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COMPUTATIONAL ANALYSIS OF A BUILDING: AN ENERGY-EFFICIENT APPROACH USING EQUEST CODE

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Abstract— **Building energy demand increases gradually as the urbanization advances. Energy consumption due to space cooling is a crucial area of research. Researchers around the globe, attempt to replicate the energy behaviour of building using numerous types of simulation tools. In this study, a model of an engineering college has been considered for analysis of energy consumption throughout a year. This article explores various factors affecting overall energy demand of a building which is located in the hot and dry climate of Bikaner (28.0229 °N, 73.3119 °E), India. An air-cooled chiller is modelled in eQuest, which is a building modelling and simulation tool, to meet the space cooling requirement of the building and a baseline model in eQuest is created in compliance with ASHRAE 90.1 and Energy Conservation Building Code (ECBC), Government of India. The impact of different building orientations and construction of roof assemblies on energy utilization is investigated. A lucid impact of aforementioned parameters on building energy requirement is observed which turns into a considerable saving in annual energy consumption up to 3.36%.**

Keywords— **Building simulation, Cooling load, Energy efficiency, eQuest, Energy modelling**

I. INTRODUCTION

In recent ages, countries have instigated energy policies to achieve low carbon energy-saving to make the decrease overall building energy consumption. Currently, buildings account for 35% of total energy consumption and growing at 8% annually as per the Bureau of Energy Efficiency (BEE) of India [1]. As of 2016, the Government of India (GoI) statistics claim 32 per cent of the country's total electricity consumption in residential and commercial spaces. As Indian urbanisation progresses, this figure is set to rise; the Niti Aayog, as part of its India Energy Security Scenarios, estimates that in a 'Determined Effort Scenario', there will be approximately 860 per cent increased electricity consumption in buildings (from 238 TWh/year to 2,287 TWh/year) by 2047. This use includes residential and commercial lighting, appliances, heating and cooling [2]. One of the big mosques in Riyadh city was considered by Al-Shaalan et al. [3] as an eQuest model to examine building energy conservation. The various affecting parameters such as zoning areas, type of roof construction, window glasses, insulation materials and sun shields were investigated as the key factors in reducing the building energy consumption. Baig & Fung [4]created three models for a building based in a Canadian climate and found that eQuest produced reasonably accurate results. It was found that electricity consumption was not significantly influenced by the weather data whereas weather conditions greatly affected natural gas consumption. The authors, Ichinose et al. [5] studied five major municipalities (Shanghai, Wuhan, Changsha, Chengdu and Chongqing) in China's hot summer and cold winter zone, using eQuest to perform numerical simulations of the shading effects by nearby buildings on electricity consumption for space heating and cooling. Space cooling demand declines as much as 10% to 20%, while space heating demand increases up to 20%. A simulation was performed by Ke et al. [6] using eQuest building tool to calibrate energy consumption using actual electricity bill data. The calibrated model was used to explore the influence of energy consumption parameters on the overall energy consumption of the building. It was found that illumination density highly affects the energy consumption profile. An investigation performed by Khasikov [7] considered a residential house with a typical wood-frame structure and energy-efficient double framing structure of the external wall to perform energy consumption. The result of the simulation indicates that usage of the energy-efficient structure of the external wall can reduce energy consumption by 4%, and gas by 12%. Two energy efficiency measures (EEMs) were implemented by Ligade & Razban [8] to the model of Indiana university using the eQuest energy software. The first EEM was a dual-fan dual-duct (DFDD) system with chilled water and steam heating, and the second EEM was a single-duct variable air volume (VAV) with chilled water and electric reheat. After comparative investigation, it was concluded that the 'single duct VAV with chilled water and electric reheat' was highly energy-efficient and saved 28% in utility costs. Ross & Straube [9] proposed an eQuest building model to predict annual Energy-Use Intensity (EUI) and month-by-month end-use. Building azimuth alone had a negligible impact. A 20% reduction in the window to wall ratio (WWR) slashed EUI by roughly 5%. Significant upgrades to the thermal resistance of the building envelop reduced EUI by nearly 40%. Setiawan et al. [10] modified RC flat roof that results in a slight reduction in overall energy consumption whereas in comparison to general glasses, installing a reflective glazing, single and double-layered glasses can reduce overall energy demand up to 8%.

