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# Design Strategies to Energy Efficient Building in Kathmandu Valley -A Case Study of CES-Zero Energy Building at Institute of Engineering.

Sundar Lakhe [a], Bharat Raj Pahari [b], Shree Raj Shakya [c]

[a, c] *Department of Mechanical Engineering, Pulchowk Campus, Institute of Engineering, Tribhuvan University, Nepal*
[b] *Department of Civil Engineering, Pulchowk Campus, Institute of Engineering, Tribhuvan University, Nepal*
**Corresponding Emails**: [a] temcotm@gmail.com, [b] bharatpahari@gmail.com, [c] shreerajshakya@ioe.edu.np,

**Abstract**

Demand for energy is skyrocketing around the globe, environmental challenges are becoming more severe than ever before.Carbon dioxide, methane gas and other greenhouse gases are rapidly contributing to global warming and ozone depletion phenomenon.Buildings are among major contributors of green house gases and consuming more than 40% of total primary energy.It is responsibility of building design professionals to address the impacts of their practice on the environment by reducing the energy consumption and carbon emission of their projects.For the purpose to promote practical design strategies to help Architects and Engineers to design energy-neutral and environment friendly buildings,The primary emphasis of study is to analyze and explore core principles of building physics into the design process and programs of study project: Center for Energy Studies Zero Energy Building (CES-ZEB) located at Institute of Engineering,Pulchowk Campus,Lalitpur.It focuses to implement the core energy saving design strategies as energy efficient measures into design and evaluate its performance with a normative simulation tool as per performance rating method established by standard to approve it for energy efficient building in Kathmandu valley.

**Keywords**

Center for Energy Study, Zero Energy Building (CES-ZEB) – Simulation tool – Energy Efficient Building

## 1. Introduction

Buildings are among major contributors of green house gases and consuming more than 40% of total primary energy[1].Concerns to global warming and climate change;scientists and environmental activists are rising in a very high rate in the past several years[2]. These global issues are becoming important agendas for politicians especially in developed countries to raise awareness of the consequences of global warming to the public and set new regulations and standards to control global warming.The energy efficient net-zero energy initiative could offer a comprehensive solution to the current environmental challenges in building sector addressing key energy issues.For the purpose,This study analyzed and explored core principles of building physics into the design process and evaluate various possible scenarios of design strategies in design process and present the way to decision making with the help of whole building energy model with normative open studio simulation tool through performance analysis of implemented design strategies of study project located at center of Kathmandu valley for energy efficient building solution.

### 1.1 Problem Statement

Buildings sector in Nepal are among the major consumer of commercial energy and contributor of greenhouse gases also facing challenges of rapid urbanization mostly centralized in Kathmandu valley [3]and leads to increase energy demand in the urban centers of the country.The electricity sales data shows electricity as main source of energy for the building, around 28% of electricity produced is consumed in the valley alone with the peak load 1,026 MW while the supply was only 40%,leads to a situation of power outage in managing the distribution i.e. almost 12 hours a day in the dry season and 6 hours a day in the wet season[4], Led to a tremendous anomaly in the captive electricity generation by imported petroleum products. So, The energy efficiency is most in each and every sector in our country.Developing the appropriate design strategies for energy efficient building technology i.e.Zero Energy Building in building sector can have a very significant impact on improving the environment addressing key energy issues[5].For the purpose,The collective efforts of individuals could lead to the most powerful initiation.

### 1.2 Purpose and Objectives

The need of the whole building energy simulation extends beyond to assist designers and engineers for testing and continuation of energy efficiency measures and promote the evolution of building metrics.The whole building energy simulation is needed to generate, simulate and analyze building models in climatic context.It offers speed, simplicity ,graphic user interface, integration multiple simulation engines, command line interface functionality, rule based code compliance checking data display,reporting and integrated graphical results with sensitive guidance in climatic context to analyze various stages of the design and operational process of building. For the purpose,The objectives of this study were:

- To evaluate and explore design strategies of CES-Zero energy building as overall building system energy efficiency measures for energy efficient building solution in Kathmandu valley.
- To develop whole building energy model reflecting study project for simulation to analyze annual operational performance of its implemented design strategies on building utility in climatic context.
- To analyze the performance of solar PV on annual building utility.
- To analyze the performance of EAT- System to maintain indoor comfort in controlled zone.

