*International Journal of Engineering Trends and Technology- Volume3Issue3- 2012*

# Energy Performance and EEMs Evaluation of a Commercial Building in Warm and Humid Climate Zone of India

Mr. Tej Singh Chouhan[#1], Dr. (Prof.) Ashish Dutt Sharma[*2]

[#]*First - Research Scholar in Mechanical Engineering*
*JJT University, Vidyanagari, Jhunjhunu–Churu Road, Jhunjhunu, Rajasthan, India*
[1]tejsingh7@gmail.com

[*]*Second - Research Supervisor, Director*
*Vedic Gurukul Institute of Engineering and Technology, Jaipur, Rajasthan, India*
[2]ads.edu@gmail.com

*Abstract*— **The effect of several energy efficiency measures on building energy performance and the potential of energy saving on the basis of economic interest has been evaluated using building energy simulation tool as eQUEST. For this study a proposed commercial building under design phase, located in Kolkata which is under warm and humid climate zone of India has been selected to identify building energy and thermal performance. A wide range of individual energy efficiency measures such as building envelope, lower U-values for roof and walls, lower U-values for glass, energy efficient water cooled chillers, variable frequency drive pumping, lower lighting power density, variable speed cooling tower fans, variable frequency drive controlled air handling units were investigated to optimize the design for energy performance of the building.**

*Keywords*— **Commercial building, energy efficiency measures, building energy performance, energy conservation, building energy modelling and simulation.**

## I. Introduction

Commercial buildings are becoming major consumers of electrical energy because of the continuous operation of their HAVC system to maintain indoor thermal comfort. Growing importance of energy conservation and energy management has resulted in demand of energy efficient systems in commercial buildings. Building envelop, HVAC and lighting system related energy efficiency measures for energy efficiency with the help of energy modeling and simulation using eQUEST-3.63b software has been used to find appropriate energy efficiency measures to improve energy efficiency of the commercial building. In this study a proposed commercial building which was under design phase, located in Kolkata has been selected to identify the building energy and thermal performance. The study objective was to evaluate energy efficiency measures and the energy performance of the building. Hence to achieve the energy savings over existing design, researcher considered few energy efficiency measures (EEMs) which have enabled the proposed building 20.9% better than the base case.

## II. General Description of Building

The facility was the upcoming commercial facilities from warm and humid climate zone of India. This multi-storey building was a four storey commercial building located in Kolkata at 22° 30’ towards North and 88° 20’ towards East. Gross floor area and conditioned areas of the building were 671393 $ft^2$ and 445375 $ft^2$ respectively. The proposed maximum occupancy of the facility was 2200. The floor to floor height was varying from 11.5 to 13.5 ft. The building comprise of offices, retail and parking areas. The overall window to wall ratio was 19%.

## III. eQUEST Energy Modeling and Simulation

The eQUEST-3.63b software is a graphical user interface to DOE 2.2, which allows whole building energy analysis. The software consists of a building creation wizard, an energy efficiency measure wizard, and a graphical reporting feature with a simulation engine.

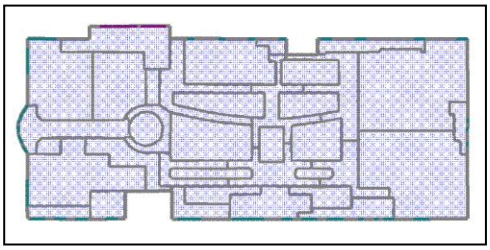

Figure 1: 2D View of the model

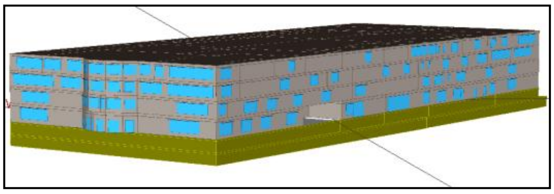

Figure 2: 3D View of the model

Energy engineering efforts such as detailed energy modeling can be extremely valuable technique for identifying energy efficiency opportunities in both existing and new commercial buildings and can go a long way towards a greener building and a greener future. Researcher has used energy modeling and simulation software tools to construct and develop the energy model for commercial building. Building simulation has been done in eQUEST-3.63b software which is a building energy simulation tool. As per the 2D and 3D views shown in *figure 1 and 2* respectively, the building has been modeled in the eQUEST. The objectives were to evaluate energy use and the energy efficiency performance of the facility.