Four factors namely lighting power density, occupancy, summer indoor design temperature and air supply temperature were utilized by Song et al. [11] to investigate the influence on building energy consumption. Results indicate that among all four parameters, lighting power density has a great impact on overall energy consumption.

Wang et al. [12] presented the strategic approach on the energy-saving analysis of the HVAC system for a library building using eQuest code. Energy consumption data acquisition from the building energy management system (BEMS) for one year has been explored to calibrate energy modelling and quantify energy-saving results. The results revealed good agreement between energy modelling and BEMS data with an error of less than 10%. The energy-saving for the HVAC system can be obtained satisfactorily at the saving of 110,362 kWh per year. Energy consumption of a building in three cities of China i.e., Changsha, Shanghai and Chongqing were performed using eQuest software by Xie et al. [13]. It was found that variation in geographic location and microclimate should be paid more focus. Window shading is a crucial parameter for reducing cooling load and energy consumption. Xing et al. [14] implemented energy retrofit measures (ERM) to examine the accuracy of major factors in the energy consumption of an existing four-star hotel building in China. The findings show that schedules of internal loads significantly affect the accuracy of the model of hotel building followed by occupancy rate and COP of the chillers. Another study performed by Zerroug & Dzelzitis [15] shows that increase in insulation thickness gradually reduces energy consumption but after a certain thickness, the percentage of energy saved will increase slowly until saturation. In this study, an effort is made to suppress the total energy consumption of the building by using a simulation program called eQuest. eQuest is a DOE-2 interface, developed by the Lawrence Berkeley National Laboratory and the Department of Energy that provides simple wizards to guide the user through model development while accessing DOE-2 capabilities. eQuest is used by the research community to observe the behaviour of the building. Energy modelling programs provide users with key building performance parameters such as thermal loads, energy use and demand, temperature, humidity, and costs. A research work [16], recognized based on unified selection criteria, which include various sets of design parameters and operating conditions. After a thorough analytical comparison, the ten energy modeling applications can be ranked in descend-ing order as follows: (1) TRNSYS, (2) Ecotect, (3)Autodesk-GBS, (4) EnergyPlus, (5) IES-VE, (6) IDA-ICE, (7) VIP-Energy, (8) DesignBuilder, (9) eQUEST,and (10) RIUSKA. J. Rana [17] validated energy simulation tool eQUEST. A comprehensive data analysis was performed to predict the optimum range of WWR (window to wall ration) percentage for the 216 design alternatives of air-conditioned office buildings. This research suggests a range of WWR that 30% to 40% is the optimum range for the air-conditioned office buildings in Bangladesh. An existing office building was able to save about 9.40% percent of electricity by incorporating optimum percentage of WWR. The study [18] examines the energy-saving potential of a base case building using eQUEST simulation models of an institutional building as per ECBC 2017. The results indicate that energy consumption can be reduced up to 33% as compared to the base case model by applying simple energy-efficient features. The payback period for replacing lights is 0.6 years and the payback period for replacing efficient fans is 4.45 years. A. Warty [19] modelled the natural gas consumption and the total electricity consumption of a 12600 sq. ft. public library building in Houghton, Preliminary results suggest that the principal factors affecting the building energy consumption are the lighting, HVAC loads, and occupancy and that the natural gas consumption of the building could be lowered by up to 20% using the furnace units alone. This research [20] focussed on active and passive strategy to reduce the electrical energy consumption of a building, by taking a hotel as a case study. The active strategy involved changing of existing luminaires with more efficient LED based luminaires and setting the thermostat of HVAC system to 26 degree Celsius. The passive strategy, which can be incorporated into the building, included a change in the window glazing having a better thermal insulation. it was observed that a reduction of 12.53 % in electrical energy consumption can be achieved. Methew Roy[21] Conducted a simulation that proved that the design case values were less than that of the base case, and 18.9 % of energy saving could be achieved.. A model for integrating the key factors during the construction of an energy-efficient building is suggested.

