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Impact of Climatic Zones of Bangladesh on Office Building Energy Performance

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A B S T R A C T

Energy analysis at the conceptual design stage assists designer to select the most energy efficient design option. Building Information modeling (BIM) has the capability to conduct building energy analysis precisely and efficiently. The principal aim of this research is to determine the energy performance of an office building located in various climatic zones of Bangladesh. A ten story high and circular shape office building conceptual model was developed by incorporating BIM tools Autodesk Revit® 2015.The whole building conceptual energy simulation was performed by Autodesk Green Building Studio (GBS).From the energy simulated results by Autodesk Revit® 2015, it was found that the office building located in Dhaka which is the main city of South central zone of Bangladesh consumed more energy than the others zones. On the contrary, the same office building located in Jessore which is the main city of the South Western region of Bangladesh consumed less energy than that from other zones. Therefore, it can be said that there has an impact of climatic zones of a country on energy efficient building design.

Keywords: Energy efficiency, Climatic zones, Bangladesh, Simulation, Performance

1. Introduction

Globalization, changing of living standard and lifestyle as well as increasing industrialization raise energy demand. Globally, around 40% of the total annual energy consumed by buildings (Barua and Billah). Bangladesh has the lowest per capita primary energy consumption within the Indian subcontinent. In 2011, per capita primary energy consumption in Bangladesh was about 205-kilogram oil equivalent (kgoe) whereas it was 614 kgoe in India, 482 kgoe in Pakistan, 383 kgoe in Nepal, and 499 kgoe in Sri Lanka. The primary energy utilization in Bangladesh was increased to 26.7 Mtoe in 2013 that is almost double from 14.8 Mtoe in 2002 (Halder et al., 2015). Moreover, residential sector in Bangladesh is responsible for around 47% of total energy consumption in Bangladesh (Alam et al., 2014).

Nowadays, building, energy and environment are the fundamental issue for the building industry worldwide because there are possible environmental impacts on ambient air conditions and fresh water supply (Fong and Lee, 2017). It is very much important to consider carefully the energy and environmental performance of building (Alrashed and Asif, 2015). However, building energy demand varies with respect to the outdoor weather conditions of a country. Therefore, selection of appropriate passive concept for building design with respect to the local climatic condition is one of the important factor (Panchabikesan et al., 2017). Energy simulation at the conceptual stage of a building plays an important role to design energy efficient building because energy efficiency is a key factor for a high-quality building.

A climatic zone may be defined as an area for which common outdoor conditions for calculating the energy demand are defined by using a few parameters (Carpio et al., 2015). Building design consultants and energy researchers could get a better idea about the possible impacts on the thermal performance of the office buildings in the different climates from energy analysis and its findings (Eskin and Türkmen, 2008). In order to examined the influences of diverse climate conditions on the thermal and energy performance of office buildings in China (Wu et al.,

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2012),Thailand (Kunchornrat et al., 2009) and Europe (Tsikaloudaki et al., 2011) were conducted through climatic data analysis to improve the thermal performance of buildings. Research have shown that total energy demand can be reduced more than 50% by identifying and implementing sensitive climatic design parameter (Zhao et al., 2015). Moreover, climatic zoning for building energy efficiency applications is an important parameter in many programs and policies (Walsh et al., 2017).

On the above circumstances it is demonstrated clearly that there are many types research has been conducted on the effect of the climatic zone on building energy performance; however, there is no research conducted in the context of Bangladeshi climatic zones. The principal objective of this study is to analyze the effect of Climatic zones on the energy performance of office building including life cycle cost, carbon emissions, and renewable energy potential.

