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Application of Passive Energy Savings Strategies for Optimization of Building Energy Performance: A Case Study

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Abstract. Application of passive strategies in building sector can be a promising and advantageous technique to enhance the building energy efficiency in terms of energy savings. Passive energy savings strategies can reduce energy consumption through proper envelope treatment and orientation. This paper presents a simulation study on passive energy savings strategy by using different types of energy efficient walls with changed thermal properties and also by redesigning the building shape and orientation. Various types of thermal insulation material can be used on wall to reduce heat transfer from outside to inside of building. Green Wall or Green Plantation on vertical wall applied to optimize energy consumption, Green roof and orientation used to get better performance of energy consumption. Advance BIM (Building Information Modeling) tools DOE-2 and Autodesk Green Building Studio used for energy simulation. Application of thermal property change, green wall, green roof and orientation of building reduced energy consumption around 31.43% per year and carbon emission 5 ton per year. Thus the findings demonstrate that, usage of passive strategies in the building sector enhances energy efficiency predominantly through mitigating building's negative environmental impacts besides optimizing its energy performance. Through extensive literature review the research able to find out various passive building energy features that can be incorporated in building design to make them energy efficient.

Keywords: energy efficiency; passive energy strategies; Simulation, building envelope, Building Information Modeling (BIM)

1. Introduction

The global building sector consumed nearly 30% of total final energy consumption for all sectors of the economy, having increased by more than 35% since 1990. When upstream power generation is taken into account, the building sector therefore represents roughly 30% of global energy-related CO2 emissions (Global Status Report 2016). In low-income countries, the residential sector represented 90 per cent of all carbon dioxide emissions from buildings in 2002 (UNECE, 2008). In Bangladesh total energy consumption by different sector was about 50264 MWh (BBS, 2017). Out of this, more than 40% was used by the residential sector alone (UNEP, 2007). Moreover, a study of the regulations in the national building code of Bangladesh shows that the building codes do not address the issues of energy efficiency in any building category. Since the building sector is a major user of energy in terms of electricity, it is high time to think about to evolve energy efficient building designs that can be a superior solution to the problems of energy crisis and environmental impact. Several policies are established alongside with advancing new technologies to control the increasing trend of energy consumption in building sector. Adopting passive strategies for designing the energy efficient buildings has been of one these solutions (Hossein and Abdul, 2016).

Energy efficiency is crucial, especially for a country like Bangladesh where the demand for electricity, as already stated, is growing at a rate of 10% per year. However, the generation of power has not grown to match the growing demand. Energy efficient building design has therefore become an important research field as energy is generally one of the most important resources used in buildings over their lifetime. An energy effective building envelope design saved as much as 35% and 47% of total and peak cooling demands respectively (Chan KT, Chow WK, 1998). A significant proportion of the energy utilization is due to the spread of the heating, ventilating, and air conditioning (HVAC) installations in response to the growing demands for better thermal comfort within the built environment (Yang et al., 2014). Building energy efficiency can be improved by implementing either active or passive energy efficient strategies. Improvements to heating, ventilation and air conditioning (HVAC) systems, electrical lighting, etc. can be categorized as active strategies, whereas, improvements to building envelope elements can be classified under passive strategies. Recent years have seen a renewed interest in environmental-friendly passive building energy efficiency strategies. They are being envisioned as a viable solution to the problems of energy crisis and environmental pollution (Sadineni et al., 2011).

It is evident from the above section that energy efficiency in buildings is vital for many reasons in Bangladesh. Having justified the needs for energy efficiency it is now important to focus on the basic principles that can bring about energy efficiency in building design. The aim of this study is to analyze the criteria for energy efficiency, resulting in a series of feasible passive design solutions towards developing and designing energy-efficient residential buildings. The study also aims at identifying changes in the design process that can affect energy efficiency in residential buildings.