II. METHODOLOGY

The Fig.1 below represents the steps adopted in the simulation process. Typical Meteorological Year-2 is used as a first step to initiate the eQuest coding followed by uploading CAD file of building layout in the Design Development Wizard.

After defining construction type, schedules and HVAC system types, space simulation is performed. The results obtained from the base case are then compared with the results of parametric runs by considering various factors affecting the energy consumption profile of the building.

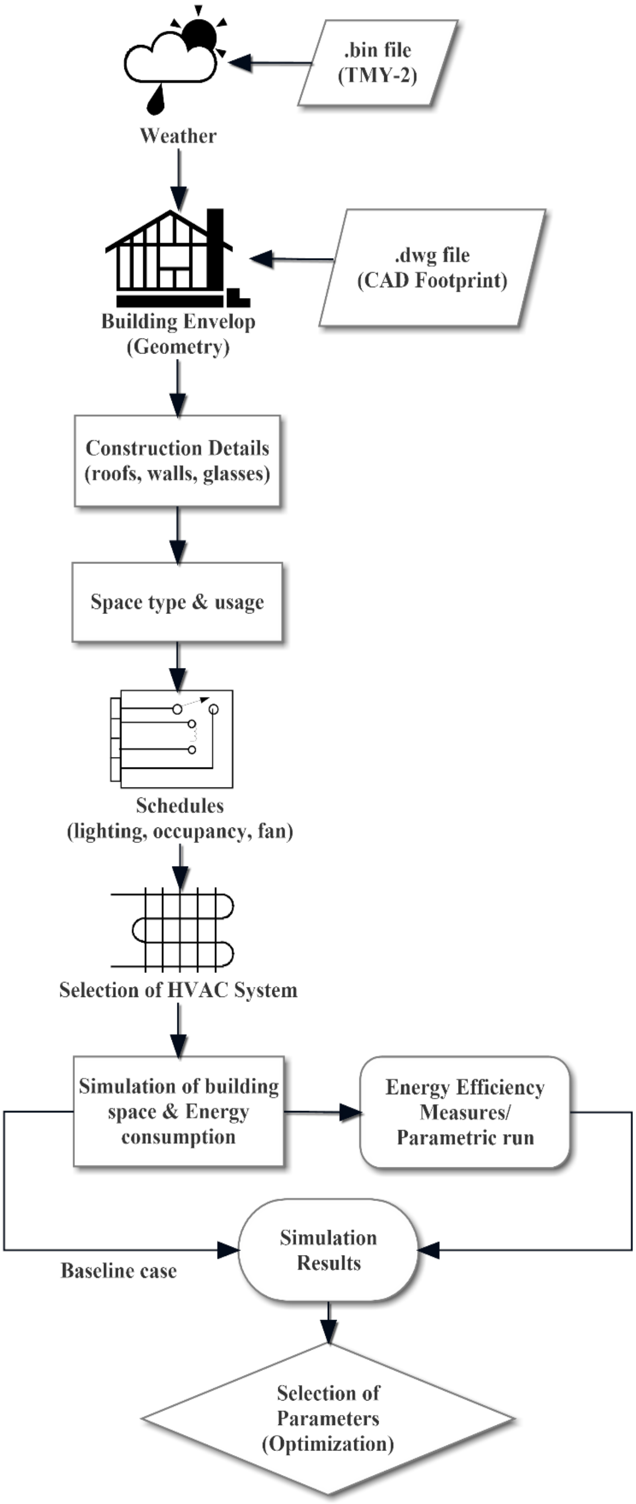

Fig. 1. Flow diagram of eQuest simulation

III. BUILDING DESCRIPTION

The footprint of building considered (Fig.2) is an engineering institute, located in Bikaner city of western India with geographics of 28.0229 °N, 73.3119 °E. The climate of Bikaner is assumed hot and dry as per the Energy Conservation Building Code, India (ECBC). The two-story building that orients its main entrance towards the north, has a total floor area of 18,109 ft^2. The footprint and eQuest model of considered building are shown in Fig.2 and Fig.3 below.

