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Impact of Envelope Design on Energy Consumption in Buildings

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ABSTRACT:

Energy requirements are increasing in line with population growth and globalization effects. Electricity generation facility development is not in pace with demand. So, efforts are being made world-wide to conserve energy resources and optimize the utilization of energy. "Energy efficiency is the fifth fuel after Coal, Oil & Gas, Renewable and Nuclear. It is lowest cost and emission free". One such direction is to use thermally efficient building materials in the construction industry so as to minimize the consumption of energy. Energy simulation of residential building is simulated to find various energy conservation measures (ECM) that can be implemented to minimize the energy consumption. ECM's were conducted related to external shading, building envelope and heating ventilation and air conditioning (HVAC) systems. By performing simulations net energy savings that can be obtained if ECMs are incorporated in the building design and construction phases.

INTRODUCTION

Energy requirements are increasing in line with population growth and globalization effects. Electricity generation facility development is not in pace with demand. So, efforts are being made world-wide to conserve energy resources and optimize the utilization of energy. One such direction is to use thermally efficient building materials in the construction industry so as to minimize the consumption of energy. Today, world's energy resources are depleting fast and this issue has placed the world in the grip of energy crises. In addition, increase in the amount of worldwide CO_2 emissions is damaging the ozone layer [1].

India's domestic energy consumption has increased from 80 TWh in 2000 to 186 TWh in 2012, and constitutes 22% of total current electrical consumption [2]. An increase of 400% in the aggregate floor area of buildings and 20 billion m2 of new building floor area is expected by 2030 [3].the net energy usage as end use is shown in figure 1 and figure 2.

Furthermore, due to the constant increase of Indian GDP, consumer purchasing power is predicted to grow leading to greater use of domestic appliances. Consequently, household electrical demand is expected to rise sharply in the coming decade. This growth of residential floor space, combined with expectations of improved domestic comfort, will require an increase in electricity production, leading to a significant escalation in damaging emissions. [4]

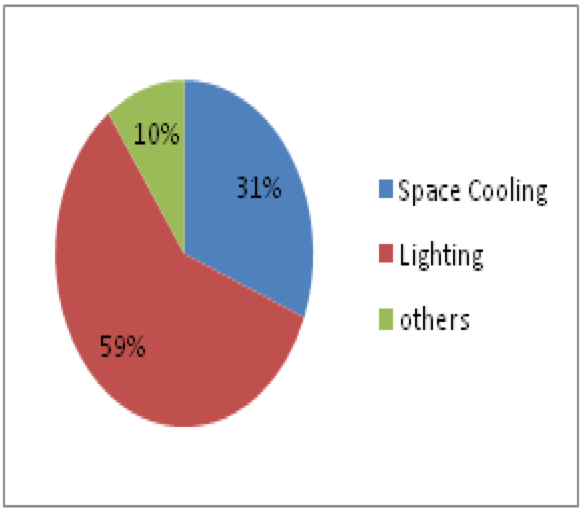

Figure 1: Electricity Usage in Commercial buildings

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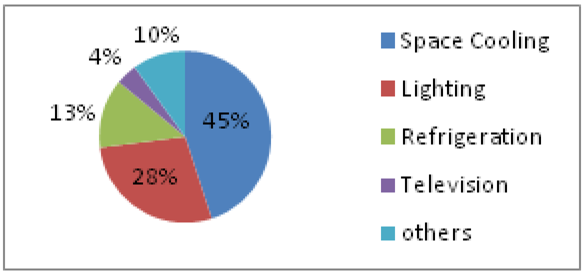

Figure 2: Electricity Usage in Residential buildings

Construction industry is the second largest economic activity in India after Agriculture and has been contributing around 8% to the nation GDP for the last 5 years (2006-07 to 2011-12) [5].