2. Case study building

Khulna city, the third biggest industrial city of the country, is located at the south-western part of Bangladesh. Khulna is situated at 22.81° North latitude, 89.57° East longitude and 18 meters elevation above the sea level, having about 1,342,339 inhabitants. It is situated on a natural levee of the Rupsha and Bhairab rivers. The case study building is a two storied residential building located at KUET road, Fulbarigate which is situated at north-western side of Khulna city. The project location from Google Map is shown in the following figure 1.

Fig. 1. Project Location from Google Map

Khulna is humid during summer and pleasant in winter. Khulna has an annual average temperature of 26.3 °C (79.3 °F) and monthly means varying between 12.4 °C (54.3 °F) in January and 34.3 °C (93.7 °F) in May. Annual average rainfall of Khulna is 1,809.4 millimeters' (71.24 in). Approximately 87% of the annual average rainfall occurs between May and October. Through climatic and geographic location study, information about the building requirement is collected.

3. Research methodologies

3.1 Model Creation and Energy Setting

Since the building owner lost the actual plan, detail information on actual building plan and material details specification were collected by taking his personal interview. The building was at East face. With the help of this information the same building model was created by using Autodesk Revit Architecture software with proper material input which is shown in figure 2. It is the actual model of the case study building with proper material details that material was some R (Resistance) value and M (Thermal mass) value. The wall materials of the building were normal/common brick and plaster layer. The wall thickness was 8 inches. Roof and Floor of the building was normal lightweight concrete with finish surface. Windows of the building was three types w1= 4'-6" X 5'-0", w2= 3'-6" X 5'-0", w3= 3'-0" X 4'-0". The toilet ventilation was about 2'-0" X 2'-0". The window and ventilation material were Aluminum and Glass.

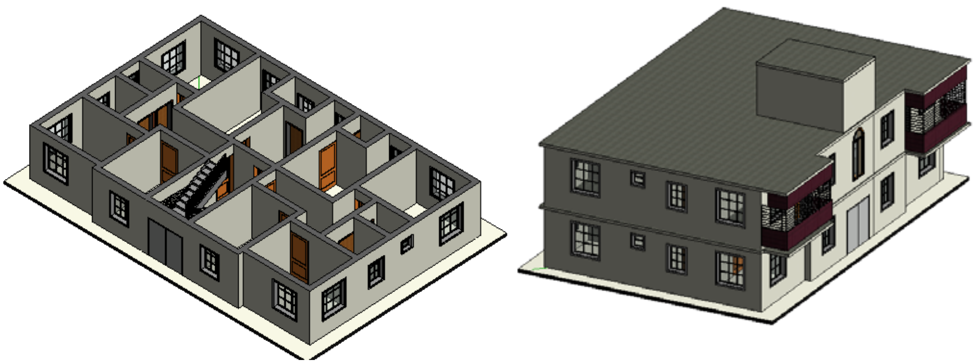


Fig. 2. Simulation Model

After performing the energy analysis of the building by energy settings option, energy is also simulated. Then the base run result is obtained. Following the same way, different run results are obtained by changing different element one by one that also change the model. Then actual result is compared with different base run result for optimization building energy.

3.2 Application of Passive Energy Strategies

The basic passive principles are established for designing energy efficient residential building after an extensive literature review. In this study the following aspects of passive energy strategies are applied for energy efficient residential building: External wall, Vertical greening/ green wall, Building roof, Building orientation, Windows ventilation.

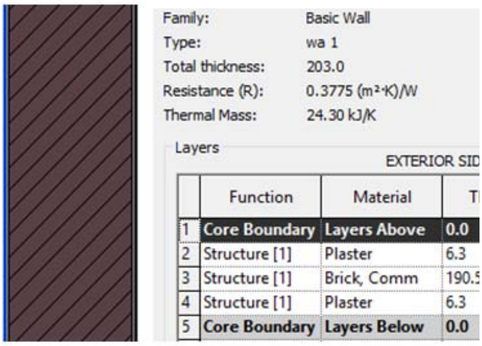
3.2.1 External Wall

Different types of external wall are created by changing the wall property. The model is run one by one using each of these changed walls to get optimized result of energy consumption and CO2 emission. If the material properties are changed, R value, U value and M thermal mass values are also changes. As it is known that if R value can be increased, U value decreases which provides better thermal performance. Building wall perform better if provision could be made to increase thermal resistance R and decrease heat loss or gain from outdoor environment. Several types wall are created to get optimized energy performance which result is given in the following Table 1.

