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Energy Conservation Measures for an Office Building in Warm and Humid Climate

Tini Grace Abraham[1], Sandhyalaxmi G Navada[1], Savitha G Kini[1] and Nidhi Gupta[2]

[1]Energy Management Auditing and Lighting (M.Tech), Manipal Institute of Technology (MIT), Manipal, Karnataka, India tinigraceabraham07@gmail.com, sandhya.girish@manipal.edu, savitha.kini@manipal.edu
[2]Environmental Design Solutions Pvt. Ltd., India; nidhi@edsglobal.com

Abstract

Objective: To study the effect of various energy conservation measures on building energy performance. Analysis: U.S Green Building Council's Leadership in Energy and Environmental Design (LEED) Rating System for green building uses energy modeling as one way to demonstrate the energy use of a building and to quantify the savings to the proposed design. A whole building energy simulation tool, Visual DOE4.0 is used to estimate the energy performance of an office building in warm and humid climate. The tool is used for recommending energy saving strategies for insulation, glazing, shading devices, lighting and controls and air conditioning equipment. Performance analysis of the building with different combinations of measures is carried out to identify the best possible strategy. Findings: It is analyzed green roof, insulated AAC wall, glazing system with low Solar Factor (SF) , shading devices, energy efficient air conditioning and efficient lighting systems & control helps in reducing the annual energy consumption of building by 20.85% compared to American Standard for Heating Refrigeration and Air conditioning Engineer's (ASHRAE) standard building. **Improvement:** Further investigation can be carried out with different configurations in wall, roof, shading devices, air conditioning system, using daylight sensors in the periphery and also by the use of renewable energy sources.

Keywords: ASHRAE; Component; Energy Modeling LEED, Energy Performance, VisualDOE

1. Introduction

Forty percent of global energy is consumed by building which accounts to one-third of the Green-House Gas (GHG) emissions both in developed and developing countries. Green house gas emissions from buildings primarily arise from their consumption of fossil fuel based energy[1]. The construction of green buildings can reduce the GHG emission to a large extent. As per United States Green Building Council (USGBC) a green building consumes less energy, less water, produces less waste and is healthier for the people living inside compared to a standard building[2]. Building more efficient structures such as green buildings helps in reducing the carbon emissions by 60% or more, which amounts to 1.35 million tonnes of carbon, it is proposed in a conference conducted in[3].

Energy simulation tools such as Visual DOE 4.0 helps in understanding the energy performance of the building in early building design stages. Design decisions can be quantitatively justified using these tools. This applies equally to the building in early and final designs, as well as to buildings under constructions, or those undergoing retrofitting or major renovations[4]. In this paper, the whole building energy simulation is performed on an office building located in Andheri east, Mumbai, India. The building is targeting USGBC, Leadership in Energy and Environmental Designs New Construction (LEED NC) certification. The US Department of Energy building simulation software (Visual DOE 4.0) is used to compare the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 90.1_2007 standard building with proposed designs of the building[2,5]. Weather

**Author for correspondence*

analysis conducted using climate consultant software 5.5 also aids in choosing the conservation measures[6]. Different measures such as envelope, glazing, HVAC and lighting are analyzed[7-10]. Comparison study conducted provided the basis for selecting building envelope parameter, HVAC and lighting systems & controls. Whole building energy simulation tool helps in analysing strategies to design an energy efficient building compared to ASHRAE standard building. The savings achieved will help in gaining points under LEED, Energy and Atmosphere (EA) credit under new construction certification[2].

2. Weather Data Analysis

2.1 Description of the Building.

The whole building energy simulation is evaluated for a seven storied building which is undergoing major renovation. The building is located in Andheri East, Mumbai, India at 19.12° North and 72.85° east. The building has a gross floor area of the building of 22736 ft^2 with a designed conditioned area of 16,193ft^2. The building contains cabins, meeting rooms (MR), training rooms, and cafeteria with no cooking facility, software testing labs, electrical rooms, toilets, Air Handling Unit (AHU) room, Lift Lobbies (LL), server rooms and open office spaces. Figure 1 shows the plan of seventh floor office area.

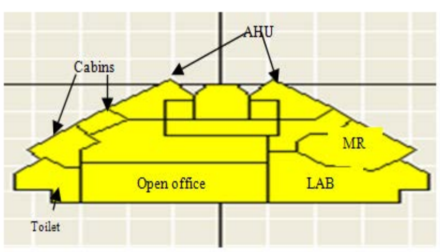

Figure 1. Plan for seventh floor.