## 2. Energy Modeling Methodology

This study is integrated type with both quantitative and qualitative research.The literature studies have been done through research reports, journals.After collecting the quantitative data from meteorological department and energy plus weather file-2017,The climatic parameter for design strategy have been analyzed through climate consultant software version 6.0. See figure-1 for passive design strategy for the climatic context in study project site.The prototype energy model of study project have been developed in sketch up and open studio for simulation with reference to prototype office building[6] and also considered existing data to reflect existing building characteristics in the context.The overall modeling methods outlined as per standard[7]provides the majority of baseline modeling information and some assumptions used for simulation analysis originated from the advanced energy design guide for office buildings [6].Then the whole building prototype energy model have been simulated to analyze and evaluate the implemented design strategies for its performance on annual building utility.

### 2.1 Building Operating Characteristics

The majority of office floor space operated between 40 to 60 hours a week. Typical occupancy, HVAC, lighting and miscellaneous equipment were considered as per standard[8].The building was assumed to follow typical office occupancy patterns with peak occupancy occurring during normal working hours from 10 AM to 8 PM Sunday through Friday. See figure-2 for occupancy Summary. Limited occupancy was assumed to begin at 10 am.After then working hours assumed through midnight for janitorial functions only. All working day occupancy was assumed to be 50% of peak occupancy while holiday and weekend occupancy were assumed to be approximately 5% of peak occupancy.

