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STUDY OF ENERGY SCENARIO AND IMPROVEMENT OPPORTUNITIES OF ICT BUILDING, PULCHOWK CAMPUS

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A PROJECT REPORT

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a project report entitled "STUDY OF ENERGY SCENARIO AND IMPROVEMENT OPPORTUNITIES OF ICT BUILDING, PULCHOWK CAMPUS" submitted by Hricha Aryal, Janu Kumar Sah and Puja Bhujel in partial fulfillment of the requirements for the Degree of Bachelor in Mechanical Engineering.

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ABSTRACT

The sharp increase in the building energy requirements, mostly in the commercial and residential sector represent a major energy challenge in the present world. The energy audit of existing buildings has received a great deal of attention due to its potential of identifying energy efficiency improvement measures and implement them for sustainable energy development in these sectors. In order to assess the patterns of energy use and to make specific suggestions to increase energy consumption efficiency and lower energy costs, an energy audit was conducted in Information, Communication and Technology Center (ICTC), Pulchowk Campus. The case study is presented in this report. A walkthrough was performed to specify the required field of study for potential energy saving. The building factors such as single pane glass, CFL bulbs, minimal use of installed solar PV electricity, uninsulated walls, unmaintained HVAC units and other equipment are costing a lot to the building.

This study shows that the replacement of the CFL with LED bulb can save as much as 52% energy consumption of annual lighting consumption. Similarly, if retrofitting of the glass is to be done with double glazed, the energy consumption can be reduced by almost 13% of thermal load. The simulation of solar panel in PV Syst software shows 11.85% reduction in electricity bill if used in full capacity and 23.7% reduction if the capacity were to be doubled. Additionally, the analytical study to support the solar simulation was completed. The analytical study suggested that for optimal functioning of the HVAC unit the torn insulation is to be replaced with 11mm foam insulation. The passive design strategies were suggested with the help of a bioclimatic chart generated from Climate Consultant software and also using the Mahoney table. The effects of various energy-saving techniques were also simulated in the Openstudio-Energyplus. From the simulation, it was found that the cavity wall, double glazing windows, efficient lighting, and electric equipment replacement can save over 37.12% of annual energy consumption.

ACKNOWLEDGEMENT

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TABLE OF CONTENT

LIST OF ABBREVIATIONS

ADB	Asian Development Bank
ACEEE	American Council for an Energy Efficient Economy
APFC	Automatic Power Factor Correction
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BF	Ballast Factor
CFL	Compact Fluorescent Lamp
CFM	Cubic feet per minute
CLF	Cooling Load Factor
CLTD	Cooling Load Temperature Difference
CRAC	Computer Room Air Control
DC	Direct Current
DBT	Dry Bulb Temperature
EC	Electrochromic
EMO	Energy Management Opportunity
EPW	Energy Plus Weather
GHI	Global Horizontal Irradiance
GSR	Global Solar Radiation
HVAC	Heating, Ventilation and Air Conditioning
IAM	Incident Angle Modifier
ICT	Information, Communication and Technology
IOE	Institute of Engineering
JIS	Japanese International Standard
KOICA	The Korea International Cooperation Agency
LED	Light Emitting Diodes
LID	Light Induced Degradation

NEA	Nepal Electricity Authority
NEEES	National Emission Energy Efficiency Strategy
NREL	Nepal Renewable Energy Laboratory
OECD	Organization for Economic Cooperation & Development
OH	Operating Hours
PR	Performance Ratio
PV	Photo Voltaic
SC	Shading Coefficient
SHG	Solar Heat Gain
TCFC	Total Final Energy Consumption
TFC	Technical Financial and Climatic
ToD	Time of Day
UNEP	United Nation Education Program
VRF	Variable Refrigerant Flow
WBT	Wet Bulb Temperature

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

ΔT Temperature difference

$\dot{q}$ Heat transfer rate

r_o Outer radius of refrigerant pipe

r_i Inner radius of refrigerant pipe

r_{ins} Outer radius with insulation

h convective heat transfer coefficient of refrigerant

h_o Convective heat transfer coefficient of air

$A_{s,i}$ Surface area of pipe with respect to outer radius r_o

A_o Surface area after insulation with respect to insulation outer radius, r_{ins}