2. Geographical and climatic condition of Bangladesh

Bangladesh, a south-Asian low- income country is located between 20°40′ and 26°38′ north latitude and 88°01′ and 92°41′ east longitude with an area of 147,570 km^2. The country is surrounded by India on the west, north, and northeast while by Myanmar on the south-east and the Bay of Bengal on the south. The density of population in the country has increased dramatically from 704.75 people /km^2 in 1990 to 1074.07 people /km^2 in 2014. The country has 32.1 million households distributed in over 59,229 small administrative zones called mauzas (Halder et al., 2015). Bangladesh has a subtropical monsoon climate characterized by wide seasonal variations in rainfall, high temperatures, and humidity. There are three distinct seasons in Bangladesh: a hot, humid summer from March to June; a cool, rainy monsoon season from June to October; and a cool, dry winter from October to March. In general, maximum summer temperatures range between 30°C and 40°C. April is the warmest month in most parts of the country. January is the coldest month when the average temperature for most of the country is about 10°C (Alam et al., 2014). Bangladesh has been divided into seven climatic sub-regions that have indicated in figure 1 and these *seven climatic sub-regions* are South-Eastern (Chittagong), North-Eastern (Sylhet), Northern part of the north region (Panchagarh), North-western region (Rajshahi), Western dry region (Bogra), South-western region (Jessore) and South-central region (Dhaka).

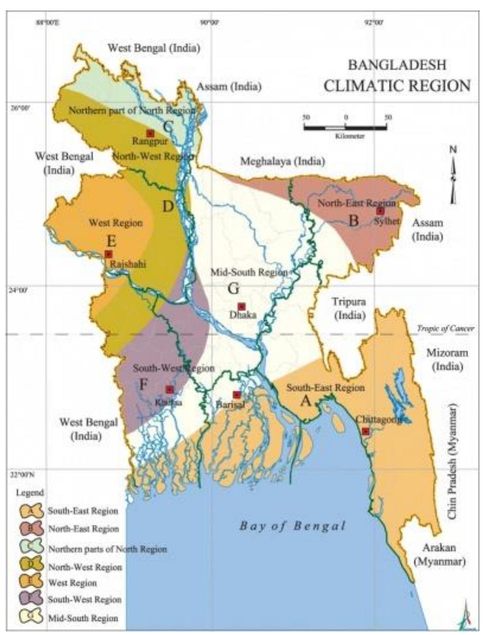

Figure 1. The climatic zones of Bangladesh

3. Building Information Modeling (BIM)

The building information modeling is a digital representation of the physical and functional characteristics of a building project & its life cycle (Wu, 2013). BIM is currently the most common denomination for a new way of approaching the design, construction, and maintenance of buildings (Abanda and Byers, 2016). In order to conduct building energy simulation during design and construction phases, various types of information such as building materials, labor force, and facilities are needed, and BIM can easily determine this information. There is various software needed in order to generate BIM models (Che et al., 2010). Several software assists the designers to create a 3D digital model of a building while also providing 4D information, 5D information and other related performance analysis such as costing, scheduling, structural analysis, energy analysis, etc. The most popular and powerful BIM software is Autodesk Revit® that has been used in this study.

4. Research methodology

The methodology proposed in this research is based on energy calculation obtained using data from Revit®. The energy simulation conducted in this study is classified into the following sub-category (i) Selection of design parameters (ii) Create modelling and run energy simulation.

4.1 Selection of design parameters

A ten-storied circular shape office building of 100 ft high and 50 ft radius with total floor area 78,529 ft^2 and net exterior wall area 31,416 ft^2 has been considered in this investigation. The analyzed model is suitable for 292 peoples. Exterior window to wall ratio has been chosen about 40%. The circular shape of office building model has been chosen in order to avoid shape effect because previous research revealed that there has an impact of building shape on energy consumption (Ourghi et al., 2007). Autodesk has provided the virtual code of weather stations for the climatic zones, outdoor maximum and minimum temperature. The key information for the seven climatic zones of Bangladesh is presented in Table 1.