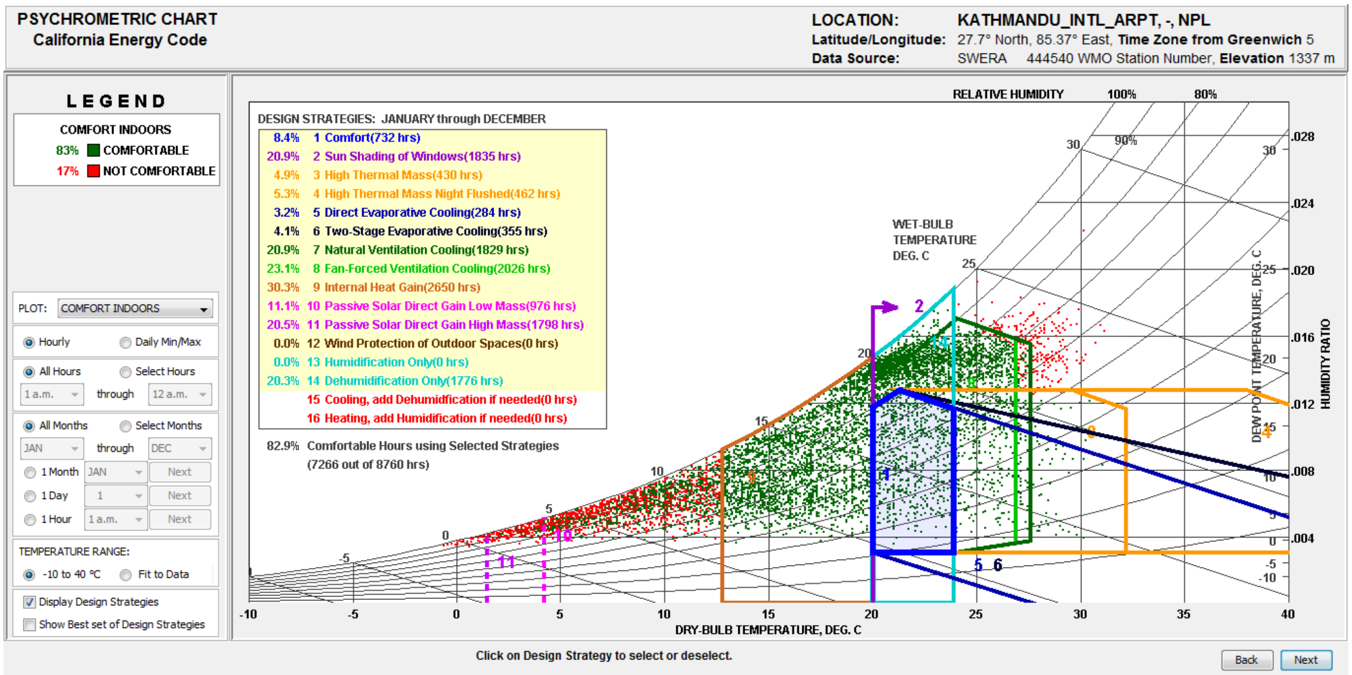


**Figure 1:** Passive Design Strategies on Project Site

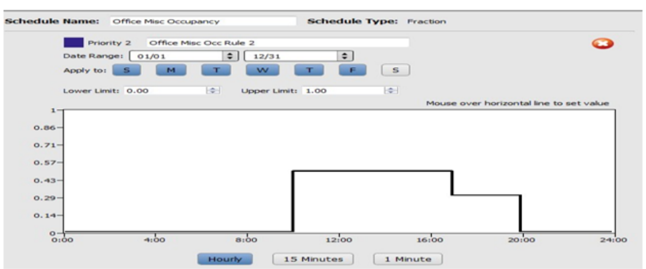


**Figure 2:** Building Occupancy Schedule

## 2.2 Building Envelope Characteristic

The majority of opaque constructions consisted of brick walls, built-up roof with roof tile for insulation above deck and concrete slab-on-grade floors with building height 3.5m floor to floor.

**Figure 3:** Energy model of Study Project-CES-Zero Energy Building

See table-1 for the building envelope characteristic and figure-3 for axonometric view of the building modeled in Sketch up.

**Table 1:** Summary of Calculated U-Value as per ASHRAE Standard[9] of Existing Building Element

| Building Element | U- Value [W/ m$^2$ $^o$C] |
|---|---|
| Exterior wall | 0.6 |
| Interior wall | 2.45 |
| Basement Floor Slab | 0.31 |
| Upper Floor Slab | 2.91 |
| Roof | 3.61 |
| Wooden Door | 3.16 |
| Glass Panel Aluminum Window | 6 |

## 2.3 Fenestration

The vertical glazing was modeled as fixed and flush with the exterior wall as in existing case. No shading projections and no shading devices such as blinds or shades were modeled in energy model,The shape,size and distribution of windows were referenced to the architectural drawing of study project building to reflect the existing case.The U-value were considered as per standard [10].

## 2.4 Air Infiltration

The infiltration rate was considered as per standard [11].The infiltration rate was based on testing buildings at greatly increased pressure difference than in normal operating conditions.The infiltration schedule was assumed as such no infiltration occurred when the HVAC system was on and occurred only when the HVAC system was off.

## 2.5 Internal and External Loads

Modeling the energy impacts of the building internal loads using the open studio simulation program required assumptions about the building internal load intensity and operation schedule.The Plug loads included equipment such as computers, printers, copy machines, refrigerators, tea makers, etc and the internal loads included heat generated from occupants, lights and miscellaneous equipment.These loads have been considered as per standard[12].

## 2.6 Interior Lighting

The model lighting levels were determined by the space-by-space method and the corresponding lighting power intensities have been calculated and considered as per standard manual[10]to reflecting existing case. For calculation each space was assigned a light power intensity based on its use and the overall zone lighting power intensity was calculated by adding the power intensities of the spaces in the corresponding zone and dividing by the zone area.See figure-4 for interior lighting considered for energy model.