L Effective length of pipe

k_p Thermal conductivity of pipe material

k_{ins} Thermal conductivity of insulation material

k_{air} Thermal conductivity of air

ρ_{air} Density of air

V_{air} Velocity of air

D_{pipe} Diameter of pipe

μ_{air} Kinematic viscosity of air

Re Reynold's number

Pr Prandtl number

Nu_o Nusselt number

U Thermal Transmittance

CHAPTER ONE: INTRODUCTION

1.1 Background

The study of energy efficiency holds a major norm of using less energy for the same application, however, the scope of energy management is diverse. One of the important techniques to understand what the existing energy scenario, typically, also known as base- case scenario, and measures that can be used for energy efficiency, reflecting the best-case scenario is the Energy Audit. It is an important science for energy management in almost every sector including buildings, and is used to ensure that the Energy Management Opportunities (EMOs)application will succeed. It may be inferred that it aids in persuading building owners and investors to implement energy efficient measures, with the payback period serving as the main incentive; at the same time, it aids in protecting the tax-paying public at large from poor implementation. According to a study, Nepal's energy usage increased by 27 per cent from 8.04 per cent in 2000 to 2013 (IEA,2016). While Nepal's energy consumption is low, the energy intensity is high. This means that Nepal has a lot of room to improve its energy use for production as well as its energy efficiency for use (ADB,2015). While energy audits are becoming more widespread around the world, they are only done in Nepal for a few industries when the government requires them or for research purposes.

According to the OECD, higher education investments are critical for economic growth, and global demand for higher education is expected to rise dramatically. Information, Communication, and Technology (ICT) sectors have made a significant contribution to social and economic gains, such as increased employment and production, as well as increased access to a greater quality of education. Meanwhile, massive data centers power data storage, and online information exchange, which in 2010 were expected to use 1–1.5 per cent of global electricity consumption, and are estimated to increase from 3 to 13 per cent consumption by 2030, depending on measures taken (Puebla et al., 2020).

The energy efficiency of any building is influenced not just only by a single parameter like electricity consumption, but also by the building envelope, materials, orientation, scheduling etc. Using the ICTC as a case study, this project seeks to determine the efficiency improvement prospects with correlation to energy demand and economic feasibility in building.

1.2 Briefing of ICT Building, Pulchowk Campus

Figure1: ICTC Building, Pulchowk Engineering College

ICT (Information and Communications Technology) Building is located inside the Pulchowk Campus premises in Lalitpur. This building was handed over by KOICA to IOE, Tribhuvan University in the year 2011 post-construction. The main functioning of this building is to conduct training programs, waived courses and research in the field of information and communication technology.

It is a south-facing building, five storeys tall. The building includes lecture rooms, computer laboratories, server room, generator room, meeting and conference halls, and seminar halls.

1.3 Problem Statement and Research Gap

Nepal being a country with high energy intensity has a lot of energy-saving opportunities. While the concept is emerging, the practice is confined to the sectors when mandated by the government. According to our observations, the practice of conducting an energy audit in Nepal focuses more on electrical factors. Thus, this study integrates Energy Audit techniques exploring thermal, mechanical, along with the electrical parameters, considering comparison of human comfort and compliance to international standards in some instances. Likewise, implementation of simulation and practical experiments in the same study are to be emphasized abridging the gap we have encountered while going through past studies in the field of Energy Audit in Nepal.

The project addresses following concerns based on the research gap:

i. This project is concerned for consideration for energy efficiency measures which can be integrated right before the construction of building and tries to show significant finding by a comparative analysis of how performance would alter if the thermal properties of the building were different.
ii. Apart from electricity, this study also explores the solar studies, which is primary source of energy for the building, and forecasts how the system ought to be operating for giving utmost saving.
iii. This study holds a concern for human comfort for lighting level, along with finding the energy efficiency potential by using retrofit measures.
iv. By further study of standards, it tries to explore on what setting energy efficient measures could be adopted for low capital cost and low operating cost for some parameters within the building.

