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Energy Performance Analysis of an Office Building Using BIM: A Case Study

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Abstract. Nowadays emphasis on construction of energy efficient building has increased and the relevant studies have been high priority worldwide, especially in developed country. As a developing country, the practice on energy efficient building in Bangladesh is not as much as in developed countries. High-energy consumption is a major issue concerning in climate change, global worming etc. This study executes the energy performance analysis and optimization of an existing building. The aim of this study is to deal with the BIM (Building Information Modeling) grounded energy performance analysis and optimize utilising Revit and Green Building Studio. The building model was developed in Revit and then energy analysis was performed in Green Building Studio. Performing the energy simulation of the building a comprehensive data of energy performance was obtained in terms of heating load, cooling load, electricity and fuel consumption. Life cycle energy cost is $80555 and annual carbon emission is 14 tons per year. After optimizing the energy system annual electricity consumption reduced by 9% and annual carbon dioxide emission reduced by 3 tons per year.

Keywords: BIM; Energy Efficient Building; Energy Simulation; Office Building; Banglades

1. Introduction

The rapidly developing global energy usage has already raised issues over supply problems, exhaustion of electricity assets and solar energy and heavy environmental impacts. Climate change, global worming, environmental degredation these are the result of increasing of consumption of energy. So energy consumption has been a vital issue globally. There are various institutions as like the European Environment Agency (EEA), the U.S. Energy Information Administration (EIA) and the International Energy Agency (IEA), which record and publish energy data periodically. Energy consumption from buildings globally, both in residential and commercial, has increased and it lies between 20% and 40% in developed countries (Pérez-Lombard, Ortiz, & Pout, 2008). The increase in population, demand of building services and comforts level will contribute to the continuing of rise of energy consumption. So demand for energy efficient building is increasing day by day. Energy efficiency is one of the significant characteristics of building materials. The main cause of using energy efficient materials is to reduce the use of artifically generated power (Moon & Kim, 2010). Due to assessing the building energy performance, Building Information Model Tools are used. It helps to analyze the energy consumption, to identify the alternative energy solution and energy saving substitutions in the design phase (Zhou, Zhang, Zuo, Huang, & Zhang, 2015). Revit is used for visualizing the 3D views of the proposed building, which executes the complex geometric or functional information. In order to analyse the energy performance different energy analysing tools are used like Revit, Ecotect, Green Building Studio, Energy-plus etc. In this Study to optimize the energy consumption some passive measures were taken as like green roof, high insulative materials(Expanded polystyrene), change of window wall ratio about less than 30% (Wang, Zmeureanu, & Rivard, 2005). Energy performance analysis would be helpful for the designers and owners to take the decision about energy related facts that is involved with building life cycle energy cost (Kriegel & Nies, 2008). It also collaborates the respective person involving with building design to have a decision about sustainable building design.

Since energy consumption and CO2 emission due to building is increasing worldwide, energy efficient building has been key concern to prevent the negative consequences of vast amount of energy consumption (Nejat, Jomehzadeh, Taheri, Gohari, & Majid, 2015). Bangladesh is not out of this significant need to contribute in creating a green, sound and safe world. Therefore, this analysis was conducted on an office building at Khulna University of Engineering and Technology (KUET) campus, in Bangladesh to analyze the building energy performance of an existing building using Green Building Studio and Revit and compare the base run results with optimized results.

2. Literature Review

Energy has become one of the most important factors for better economic growth and people's life. The increasing amount of world energy consumption has been a key concern in this era. However, total energy increasing; there is negative impact of energy consumption over the resources and environmental effect (global warming, ozone layer depletion, ice melting etc.). Mainly total energy is consumed by three categories like industry, transportation and building. The nations with emerging economies (Middle East, Southeast Asia, South America and Africa) use energy at an average annual rate of 3.2% and it will exceed by 2020 (Pérez-Lombard et al., 2008). In office building energy is used in USA is 18%, in Spain 33% and in UK 17% (Cabeza, Rincón, Vilariño, Pérez, & Castell, 2014). The following table-1 showed the amounts of energy consumed worldwide in 2012 by four sectors, according to the Energy Information Administration of the US Department of Energy.