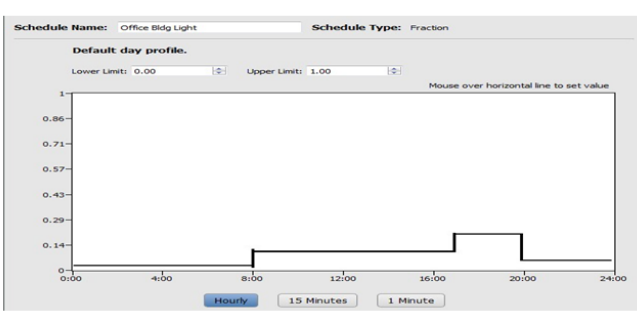


**Figure 4:** Interior Lighting Schedule

## 2.7 Miscellaneous Equipment/Plug Load

Plugs loads increase electrical usage, to determine plug load intensity; a break-down plug load calculation was developed as per standard for various office equipment and appliances[10]. The amount and type of equipment was assumed based on existing architectural drawings. See table-2 for summary of the people definition, lighting power intensity plug load intensity considered for energy model of study project by zone and standard space as per standard[13]

## 2.8 Building HVAC-EAT System Operating Schedule

There is no any other means of HVAC system other than EAT System .The EAT system operating schedule was based on building occupancy. The system was scheduled "on" one hour prior to occupancy to pre-condition the space. Then the system was scheduled "off" at 8 pm. When the system was "on", the air blower fan ran continuously to supply the required ventilated air as per standard [14] to controlled zone.For the purpose,single EAT-system was used for conditioning the controlled zone in the building and Natural ventilation has been considered as main source for ventilation of normal zone.

## 2.9 HVAC-Zone Heating and Cooling Thermostat Set Point

The study model of building was divided into two thermal zones i.e.Controlled Zone and Normal Zone. The systems with EAT maintained a 20 $^{o}$C heating set point and 24 $^{o}$C cooling set point during occupied hours.The setback thermostat control called for heating or cooling to maintain the setback temperature as per standard[14].See table-3 for zone summary.

# 3. Results and Discussion

**Table 2:** People,Plug Load and Light Intensity by Space Type

| Zone/Standard Space Type | Area (m$^2$) | People Definition (People/m$^2$) | Electrical Plug and process load Intensity (W/m$^2$) | Lights Intensity (W/m$^2$) |
|---|---|---|---|---|
| Conference/Class Room/Multipurpose Hall | 273.04 | 0.5 | 4.5 | 7.8 |
| Corridor/Waiting/Lobby | 228.9 | 0.009 | 1.35 | 2.7 |
| Elec./Mechanical | 167.78 | - | 2.7 | 5.13 |
| Office Room/Research Cubical/ | 410.25 | 0.05 | 5.8 | 6.75 |
| Rest Room | 64.75 | 0.1 | 0.60 | 1.60 |
| Stair | 315.4 | - | - | 0.90 |
| Store | 170 | - | - | 3.15 |

**Table 3:** Thermal Zone Summary

| Thermal Zone | Area(m$^2$) | Wall Area(m$^2$) | Window Glass Area(m$^2$) |
|---|---|---|---|
| EAT Conditioned Space | 117.72 | 125.25 | 22.44 |
| Normal Space | 1511.72 | 1578.66 | 257.42 |
| Total | 1629 | 1703.91 | 279.86 |