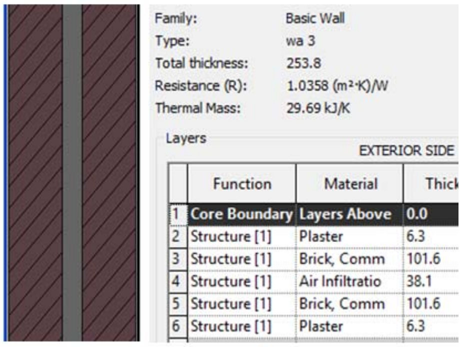
Table 1. Wall properties and thermal value

Type	Materials	R value $(m^2\text{-}k)/w$	U-value $w/(m^2\text{-}k)$	Thermal mass (KJ/K)
Wall-1	Plaster + Common Brick+ Plaster	0.3775	2.649	24.30
Wall-2	Plaster+ Common brick + Air + Common brick + Plaster	1.0358	0.9654	29.69
Wall-3	Plaster+ Common brick + EIFS insulation + Common brick + Plaster	3.1146	0.3210	22.98
Wall-4	Plaster+ Common brick + Rock Wool insulation + Common brick + Plaster	2.2214	0.4501	23.59
Wall-5	Plaster+ Common brick + Air + Rock Wool insulation+ Air + Common brick + Plaster	3.1904	0.3134	20.52

Thermal property of wall is very important for better energy performance and passive energy control system. In this regard different types of wall with same thickness but different material with non-homogeneous layer combination are created to get better result or better performance. These walls are shown in figure 3. Wall-1 is 8" thickness which is the basic building wall, and then other wall of 10" thickness with different combination of material and thermal properties are created for better performance.

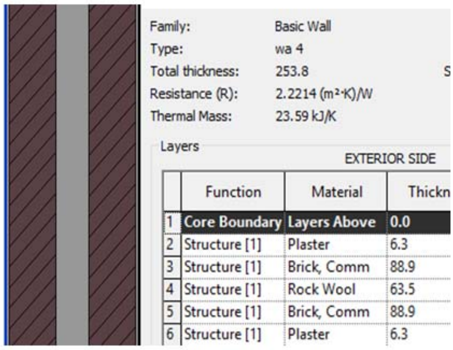


(a) Wall-1

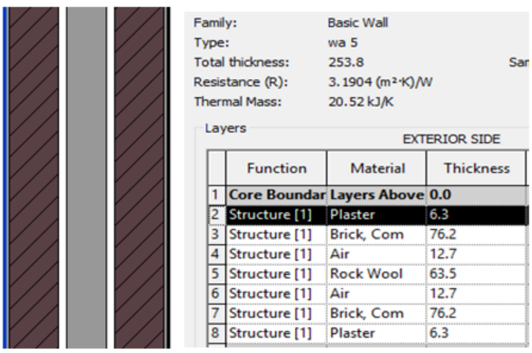


(b) Wall-2

(c) Wall-3



(d) Wall-4



(e) Wall-5

Fig. 3. Walls with Different Material and Thermal Properties

3.2.2 Vertical Greening/ Green Wall

The basic wall of the study building is created in accordance with actual specification and energy performance being observed and noted. Following the same procedure but changing the material specification different types of vertical wall are created and energy performances are also observed. From all these combination vertical greening or green wall shows the best optimized energy performance. Vertical green walls are created (Plaster+ Common brick + Air + Rock Wool insulation+ Air + Common brick + Plaster) which are shown in figure 4 and from the vertical plantation or green wall concept this vegetation system is provided on vertical wall. Finally, energy analysis and simulation of the vegetation or vertical plantation system is conducted by using Revit.