Table 1. Energy consumption by four major sectors

Sector	10^{15} Btu	Petawatt-hours	Percentages
Residential	53.0	15.5	13
Commercial	29.3	8.6	7
Industrial	222.3	65.1	54
Transportation	104.2	30.5	26
Total	408.9	119.8	100

[Source: US DoE. PWh from 0.293 times Btu column]

Energy consumption in offices by end use in different countries is showed by the table-2 in accordance with the study of (Pérez-Lombard et al., 2008). In this study it was found that mostly energy is consumed by HVAC (Heating, Ventilation and Air Conditioning System) in USA (48%), Spain (55%) nad UK (52%).

Table 2. Energy consumption by different elements.

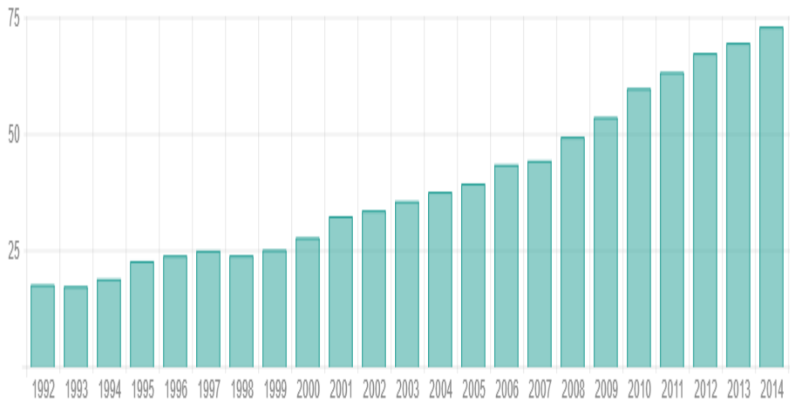
Energy end uses	USA %	Spain%	UK%
HVAC	48	55	52
Lighting	22	17	33
Equipment	13	5	10
DHW(Domestic Hot Water)	4	10	…..
Food Preparation	1	5	…..
Refrigeration	3	5	…..
Others	10	4	5

According to World Data.info, the total energy consumption in Bangladesh is about 48.98 billion KWh per year and total CO2 emissions in 2014 is 73.19 million ton and 0.45 ton per capita (Data, 2015). The following data shows the development of CO2 emissions from 1992 to 2014 in million tons.

Figure 1. Development of CO2 emissions from 1992 to 2014 in million tons

To reduce the energy consumption and CO2 emission from building there are various types of way as like usage of green roofing, proper orientation of building, proper window wall ratio, usage of high performance glass in window, usage of high insulation materials in the walls related with low thermal conductivity. The following table-3 executed the thermal conductivity of different materials that is used for insulation and the lowest thermal conductive material is Expanded Polystyrene (EPS). The following table's data is in accordance with DOE (US. Department Energy) and ("Energy consumption in Bangladesh," ; Heravi & Qaemi, 2014).

Table 3. Thermal conductivity of different materials



Name of materials	Thermal conductivity(W/mK)
Earth	0.837
Expanded Polystyrene(EPS)	0.033
Glass, Clear Glazing	1.100
Glass-Marvin-IG Low E II with Argon	0.753
Glazing -glass	0.209
Gypsum Wall Board	0.650
Jute Fiber	0.067