## 3.1 Energy Consumption

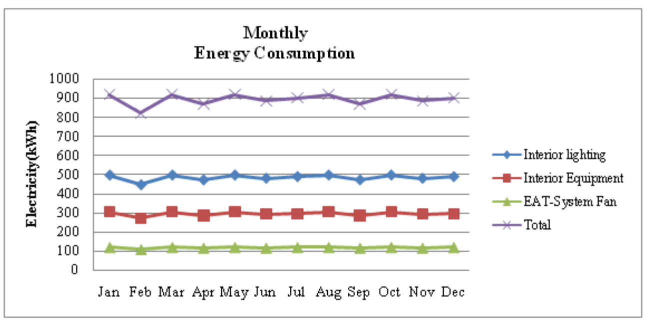


**Figure 5:** Monthly Energy End use Break Down

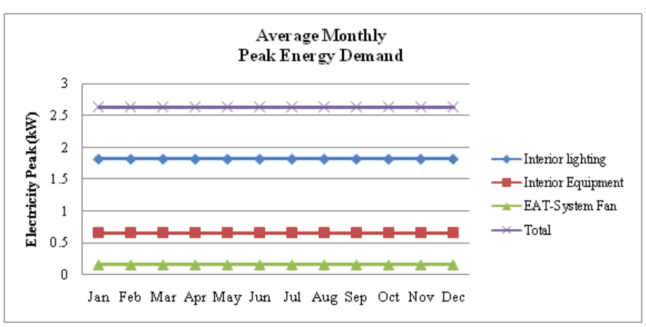


**Figure 6:** Monthly Peak Energy Demand

**Table 4:** Annual End Use Energy Break Down

| Component | Electricity(kWh) |
|---|---|
| Heating | 0 |
| Cooling | 0 |
| Interior lighting | 5823.74 |
| Interior Equipment | 3532.39 |
| EAT-System Blower Fan | 1390.55 |
| Total | 10746.69 |

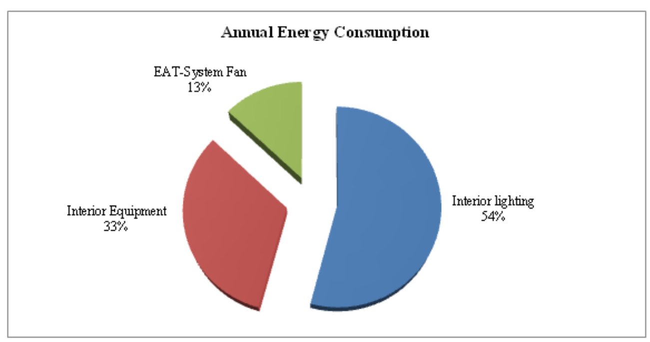


**Figure 7:** Annual Energy End Use Percentage Break Down

The simulation result shows that the model reflecting existing study project building consumes electricity within the range of about 446.66 kWh to 498.11 kWh monthly for interior lighting, 270.88 kWh to 303.68 kWh monthly for interior equipment and 106.67 kWh to

118.1 kWh monthly to operate EAT –System air blower fan and finally results to consume total electricity within range of about 824.22 kWh to 919.90 kWh monthly throughout the year.It demands peak electricity load of about 1.82 kW average monthly for interior lighting, 0.66 kW average monthly for interior equipment and 0.16 kW average monthly to operate EAT system air blower fan finally results to demand total peak electricity of about 2.64 kW average monthly throughout the year.So that it results to consume electricity of about 5823.74 kWh annually for Interior lighting i.e. about 54 % of total annual consumption, 3532.39 kWh annually for interior equipment i.e. about 33 % of total annual consumption and 1390.55 kWh annually to operate EAT-System air blower fan i.e. about 13 % of total annual consumption but no electricity end use for heating and cooling .It utilizes ground sourced thermal energy i.e. Geo-thermal energy to fulfill the heating and cooling demand of building so there is no heating and cooling electrical load in its annual end use energy.See figure-5 and figure -6 for monthly end energy use break down consumption and monthly peak energy end use breaks down and see figure-7 and table-4 for annual end energy use break down consumption of study project.

