Studio. The software allows the simulations of building performance for energy optimization in the building design process incorporating building elements and thermal properties (Autodesk, 2008). In addition, the software also accounts for energy cost projections as well as life cycle analysis, thus, it is suitable for this study.

2.2 Building Data

The case study building is located in Padang City, West Sumatra, Indonesia, at latitude -0.88º S and longitude 100.38º E. The building is facing azimuth 145º as illustrated in Figure 1.

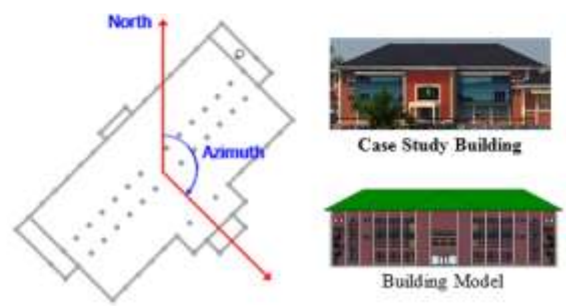

Figure 1: Simulation target: Bung Hatta University Building, Padang, West Sumatra, Indonesia

The building is a typical 3 story reinforced concrete structure commonly found in Indonesia. The total area of the building is 2,429 m^2, which is functioned as lecture theatres, meeting rooms, and lecturer's working spaces on the first floor; general office on the 2nd floor; and lecture theatres on the 3rd floor. The exterior façade are mostly red brick walls. However, curtain walls are also used at certain locations of the building façade. The interior walls are mostly partitioned with wood frame panels covered with calcium silicate board. The roof material is metal with the ceiling constructed from calcium silicate. Single glazing windows are used with the exterior window ratio of 0.48 assumed in the analysis. The building is only accessible during weekdays from 7 am to 6 pm with the assumed number of occupancy of about 250 people. Lectures theatres, meeting rooms, general office as well as lecturer's working spaces are equipped with split air conditioners with the capacity varied according to the size of the room.

2.3 Energy Simulations of Building

In this study, the energy simulations are performed to estimate the annual energy cost, lifecycle energy cost for 30 years, annual energy consumption as well as the resulting carbon emission. The simulations were conducted to a building at Bung Hatta University as a case study by applying seventeen different orientations as shown in Table 1. The outcomes then compared to get the optimized orientation in terms of the most efficient energy use and carbon emissions.

Table 1: Energy simulations for different building orientations

No.	Azimuth	Direction	No.	Azimuth	Direction
1	0.00º	N	10	180.00º	S
2	22.50º	NNE	11	202.50º	SSW
3	45.00º	NE	12	225.00º	SW
4	67.50º	ENE	13	247.50º	WSW
5	90.00º	E	14	270.00º	W
6	112.50º	ESE	15	292.50º	WNW
7	135.00º	SE	16	315.00º	NW
8	145.00º	Existing	17	337.50º	NNW
9	157.50º	SSE			

2.4 Building Orientation vs. Energy Use

Morrissey, Moore, and Horne (2011) show that building orientation plays an important role in passive solar design. Morrissey *et al.* (2011) stated that building orientation is a low cost alternative to maximize passive solar benefits, which will result in the reduction of energy use. From a southern hemisphere perspective, building orientation will change building energy behavior such as: (1) optimize daylight availability; (2) enhance heating benefits from solar gain in winter; and (3) for warmer climates, reduce cooling loads in summer from solar gain (Morrissey *et al*., 2011).

For hot humid climate, overheating is the main problem (Ling, Ahmad, & Ossen, 2007). Appropriate building orientation allows solar radiation to be minimized. As a consequence, the buildings require less energy to provide active cooling.

3.0 RESULTS AND DISCUSSION

Based on the outcomes, it is observed that the optimized orientation of the case study building in terms of Energy Use Intensity (EUI) is when the building faces South (S) and South-South-West (SSW) direction as shown in Figure 2. The yearly EUI for the best orientation is 208 KWh/m^2/year. For the existing orientation (azimuth 145º), the EUI is 212 kWh/m^2/year, about 4% higher than that of the optimized orientation. Highest EUI is obtained when the building is oriented on the East direction with an increase of EUI up to 8%.

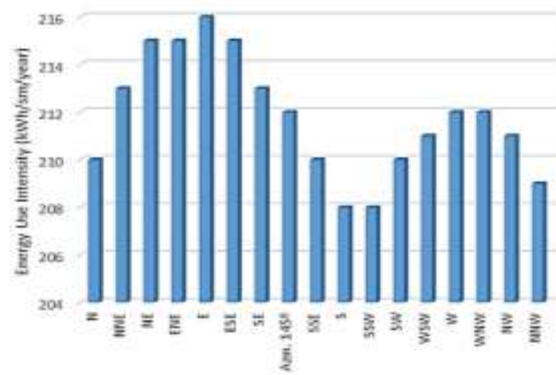

Figure 2: Energy use intensity of the building with different orientations

The energy for hot and humid climate such as found in this study are mostly used for cooling, lighting and miscellaneous equipment. Figure 3 and Figure 4 shows that the major energy use is for heating, ventilation and cooling (HVAC) with the percentage reaching 64%. For lighting and miscellaneous equipment, the energy use is proportional for about 18%. Based on the outcomes, the variation of energy use percentage is mostly contributed by the HVAC with a standard deviation of 0.6. Therefore, it can be concluded that building orientation is mainly affected the HVAC energy, particularly cooling.