Plastic	0.502
Rock Wool	0.034
Natural Rubber Foam	0.042
Concrete	1.75

Over the past couple of decades different types of building energy simulation and analysis tools as like EnergyPlus, BLAST, TRACE, eQUEST, DOE2, Ecotect, Integrated Environmental Solution (IES-VE) and Green Building Studio has developed and implemented in the building industry (Cowie, Hong, Feng, & Darakdjian, 2017; Crawley, Hand, Kummert, & Griffith, 2008). According to a survey of 91 design and construction firms in the United States found that there are three commonly used BIM-based sustainability analyses software like Autodesk Ecotect, Autodesk Green Building Studio (GBS), and Integrated Environmental Solutions (IES-VE) (Azhar, Brown, & Sattineni, 2010). In the recent years, the use of Building Information Modeling (BIM) has increased in the construction industry (Jalaei & Jrade, 2015). There are different types of interoperable file format for BIM tools as like Industry Foundation Classes (IFC), Extensible Markup language (XML). These are used to share information from one BIM tool to another. According to the study of (Jrade & Jalaei, 2013), gbXML has a simplified schema for energy analysis.

By using the BIM tools, all the optimizing strategy can be incorporated and energy performance can be evaluated. It would be helpful for the designers and the owners to take the pragmatic decision over life cycle cost, energy usage and CO2 emission.

3. Building Description

It is a well-furnished two-storied office building that is used for performing activities related a bank. It is located in Khulna, Bangladesh. It considered for a case study analysis. The gross floor area of the house is 3,963 Square feet (sf).Exterior wall area is 2,219 sf. Each storey has an internal height of 10 feet and 6 inches. Windows of the building are of high performing double glazing aluminum frame. A staircase connects the two stories. The following figure-2, figure-3 and figure-4 showed the location, ground floor and first floor plan. The figure-2 indicate the project location, which at southern part of Bangladesh near to the Bay of Bengal and the Sundarban. The coordinate of the building area is 22.8977° N, 89.5033° E. Figure-3 describes the ground floor space allocation and architectural plan and the figure-4 represents the 1st floor plan with specific details.

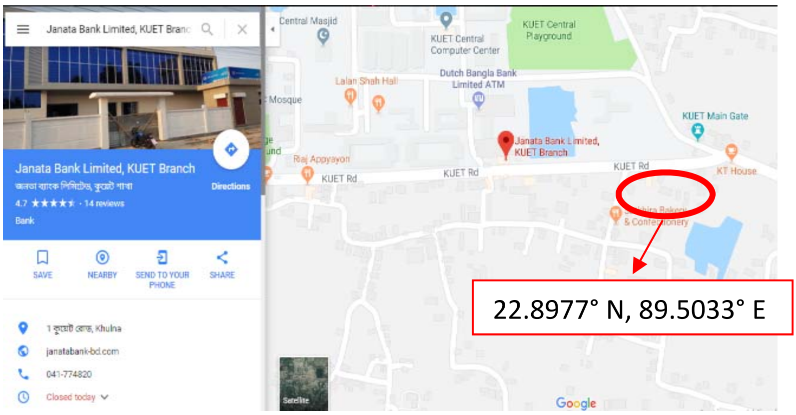


Figure 2. Location of Janata Bank building

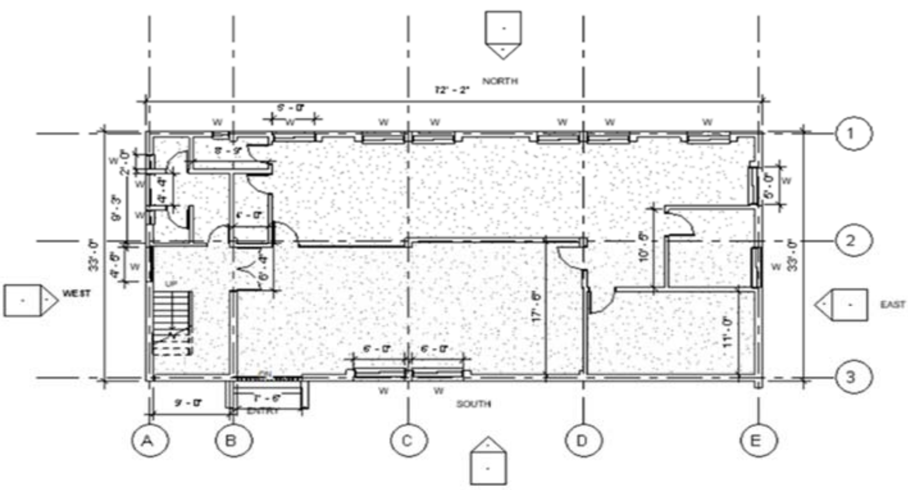


Figure 3. Ground Floor Plan (W=window)