As the building is undergoing major renovation, the orientation and shell of the building remains the same. These parameters cannot be altered while doing energy simulation.

2.2 Strategies Recommednded using Climate Consulatant Software

Mumbai is classified under warm and humid climatic zone. The climate of Mumbai can be characterized as having four principal seasons: Summer (March to June); Monsoon (July to September), Post monsoon (October to November) and winter (December to February). The maximum temperature in summer is 36°C and minimum temperature is 19°C[6].

The thermal comfort of an occupant in a particular environment is not fixed and it depends on the outdoor weather conditions. Therefore, with the variation in mean monthly outdoor dry bulb temperature the adaptive thermal comfort temperature also varies. Climate consultant software is used to analyze dry bulb temperature, wet bulb temperature, wind velocity and solar radiations in Mumbai. It showed that the maximum dry bulb temperature with high wet bulb temperature is observed in the months March to June (Figure 2). The wind velocity throughout the year is in the range of 6-15m/s. The phychrometric chart in Figure 3 is used to identify the cooling strategies that can be implemented in the building throughout the year for comfort. Strategies recommended for a building in warm and humid climate are:

- Shading to be provided at all openings in order to reduce the heat gain and thus reducing the energy consumption. This also helps in reducing the glare.
- Vegetation on the west side to be retained to reduce heat gain and glare.
- Wall window ratio to be minimized for the south and west facing facades. Use glazing with low solar heat gain coefficient to reduce the heat gain.
- Insulation to be provided on the roof to reduce heat gain.
- High thermal mass to be used to absorb the heat during the day time for reducing the cooling load.

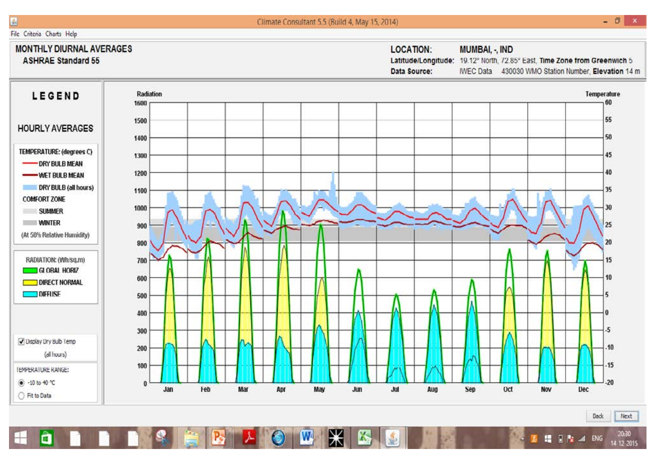

Figure 2. Monthly diurnal averages for Mumbai, India.

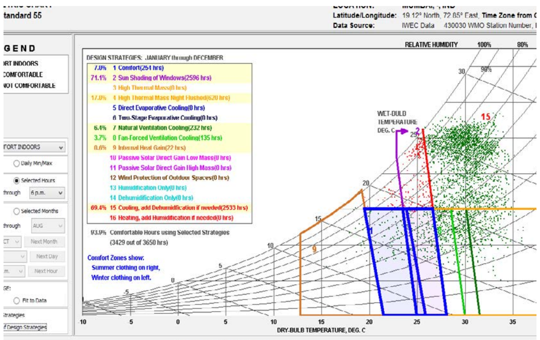

Figure 3. Phychrometric chart from climate Consultant software recommending the strategies to reduce the cooling demand throughout a year.

3. Whole Building Energy Simulation

Whole building energy simulation is performed using Visual DOE 4.0. Figure 4 illustrates the analysis methodology. First, base cases are modeled according to ASHARE standards with present orientation and by rotating the building in 90, 180 and 270 degrees[2]. Then different energy conservation measures on envelope, lighting and HVAC system will be modeled. Envelope measures include different configurations for roof, wall and glazing. Lighting measures include reduction in Lighting Power Density (LPD) and by using controls. HVAC measures include the use of efficient HVAC system. The best suited option for the building will be selected to be the proposed case. Then, overall savings is obtained by comparing the proposed case with the base case.

Two types of loads, process and non-process loads are considered while modelling the building. The process energy is considered to include but is not limited to office, general equipment, computers, and elevators. The non process energy includes lighting (for interior, parking garage, surface parking), Heating, Ventilation And Air Conditioning (HVAC) (for space heating, space cooling, fans, pumps, toilet exhaust). While modeling the base case and the proposed case certain parameters are considered constant. The constant parameters are building area, orientation, floor, height, function, occupancy schedules, process loads, and holidays, air conditioned area and wall window ratio[2].