Council of Australian Governments (COAG) (2012) released the average energy intensity by building types. For a university building, the projected average energy intensity in Australia in 2009 is 868 MJ/m^2 (equivalent to 241 kWh/m^2). Thus, the EUI obtained in this study appeared to be lower for about 14% than that in Australia. However, this appears to be reasonable considering that heating system is not required in most buildings in Indonesia due to its hot and humid climate.

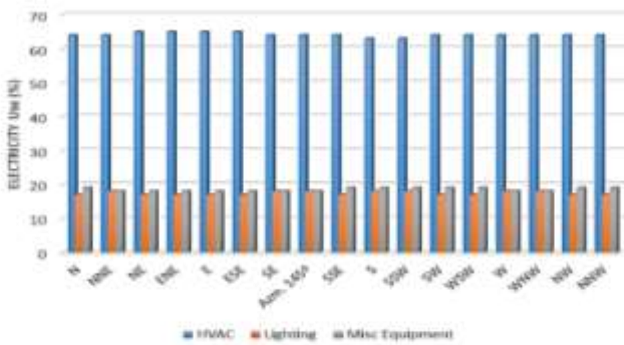

Figure 3: Electricity use intensity of the building with different orientations

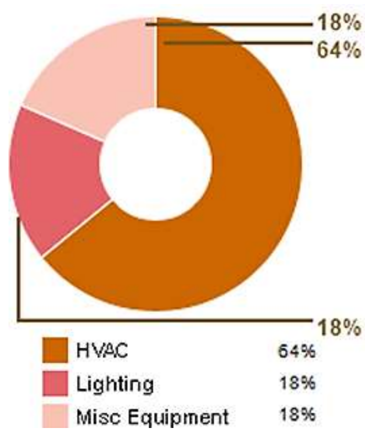

Figure 4: Energy use distribution of the case study building

In addition, renewable energy potential for the existing building is summarized in Table 2. Based on the outcomes, the renewable energy potential of the building is at its greatest if the building faces North with an increase of almost 90%.

Table 2: Renewable energy potential for existing building

No.	PV Type	Energy (kWh/year)
1	Roof Mounted PV System (Low efficiency)	1,448
2	Roof Mounted PV System (Medium efficiency)	2,896
3	Roof Mounted PV System (High efficiency)	4,344
4	Single 15' Wind Turbine Potential	2,969

*PV efficiencies are assumed to be 5%, 10% and 15% for low, medium and high efficiency systems

The estimated annual carbon emission for the existing building is illustrated in Figure 5. The electricity consumption appears to be the greatest contributor of CO_2 emission at the building reaching an estimates number of 93 metric tons/year. If the building utilizes renewable energy such as roof PV and wind turbine, the net carbon rating (net CO2) can be reduced to be 96 metric tons/year.

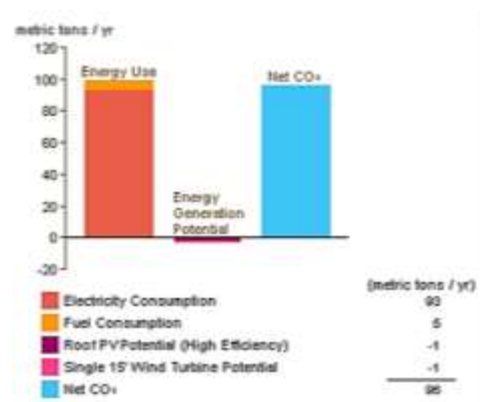

Figure 5: The annual carbon emission of existing building

Table 3 shows the Life Cycle Cost Analysis (LCCA) for all building orientations performed in this study. The LCCA for the existing building orientation is USD 872,995.29. Comparing the LCCA between the best building orientation (azimuth 202.5º or SSW direction) and existing building orientation (azimuth 145º), it can be concluded that the electricity cost could have been saved by USD 15,896 for 30 year period. Furthermore, the difference of LCCA between the best and the worse orientations (azimuth 90º or East direction) reaches USD 32,676 for 30 year period. In other words, a proper orientation of building in this study can save the electricity cost by 4%.