1.4 Objectives

1.4.1 Main Objective

To depict current building energy performance, and energy consumption within the building, and integrate the results from energy efficiency planning based on performance evaluation and financial viability of EMOs (Energy Management Opportunities).

1.4.2 Specific Objectives

i. To find the base case energy scenario of solar, mechanical, and electrical/electronic devices of the building.
ii. To study solar heat gain by the window system and its effect on heating and cooling load by altering window parameters.
iii. To analyze the optimal insulation thickness of air-conditioning unit for energy efficiency.
iv. To extract data of solar resources and the potential of photovoltaics by utilizing a comprehensive valley-wide dataset for enhancing accuracy.
v. To analyze the need for retrofitting existing CFL by LED lights, along with finding the need for additional lighting.

vi. To find out relevant recommendations for the building for energy efficiency measures.

1.5 Limitation

i. The study shall be limited to the geographical and meteorological conditions of Kathmandu Valley.
ii. Nepal doesn’t have its own standard for the energy efficiency. As such several standards from the globe, whenever used may not exactly be appropriate for the Nepalese settings.
iii. The scope of this project has been defined to look out for energy efficiency findings and does not strongly provide bases for investment grade audit which are much more detailed.
iv. The cost figures used in the financial analysis would be heavily dependent on present exchange rates of USD vs NRs. Hence, the results of analysis may not stand accurate when the exchange rate fluctuates.

CHAPTER TWO: LITERATURE REVIEW

Out of total energy, one-third produced is consumed in buildings, with 60% to 70% of that used alone by HVAC systems, implying that improving HVAC load and energy alone can contribute significantly to energy saving. (Alghoul et. al, 2017). Based on a study conducted by Thapa and Maruyama (2010), the proportion of mixed residential/commercial properties in Kathmandu Valley increased by 524 per cent over two decades (1990-2010). Buildings in the Kathmandu Valley are not designed with the energy efficiency of HVAC systems in mind, resulting in significant energy consumption and costs during the building's operational life. (Thapa, 2020). Since 1985, energy efficiency research and assessments have been conducted in Nepal, and between 1999 and 2005 AD, initiatives like energy audits of industries, training in energy efficiency-related topics, widespread community awareness, and management of borrowings for energy conservation in industries were also managed to carry out. The NEA then carried out projects such energy audits, demand side management of power, the study of electricity load profiles, creation of policy concepts for the promotion of energy efficiency, and the replacement of conventional lighting with energy-efficient bulbs between 2009 and 2011. (NEES, 2075). In an International Seminar on Energy Efficiency held in 2011, the then Senior Energy Officer of Nepal, Deepak Kharel, talked about "Energy Efficiency Initiatives in Nepal". According to Kharel, the audit process in Nepal is less in practice. And the sector that performs auditing is more focused on electricity only. Other sources are fairly neglected or often ignored during energy auditing.

According to the report, energy efficiency improvement strategy alternatives in the commercial sector may lessen total final energy consumption (TFEC) by 20.2 per cent in 2020, and by 2030, the energy efficiency improvement in TFCE will be 57.3 per cent. (Shakya 2015)In low-latitude nations (such as India, China, Africa, Northern Australia, South and Latin America, and the Middle East), space cooling is predicted to increase from 32 percent of total building energy consumption to 72 percent by 2100, mostly due to higher outdoor temperatures brought on by climate change. (EPA,2019). The heat that exits or enters windows accounts for around 30% of the energy consumed to heat and cool buildings, according to the US Department of Energy. Windows and glazing systems are now viewed as potential energy-saving platforms. (Gültekin et al.,2016).

2.1 Building parameters

One can start by cutting down on energy usage during the building construction process and the other by reducing the energy consumption associated with the building ontology in order to reduce the energy consumption throughout the whole life cycle of buildings. (Zhang, Kang, and Jin 2018)

How the building is designed, and what devices are being used greatly influence its energy usage pattern. Attention should be paid to energy saving, especially in buildings. The energy consumption of both residential and commercial buildings accounts for 20–40% of the total energy utilized in developed countries.