Fig. 4. Vertical Greening / Vertical Plantation

3.2.3 Building Roof Change

The case study 4 ksi concrete building roofs of 5 inches thickness are created and energy performance is analyzed. After literature review it is found that Green Roof has positive impact on energy consumption.

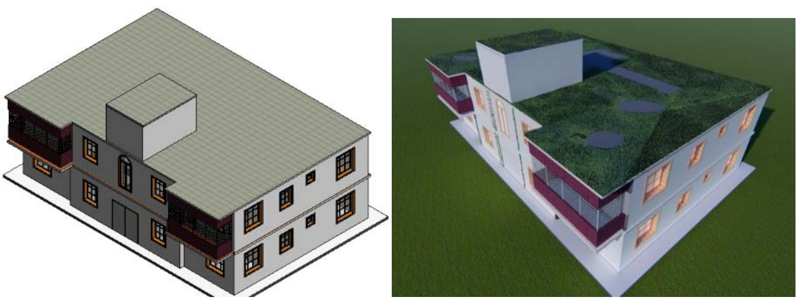


Fig. 5. Normal concrete roof changed as Green Roof

With this concept green roof is created (Grass+ Earth + Concrete + Plaster finish) which are shown in figure 5. The thickness of concrete slab is changed with grass and earth that gives positive result on energy performance. By following the previous procedure optimized energy performance of the building is find out by observing different energy performances obtained from different roofs created by changing the material properties and thickness passive control.

3.2.4 Building Orientation

A model of the case study building is created which is East faced. To get optimize result of energy performance then the building model is rotated with an angle of 300, 450, 600 and 900 with respect to the east direction. The building is also rotated Anti- clockwise with different angle and at the time the North on 2D view is selected as True North. Each time the effects on building energy performance or energy savings are observed due to different building orientation.

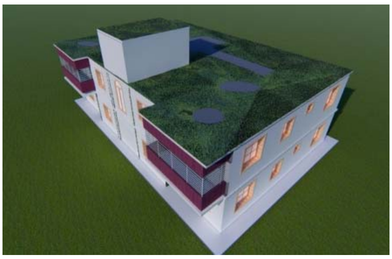


Fig. 6. Different Building Orientation

3.2.5 Windows Ventilation System

Fenestration refers to openings in a building envelope that are primarily windows and doors. The fenestration plays a vital role in providing thermal comfort and optimum illumination levels in a building. Basically window is one of the prominent passive control systems that have positive effect in energy. The case study building windows are Single Glazed low E Aluminum Frame. Then new windows are created with Double Glazed Timber Frame solar control glasses with Low, E coating. The energy effects are observed in both combinations.

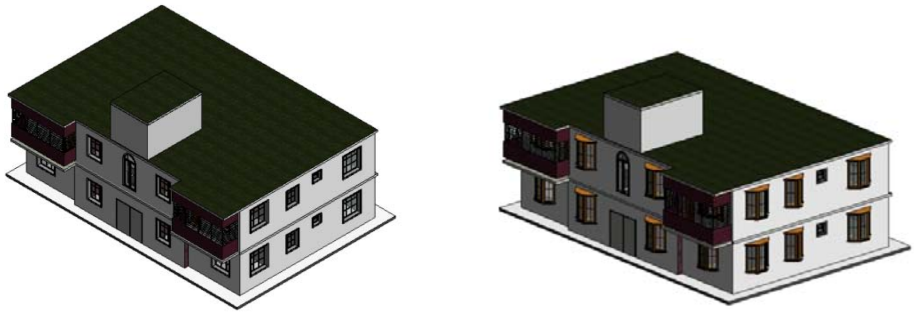


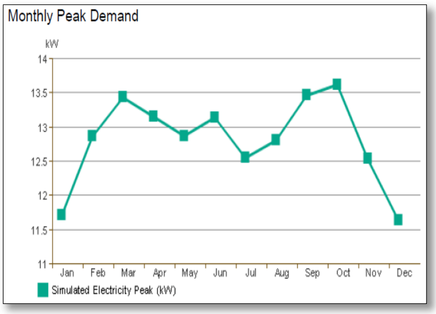
Fig. 7. Model Simulation with Changed Window