## IV. Building Envelop, HVAC and Lighting System

The exterior walls of the building were designed as 230 mm normal brick wall with 19 mm plaster on each side. The roof was configured as (from outer to inner) 25 mm thick China mosaic tiles, 15 mm thick Brickbat coba, 150 mm thick RCC slab and inside plaster layer of 20 mm. The façade glass was 6 mm thick single glazed unit (SGU) having overall heat transfer coefficient (U-value) as 1.03, shading coefficient (SC) as 0.59 and solar heat gain coefficient (SGHC) as 0.51. The overall window to wall ratio (WWR) was 19%. The building's HVAC water side system was designed with 3 water cooled electric open centrifugal chiller. The equipment capacity of each chiller was 700 TR. The air side system was designed with 71 constant air volume (CAV) air handling units (AHUs) serving the different zones of the building. The cooling of the building was provided by chilled water from the plant. Chillers were rejecting heat in open cooling towers having constant speed fans. Water side of HVAC system has primary and secondary chilled water pumping system. Each zone had separate thermostat control linked to each corresponding air handling unit. The space temperature set points was designed to vary from 22°C to 28°C for summer and 20°C to 24°C for winter for all conditioned zones were designed for interior as well as exterior illumination. The elevator load in the facility was 137 kW.

## V. Base Case Assumption

The base case assumptions and data were based upon the project architectural drawings, HVAC floor plans, HVAC BOQ and technical specifications. The base case was developed for simulation model that would represent similar energy consumption pattern as well as magnitude. The base model was developed with the help of questionnaire survey, consultation with the facility design teams and the data provided by them. As the building surveys data are often incomplete for detailed simulation requirement. Therefore, some appropriate assumptions have been made to select and determine the necessary inputs for modeling and simulation.

## VI. Zoning Plans

A zoning plan has been developed for each floor and entered into the simulation models. Each zone was assigned a set of properties to implement energy efficiency measures in existing design, to optimize the energy performance of the design. In order to reduce the actual zoning complexity of the case study modeling for energy simulation and the thermal zones was modified from the specified HVAC layout. The floor zones of the building have been shown in *figure 3(a) to figure 3(f).*