Building energy-efficient structures that rely on passive controls like sunlight, wind, and other climatic variables is typically advised. It is well known that energy star-rated devices should be used, likewise, the initiatives to make provisions ensuring such devices are working at closed requirable conditions is also necessary. Thus, following areas have been enlisted as of major concern for this project based on the assessment by the walkthrough audit:

I. Windows
II. Cooling and heating load
III. Solar PV
IV. Server orientation
V. LED retrofitted lighting
VI. Electricity
VII. Insulation thickness

2.1.1 Lighting

Energy-efficient lighting has a number of benefits due to the fact it frequently has the lowest life-cycle costs. It decreases peak loading, customer costs, mercury levels, and the amount of waste delivered to the landfill. As per study, we currently consume 2,900 TWh of electricity for lighting per year globally. Also, it is anticipated that demand for lighting services over the next 20 years will increase by around 50% compared to current levels (Environment et al., n.d.). According to the UN Environment model, the policy changes would result in a widespread switch from conventional lighting technologies like incandescent, halogen, and fluorescent lathe mps to light emitting diodes by the year 2030, reducing the annual electricity demand for lighting to 2160 TWh and saving up to 640 TWh of electricity. With this decrease in electricity, 290 major coal-fired facilities would have required investments totaling $360 billion (UNEP,2017).

Functions of Lighting:

Interior lighting ought to serve three purposes. It ought to: (a) guarantee interior occupants' safety; (b) make visual duties easier to execute; and (c) support the development of a suitable visual environment. (Kisan et al., 1992).

Fluorescent Lighting:

When compared to incandescent lamps, CFLs, which were invented in the 1970s, use roughly 75% less electricity while producing the same amount of light and last nearly 10 times longer.

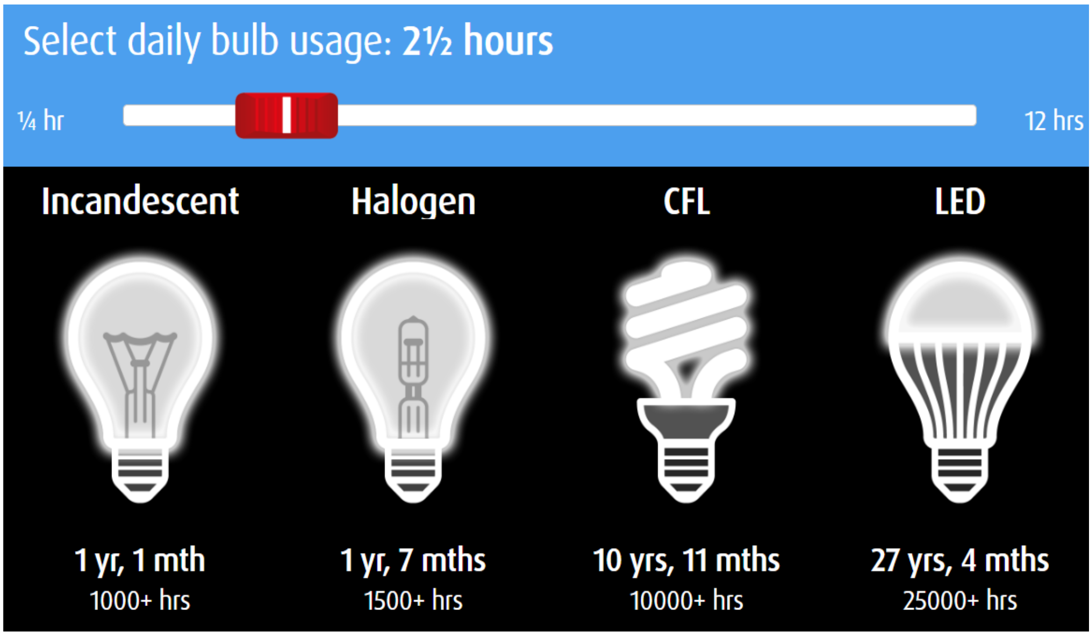
LED Lighting:

Because of the performance improvements and cost reductions in this technology, LED lamps are being used more and more in general lighting applications. They are small, durable, vibration- and breakage-resistant, function best in a cold environment, and certain models can be dimmed.