4. Results and data analysis

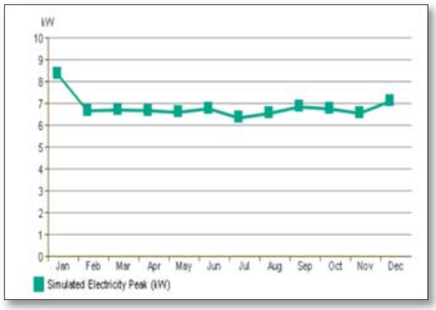
After analyzing the building model at its actual condition and also incorporating all the relevant features of passive energy strategies, the results are compared. In this study the passive energy strategies are used in terms of Wall thermal properties, Green Wall, Green Roof, Orientation and Natural ventilation. All these strategies result positive effects on optimized passive energy consumption. The results are shown comparatively with different building parameter such as monthly electricity peak demand, monthly cooling load, life cycle energy use/ cost, humidity and level and annual carbon emission.

4.1 Monthly Electricity Peak Demand

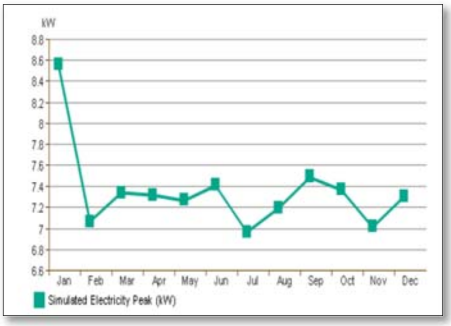
Monthly base run electricity peak demand of the case study building is 13.5 kw. By changing the parameter of the building envelope and orientation monthly electricity peak demand decreasingly changed and the final result of monthly electricity peak demand is 7.4 kw. So, all the passive energy strategies able to reduce 6.1 kw of electricity peak demand.



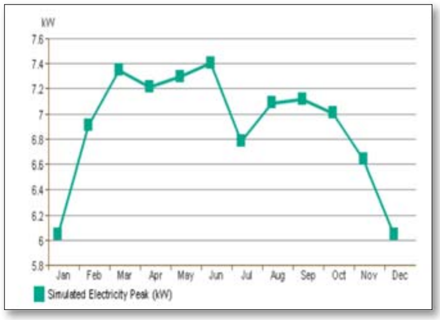
(a) Base Run Electricity Monthly Peak Demand