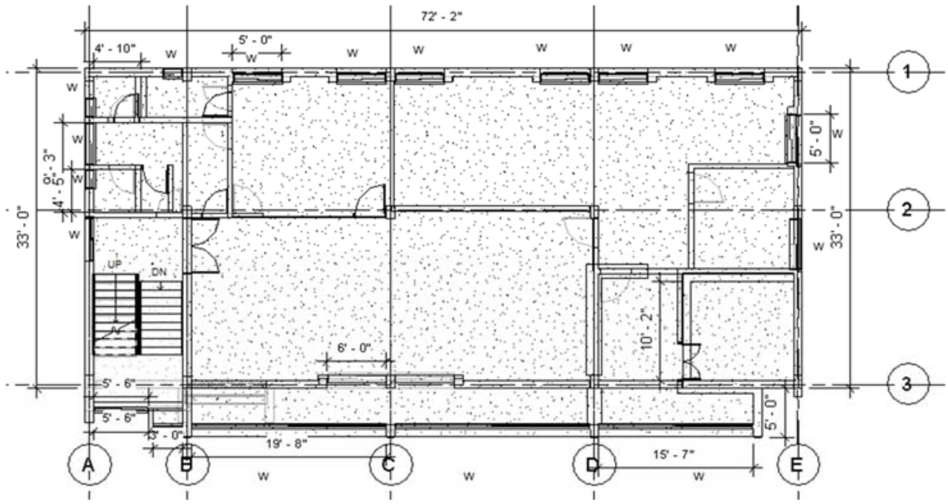


Figure 4. First Floor Plan (W=window)

4. Research Methodology

A systematic way followed due to analyzing the energy performance of a proposed building. The following stages showed in figure-5 were followed to perform the analysis. In initial stage, the relevant information was collected of the existing building to prepare a 3D model of the building to visualize the different views of the building. Then the interior energy analysis was performed using Green Building Studio (GBS). Due to analyze the energy performance in Green Building Studio, the Revit file was transferred to Green Building Studio as gbXML file format.

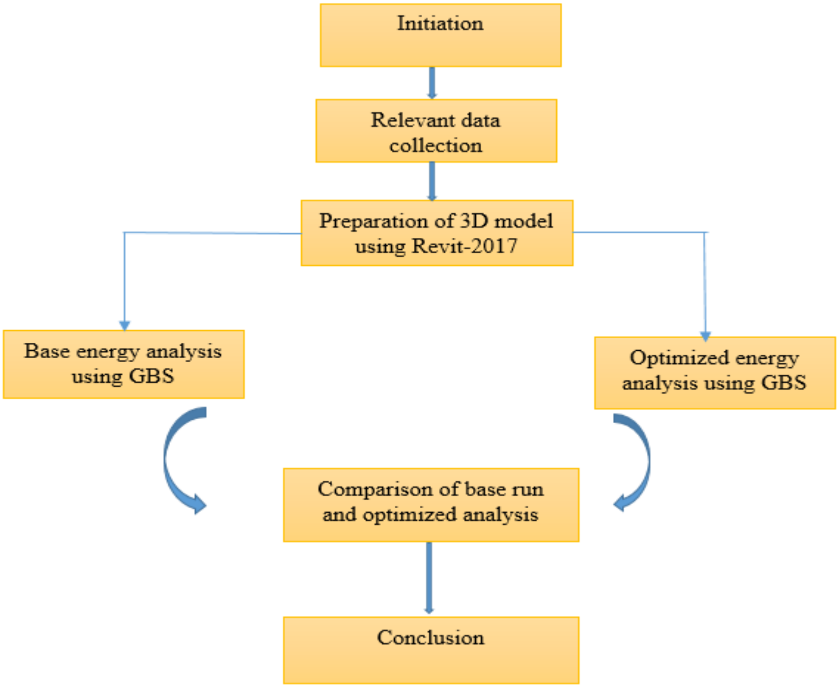


Figure 5. A schematic flow diagram of the study

4.1. Preparation of 3D model

The following steps were performed to prepare the 3D model of the proposed building for the case study:

- An office building was selected for energy analysis (Janata Bank Building, KUET branch, Khulna, Bangladesh)
- On site visit was conducted to see the building physically.
- A meeting was conducted several times with the contractor and the respective engineers who were responsible for the construction of the building.
- All the information relevant to the building as like whole building plan, materials properties, HVAC system etc. were collected from the engineers.
- According to information about material and plan, architectural model of the proposed building was prepared in Autodesk Revit-2017.

4.2. Energy analysis process using GBS and optimization

The figure-6 executed the overall process of energy performance evaluation Total energy evaluation system is categorized in two issues, one is the influencing factors and another is energy analysis. Again, the influencing factors include climate, design and occupant. Occupant and climatic information are taken to the BIM tool as location is specified. Design factors depend on the building orientation, building types like whether it is office building, residential building or others. Materials information that were used in preparing the 3D model of the building in Revit-2017 are extracted in the form of gbXML file format and imported in the energy analysis tool.

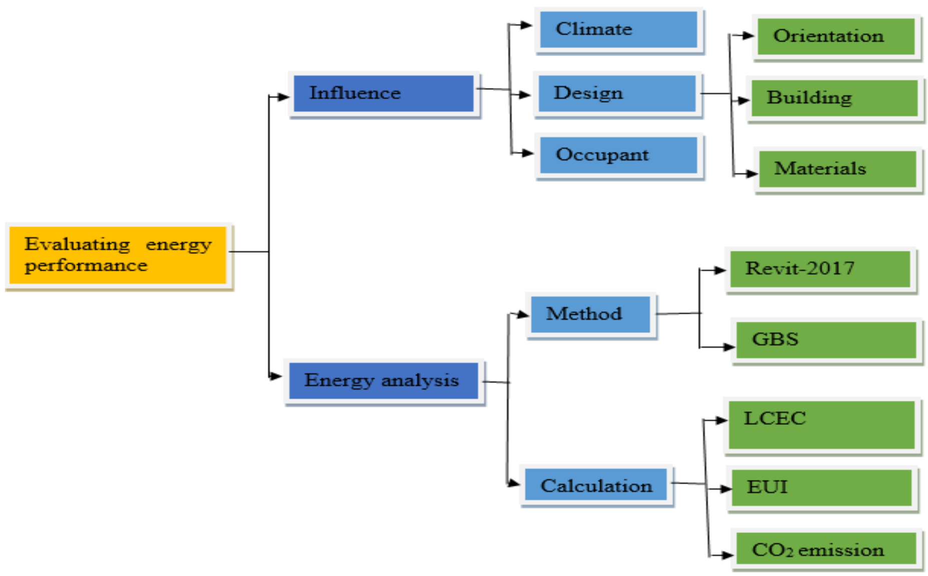


Figure 6. Overall process of energy performance evaluation

The second category of energy performance evaluation is energy analysis. Two BIM tools were used to analyze the energy. After preparing the energy model in Revit-2017, energy analytic model was prepared by selecting the building location, building type as office building and operating schedule as 12 hours per day and 5 days per week (12/5). The figure-7 shoed the energy setting system.