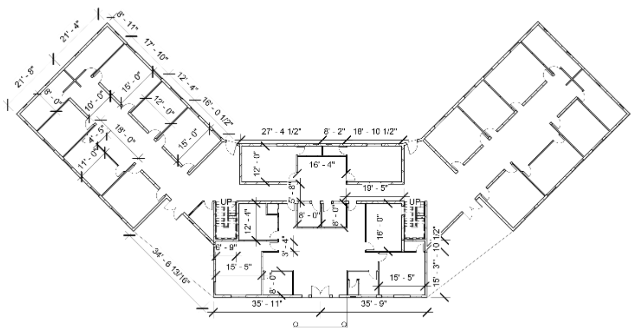

Fig. 2. CAD footprint of the building

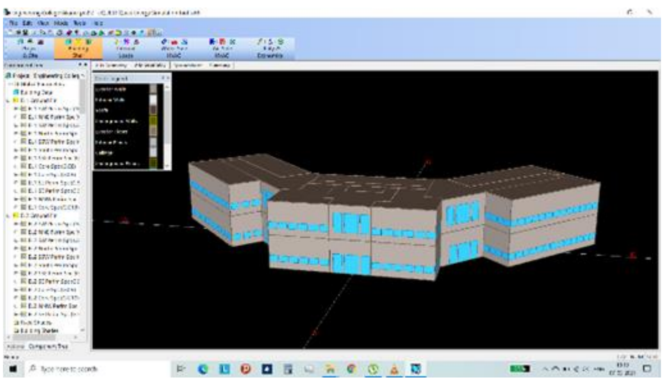

Fig. 3.eQuest model of the building

A. Building Parameters

The initial step in eQuest is to develop the building envelop model by supplying different building input parameters as shown in Table.1 followed by internal load profile and setting up HVAC system model. The values of parameters have been choosen as per ASHRAE 90.1 and Energy Conservation Building Code (ECBC) provided for the selected location.

Table.1: Input Parameters of Building Envelope

Parameters	**Input Data**
Area per floor	841.14 m^2

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Floor to floor height	4.572 m
Plenum height	0 m
Wall Construction	12.5 mm cement plaster + 225 mm brick + 25 mm expanded polystyrene + 12.5 mm cement plaster, (U=0.851 W/m^2-K)
Roof Construction	100 mm RCC + 30 mm Expanded polystyrene (24.03 kg/m^3), (U= 0.823 W/m^2-K)
Window Glass	Body tinted with metal frame, (U=3 W/m^2-K, VLT=0.65)

B. Weather Data

The maximum outdoor temperature of the city falls in May and June as per Typical Meteorological Year (TMY-2). The maximum temperature and solar insolation are observed around 43°C and 1050Wh/m^2 as illustrated by the Fig.4 and Fig.5 respectively. It has been observed that global horizontal radiations follow almost similar trends in all the typical hotter months.