## 3.2 Performance of On site Energy Generation

In order to meet the on-site energy needs, Solar PV system of 6.5 kWp is the main source of energy in the existing building. 100 number of Solar PV modules each of 65 watt are kept as a roof on the main entrance of the building. The slope of the panel is 30$^o$ to the North covers about 56m$^2$. The electricity generated is stored in battery banks kept at the basement of the building. 120 batteries of heavy duty nature, each of 2 Volt capacities 468 AH, are connected in series which produce 240 Volts. Such two battery banks are connected in parallel and each produces 240 Volt DC. An automatic software controlled inverter continuously monitors the whole process of the electricity generation from solar panel, storing in batteries and the connection to the grid as well. The on site energy generation data shows that the installed solar PV- system generates electricity within the range of about 703.27 kWh to 1152.25 kWh monthly throughout the year and generates effective and usable solar electricity of about 10770 kWh annually with the average sunshine hours of 5.11 hour as peak sun in a day and generates average effective usable solar electricity of 29.5 kWh in a day to fulfill the existing building's 29.4 kWh of average daily energy demand and 10746.69 kWh annual end use energy demand see figure 4.6 for monthly effective energy output and energy demand comparison. It Shows that 6.5kWp PV system on average 5.11 hours of peak sun with 90% of overall system efficiency could generate excess electricity of about 24 kWh annually and hence satisfy 100% building's annual end use energy demand and balance all annual utility costs for electricity, and proven to reduce the footprint of the end use energy so the whole building system is 100% efficient zero energy building in terms of end use energy .i.e. Net On site Energy Production=Net Energy Consumption.See figure-8 and figure-9 for monthly and annual energy generation by installed solar panel and See figure-10 for energy generation and energy demand comparison.

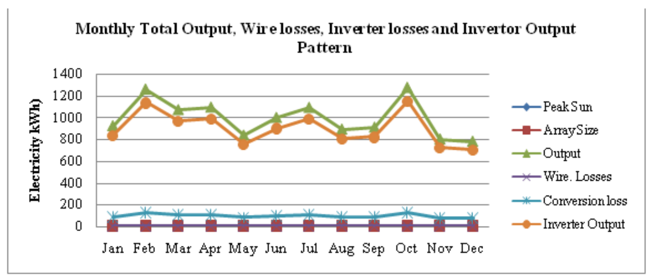


**Figure 8:** Monthly Energy Output,wirelosses,Inverter lossess and Inverter out put of BIPV

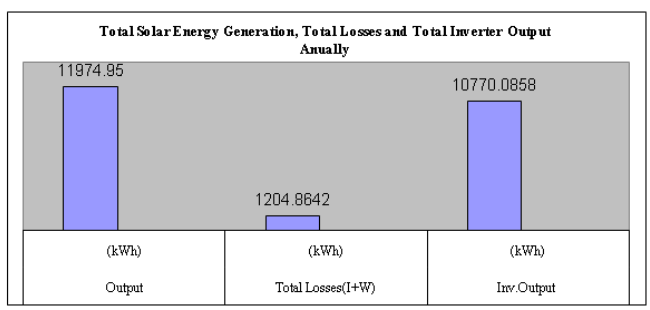


**Figure 9:** Annual Energy Generation,Total Losses and Inverter Output Annually

## 3.3 Performance of Earth Air Tunneling System

The concept of the earth air tunneling for air conditioning i.e. heating and cooling spaces in winter as well as in summer has been materialized in the study