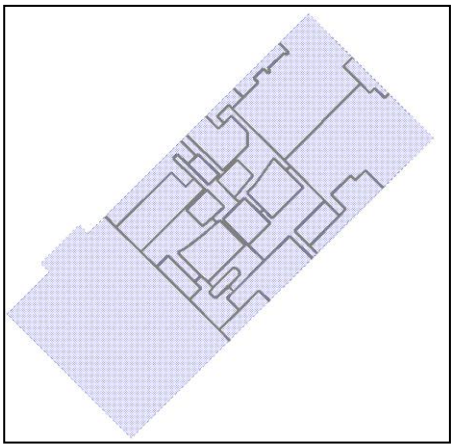

Figure 3(a): Lower Basement Zoning Plan

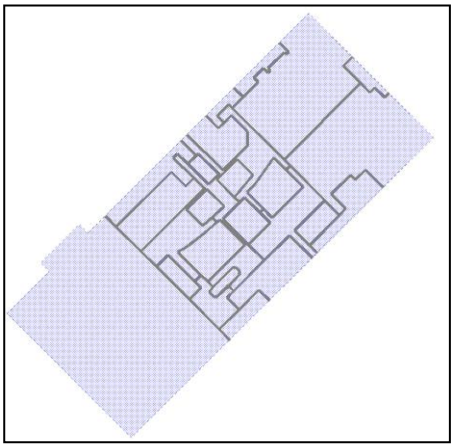

Figure 3(b): Upper Basement Zoning Plan

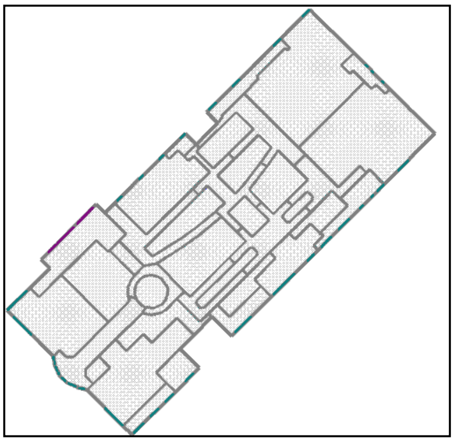

Figure 3(c): Ground Floor Zoning Plan

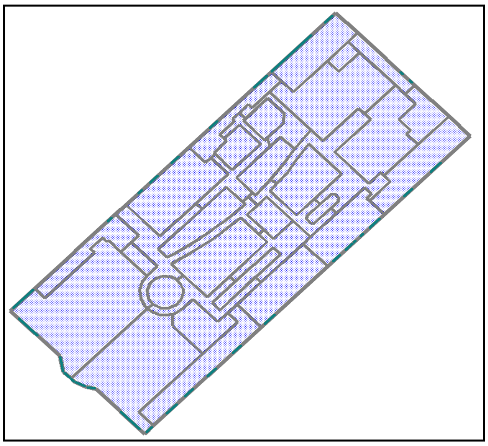

Figure 3(d): First Floor Zoning Plan

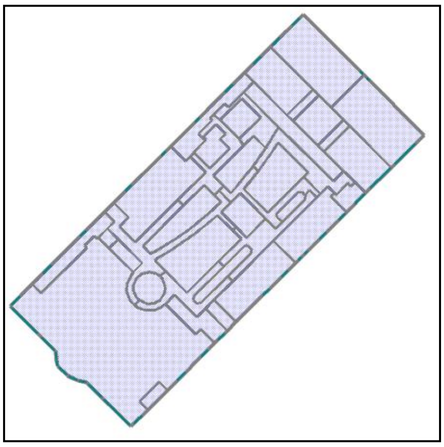

Figure 3(e): Second Floor Zoning Plan

Figure 3(f): Third Floor Zoning Plan

## VII. Energy Consumption Breakdown

The energy performance to evaluate the relative energy consumption of the building, energy breakdown of the building has been studied. The energy modeling and simulation results of the baseline building have provided comprehensive records of all energy consumption breakdown of the facility. The base case energy simulation results for the facility have been shown in figure 4. The energy simulation results of the building has represented that the energy use in air-conditioning (space cooling) was 35%, ventilation fan 23%, area light 21% and pumps 10%. This constitutes around 89% of the building's total energy consumption. Therefore, the researcher has targeted these areas to reduce the energy consumption.

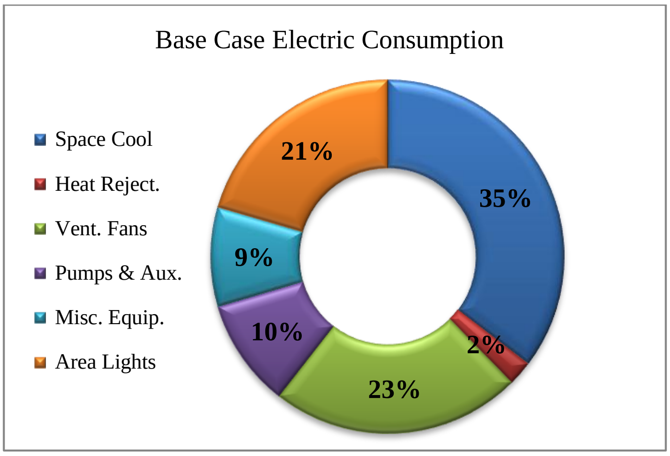


Figure 4: Base case energy consumption breakdown in percentage

The researcher has recommended the energy efficiency measures such as better building envelope parameters for reduced U-value of wall, roof and glazing, the energy efficiency measures such as efficient chillers and efficient operation of HVAC equipment like variable frequency drive on secondary chilled water pump, air handling units and cooling tower fans, supply air temperature reset and chilled water supply temperature reset based on outside air temperature. The other energy efficiency measure was to reduce building's area light. As shown in *figure 4* remaining 9% energy has been consumed by the miscellaneous equipments such as building's office, restrooms and kitchen equipments, elevators and lifts. The researcher has not considered any energy savings under this end use.