Incorporation of energy efficiency in the building sector would result in the development of a market for energy efficient products viz., Building Insulation, energy efficient windows, glass and frames, high efficiency HVAC equipment, improved design practices for lighting , natural ventilation / free cooling systems lower energy use and electricity bills and a reduced connected load and improved power factor . However, there exist certain barriers like lack of awareness about the benefits of incorporation of energy efficiency measures, a higher initial cost of energy efficient technologies, and lack of information about the pay back periods and an asymmetry in the sharing costs and benefits.

Building energy modeling has been deployed to quantify comfort benefits and the energy savings potentials of better-performing building envelopes. Energy conservation building code (ECBC) envelope characteristics have been used to determine the features of effective building envelopes. While ECBC is primarily focused on air-conditioned commercial buildings, the specified envelope characteristics in the code provide a benchmark for assessing savings potentials by building envelopes. Building energy modeling has also been used to predict energy consumption increases for higher comfort expectations and appliance usage [4].

Significance

The buildings consume large amounts of energy and entirely depend on the availability of electricity. Most importantly, the primary/basic sources for producing electricity are non-renewable energy sources such as coal, petroleum, natural gases, etc. Thus, there is a need to conserve energy at least in residential sector wherever possible. The high energy consumption is mostly related to poor thermal performance of building envelope. Hence, the energy performance of the typical building is studied to identify the potentials to conserve energy and reduce energy consumption.

ENERGY EFFICIENT BUILDING ENVELOPE

The energy efficiency of the building envelope will significantly affect the energy use in a Building. Energy efficient is easy to incorporate in the initial construction of the building, but very costly to retrofit. The following suggestions should be considered in the initial design:-

- Minimize the wall perimeter area. Use regular-shape building- square or rectangular. This minimizes the wall area and thus minimizes the heat loss.
- Insulate the building well. Install insulation in the ceiling and the walls. Check for local recommended levels.
- Use energy efficiently consideration in window selection. Use minimum amount of glass- will place.
- Consider installing insulation glass, double or triple glazed windows are cost effective.
- With proper placement of windows, natural ventilation is also feasible. Therefore, consider the use of windows that can be opened to utilize natural ventilation.
- Consider the use of tinted windows glass on all walls except the south one. The west and the east walls are strong candidates for tinted glass.
- Utilize overhangs on awnings. On the south exposure. Overhangs block the summer sun but allow the winter sun to enter. An architect can tell

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you the proper amount of overhang to allow for sunlight in winter months. It varies with location.

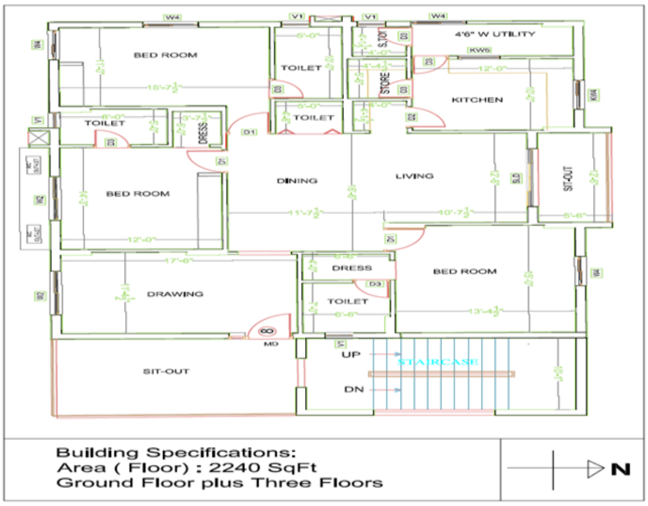

Figure 3: Floor Plan of the building under study

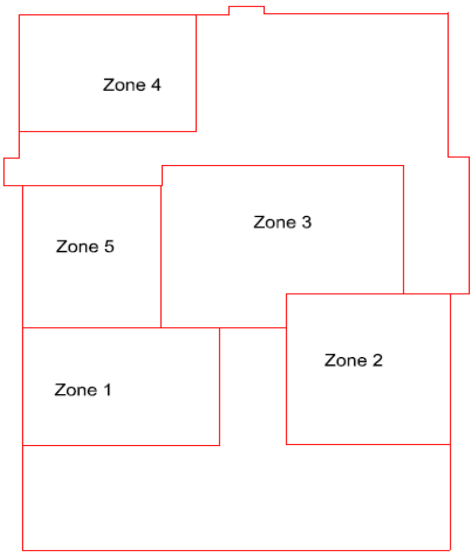

Figure 4: Single line diagram of the above floor plan Indicating Zones Under Study