(b) Intermediate Run Electricity Monthly Peak Demand



(c) Intermediate Run Electricity Monthly Peak Demand

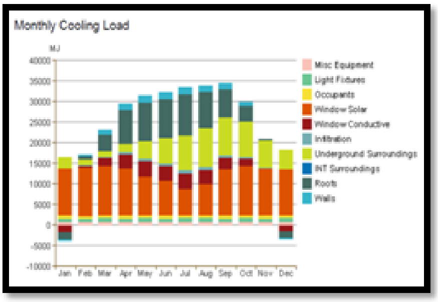


(d) Final Run Electricity Monthly Peak Demand

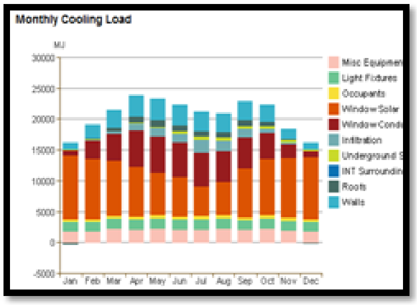
Fig. 8. Monthly Electricity Peak Demand

4.2 Monthly Cooling Load

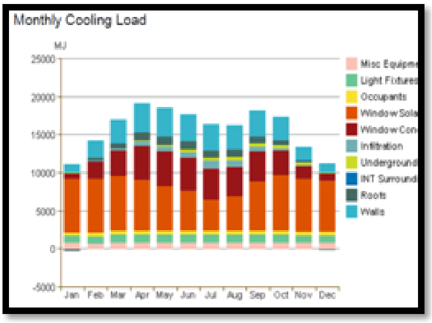
As Bangladesh has a subtropical monsoon climate characterized by wide seasonal variations in rainfall, high temperatures and humidity. There are three distinct seasons in Bangladesh: a hot, humid summer from March to June; a cool, rainy monsoon season from June to October; and a cool, dry winter from October to March. Khulna has an annual average temperature of 26.3 °C (79.3 °F) and monthly means varying between 12.4 °C (54.3 °F) in January and 34.3 °C (93.7 °F) in May. With this type of climatic condition building heating or heating load can be reduced by implementing passive energy strategies. The base run monthly cooling load is around 34500 MJ and the passive strategies able to reduce this value to 16000 MJ.



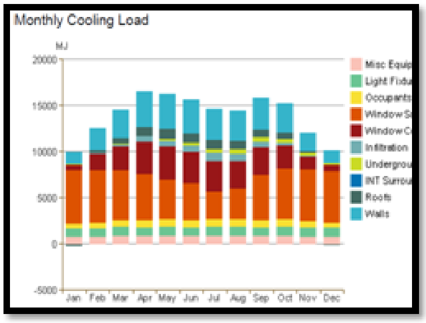
(a) Base Run Monthly Cooling Load



(b) Intermediate Run Monthly Cooling Load



(c) Intermediate Run Monthly Cooling Load



(d) Final Run Monthly Cooling Load

Fig. 9. Monthly Cooling Load

4.3 Life Cycle Energy Use/ Cost

The concept of passive energy is implemented in order to achieve the optimum building performance. The base run result of the study building is about $71,452 and with the implementation of passive strategies in terms of material change and treatment of building envelope as wall thermal property change, green wall, green roof, orientation and proper ventilation the final output of life cycle energy use/ cost is $48,993. All the passive energy strategies are able to reduce 31.43% of life cycle or annual energy use/ cost.