3.1 Base Case

The baseline building performance is calculated as per the building performance rating method in Appendix G of ASHRAE 90.1_2007. The building is simulated with its actual orientation and again rotating the entire building by 90, 180, 270 degrees, then averaging the results to get the ASHRAE baseline building annual energy consumption in Kilowatt hours.

Table 1 shows the input parameters of the building as per appendix G of ASHARE 90.1_2007. The wall window ratio is kept as per the design as it is lower than 40% as mentioned in ASHRAE standards.

Table 1. Input parameters of the building.

Component	Description	
Wall	Material	Steel Frame Construction
	U value	0.124 Btu/hr.ft2.°F
Slab	Material	ASHRAE Steel Joist Floor
	U value	0.35 Btu/hr.ft2.°F
Roof	Material	RCC slab + Over deck Insulation
	U value	0.063 Btu/hr.ft2.°F
	Reflectivity	0.30
Fenestration	Material	Double Glazed Unit
	U value	1.22 Btu/hr.ft2.°F
	SHGC	0.25
	VLT (%)	35%
Window to Wall ratio	(%)	25.1%
Shading Devices		None
Lighting power density	Office spaces	$1W/ft^2$
	Parking spaces	$0.3W/ft^2$
HVAC-Water cooled screw chiller	Capacity	112Ton; 0.79kW/ton
	Number	112
	Water supply temperature	44°C
	Return water temperature	85°C
	Set point temperature	24°C

Schedules of people, lighting, equipment and infiltration rates are adjusted according to the building operational schedules. The infiltration rates for the build-

Table 2. Annual energy consumption for base case with different orientations.

	Base Case 0	Base case 90	Base case 180	Base case 270	Average base case
Total energy consumed (kWh)	562,217	5,21,898	5,28,909	5,58,036	5,42,765

ing are assumed to be 0.3 ACH. The model is simulated with the above parameters and it is found that the present orientation consumes more energy than other building orientations. It is seen that 62% of total energy is consumed by the HVAC system. Table 2 shows the variation in energy consumption in base case with different orientations.

3.2 Energy Conservation Measures

The study of base case indicates that HVAC system consumes more power compared to other loads in the system. Energy Conservation Measures (ECM) is opted in order to reduce the cooling load of the building. The air conditioning load depends on two major factors; the internal heat gain and external heat gain. The internal heat gain depends on occupants and the lighting equipment used in the building. External heat gain depends on building elements such as roof, wall, slab, window etc. So ECM's are opted based on the study conducted in climate consultant software to reduce the active load on the building. The ECM's selected for study includes suitable selection of building envelope materials, lighting design and HVAC system[11-16]. Using energy simulation model, several different opportunities for energy conservation were investigated. The first investigation involves modification of envelope materials. The purpose of this investigation is to evaluate how energy consumption varies in a building by using different envelope materials. In the second investigation is to evaluate how lighting and air handling energy consumption can be reduced by changing the lighting power density by using efficient fixtures and by the use of occupancy sensors. The third investigation is done to evaluate the savings achieved by use of efficient air conditioning systems. The final investigation is to see how much overall savings is achieved by combination of first, second and third investigation measures. All ECM's will be compared with ASHRAE base case 0 in order to analyse the savings achieved. Combined case will be compared with ASHRAE average base case to analyse the overall percentage savings and thus the LEED points achieved.

3.2.1 Envelope Measures

These measures include changing the parameters of the roof, wall, floor, glazing system.

3.2.1 Using Shading Devices

This building has its glazing facing the east, west, south and north sides. A large part of the office areas faces south direction. In order to reduce the heat gain through the facades shading devices are implemented. Two options are being selected for shading devices. Table 3 shows the effect of shading devices on energy consumption.

Shading option 1: The shading devices are modeled with a fin depth of 0.66ft and 7.9ft fin to fin distance in the south facing façade. For east and west facing facades the horizontal louvers are modeled with a depth 1.9ft and vertical fins with a depth 19ft. The distance between the windows is the distance between the vertical fins. Horizontal fins are placed at the top of the windows with length equal to the width of the window. The shading device saves 2.28% when compared with the ASHARE base case 0.

Shading option 2: The shading devices are modeled with a fin depth of 1.3ft and 4ft fin to fin distance on the south facing façade and for east and west facing facades the horizontal louvers are modeled as same as that of shading option I. The shading device designed in this manner saves about 2.25% compared to the ASHRAE base case 0. This option is not selected for combined case as it gives lesser amount of savings compared to option 1.

Table 3. Effect of shading on annual energy use.