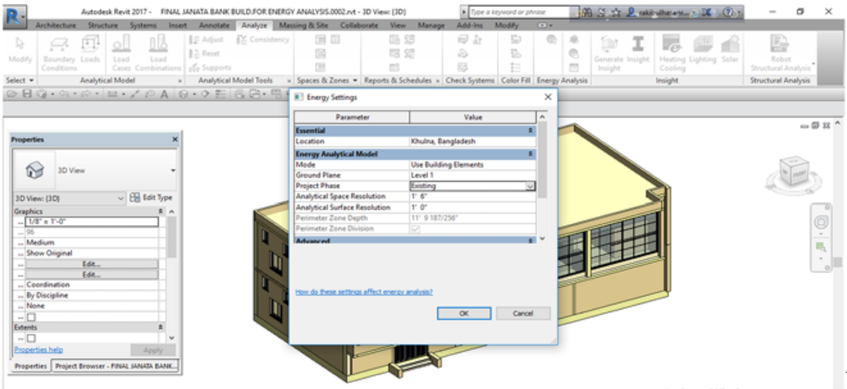


Figure 7. Energy model setting

After performing the energy analysis, the following items were determined.

- LCEC- Life Cycle Energy Cost
- EUI- Energy Use Intensity
- CO2 emission

Finally, due to performing energy optimization high-insulated materials (Expanded Polystyrene) with low thermal conductivity, high performance glass (double-glazing), green roof, reduction of window wall ration (WWR) (less than 30%) was considered. In this context, the main items for optimization was wall insulation, roof, WWR, glass performance, orientation as a measure passive optimization. Then the base run analysis and optimized results are compared.

4.3. Model validation

After performing the model validation, actual electricity cost per month of the Janata Bank Building is compared with the electricity cost per month that found from the Green Building Studio (GBS) results of the building. This building is located at KUET, in Khulna city of Bangladesh. All the information about electricity cost per month of the building was collected from the Janata bank information desk. There average electricity cost per month is about 15131 Taka (TK) of the month of May to September. From the GBS result sheet it was found that monthly 5406 KWh electricity was consumed of the month May to

September. This value executes for whole building. The shape and total floor area of first floor is alike ground floor. Only first floor is running at this moment. Therefore, the electricity consumption is half of the found result is about 2703 KWh. This amount was multiplied with 5.50 (cost per KWh) to have electricity cost per month. The average electricity cost according to GBS result is about 14866 Taka per month. The variation is about 2% from the actual electricity cost to GBS electricity cost per month. It is almost reasonable. This considerable variation executes the validation of the Green Building Studio (GBS) tool.

5. Results and Data Analysis

After analysis the building model at the initial condition incorporating all the relevant information in existing condition, following result was found. There are considered some factors by default in accordance with building type and location of the building as like occupants, average lighting power, electricity unit cost, fuel cost per unit etc.

5.1. Energy Use Intensity (EUI)

According to energy analysis result the table-4 showed the energy use intensity for electricity is 17 kWh / sf / year and fuel is 2 kBtu / sf / year. As a whole, energy use intensity is 59 kBtu / sf / year. (1 kWh = 3.14 kBtu).

Table 4. Energy Use Intensity

Electricity EUI:	17 kWh / sf / year
Fuel EUI:	2 kBtu / sf / year
Total EUI:	59 kBtu / sf / year

5.2. Life cycle energy use/cost

The following table-5 executed the total life cycle energy cost is about $80,555. Life cycle time period is considered by the tool is about 30 years. (1kWh = 0.034

Therms)

Table 5. Total life cycle energy cost

Life Cycle Electricity Use:	1,872,490 kWh
Life Cycle Fuel Use:	2,050 Therms
Life Cycle Energy Cost:	$80,555

5.3. Renewable energy potential

The table-6 showed that there is better renewable energy potential using roof mounted photovoltaic (PV) cell and it is about 40001 kWh/year. There is also another energy generation potential from using single 15 feet wind turbine. PV efficiencies are assumed to be 5%, 10% and 15% for low, medium and high efficiency systems.