Table 1. Key information for the climatic zones of Bangladesh

Climatic Zones	Regions	Major city	Coordinates	Code of weather station	Outdoor Temperature (^{0}F)		
					Max	Min	Average
A	South Eastern	Chittagong	22°22′N 91°48′E	756952	96	51	73.5
B	North-Eastern	Sylhet	24°54′N 91°52′E	756334	101	49	75
C	Northern part of the northern region	Panchagarh	26.25°N 88.50°E	456719	100	45	72.5
D	North- western region	Rajshahi	24°51′N 89°22′E	456026	102	44	73
E	Western zone	Bogra	24°22′N 88°36′E	458057	101	47	74
F	South-western zone	Jessore	23.17°N 89.20°E	457028	101	43	72
G	South-central zone	Dhaka	23°42′N 90°22′E	460412	101	46	73.5

4.2 Modelling and energy simulation

Computerized building information modeling (BIM) tools such as Autodesk Revit ®2015 has been used as a tool to create the mass model. Building categories have been selected as the office building. The same model has been used for energy simulation at seven climatic zones. The percentage of glazing was kept 0.4 for all the models. The office buildings operating schedule was 24/7 and HVAC system was central VAV, HW heat, chiller 5.96. Typical energy analyzed model and sun path diagram is shown in figure 2 & 3 respectively. The whole simulation process of building is described in figure 4.

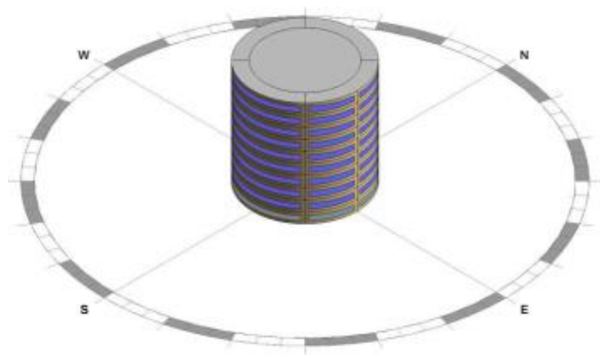

Figure 2. Energy analytical model for the analyzed building

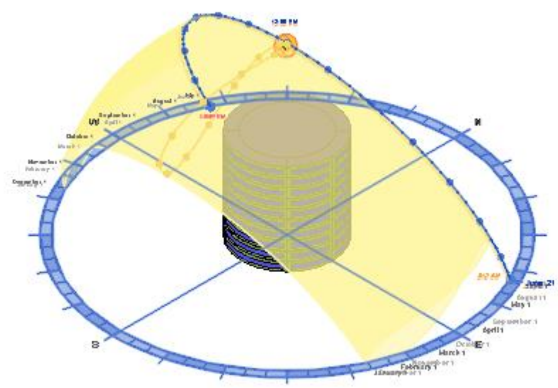

Figure 3. Sun path diagram at Dhaka city for summer session

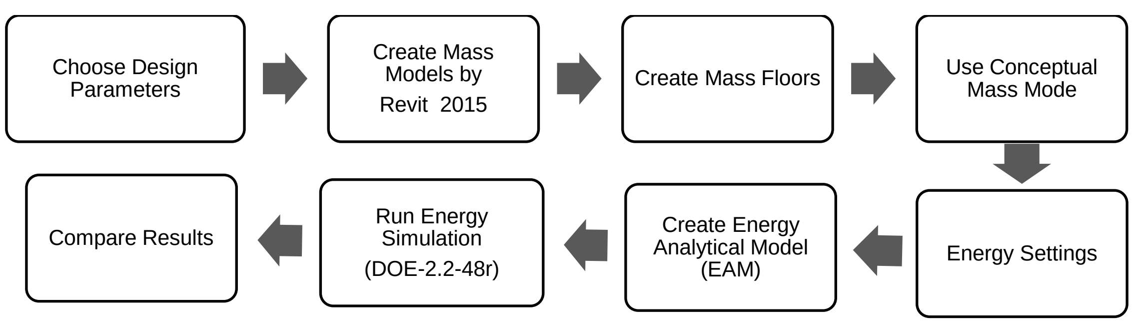

Figure 4. Conceptual energy simulation flow diagrams by BIM

5. Results and discussions

5.1 Effect of climatic zones on life cycle energy performance

In figure 5, the simulation results determined that life cycle energy consumption varies from climatic zone to climatic zone of Bangladesh. Whole life energy consumption shows almost identical results at Chittagong, Sylhet, Panchagarh, Rajshahi, Bogra & Jessore; however, Dhaka city consumed around 20% higher than the rest of the zone of Bangladesh. It was found from the simulated results that natural gas used in Dhaka city around 13% of total energy. Similarly, the rest of the cities individually used around 6-7 % of total energy.