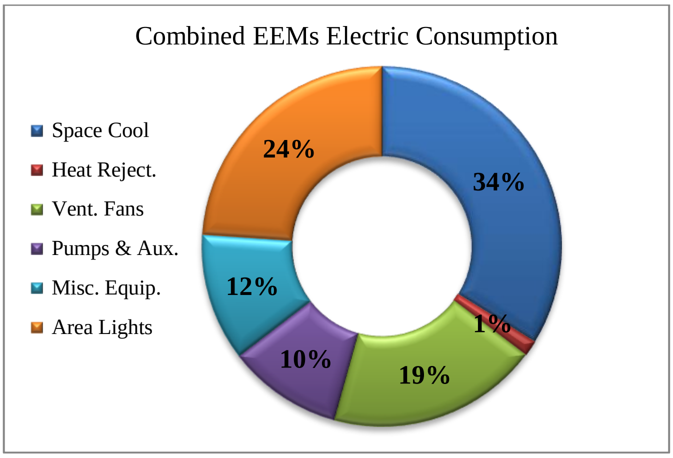


Figure 5: Combined EEMs energy consumption breakdown in percentage

The energy use breakdown of the building after implementing all energy efficiency measures (EEMs) has given in *figure 5* which represents that the energy consumption has been reduced significantly after implementing the EEMs. Space cooling and ventilation fan energy consumption has been reduced after improving the building's enveloping parameters, use of energy efficient low EIR chillers, VFD on AHUs and SAT reset control on AHUs. Pump energy consumption reduces after implementing VFD control on secondary chilled water pumps and chilled water supply temperature reset control. Energy consumption in heat rejection has reduced after implementing VFD control on cooling tower fans and area lighting energy consumption has reduced after using reduced lighting power density (LPD) for basements and car parking.

## VIII. ENERGY EFFICIENCY MEASURES (EEMS)

An easy way to comply
The following EEMs have been analyzed for systematic assessment of building energy performance in the commercial building:

(a). Insulated Wall (EEM-01): 26 mm XPS insulation has been provided in the exterior walls. Overall heat transfer coefficient (U-value) of the wall became as 0.123 Btu/hr ft$^2$ °F. The reduced U-value has reduced the building heat gain.

(b). Insulated Roof (EEM-02): Over-deck extruded polystyrene (XPS) insulation of 60 mm has been provided. The U-value of the insulated roof comes out as 0.0633 Btu/hr. ft$^2$ °F. The reduced U-value has reduced the building heat gain.

(c). Efficient Glazing System (EEM-03): The overall heat transfer coefficient (U-value) and Solar Factor (SF) or Solar Heat Gain Coefficient (SHGC) or Shading Coefficient (SC) is lower for the double glazed units. The double glazed unit which has been used with U-value = 0.56 Btu/hr ft$^2$ °F, SF/ SHGC = 0.25 and SC = 0.29.

(d). Energy Efficient Chillers (EEM-04): The COP of the chillers 5.4 has been replaced in this EEM with the most energy efficient chillers having COP of 6.1 (EIR = 0.1639). It has resulted in reduced energy consumption of the chiller.

(e). VFD Control on Secondary Chilled Water Pumps (EEM-05): In this EEM the secondary chilled water pumps has been made equipped with variable frequency drives (VFD).

(f). Air Handling Unit Fan VFD Control (EEM-06): In this EEM the constant speed AHU fan motor has been equipped and controlled by variable frequency drives (VFD).

(g). VFD Control on Cooling Tower Fans (EEM-07): In this EEM the cooling tower fan motors has been equipped and controlled by variable frequency drives (VFD).