Table 6. Renewable Energy Potential

Roof Mounted PV System (Low efficiency):	13,334 kWh / year
Roof Mounted PV System (Medium efficiency):	26,667 kWh / year
Roof Mounted PV System (High efficiency):	40,001 kWh / year
Single 15' Wind Turbine Potential:	436 kWh / year

5.4. Annual Carbon Emission

From the figure -8, it was found that net carbon dioxide (CO_2) emission at existing condition is 14 tons per year. There is great potential of energy generation using photovoltaic cell is 24 tons per year and carbon dioxide emission by electricity consumption is 38 tons per year. No carbon dioxide emission due to fuel consumption.

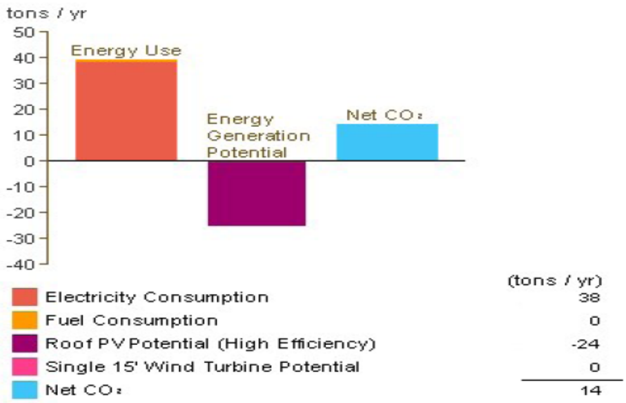


Figure 8. Annual carbon emission

5.5. Comparison of base energy simulation results with optimized results

All the building performance factors are unchanged. The following pictures in figure-9(a) & 9(b) show the 3D model of the Janata bank building in existing and optimized condition.

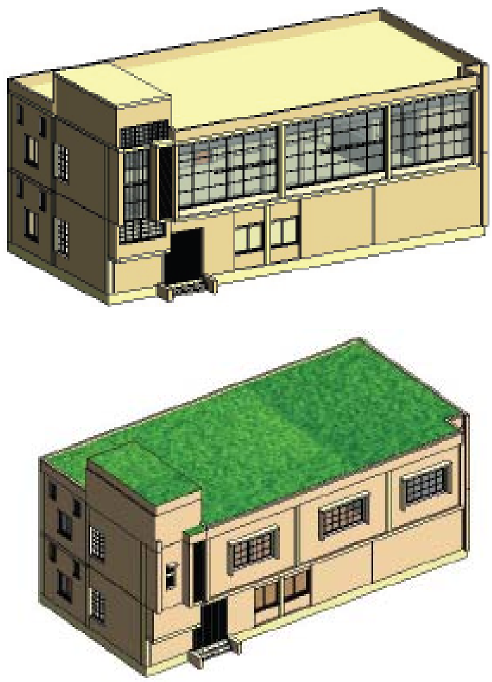


Figure 9 (a). Base Run of building model Figure 9(b). Optimized Run of building model

5.5.1. Energy Use Intensity (EUI)

According to table-7(a) & 7(b), it was found that after optimizing, the building electricity use intensity reduced about 1 kWh/sf/year and total EUI decreased to 56 kWh/sf/year.

Table 7 (a). Base Run (EUI)

Electricity EUI:	17 kWh / sf / year
Fuel EUI:	2 kBtu / sf / year
Total EUI:	59 kBtu / sf / year

Table 7 (b). Optimized Run (EUI)

Electricity EUI:	16 kWh / sf / year
Fuel EUI:	2 kBtu / sf / year
Total EUI:	56 kBtu / sf / year

5.5.2. Life Cycle Energy Cost (LCEC)

According to table-8(a) & 8(b), it was found that after optimizing, life cycle energy cost for about 30 years reduced from $80555 to $73,279. Life cycle electricity usage decreased in 170276 kWh and fuel consumption decreased in 48 Therms.