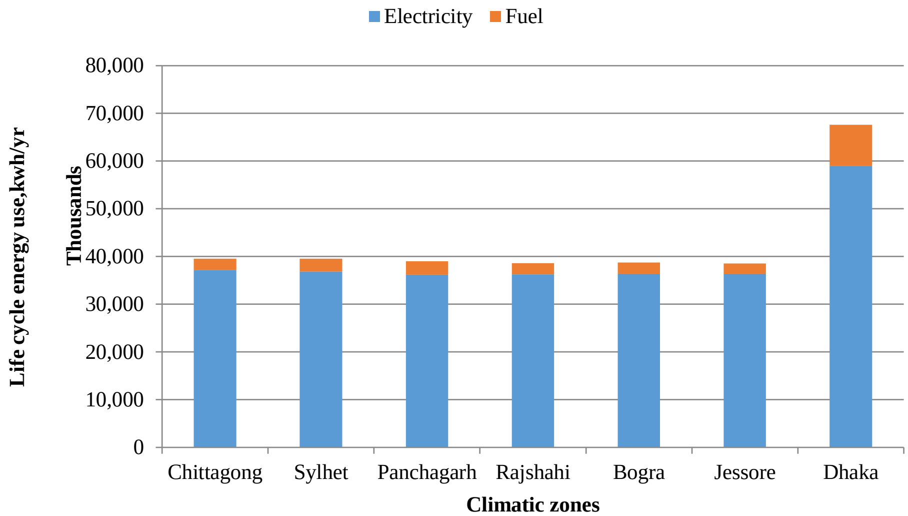

Figure 5. Life cycle energy consumption at various climatic zones

5.2 Monthly electricity consumption

Monthly electricity consumption for the analyzed building model at various climatic zones of Bangladesh is presented in figure 6. From the simulated results it was obtained that except Dhaka city the energy consumption pattern for the rest of the city almost quite similar, but Dhaka city consumed almost 33% higher than other zones. In addition, the energy requirement for all cities is low from November to February because of low temperature during the winter season. The principle influencing factors that were responsible for the variation of energy consumption were weather condition which is temperature, relative humidity, wind condition and solar radiation. Another factor that is responsible for high energy consumption in Dhaka is urban heat island (UHI) effect. The similar finding has been observed in the previous study (Okeil, 2010).