- Passive solar system help to further reduce energy cost, and they provide attractive for the personnel.
- Design the roof carefully. Use light colors in warm climate and dark I cold. Design the roof so it can be sprayed in the summer. Be careful not to flood the roof—it will leak eventually.
- Engineer all wall opening for energy efficiency. Minimize the number of openings. Caulk and weather-strip the door and windows well.
- Consider interlocking the doors and the heating units so that when the doors are open, the heat is off. Utilize automatic doors various types of “see through” material (plastic strips, Plexiglass, etc) for doors that must be used frequently. Air curtains are another option for minimizing heat loss.

BUILDING DESCRIPTION

The building considered in this study is a three story building located in Hyderabad, Telangana in the south of India. The floor area of the building is 2220 sq ft and its floor to floor height is 13 ft. The walls of the building consist mainly of brick and plaster without any insulation. The roof consists of 125mm concrete block and without insulation. The windows are dotted plane with a shading coefficient of 1.0 is considered. The HVAC systems used in the building is direct expansion system (DX) system one for each zones on each floor.

The building drawing as shown in figure 3 and Single line diagram of the above floor plan Indicating Zonesin figure 4 under study

ENERGY ANALYSIS SIMULATION METHODS & TECHNIQUES

Many of the popular building energy simulation programs around the world are reaching maturity, some use simulation methods (and even code) that originated in the 1960s. BLAST (Building Loads Analysis and System Thermodynamics) and DOE-2 (Department of Energy) are two mainly used energy simulation software’s in USA. The 30 years have seen significant advances in analysis and computational methods and power, providing an opportunity for significant improvement in these tools. The main difference between the two programs is load calculation method, DOE-2 uses a room weighting factor approach while BLAST uses a heat balance approach. Both programs are widely used throughout the world.

eQUEST® v3.65 is a sophisticated, yet easy to use building energy use analysis tool which provides professional-level results with an affordable level of effort. This tool was designed to allow to perform detailed analysis of today's state-of-the-art building design technologies using today's most sophisticated building energy use simulation techniques but without requiring extensive experience in the "art" of building performance modelling. This is accomplished by combining a building creation wizard, an energy efficiency measure (EEM) wizard and a graphical results display module with an enhanced DOE-2-derived building energy use simulation program.

eQUEST = enhanced DOE-2 + Wizards + Graphics

This is accomplished by combining a building creation wizard, an energy efficiency measure (EEM) wizard, and graphical reporting with a simulation "engine" derived from the latest version of DOE-2.

eQUEST features a building creation "wizard" that walks you through the process of creating an effective building energy model. This involves following a series of steps that help you describe the features of your design that would impact energy use, such as: architectural design, HVAC equipment, building type and size, floor plan layout, construction materials, area usage and occupancy, lighting system.

Building Creation Wizard

The eQUEST building creation wizard first requests the most general information about your building design, and then delves into progressively deeper detail. In all, the building description process comprises 23 data-entry steps - each represented by a "wizard" screen.

At each step of describing your building design, the wizard provides easy-to-understand choices of component and system options. It also offers advice in the form of "intelligent defaults" for each choice. (These defaults are based on more information gathered early in the description process). In addition, eQUEST automatically skips steps that do not apply to your design. Although the building description process can get quite detailed, it isn't necessary to complete every single step in the wizard.