(h). Supply Air Temperature Reset (EEM-08): The use of supply air temperature (SAT) reset technique where in researcher has reset the SAT supply temperature upward on a reduction in SAT load.

| Outside Air Temperature | Supply Air Temperature Set Point |
|---|---|
| 60 °F | 55 °F |
| 82 °F | 70 °F |

(i). Chilled Water Supply Temperature Reset (EEM-09): The researcher has recommended the use of chilled water supply temperature reset technique where in researcher has reset the chilled water supply temperature upward on a reduction in chilled water.

| Outside Air Temperature | Chilled Water Supply Set Point |
|---|---|
| 60 °F | 54 °F |
| 82 °F | 44 °F |

(j). Car Parking Lower Lighting Power Density (EEM-10): In this EEM the LPD for the car parking area has been reduced to 0.15 W/ft$^2$.

## IX. ENERGY SIMULATION RESULTS

The results of energy simulation tabulated in *table 1*, has shown that an overall energy savings of 2397466 kWh, which was 20.9% over base case has been achieved by combined effect of energy efficiency measures under study.

TABLE I
ENERGY SIMULATION RESULTS

| S. No. | Base Case / EEMs | Energy Consumption (kWh) | Energy Consumption (kWh/ft$^2$year) | Energy Savings (kWh) | Energy Savings (kWh/ft$^2$year) | Percentage Savings over Base Case |
|---|---|---|---|---|---|---|
| 1 | Base Case | 11471259 | 17.086 | NA | NA | NA |
| 2 | EEM-01 | 11317821 | 16.857 | 153438 | 0.229 | 1.34 |
| 3 | EEM-02 | 11204994 | 16.69 | 266265 | 0.396 | 2.32 |
| 4 | EEM-03 | 11363166 | 16.925 | 108093 | 0.161 | 0.94 |
| 5 | EEM-04 | 11037337 | 16.439 | 433922 | 0.647 | 3.78 |
| 6 | EEM-05 | 11347793 | 16.902 | 123466 | 0.184 | 1.08 |
| 7 | EEM-06 | 10642157 | 15.852 | 829102 | 1.234 | 7.23 |
| 8 | EEM-07 | 11363699 | 16.925 | 107560 | 0.161 | 0.94 |
| 9 | EEM-08 | 11313850 | 16.852 | 157409 | 0.234 | 1.37 |
| 10 | EEM-09 | 11430418 | 17.025 | 40841 | 0.061 | 0.36 |
| 11 | EEM-10 | 11293889 | 16.822 | 177370 | 0.264 | 1.55 |
| | | | Total = | **2397466** | **3.571** | **20.90** |

On the basis of the evaluation of annual energy use pattern of the building, all proposed energy efficiency measures has been analyzed and categorized on the basis of economic interest as tabulated in *table 2*.

TABLE III
ECONOMIC INTEREST OF ENERGY EFFICIENCY MEASURES

| Level of Measures | Energy Efficiency Measures | Description | Percentage Savings | Payback Period (Years) |
|---|---|---|---|---|
| Low Payback Period Measures | EEM-05 VFD Control on SCHWP | VFD Control on Secondary Chilled Water Pump | 1.08 | 0.2 |
| | EEM-06 AHU Fan VFD Control | VFD Control on Air Handling Units | 7.23 | 0.4 |
| | EEM-07 VFD on CT Fans | VFD Control on Cooling Tower Fans | 0.94 | 0.2 |
| | EEM-09 CHWST Reset Control | Chilled Water Supply Temperature Reset Control | 0.36 | 0.2 |
| Medium Payback Period Measures | EEM-03 Efficient Glazing System | Low U-value, Double Glazed Unit Glass with U-value = 0.56 Btu/hr ft$^2$ °F, SF/ SHGC = 0.25 and SC = 0.29 | 0.94 | 0.9 |
| | EEM-08 SAT Reset | Supply Air Temperature Reset Control | 1.37 | 0.9 |
| | EEM-10 Car Parking Lower Lighting Power Density | Car Parking Lower Lighting Power Density reduced to 0.15 W/ft$^2$ with lux around 100-150 | 1.55 | 1.5 |
| High Payback Period Measures | EEM-01 Insulated Walls | 26 mm extruded polystyrene (XPS) insulation between the exterior plaster and brick wall | 1.34 | 3.4 |
| | EEM-02 Insulated Roofs | 60 mm over-deck extruded polystyrene (XPS) insulation | 2.32 | 3.1 |
| | EEM-04 Energy Efficient Chillers | Efficient Chiller for HVAC System with COP of 6.1, EIR = 0.1639 | 3.78 | 4.0 |
| Cumulative Savings & Payback Period of EEMs = | | | **20.90** | **1.7** |