Table 3: Life cycle energy use

No.	Azimuth	Electricity Use Per Year (kWh)	Life Cycle Electricity Use* (kWh)	LCCA (USD)*
1	0.00	241,920.00	7,265,733	866,075.37
2	22.50	245,376.00	7,358,541	877,138.09
3	45.00	247,680.00	7,415,178	883,889.22
4	67.50	247,680.00	7,424,679	885,021.74
5	90.00	248,832.00	7,464,558	889,775.31
6	112.50	247,680.00	7,435,524	886,314.46
7	135.00	245,376.00	7,370,772	878,596.02
8	145.00	244,224.00	7,323,786	872,995.29
9	157.50	241,920.00	7,262,229	865,657.70
10	180.00	239,616.00	7,198,761	858,092.31
11	202.50	239,616.00	7,190,430	857,099.26
12	225.00	241,920.00	7,239,165	862,908.47
13	247.50	243,072.00	7,288,164	868,749.15
14	270.00	244,224.00	7,320,465	872,599.43
15	292.50	244,224.00	7,320,690	872,626.25
16	315.00	243,072.00	7,288,653	868,807.44
17	337.50	240,768.00	7,233,174	862,194.34

*30-year life, with electrical cost USD 0.2 per kWh

One way to reduce active cooling energy in a building is through wind ventilation. The wind ventilation is the easiest and least expensive means of passive cooling, which is commonly found on buildings. An effective wind ventilation really depends on building orientation as well as sizing and placing openings. Therefore, the wind ventilations should be placed on windward and leeward directions to create cross ventilations. Figure 6 and Figure 7 show the speed and frequency distributions of wind rose diagram in the investigated area. Based the diagrams, the inlet and outlet ventilations should be placed on North-West (NW) and South-East (SE) directions, respectively.

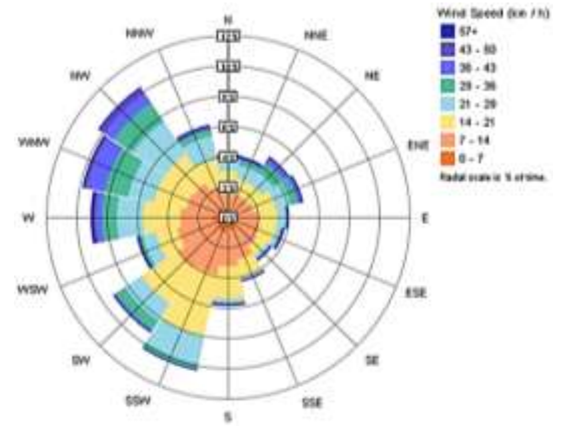

Figure 6: Annual Wind Rose (Speed Distribution)

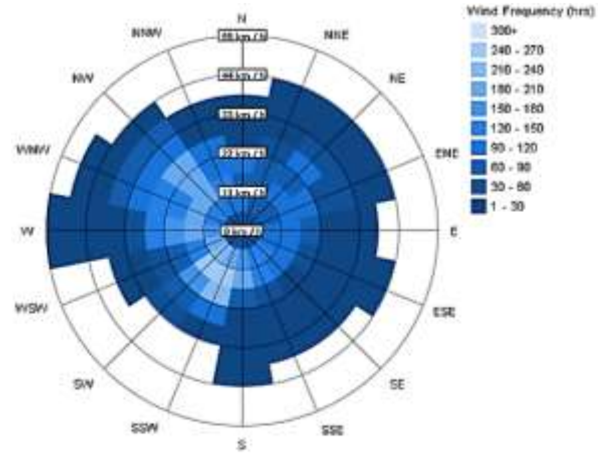

Figure 7: Annual Wind Rose (Frequency Distribution)

4.0 CONCLUSIONS

In hot and humid climate like Indonesia, energy are mostly used to provide cooling, lighting and miscellaneous equipment of buildings. The orientation of building plays an important role to reduce building energy consumption. In this study, it is found that building orientations mainly contribute to reduce active cooling on buildings compared with lighting and miscellaneous equipment. The percentage of energy use for heating, ventilation and cooling (HVAC) is 64% and the energy use for lighting and miscellaneous equipment are equivalent to 18%.

This study found that a good building orientation can save up to 4% of energy (EUI) compared with the EUI of the existing building. However, the difference of EUI between the best and the worse orientations can reach 8%. The Life Cycle Cost Assessment (LCCA) of the existing building is USD 872,995.29. This cost can be reduced by almost 4% if the building is oriented appropriately.

As a passive cooling strategy, wind ventilations should be placed carefully on the buildings. Based on wind rose diagrams obtained in this study, the inlet and outlet ventilations should be placed on North-West (NW) and South-East (SE) directions, respectively.

5.0 LIMITATIONS OF THE STUDY

There are some limitations should be addressed in this study. First, the outcomes needs to be verified with actual operating data to enable predicting actual energy used during occupancy. Second, the fluctuations in occupant behaviour or utility cost do not accounted in this study.

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