After compiling a building description, eQUEST produces a detailed simulation of your building, as well as an estimate of how much energy it would use. Although these results are generated quickly, they are quite accurate because this software utilizes the full capabilities of DOE-2 (the latest version of a well-respected and popular building energy simulation program developed over the last 20 years by the U.S. DOE). Within eQUEST, DOE-2 performs an hourly simulation of your building design for a one-year period. It calculates heating or cooling loads for each hour of the year, based on the factors such as: walls, windows, glass, people, plug loads, ventilation

Viewing eQUEST Results

eQUEST offers several graphical formats for viewing simulation results. For instance, you can display graphs of estimated overall building energy on an annual or monthly basis. (See Figure 5.) You also can compare the performance of alternative building designs. (See Figure 6.)

In addition, eQUEST allows you to perform multiple simulations and view the alternative results in side-by-side graphics. It offers: Energy cost estimating, Daylighting and lighting system control, Automatic implementation of common energy efficiency measures (by selecting preferred measures from a list)

The current version of eQUEST provides even more comprehensive analysis capability. It allows the advanced user to input additional building details to analyze complex buildings. A three-dimensional view of the building geometry is available in this version, as well as HVAC system diagrams. In addition, rate schedules for PG&E, SCE, and SDG&E are embedded in the program.

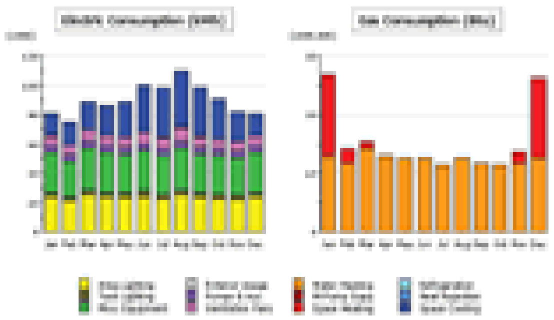

Figure 5: A building's projected monthly energy consumption, with consumption attributed to various end-use categories

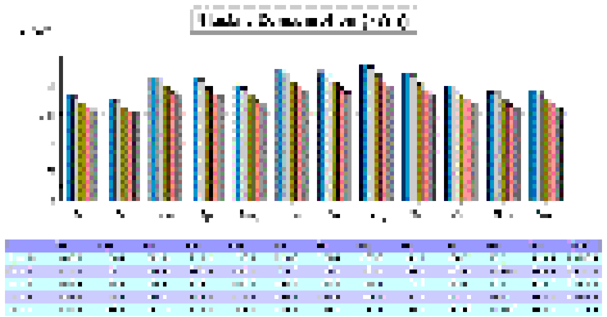

Figure 6: Comparison of monthly energy use for base building design and four alternatives which incorporate Energy Efficiency Measures (EEMs)

In this project, the building model is used to investigate two specific energy conservation opportunities. The first investigation involves modifications to the building envelope. The purpose of this investigation is not only to evaluate any economic savings available with these types of modifications but also to determine how sensitive energy consumption and demand are to envelope changes. In the second Investigation the lighting system requirement for a residential building is studied and its effect on energy consumption is been studied. Several parametric studies were conducted to enable sensitivity analyses of energy-efficient Residential buildings namely relating to building envelope, lighting system, Interior Shading to the Windows [6].

DEVELOPMENT OF BASE MODEL

This section summarizes the development of the base model characteristics of the building in eQUEST as the base case model. First relevant data pertaining to the building was retrieved and was then used to develop the model. The retrieved data included information pertaining to the floor plans, lighting, air handling unit (AHU), fan coil unit (FCU), wall assembly, roof assembly, windows, etc. Based on the availability of the data, the final model of the building was considered as the base case as shown in table 1.