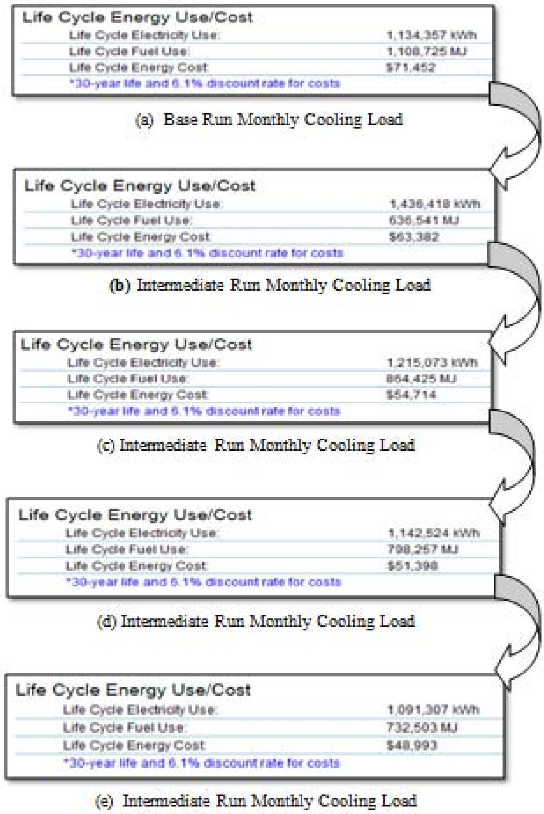
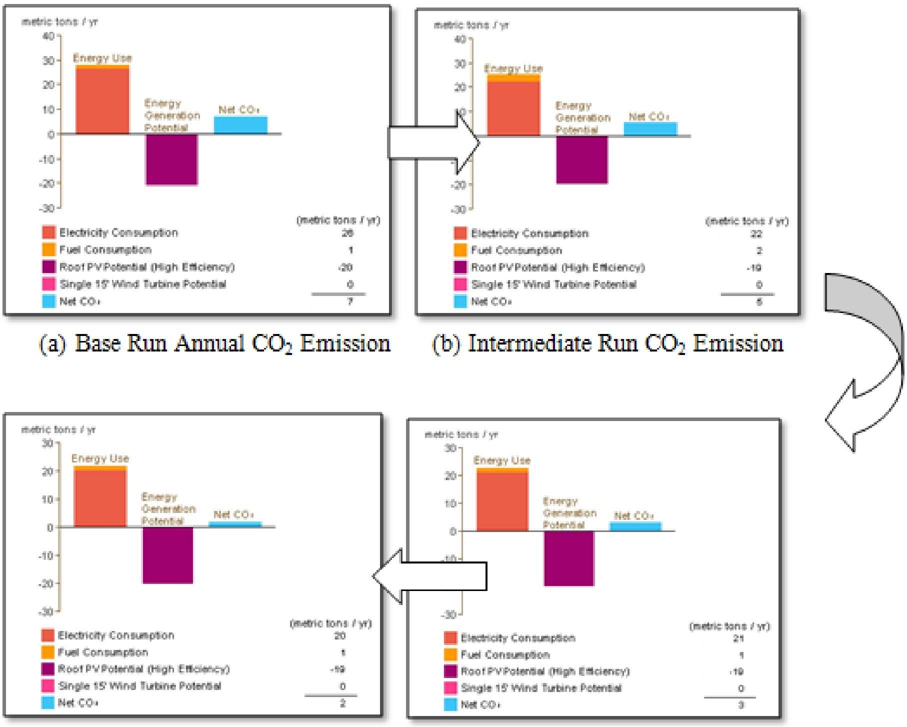


Fig. 10. Life Cycle Energy Use/ Cost

4.4 Annual Carbon Emission

From the figure 11, it is found that the net carbon dioxide (CO2) emission at existing condition of the study building is 7 tons per year. There is great potential of energy generation using roof PV is 20 tons per year and carbon dioxide emission by electricity consumption is 26 tons per year. Carbon dioxide emission due to fuel consumption is 1 ton per year. In case of optimized result, the annual carbon emission has decreased to 2 ton per year through building treatment with reduced virgin material production and green concept.



(a) Base Run Annual CO_2 Emission (b) Intermediate Run CO_2 Emission

(d) Final Run Annual CO2 Emission (c) Intermediate Run CO_2 Emission

Fig. 11. Annual CO2 Emission

5. Conclusions

With the increasing population and living standards, energy issues are becoming more crucial and challenging throughout the world. Energy issues should be given more priority because of a possible energy shortage in the future and also inefficient use of energy can have negative impacts on the environment. In order to tackle the issue of growing demand for energy, this study was carried out aiming to address the impacts of implementing passive strategies on diminishing the building energy use. The following important findings were derived from the study:

- The amount of electricity peak demand reduced to 7.4kw from 13.5kw that means the undertaken passive energy strategies able to reduce 6.1kw of electricity peak demand.
- Amount of CO_2 emission reduced around 5% per year by proper passive building treatment.
- Monthly peak demand of cooling load reduced 34500 MJ to 16000 MJ.
- Finally, it is possible to save 31.43% of life cycle or annual energy use/ cost by proper treatment of building envelope as passive energy strategy.

The results indicate all the other passive strategies applied have marginal effects on decreasing the building energy. Since it is evident that the passive strategies are more advantageous in terms of energy savings, passive building energy strategies should be primarily addressed while designing residential building.

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