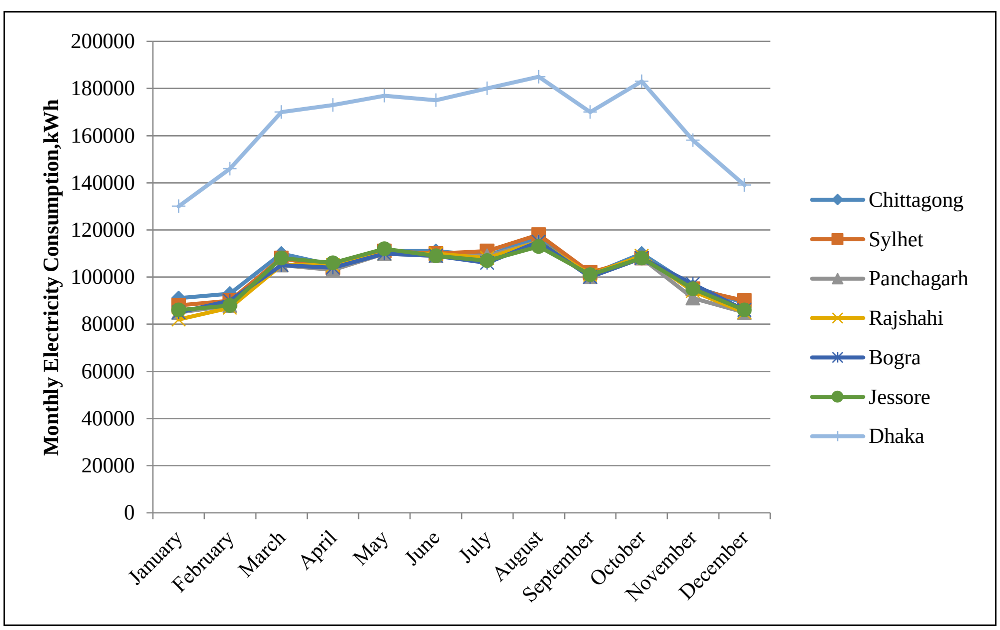

Figure 6. Monthly energy consumption at various climatic zones

5.3 Contribution of PV system on annual energy demand

All roof surfaces were considered for the estimated potential to generate electricity using Photovoltaic (PV) panels. These analyses are based on the data from the weather station specified for the project location. Simulated results in figure 7 illustrated that the annual energy contribution of renewable energy potential for roof- mounted PV system at the various climatic zone of Bangladesh. The contribution of PV system on total annual energy requirement was varied at the different climatic zone of Bangladesh. It was observed that roof-mounted PV system generate more annual energy at Chittagong and low at Jessore city. However, maximum contribution over annual energy demand is at Panchagarh city which is around 13.6 % of total annual energy requirement and minimum contribution is at Dhaka city which is around 7% of total annual energy requirement. Higher the contribution of renewable energy, lower the dependency on electricity from the national grid as well as reduce the emission of CO_2.

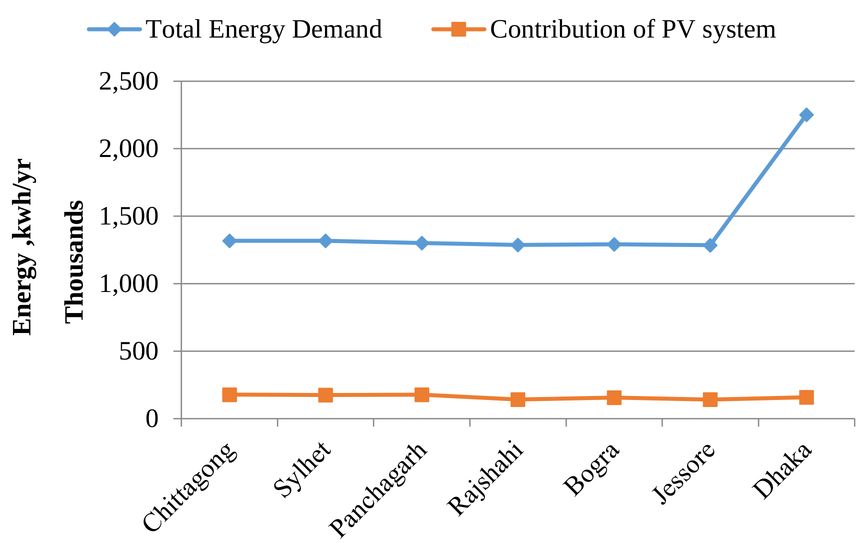

Figure 7. Renewable energy potential at various climatic zone of Bangladesh

5.4 Impact of climatic zones on net carbon emission

Autodesk uses Carbon Monitoring for Action (CARMA) data in order to estimate emission of CO_2 for the analyzed model. Net CO_2 is estimated based on the following equation:

$$\text{Net } CO_2 = \text{Energy use CO2} - \text{Energy generation potential } CO_2$$

The results obtained from the simulations in figure 8 have shown that the annual carbon emission is varied at the different climatic zone of Bangladesh. It has been found that the annual carbon emission is highest at Jessore and lowest at Chittagong city. The analyzed building in Dhaka city emits second lowest carbon emission even though it consumed high energy. Generally, the amount of carbon emission is proportional to energy consumption(Suzuki and Oka, 1998). But in this study carbon emission result is not fully depend on energy consumption because the emission data is based on the source of fuel for the electricity generation. In other words, emission of carbon is more if the electrical power plant powered by coal and less if powered by hydroelectricity.