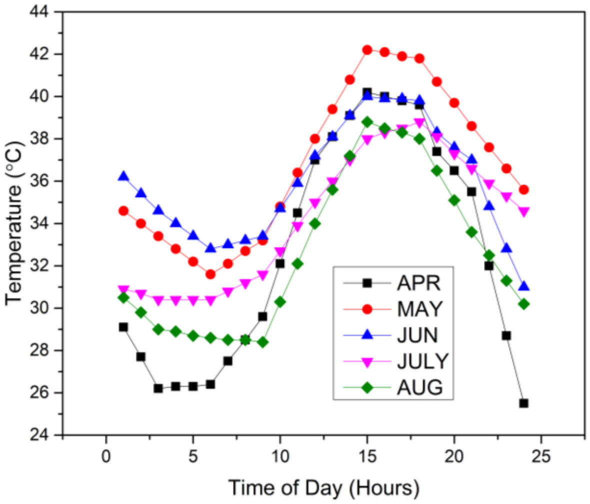

Fig. 4. Temperature variations in typical hottest months

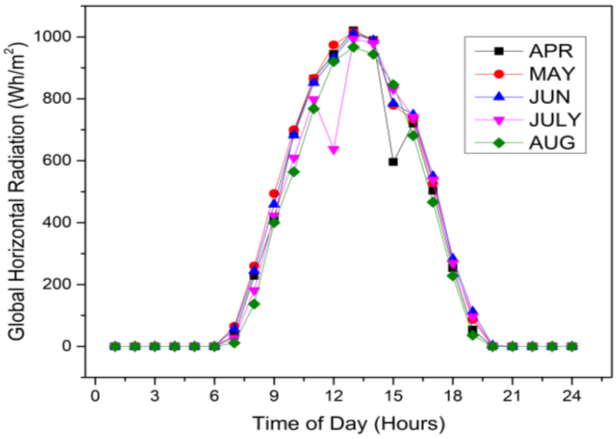

Fig. 5. Global horizontal radiations in typical months of summer

IV. SELECTION OF HVAC SYSTEM

An electric screw type of chiller with an air-cooled condenser was used to meet the space cooling demand of 250 tons. The chiller input data used to model the HVAC system is shown in Table. 2.

Table 2. Input Parameters for Hvac System

Parameters	Input Data
COP	3
Electric Input Ratio (EIR)	0.33
Mechanical Efficiency of Fan	0.65
Mechanical Efficiency of Pump (Chilled Water Loop)	0.75

A. Pump charactestics of chiller

In this study, a variable speed pump is considered for automatic capacity control. The chiller pump characteristics are shown as following by Equation 1 and Equation 2:

Pump Head f-flow:

$$Z = a + bX + cX^2 \tag{1}$$

$a = 1.35348296, b = 0.01593170,$

$c = -0.36941442$

Pump Power f-flow:

$$Z = a + bX + cX^2 \tag{2}$$

$a = 0.36977392, b = 0.84037501,$

$c = -0.21014881$

V. SCHEDULES

Table 3. Lighting Power Density for Various Types of Building Space

Space type	Lighting Power Density (LPD)
Office	1.04
Library	0.93
Corridor	0.65
Laboratory	1.4
Class room	1.27
Conference	1.03

Fig.6 represents schedules for space occupancy, lighting and fan over 24 hours of operation. The building operation commences at 7 am and terminates at 6 pm while remains inactive on weekends. Table.3 represents the lighting power density (LPD) which is a measure of a load of any lighting equipment in a defined area.

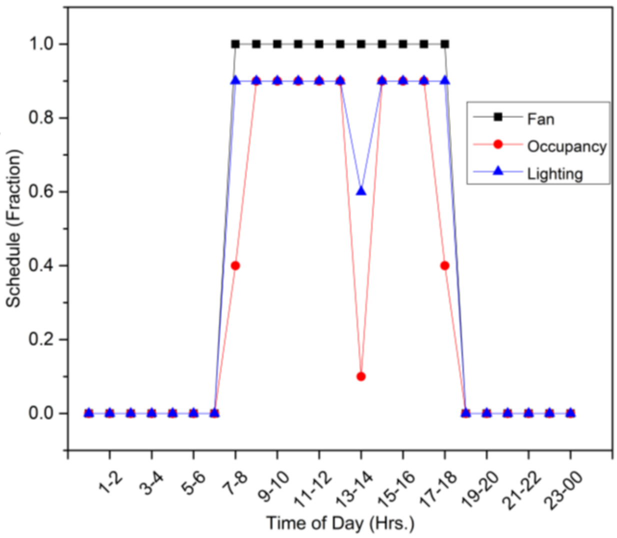

Fig. 6. Schedules for Fan, Occupancy and Lighting

VI. RESULTS AND DISCUSSION

Monthly electric consumption for various usage is shown in Fig.7. Maximum energy is consumed to meet the space cooling demand of the building followed by area lighting and ventilation fans. Total electric consumption reaches its peak value in July up to 70 kWh.