Table 1: Energy simulation of the base case residential building

Characteristics	Description of the Base Case
Location	Hyderabad 17.37N latitude, 78.48˚ E Longitude
Orientation	Front Elevation facing East
Plan Shape	Polygon
Number of floor	Three (3)
Floor to Floor Height	13 FT
Floor Area	2220 SQFT x 3
Window Area	15.25%
Type of Glass	Plane dotted glass 4mm
Solar Absorbance (for Exterior Surfaces)	0.6
Exterior Walls	8” thick Brick walls
Roof	5” mm Concrete slab
Floor	G+3
Occupancy Density	6
Lighting Power Density	Living Area 1.2 w/sft, Sleeping Area 1.2w/sft
Equipment Power Density	10
Infiltration	0.5 ACH
System Type	Direct Expansion System
Thermostat Setting	2478 degree F
Weather File	ISHRAE Hyderabad

The drawing was examined to know the orientation of the building. The x and y coordinate option in the custom block of eQUEST was used to develop the model zone by zone. All the required input values were calculated and supplied to the tool. Care was taken in calculating lighting power density and equipment power density for various zones in the building. The model of the building was divided into three levels comprising one floor at each level. Proper care was taken to relate the opening of higher levels to lower levels. Information with respect to wall and roof assemblies and windows was provided by constructing them in eQUEST.

ENERGY ANALYSIS OF THE BASE CAES

With the input of the required information, the building's base case model was ready for carrying out simulations in order to assess its energy performance. Figure 7 below shows monthly base case energy consumption.

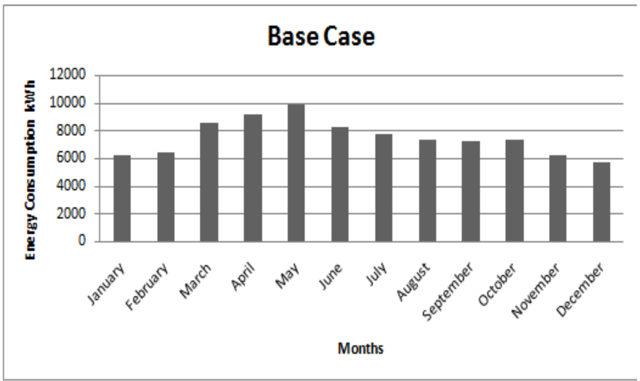

Figure 7: Monthly Energy Consumption of the Base Case Building.

After performing the simulations, the area is identified which has the potential to conserve energy was found in space cooling. Electricity end-use of about 45,490kWh was being consumed for space cooling throughout the year as shown in figure 8. Compared to the total electricity end-use which was found to be 89,740 kWh, space cooling accounted for about 50.69%.

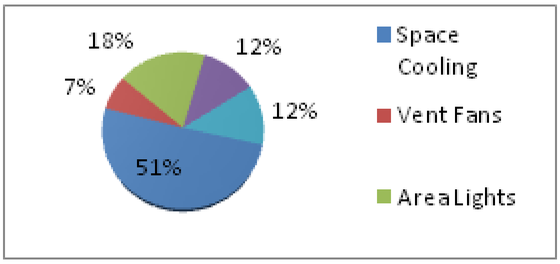

Figure 8: Electricity End Use of Base Case

ENERGY CONSERVATION MEASURES

After the identification of energy conservation potentials various energy conservation measures were considered in the analysis. Section 7.1 talks about the impact of glazing type and external shading on energy consumption. Section 7.2 deals with the impact of the envelope thermal design on energy performance of the building. The third and the last section, i.e. section 7.3, deals with the utilization of ECBC Code in achieving reduced energy consumption all year round

Impact of Glazing Type and External Shading

This section is divided into three different cases. These include the following

- Base case + External Shading (Overhangs & Fins)
- Base case + External Shading + Double Glazing
- Base case + External Shading + Double Low-e

Base case + External Shading

Depending upon the orientation of the building, the windows on east and west side contribute large amount of heat gain into the building. As it is described earlier, space cooling accounts for highest energy consumption. Energy conservation measure such as over hangs and fins are added on windows, so that heat gain can be reduced through windows. The depth of over hangs and fins are taken as 2ft on each side, which are predominant in Hyderabad.

The result after incorporating the external shading into the model was much reduced energy consumption of about 88,090 kWh with a percentage reduction of 1.83% when compared to the Base Case. These are depicted in figure 9.

Base case + External Shading + Double Glazing

Double Glass clear/tint with the cross-sectional dimensions of 4/6/4mm was considered. It is characterized by a shading coefficient of 0.86 and solar heat gain coefficient of 0.76.