## X. EVALUATION OF ENERGY EFFICIENCY MEASURES

The savings in annual energy consumption by each EEM over its base case have been graphically represented in *figure 6*. The graph reveals in single appearance that a very good savings 7.23% has been achieved by VFD control on air handling units, and a good savings 3.78% by energy efficient chillers. The lowest energy savings of 0.36% has been accounted by chilled water supply temperature reset controls but having a payback period of only 0.2 years. As well as this low energy saving by EEM-09 can be deduced with low initial investment cost, and therefore can be adopted.

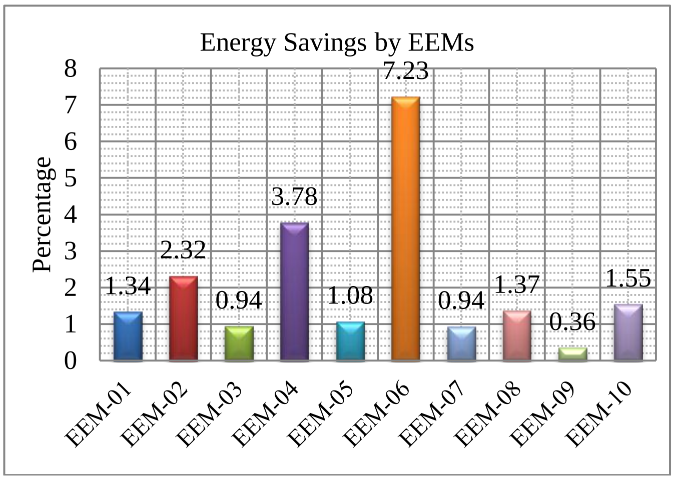


Figure 6: Comparison of percentage savings in annual energy consumption by energy efficiency measures

## XI. COMBINED EEMS HVAC SYSTEM AND BUILDING ENVELOP

The chart in *figure 7* has shown the effect for building envelop, HVAC system and lighting system related to energy efficiency measures on percentage savings in annual energy consumption. This graph has shown category wise percentage energy savings by these groups of energy efficiency measures. The bars shows that by implementing combined HVAC system related EEMs (EEM-04 to EEM-09) has reduced energy consumption by 14.75%, implementing combined building envelop related EEMs (EEM-01 to 03) has reduced energy consumption by 4.6% and lighting energy consumption has been reduced by 1.55% by implementing lighting related energy efficiency measure i.e. (EEM-10). Lighting energy savings percentage has been very less as compare to the other end use because this measure has been implemented to only basement and car parking area. It has contributed only 30% of the total built up area of the building.

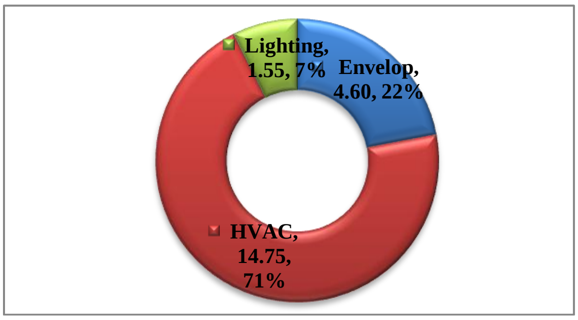


Figure 7: Effect of building envelop, HVAC system and lighting system related EEMs in percentage savings of annual energy consumption