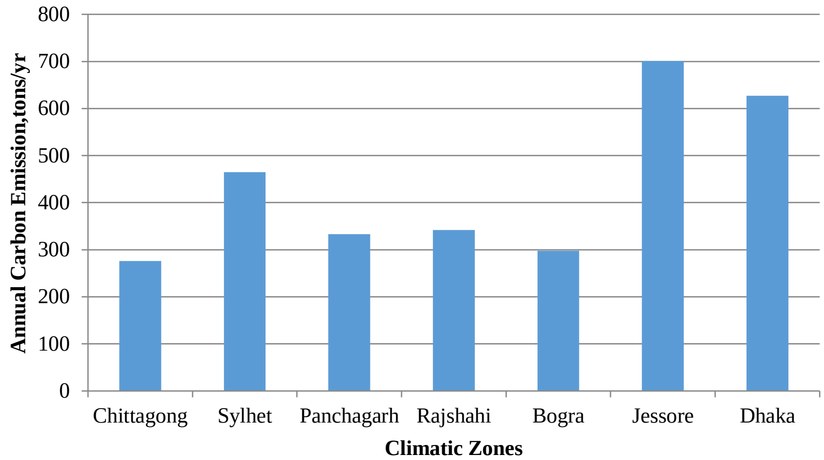

Figure 8. Annual carbon emissions at various climatic zones

5.5 *Assessment of life cycle energy cost*

The estimated energy usage and cost over the life of the building is assumed a 30-year life-span. In order to estimate life cycle cost, the unit rate of electricity is $0.09/kWh and natural gas is $0.78/Therm has been considered. The rate has been chosen by Autodesk based on state wide, territory-wide or nationwide average utility rates. From the simulated result, it was noticed that the life cycle energy cost varies from climatic zone to zone that has been represented in figure 9. The life cycle cost for the selected building model is higher at Dhaka city and lower at Rajshahi city. Except for Dhaka city, the variation of life cycle cost for rest of the city is very little. Life cycle cost for the analyzed office building in Dhaka city is around 64 % higher than the average cost of the other climatic city.

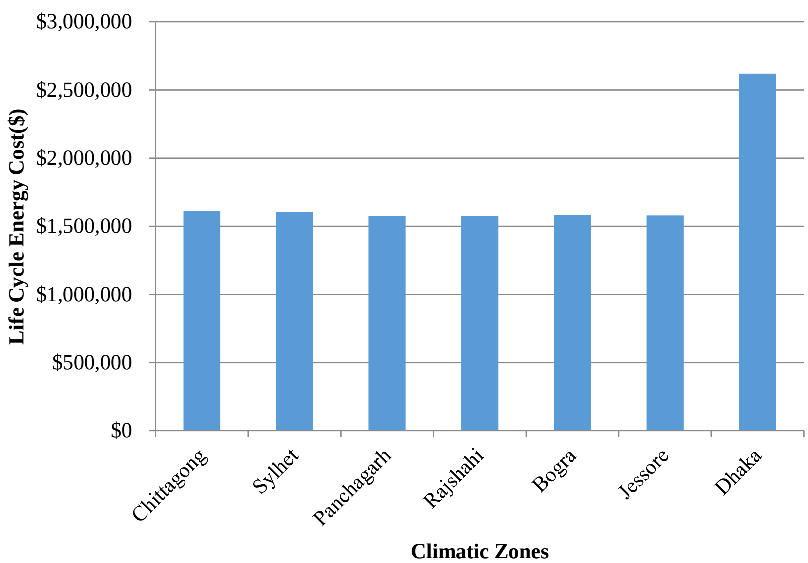

Figure 9. Life cycle energy cost at various climatic zones

6. Conclusion

Bangladesh is divided into seven climatic zones and the energy simulation of the analyzed building model conducted for each climatic zone. From this research, it has been concluded that climatic zone of Bangladesh plays a significant role in building energy performance. Building located in the South-central region of Bangladesh where Dhaka is the main city consumed around 20% more life cycle energy than other zones of Bangladesh. Energy consumption for all climatic zones except South-central region is almost identical. The energy performance of the analyzed building model at Dhaka city is greatly affected by temperature, relative humidity, solar radiation & wind condition. However, it is very much important to classify the climatic zone precisely otherwise energy simulation results will not consistent with real climatic characteristics.

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