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Results after the simulation show even more reduced energy consumption compared to the base case. These are depicted in figure 9.

Base case + External Shading + Double Low-e

The double glazing considered in the previous case was replaced by Double Low-e characterized with a shading coefficient of 0.60, solar heat gain coefficient 0.53. The results are portrayed in figure. The total energy savings as a result of the energy conservation measures discussed above are shown in figure 9.

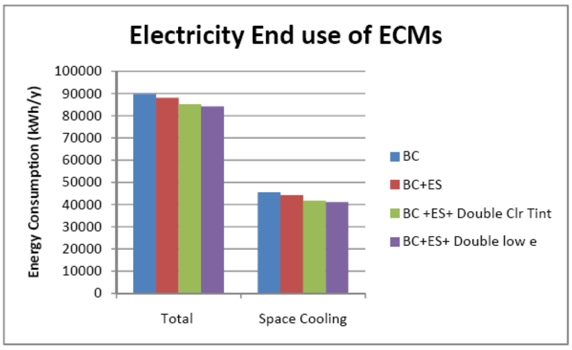

Figure 9: Electricity End-Use of different ECMs (Windows)

The total electricity end-use after implementing all the ECMs in this section is about 85,100 kWh and 84,230 kWh for Double Bronze and Double Low-e glazing types respectively. The selection of the double glazing and low e type depends on the cost analysis. The plots in figure 9 show great decrease in cooling energy consumption. Total percentage decrease when “Double Bronze” and “Double Low-e” were separately considered was found to be 5.17% and 6.14% respectively compared to the Base Case. Decrease in the percentage of cooling energy for both “Double Bronze” and “Double Low-e” was 8.22% and 9.76% respectively.

Impact of Code Compliance

The separate analysis was carried out to know the impact of code requirements (for wall design, roof design and lighting design) on the energy performance of the Base Case. With respect to wall and roof code requirements, ECBC user guide-2009 and NBC of India 2005 has best suitable guidelines from the view point of energy efficiency. This was followed by the lighting requirements for buildings by selecting Lighting Power Density (LPD) from appropriate tables, building area method and space function method. All these measures were based on Energy Conservation and Building Codes (ECBC) [7]. NBC of India 2005 [8] was also used in identifying appropriate ECBC 2009 requirements.

Impact of Wall & Roof Design

The R-value of wall and roof assemblies as per the ECBC 2009 requirements for climatic conditions of Hyderabad which is composite climate zone (tropical wet and dry climate) [7]. This was identified based on the climate zone mentioned in the ECBC 2009. The appropriate climate zone was identified based on the degree days for Hyderabad as per NBC of India 2005. The R-value of the Base Case wall was not in compliance with ECBC 2009 and need to be changed and also the new roof had to be changed in the Base Case model. Care was taken while modelling to overcome the unavailability of materials mentioned by concentrating on the U-value of the wall and roof. The roof with an additional insulation of 75 mm polyurethane and additional insulation in the wall of polyurethane. Simulations were carried out after modelling the wall and roof assemblies. The results are shown in figure 10. The total energy consumption reduced to 86,740 kWh with a percentage decrease of 3.34% whereas there was a percentage decrease in cooling energy consumption of 6.06%.

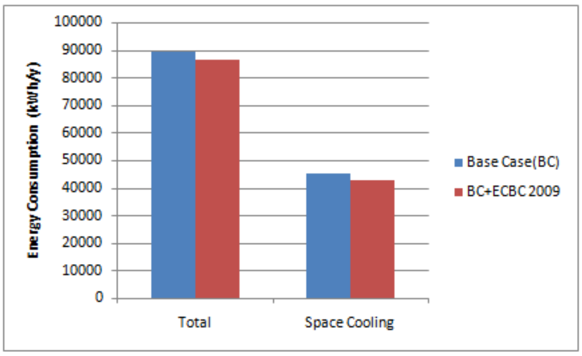

Figure 10: Total & Cooling Energy Consumptions (ECBC Envelope)

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Impact of Lighting

The lighting power density selected was as per the ECBC 2009 for buildings, as per space requirement. As per the code, the interior lighting power densities is specified for various building types which is based on two methods Building Area Method and Space function Method. Lighting Power Density (LPD) is taken proportionately based on area of the floor space. Results of lighting are shown along with the ECBC wall and roof requirements in figure 11.