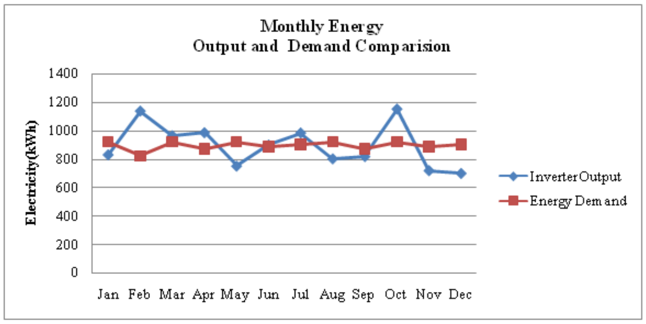


**Figure 10:** Monthly Energy Generation and Demand Comparison

project building. The one conference room to the east and one class room to the north of the building are conditioned with EAT-System. It intakes ambient air from a 75 long tunnel made of 0.5m dia. Hume pipe 4m deep down from the earth surface. Inside the tunnel, The air exchanges heat with the surrounding earth around it. The monthly average temperatures of air supplied by EAT- System at average solar temperature of 20.50 $^{o}$C.See figure-11 for The EAT-System supplied air temperature. The data shows that at 4 m depth from the soil surface, the system is effective to maintain the average temperature of pass through air of system about 20.5 $^{o}$C on an average monthly throughout the year by utilizing ground sourced thermal energy by effective heat exchange. It could cool down the room in summer and it heats up the room in winter when the underground air blower supplied and distributed air to conditioned room through duct and exhausted stale air through the solar chimney.

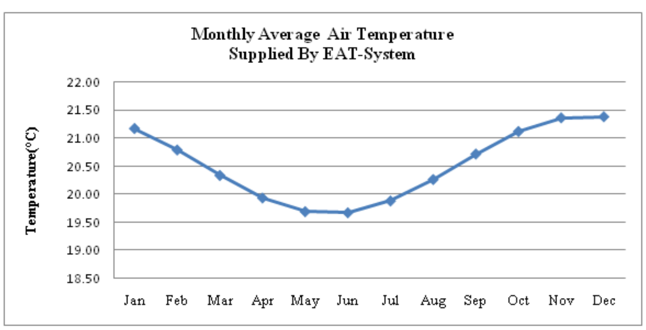


**Figure 11:** Average Monthly Air Temperature Supplied by EAT-System

This shows that, it is potential to save thermal electrical load for heating and cooling of controlled zone of building to maintain comfort indoor in both winter and summer seasons.See figure-11 and figure-12 for the performance of EAT-System installed in study Project.

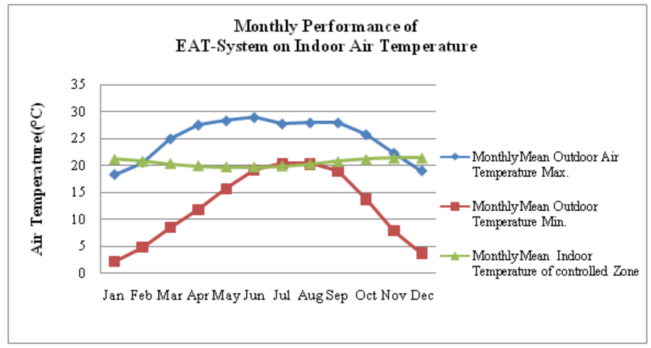


**Figure 12:** Performance of EAT-System Supplied Monthly Air Temperature

## 4. Conclusion

This study has been focused on study of Prototype CES-ZEB located in center of Kathmandu valley for its implemented design strategies in prospect of energy efficiency.A building energy model was simulated in operational context as per the performance rating method established by standard[12].From the study,It shows that 6.5 kWp PV system on average 5.11 hours of peak sun with 90% of overall system efficiency generates effective usable solar electricity of about 10770 kWh annually. Hence, Satisfy 100% building's annual end use energy needs .i.e. 10746.69 kWh , balances all annual utility costs for electricity and reduce the footprint of the end use energy demand and independent to commercial source of energy, the whole building system is 100% efficient ideal zero energy building in terms of end use energy without any GHGs emission .i.e. Net On-site Energy Production=Net Energy Consumption and its installed efficient EAT system for conditioning of controlled zone is capable to maintain comfort indoor air temperature of about 20.50 $^{o}$C average monthly utilizing the Geo-thermal energy throughout the year for both winter and summer seasons without adding extra heating and cooling electrical load on annual building utility.Further its energy efficiency can be enhanced by 12.25% with efficient EAT-System, implementing additional design strategies to existing building with use of double glaze window and double door, reduction in electrical load by using energy star rated efficient electrical appliance with smart control system. It shows that the future of implemented design strategies of study project as energy efficiency measures for efficient building system is bright and applicable to future building without any technical difficulties in composite climate of Kathmandu valley.It helps to enable the environment and resources to be sustained for future generations ,control rising energy costs, reduce environmental footprints, increase the value and competitiveness of buildings addressing key energy issues in context.