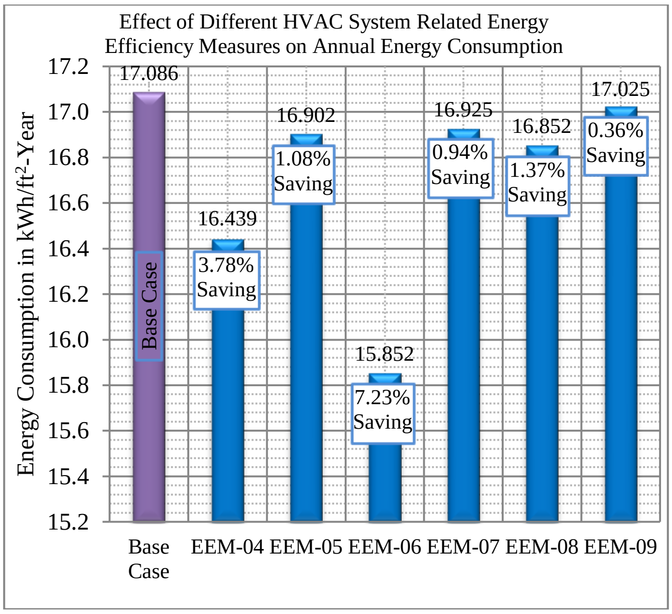


Figure 8: Effect of Different HVAC System Related EEMs on Annual Energy Consumption

The savings through HVAC system design and operation related EEMs on annual energy consumption has been shown in *figure 8*. The graph represents that implementing EEM-04 to EEM-09 results in annual overall energy savings as 14.75%. By implementing all ten EEMs the overall energy savings has been achieved as 20.9%. This shows that more than 50% of the energy savings has been achieved by using HVAC system design and operation related EEMs. It can deduce that the contribution of HVAC system design and operation related EEMs can even give up to 70% savings out of total energy savings achieved by all EEMs.

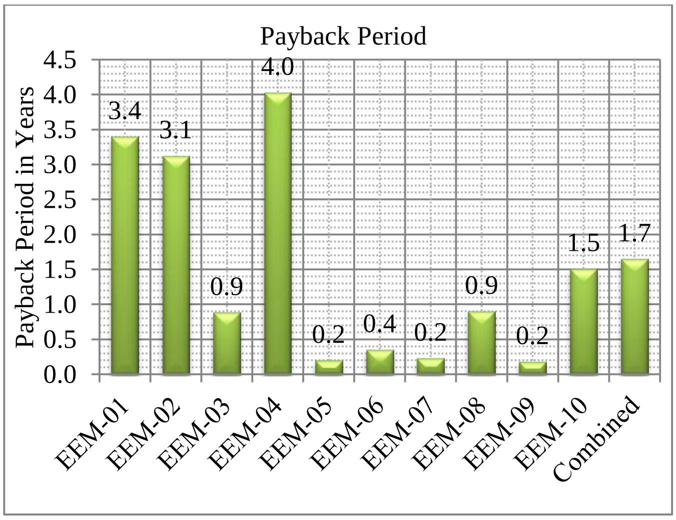


Figure 9 Effect of EEM on payback period

The *figure 9* has shown that the highest payback period for energy efficient chillers have been obtained as 4 years, which has been due to high capital investment cost of this EEM. However, most of the EEMs have resulted quantifiable payback period in the range from 0.2 years to 1.5 years except EEMs for insulated wall and insulated roof. The EEM of insulated wall and insulated roof have obtained payback period of 3.4 years and 3.1 years respectively, which was again due to high capital cost of investment. The combined payback period for this facility found was around 1.7 years. Hence, there were aforesaid three EEMs, for which the payback period was higher than the combined number.

## XII. CONCLUSIONS

The impacts of building envelop parameters, HVAC systems design, selection and operation and lighting system design on energy consumption in the commercial building from warm and humid climate zone was studied. The annual energy consumption obtained for the base model was compared with energy consumption obtained after implementing the energy efficiency measures. The researcher has implemented ten energy efficiency measures. The energy simulation results have shown that EEM-06 gives maximum savings 7.23%. The EEM-06 has been implementing the VFD control on Air Handling Units. The facility was consisted of large number of AHUs, thus energy savings potential was also very high in this EEM. The results also have shown that the capital investment for this EEM was medium whereas the payback period was low because of high energy saving potential. The minimum savings 0.36% have been achieved by EEM-09 i.e. chilled water supply temperature reset control based on outside air temperature among all ten EEMs. As there has been only one chilled water loop in this facility; hence, the energy savings potential was very low. The results computed that the cost of implementation and payback period for this EEM was low. This makes this EEM feasible and can be acceptable by the project design team. The category wise energy analysis of the energy efficiency measures shown that the HVAC energy consumption has been reduced by 14.75% by implementing HVAC related EEMs (EEM-04 to 09) and 4.6% by implementing improved building envelop parameters related EEMs (EEM-01 to 03) and lighting energy consumption has been reduced by 1.55% by implementing lighting related EEM (EEM-10).