	Base Case 0	Shading option 1	Shading option 2
Total energy consumed (kWh)	562,217	549,405	549,559

Cooling energy (kWh)	348,384	335,572	335,726
Savings		2.28%	2.25

3.2.2 Wall Components

Analysis is carried out to find the best wall configurations that can be implemented in the project to reduce the cooling load so as to reduce the overall energy consumption of the building. Different types of wall configurations are modeled and simulated. Table 4 shows the effect of different wall materials on energy consumption.

- *Wall type 1: Autoclaved aerated concrete (AAC):* Using an AAC wall with a U value of 0.1348 Btu/hr.ft^2.°F and with thickness of 11 inches saves up to 1.55% of annual energy consumption.
- *Wall type 2: Insulated AAC wall:* An AAC wall with fiber wool and gypsum board insulations with an overall U value of 0.0677 Btu/hr.ft^2.°F saves up to 3.87% of annual energy consumption.
- *Wall type 3: Brick wall with fiber wool insulation:* This type of wall with a U value of about 0.1078 Btu/hr.ft^2.°F saves 3.13% on annual energy consumption.
- *Wall type 4: Brick wall with polystyrene insulation:* this wall with a U value of 0.098 Btu/hr.ft^2.°F saves approximately 3.24%.

AAC wall with insulation is preferred against other wall components.

3.2.3 Roof Insulations

Roof being exposed throughout the day receives maximum amount of solar radiation. Heat gain through the roof surfaces can be reduced by providing proper insulations. Two options are modeled and simulated for roof with insulation. Table 5 shows the effect of different type of roof insulation on energy consumption.

- High albedo insulation on the top of reinenforced cemenet concrete roof gives an overall U value of 0.0607 Btu/hr.ft^2.°F and saves about 0.78% of the energy.
- Green roof with an overall U value of 0.045 Btu/hr.ft^2.°F saves about 0.86% of energy.

Table 5. Effect of roof insulation on annual energy use.

	Base case 0	**Albedo**	**Green roof**
Total energy consumption(kWh)	562,217	557,820	557,364
Cooling energy consumption(kWh)	348,384	343,987	343,531
Savings		0.78%	0.86%

Green roof is selected for roof insulation as it gives more savings compared to high albedo roof. The savings achieved is very low as the roof area is very small compared to the building area.

3.2.4 Window Glazing

The window selected in base case is based on the prescriptive requirements of ASHRAE 90.1 and is very energy efficient. This energy conservation measure evaluates the impact of replacing the glazing with a more efficient one. Table 6 shows the effect of different glazing systems on energy consumption. Different types of glazing's selected are:

a) Double Glazed unit with solar factor of 0.23, solar coefficient of 0.27 and visual light transmittance of 42% saves 1.76% on annual energy consumption.
b) Double glazed unit with solar factor of 0.22, solar coefficient of 0.25 and visual light transmittance of 31% saves 2.17% on annual energy consumption.

Table 4. Effect of wall on annual energy use.

	Base case 0	**Wall type 1**	**Wall type 2**	**Wall type 3**	**Wall type 4**
Total energy consumption (kWh)	562,217	553,483	540,464	544,647	543,998
Cooling energy (kWh)	348,384	339,650	326,631	330,814	330,165
Savings		1.55%	3.87%	3.13%	3.24%

Table 6. Effect of glazing on annual energy consumption.

	Base case	Glazing type I	Glazing type II
Total energy consumption(kWh)	562,217	552,350	550,007
Cooling energy consumption(kWh)	348,384	338,517	336,174
Savings		1.76%	2.17%

The glazing system plays an important role in reducing the external heat gains and thus affecting the energy use pattern for the building. Option b) is most suitable for the building as large percentage of facades is on the south and west side. Glazing with a solar factor in option a) is selected as preferred by the architect.

3.2.5 Lighting Loads

Lighting energy in the building is approximately 12% of the total energy consumption. Efficiency of the lighting system within a building can be improved by variety of methods. These measures include usage of efficient lighting lamps for both interior and exterior spaces and control devices. The usage of efficient lighting systems, saves approximately 7.57% energy in interior lighting. This is achieved by reducing the LPD value from 1W/ft^2 to 0.65w/ft^2 in all office spaces and 0.3W/ ft^2 to 0.2 W/ ft^2 in parking spaces. Total wattage of exterior lighting for base case is calculated using ASHRAE standards and was found to be about 2.241kW. The use of efficient fixtures reduces the wattage of exterior lighting to 2kW thus saving 0.63% on annual energy consumption.