Table 2.1: Comparison of Types of Lamp (Lighting)

Characteristics	LED Lamp Typical Quantity	CFL Typical Quantity	Incandescent Lamp Typical Quantity
Luminous Efficacy Range (initial)	60-130 lm/W	50-70 lm/W	8-17 lm/W
Lamp Lifetime	15000-30000 hr	6000-15000 hr	1000-1500 hr

Source: united4efficiency.org



Source: Energy Star/Energy.gov

Figure 2.1: Types of Bulb Comparison

Illuminance:

Illuminance is defined as the ratio of the light flux incident on an element of a surface at a point by the area of that element. Lux is its measure. Illumination is the process of exposing an object to visual radiation.

Outdoor illumination levels can range from 130,000 lux on a clear day to 15,000 lux in shady or gloomy conditions, depending on the weather, geographic region, and elevation.

(Lanca C. et al.,2019).

The higher value of the range should be used when:

- Unusually low reflectance or contrasts are present in the task
- Errors are expensive to fix
- Work with images is crucial
- Precision or increased productivity is important

Likewise, the lower value of the range may be used in the following circumstances:

- Extremely high reflectance or contrast levels
- Speed and precision are not crucial
- The action is rarely carried out

The average illumination for each space or room can be calculated using either the 5-point approach or the 4-point method (JIS).

i) 5-point method:

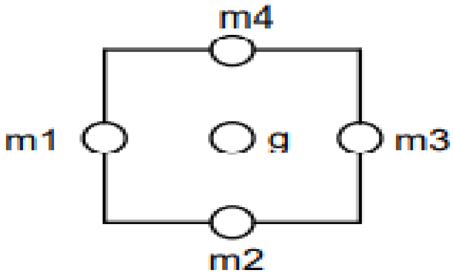


Figure 2.2: 5 Point Method

(Source: Japanese Industrial Standard)

The illuminances Em and Eg are obtained by measuring the middle of each side (the m point) and the center of gravity (the g point) respectively, and the average illuminance for each region is then calculated using the formula:

EE0= (Em1+Em2+Em3+Em4+2Eg)/6 = (∑Em+2Eg)/6

ii) 4- point method:

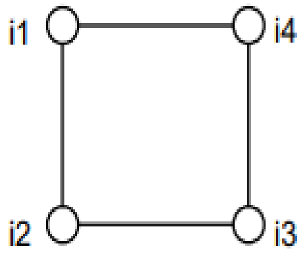


Figure 2.3: 4-point method

(Source: Japanese Industrial Standard)

When there is little illuminance change, the 4-point technique is utilized. The four corners (the I points) must be measured in order to acquire the illumination Ei, and the average illumination for each area must then be calculated using the formula below:

E0= (Ei1+Ei2+Ei3+Ei4)/4 = (∑E)/4

The room lighting level according to lighting and sunlight entering the room can be directly measured with a lux meter (Salim et al., 2022). The readings can be analyzed following the provisions of:

i. Indian National Lighting Policy 2010
ii. Indian Standard Code of Practice for Interior Illumination
iii. Standard Nasional Indonesia/ Indonesia National Standard

Luxmeter:

It is a device for determining illuminance. The value does not refer to the light source, but to the illumination i.e., how much of the luminous flux emitted by light sources reaches a specific surface.

Annual Energy Consumption by Lighting

The annual energy consumption in a year for both the existing case and replacement case were found by the expression (Duwal, 2019) as:

$$EC[kWh] = \frac{N*W*OH}{1000}$$

Where, N = number of lights

W= Power (Watt)

OH= Operating Hours

The same literature provides bases for calculating Energy Reduction percentage as:

$$ERP = \frac{EC(Existing) - EC(Retrofitting)}{EC(Existing)} * 100\%$$

2.1.2 Solar

According to U.S. experiences, a well-designed building that is using solar energy and has the same area as a conventional building can save 50% or more on energy for a first-time additional investment of 5 to 10%.