The total energy consumption reduced to 82,340kWh with a percentage decrease of 8.25% whereas there was a percentage decrease in lighting energy consumption of 20.08%.

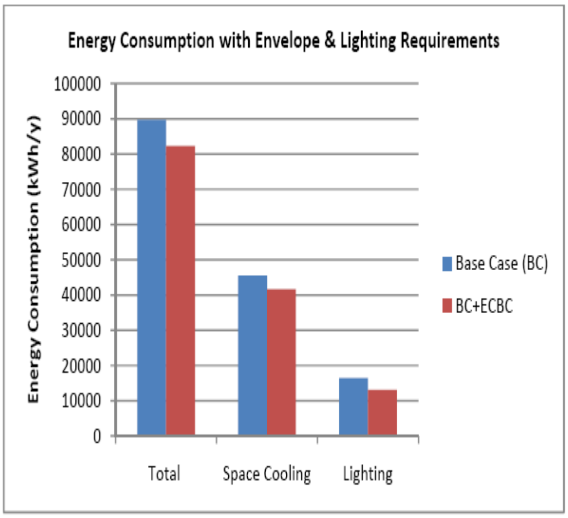

Figure 11: Energy Consumption with Envelope & lighting Requirements

Impact of HVAC systems

The HVAC system used to supply cooling requirements to the building is a direct expansion (DX) system. The same system with a better Energy Efficiency ratio (EER) of 10.24 & Coefficient of Performance (COP) of 3.00 is used to understand its impact on energy consumption. Unlike in the base case EER and COP was 8.8 and 2.72 respectively. The DX system is described briefly in table 2.

Table 2: DX system description in BC and BC+ECMs

Systems	Base Case	BC + ECMs
Operating Time	5 PM-9 AM	5 PM-9 AM
Thermostat location	Within Zone	Within Zone
Thermostat Settings	78°F	78°F
EER	8.80	10.24
COP	2.72	3.00

The package HVAC unit have EER = 10.24.The total energy consumption reduced to **82,970 kWh** with a percentage decrease of **7.54%** whereas the percentage decrease in cooling energy consumption of **14.88%**. The total energy savings as a result of the energy conservation measures with respect to HVAC system are shown in figure 12.

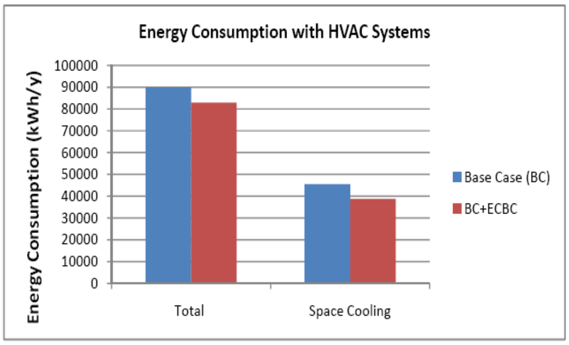

Figure 12: Energy consumptions with HVAC systems

CONCLUSION

Energy analysis of a residential building located in Hyderabad is performed. Considered in the analysis were various strategies to achieve energy efficiency. Code compliance was also used to appreciate the corresponding energy performance. Three recommendations were given that incorporated the window system design, Envelope design as per ECBC and HVAC system selection. The ECMs selection is analyzed as recommendations to achieve energy efficiency. Percentage energy reductions when all of the ECMs are incorporated in construction phase the net energy savings of 23.59% can be obtained. Further analysis needs to be carried out to better understand the impact of supply air temperature in the HVAC system, the envelope design, the development of near real building Base Case model and in the Base Case considerations.

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