## 5. Recommendations

### 5.1 Recommendations for Improvement in performance of Existing CES –ZEB

The following recommendation could be made for improvement in better performance of existing CES-ZEB.

- The external door and window are made of material with high U -value these are the reason behind un-favorable heat loss and heat gain so it is recommended to use double glazed window or window with glaze up to 12mm thick at least and double door for good thermal performance as well as sound insulation resulting to save 10% of total building end use energy.
- For air conditioning and ventilation, the EAT-System can extend to maintain comfort indoors to other room that are often occupy.
- For better performance of Solar PV-system,The solar panel should be cleaned and maintained regularly for better exposure to the solar radiation and also the whole system should be maintained to the good and workable state.

### 5.2 Recommendations for Designers and Engineers

Based on study and analysis, the designers and Engineers are the influential body for the energy efficient building construction. They are the one who can influence the clients and change the ongoing pattern of construction of buildings. The Designers and Engineers should be made aware of the benefits of energy modeling at initial stages for construction of energy efficient buildings and its necessity for sustainable construction from planning phase to project finalization and decision making phase.For the purpose,They should be encouraged to design and control built environment considering design strategies and energy efficiency measures considering building orientation, internal room layout, window placement, sizing and shading, use of insulation, ventilation,use of heat absorbing building materials, landscaping, use of energy efficient appliances and smart control system, recycling of material and renewable energy resources etc. as in study project.From the study following recommendation can be made at least for energy efficient building in Kathmandu valley.

- The orientation of the building should be along east and west direction as such if there is no other site constriction on orientation to take advantages of active and passive system for sustainable energy solution.
- For the general construction of wall, cavity wall with lower U-value behaves as good thermal mass and provides good insulation against heat loss.
- Double glazed window has low U-value and recommended to use instead of single glazed window because thermal performance of these window are better than single glazed window. Beside thermal insulation,It also provides sound insulation.
- The household should have at least one renewable energy technology such as solar water heater or solar PV installed at their buildings with building integrated photo voltaic system(BIPVS) and building energy management system(BEMS)for effective use of green energy.
- The EAT-System should be promoted for efficient way of heating ventilation and Air conditioning (HVAC)system to condition space to maintain comfort indoor.
- Less energy efficient appliances should be replaced by more energy efficient one with smart control system in household so as to reduce its annual operating costs by 10%.

### 5.3 Recommendations for Future Research

The goal to achieve efficient zero energy buildings for energy efficiency is hindered by cost itself. However, finding the optimal cost effective energy saving strategies for a particular location can be a daunting task. Research into automated optimal designs through energy modeling and simulations can provide a deeper understanding of the trade-offs between energy efficiency measures (EEMs).Automated optimization tools can evaluate individual energy measures and determine the marginal benefit and cost of each measure in various combinations of measures for any particular location so would likely to be a welcome for the energy modeler.However, Potential EEMs like building envelope measures, lighting measures ,plug load measures, HVAC measures already evaluated are worth considering and could be further refined. The new and refined measures have the potential to achieve the goal of energy neutral in a more cost-effective manner for energy efficient building. For the purpose, The research could also include:

- Daylight Harvesting - Investigate most cost-effective ways to provide top lighting and side lighting.
- Window Shading - Consider advanced window shading measures for better control of cooling loads and support day lighting.
- Window Area - Investigate optimal window areas for the combined impact on heating, cooling and day lighting.
- HVAC Controls – HVAC control strategies that control heating and cooling set points based on occupancy
- Life Cycle Cost Analysis and Risk Analysis-Analysis based on cost for various options to incorporate it as optimum design strategies

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