Control devices such as occupancy sensor, daylight sensor can be used to reduce the energy associated with the lighting and conditioning systems. According to ASHRAE standards the placements of occupancy sensors in closed rooms spaces can be modeled by reducing the LPD values by 15%. By placing occupancy sensor in closed rooms, savings of 2.10% is achieved in simulation. Table 7 shows the effect of LPD reduction and occupancy sensor on annual energy consumption.

3.2.6 Efficient Air Conditioning System

Base case is modeled with water cooled screw chiller with 0.79kW/ton and two speed fan for cooling tower as per ASHRAE 90.1 standards. Energy conservation measures include using water cooled screw chiller with full load efficiency of 0.527kW/ton, variable speed fan for cooling tower, variable speed secondary pump, and heat recovery ventilator. Using these measures saves 14.38% on annual energy consumption. This energy conservation measure resulted in significant savings. Table 8 shows the effect of this conservation measures on the annual energy consumption.

Table 7. Effect of LPD reduction and occupancy sensor on annual energy consumption.

	Base case	LPD reduction	Occupancy sensor
Total energy consumption(kWh)	562,217	519,639	550,598
Cooling energy consumption(kWh)	348,384	328,972	338,058
Lighting energy consumption(kWh)	66,244	43,078	64,751
Savings		7.57%	2.10%

Table 8. Effect of efficient air conditioning system annual energy consumption.

	Base case	Efficient energy air conditioning system
Total energy consumption(kWh)	562,217	481,391
Cooling energy consumption(kWh)	348,384	267,558
Savings		14.38%

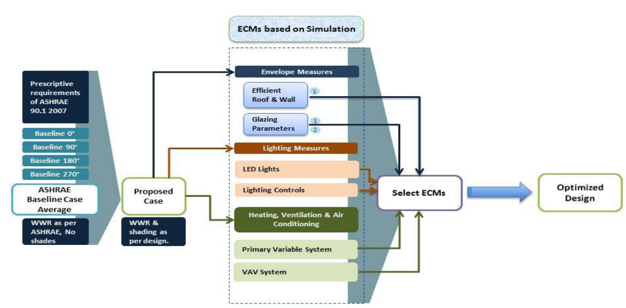

Figure 4. Graphical representation of analysis methodology.

3.3 Energy use for Combined ECM

The annual energy consumption for the combined ECM is shown in Figure 5. With shading option 1, AAC wall with insulation, green roof, glazing with solar factor of

0.22, LPD of 0.65 W/ft^2 for office spaces and 0.2W/ft^2 for parking spaces and with use of efficient air conditioning system, total savings of 20.85% is achieved by comparing the combined ECM's with average base case.

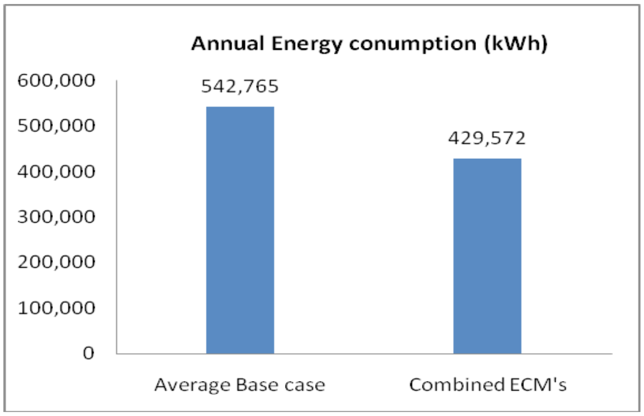

Figure 5. Annual energy consumption of combined ECM's and average base case.

4. Conclusion

The climate consultant software 5.5 helped in analyzing the passive design strategies that can be implemented in a building in order to reduce energy consumption by active design strategies. Night flush out is a strategy that can also be carried out when night temperatures are lower than the day time temperatures. Thus, reducing the cooling load on the building. With the help of energy simulation tool, Visual DOE 4.0 it was analyzed that the present orientation of the building consumes more energy than other orientations. The impacts of building envelope parameters such as shading devices, roofs, wall and selection of HVAC and lighting system on the energy consumption on a commercial building in warm and humid climate was studied. Implementation of shading devices, AAC wall with insulation, green roof, window with solar factor of 0.23, lighting power reduction in all spaces, usage of occupancy sensor and efficient HVAC system helps in achieving savings of about 20.85% compared with an ASHRAE standard building. Furthermore, savings can be achieved by proper operation of the building. The savings achieved from average ASHRAE base case helps in gaining 7 points under LEED new construction certification.

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