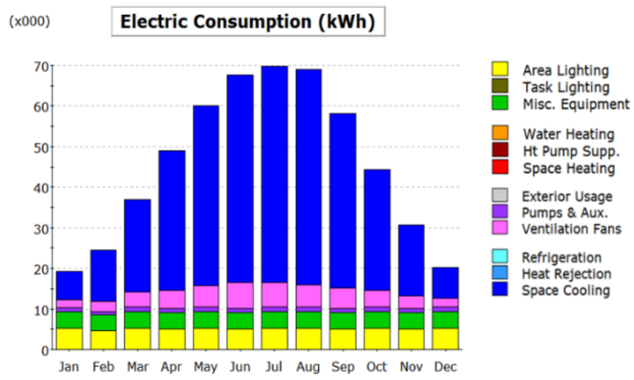

Fig. 7. Monthly energy consumption by endues (baseline)

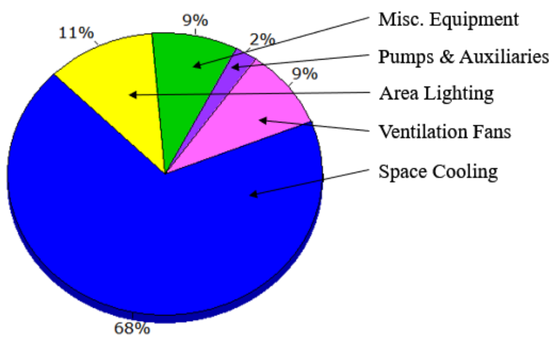

Fig. 8. Annual electric energy consumption (kWh) by end-use (baseline)

Fig.8 indicates that 68% of total energy is used annually for cooling the building whereas area lighting, ventilation fan and miscellaneous equipment consume 11%, 9% and 9% of total electric energy respectively.

The effect of building orientation on cooling load is investigated for seven azimuth angles in addition to the baseline case. From Fig.9, it is found that energy consumption is maximum for 270° orientation while it is minimum for 180°. However, cooling load profile is not significantly affected by the variation of building orientations. Fig.10 shows that maximum 0.7% of total energy consumption can be saved by positioning the building at 180° of azimuth.

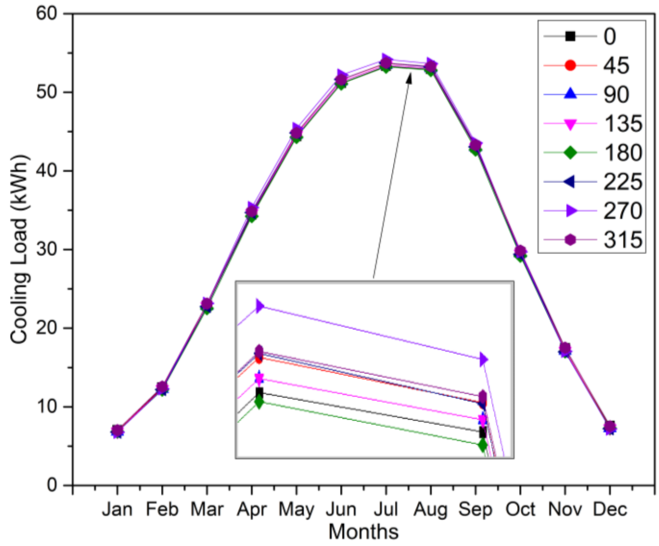

Fig. 9. Variation of cooling load with building azimuth (degree)

Another investigation is done to explore the effect of roof construction assembly on cooling load requirements. Four different types of roof construction assemblies are considered to examine the energy behaviour of the building.

For construction type, U=0.2 W/m^2-K, electric energy consumption is found minimum as shown in Fig.11.

By increasing the value of overall heat transfer co-efficient, electric energy consumption increases maximum up to baseline case. Total energy consumption of 3.36% can be saved annually by using roof construction material having U=0.2 W/m^2-K as shown in Fig.12.