## REFERENCES


[1] ASHRAE Handbook. (2001). *Fundamentals.* Atlanta, Georgia: American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.

[2] Bae, C., & Chun, C. (2009). Research on Seasonal Indoor Thermal Environment and Residents' Control Behavior of Cooling and Heating Systems in Korea. *Elsevier Ltd., Building and Environment, 44*, 2300–2307.

[3] Batista, N. N., & Rovere, E. L. (2009). Energy Building Performance and Energy Efficency Level Evaluation. *RIO 9 - World Climate & Energy Event* (pp. 17-19). Brazil: Rio de Janeiro.

[4] Bertagnolio, S., Masy, G., et al. (2008). Building and HVAC System Simulation with the Help of an Engineering Equation Solver. *Third National Conference of IBPSA-USA* (pp. 53-60). Berkeley, California: SimBuild 2008.

[5] Chen, C., Pan, Y., et al. (2006). Energy Consumption Analysis and Energy Conservation Evaluation of a Commercial Building in Shanghai. *Control Systems for Energy Efficiency and Comfort, (V-6-4).* Shenzhen, China: ICEBO2006.

[6] Dimoudi, A., & Kostarela, P. (2009). Energy Monitoring and Conservation Potential in School Buildings in the C' Climatic Zone of Greece. *Elsevier Ltd., Renewable Energy, 34* , 289–296.

[7] Erhorn, H., Mroz, T., et al. (2008). The Energy Concept Adviser - A Tool to Improve Energy Efficiency in Educational Buildings. *Elsevier B.V., Energy and Buildings, 40*, 419-428.

[8] Franken, J. (2008). *Green Building at Duke University: Potential Energy Savings and GHG Benefits Achieved by Renovating Existing Residence Halls.* Nicholas School of the Environment and Earth Sciences of Duke University.

[9] Holmes, M. J., & Hacker, J. N. (2007). Climate Change, Thermal Comfort and Energy: Meeting the Design Challenges of the 21st Century. *Elsevier B.V., Energy and Buildings, 39*, 802–814.

[10] Majali, V., Prasad, B., et al. (2005). Computer Aided Building Energy Simulation. *IE(I) Journal-AR, 86*, 28-31.

[11] Mathews, E. H., & Botha, C. P. (2003). Improved Thermal Building Management with the Aid of Integrated Dynamic HVAC Simulation. *Building and Environment, 38*, 1423-1429.

[12] Mathews, E. H., Botha, C. P., et al. (2001). HVAC Control Strategies to Enhance Comfort and Minimize Energy Usage. *Energy and Building, 33*, 853-863.

[13] Moreira, D. F., Quelhas, O. L., et al. (2011). Energy Efficiency in Brazilian Buildings: Analysis of Software to Support Energy Assessment. *Canadian Journal on Electrical and Electronics Engineering, 2* (5), 159-168.

[14] Mwasha, A., Williams, R. G., et al. (2011). Modeling the Performance of Residential Building Envelope: The Role of Sustainable Energy Performance Indicators. *Elsevier B.V., Energy and Buildings , 43*, 2108–2117.

[15] Poel, B., Cruchten, G. V., et al. (2007). Energy Performance Assessment of Existing Dwellings. *Elsevier B.V., Energy and Buildings, 39*, 393–403.

[16] Radford, J., Addison, M. S., et al. (2001). Energy Efficient Design of Large Office Buildings. *Energy Engineering, 98* (1), 61-79.

[17] Thomas, L., Dear, R. D., et al. (2010). Air Conditioning, Comfort and Energy in India’s Commercial Building Sector. *Adapting to Change: New Thinking on Comfort Cumberland Lodge* (pp. 9-14). Windsor, UK: London: Network for Comfort and Energy Use in Buildings.

[18] Underwood, C. P., & Yik, F. (2004). *Modelling Methods for Energy in Buildings.* Malden, USA: Backwell Publishing Ltd.