Table 8 (a). Base results (LCEC)

Life Cycle Electricity Use:	1,872,490 kWh
Life Cycle Fuel Use:	2,050 Therms
Life Cycle Energy Cost:	$80,555

Table 8 (b). Optimized results (LCEC)

Life Cycle Electricity Use:	1,702,214 kWh
Life Cycle Fuel Use:	2,002 Therms
Life Cycle Energy Cost:	$73,279

5.5.3. Renewable Energy Potentials (REP)

From the table-9(a) & 9(b), it was found that after optimizing the building energy system, renewable energy potential has increased. Maximum amount of energy potential has increased by high efficiency roof mounted photovoltaic cell system and it is about 320 kWh/ year than previous. There is no change for wind turbine system.

Table 9(a). Base run results (REP)

Roof Mounted PV System (Low efficiency):	13,440 kWh / year
Roof Mounted PV System (Medium efficiency):	26,881 kWh / year
Roof Mounted PV System (High efficiency):	40,321 kWh / year
Single 15' Wind Turbine Potential:	436 kWh / year

Table-9(b): Optimized results (REP)

Roof Mounted PV System (Low efficiency):	13,334 kWh / year
Roof Mounted PV System (Medium efficiency):	26,667 kWh / year
Roof Mounted PV System (High efficiency):	40,001 kWh / year
Single 15' Wind Turbine Potential:	436 kWh / year

5.5.4. Annual carbon emission

In case of optimized result, there annual carbon emission has decreased. The following figures no 10(a) & 10(b) showed the reduction of carbon emission per year is 3 tons. It occurred due to reduction of electricity consumption. Initially carbon dioxide emission was 14 tons/year then it reduced to 11 tons/year.

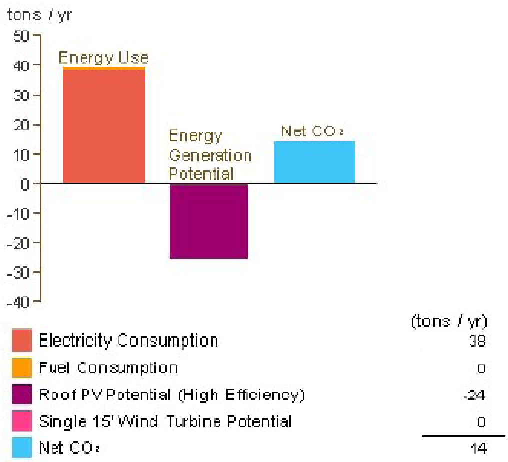


Figure 10 (a). Base run of CO2 emission

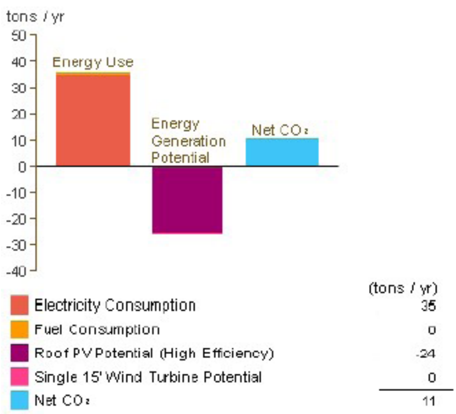


Figure 10 (b). Optimized CO2 emission

6. Conclusions

The faster increase in global energy usage has developed some vital issues over supply problems, exhaustion of electricity assets and solar energy and heavy environmental impacts. About 40% of the total energy is consumed by building. Therefore, energy efficient building has great impact to reduce the harmful effect of building energy consumption. Due to designing of energy-efficient and high-performance buildings equates that building performance and simulations tools are utilized. The aim of this research was to document the energy performance analysis of existing building and comparative analysis of base run simulation and optimized simulation results. According to the analysis in current situation, Life cycle electricity and fuel consumption is 1872490 kWh and 2050 Therms respectively. After optimization, energy consumption is reduced by taking some optimizing measures as like building envelop, green roof, changing window wall ratio etc. Life cycle electricity consumption reduced by 9% and it is about 170276 kWh. It also reduced carbon dioxide emission about 3 tons per year. This analysis would assist the designers and owners to some significant decisions over reducing the energy consumption and CO2 emission to approach in an energy efficient building and they can use the lesson learn from this analysis in their future works

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