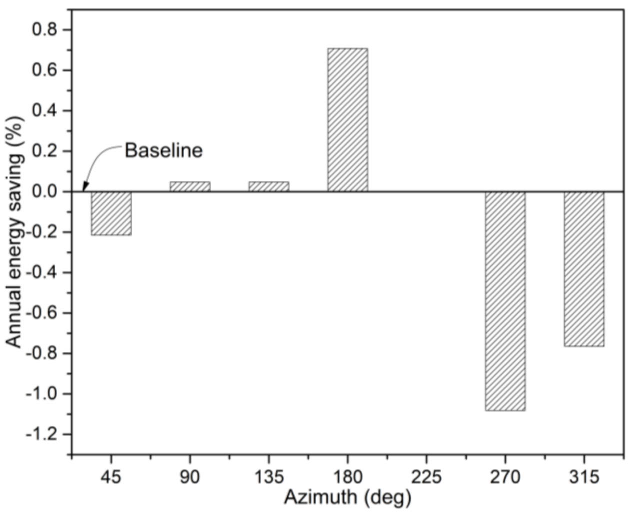

Fig. 10. Percentage of annual energy saving vs. building orientation

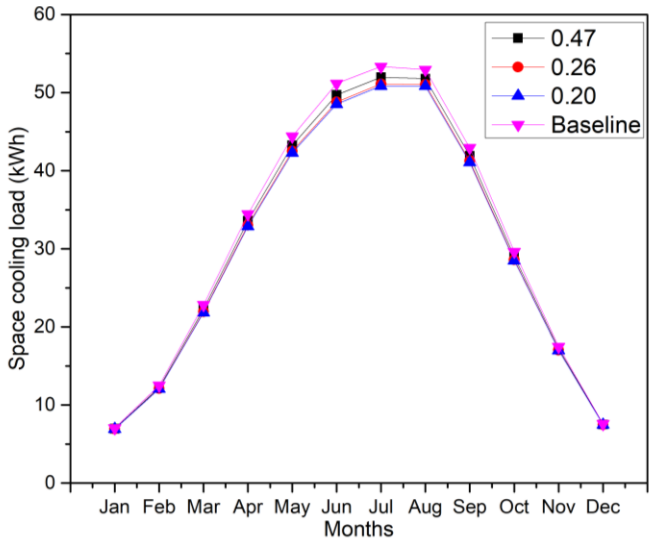

Fig. 11. Variation of building cooling load with different U-value of roof materials

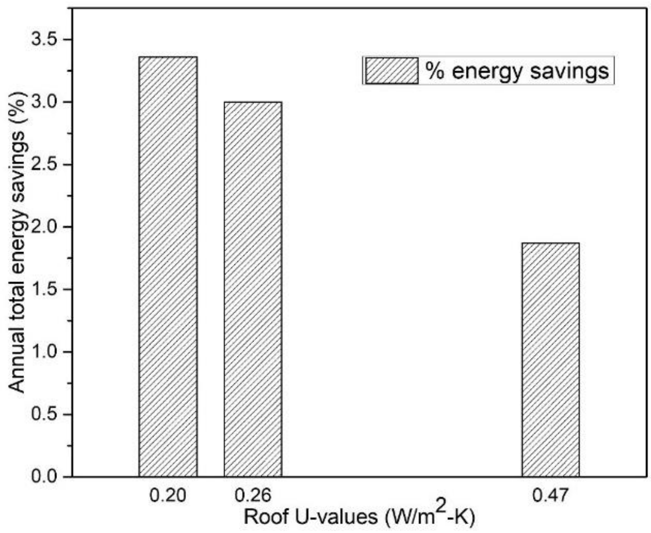

Fig. 12. Energy saving variations with different U-values of roof assemblies

VII. CONCLUSIONS

The performance of the building is examined by varying the orientations to different azimuth angles. Results show that change in orientations does not affect cooling load profile significantly. Furthermore, roof assembly offers a viable means of lowering building energy use. Different U-values of roof construction materials are used to determine the effect of energy consumption. Roof construction assembly (U=0.20 W/m^2-K) can be employed to limit the heat transfer rate resulting in reduced cooling load and saves almost 3.36% of overall energy consumption. The outcomes emanated from this research can be utilized to compare actual energy consumption by collecting the data for an existing building architecture.

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