The annual average of horizontal irradiation is between 1900 and 2100 kWh/m^2 for the majority of Nepal. Nepal has a higher potential for PV power generation than other nations that are farther from the equator since its seasonal variability is lower. (SOLARGIS, 2021).

Solar irradiance is the quantity of solar power (immediate energy) falling on a unit area per unit time [W/m^2]. Solar irradiation is the quantity of solar energy [Wh/m^2 or kWh/m^2] that is incident on a unit area over a specified period of time. Every 24 hours, the earth performs one rotation around its axis, and it takes roughly 365.25 days for the earth to complete one revolution around the sun. Its axis is tilted at a 23.5-degree angle. The durations of the days and nights consequently fluctuate. About 30% of the sunlight that hits the planet is reflected which is known as earth's albedo. At an average sun-earth distance of $1.495*10^{11}$m, or one astronomical unit, the sun forms a 32' angle with the earth.

Extraterrestrial radiation is the term used to describe solar radiation that enters the earth's upper atmosphere. Changes in atmospheric circumstances have no impact on it. Depending on the atmospheric conditions, extraterrestrial solar radiation is prone to atmospheric absorption and scattering while passing through the atmosphere. Terrestrial radiation is the term for the solar radiation that reaches the surface of the planet. It consists of two types of solar radiation: diffuse radiation, which has a direction that is affected by scattering and reflection, and direct or beam radiation, which has an unaltered direction.

Solar radiation on an inclined plane surface:

Three types of radiation make up the total radiation incident on any sloped surface: beam radiation, diffused radiation, and radiation reflected from the surrounding area.

Global Solar Radiation, which is the total radiation at any point on the surface of the globe as a result of both beam radiation and diffuse radiation (GSR). The difference between GSR and Global Horizontal Irradiance (GHI) is that GSR includes all of the sun's rays that strike the earth's surface, while the GHI includes the sun's rays that strike the earth's surface at a 90-degree angle.

The formula is:

$GHI = GSR * \cos \Theta$

where Θ is the angle of the sun above the horizon.

Solar Radiation Geometry:

a. Latitude (Angle of Latitude, Φ)

The angle formed by a radial line from a given site to the earth's center and its projection onto the equator plane is the location's latitude. For the northern and southern hemispheres, respectively, the latitude is positive and negative.

b. Tilt Angle(ß)

It is the angle between the horizontal and the inclined plane surface (collector) under consideration.

c. Surface Azimuthal Angle (Y):

It is the angle in the horizontal plane formed by the horizontal projection of the normal to the inclined plane surface and the line going due south of collector. When measured from the south toward the west, it is considered to be positive. According to SOLCAST, which is a global solar forecasting and solar irradiance data modeling company, the surface azimuthal angle of a collector can be found by the use of Google Earth such that the geography is oriented in the exact NS direction, the angle taken concerning south the towards the west.

Photo Voltaic System:

Global horizontal or tilted irradiation, which is made up of direct and diffuse components, is what photovoltaic technology takes advantage of. PV module installation options come in two different varieties. (SOLARGIS, 2021):

- PV modules mounted on the ground in a fixed position or on sun-trackers
- PV modules mounted on rooftops or facades of buildings

For Nepal, three different types of PV systems might be used. (SOLARGIS, 2021):

- Grid-connected PV power plants
- Mini-grid PV systems
- Off-grid PV systems

Typically, roof or façade-terms range in size from small to medium, ranging from a few hundred watts to hundreds of kilowatts. As a result of these modules frequently being positioned suboptimal angle, performance efficiency is reduced.

PV systems that are off-grid are those that are not linked to the distribution grid. They typically connect to lights, LED displays, or other electronics and have energy storage (lead acid in this project). Charge controllers are used to maintain the batteries in order to safeguard them against deep drain or overcharging. Depending on the size and functionality of the off-grid system, it can operate with an AC (in conjunction with an inverter) or DC electricity source.

2.1.2.1 PV System

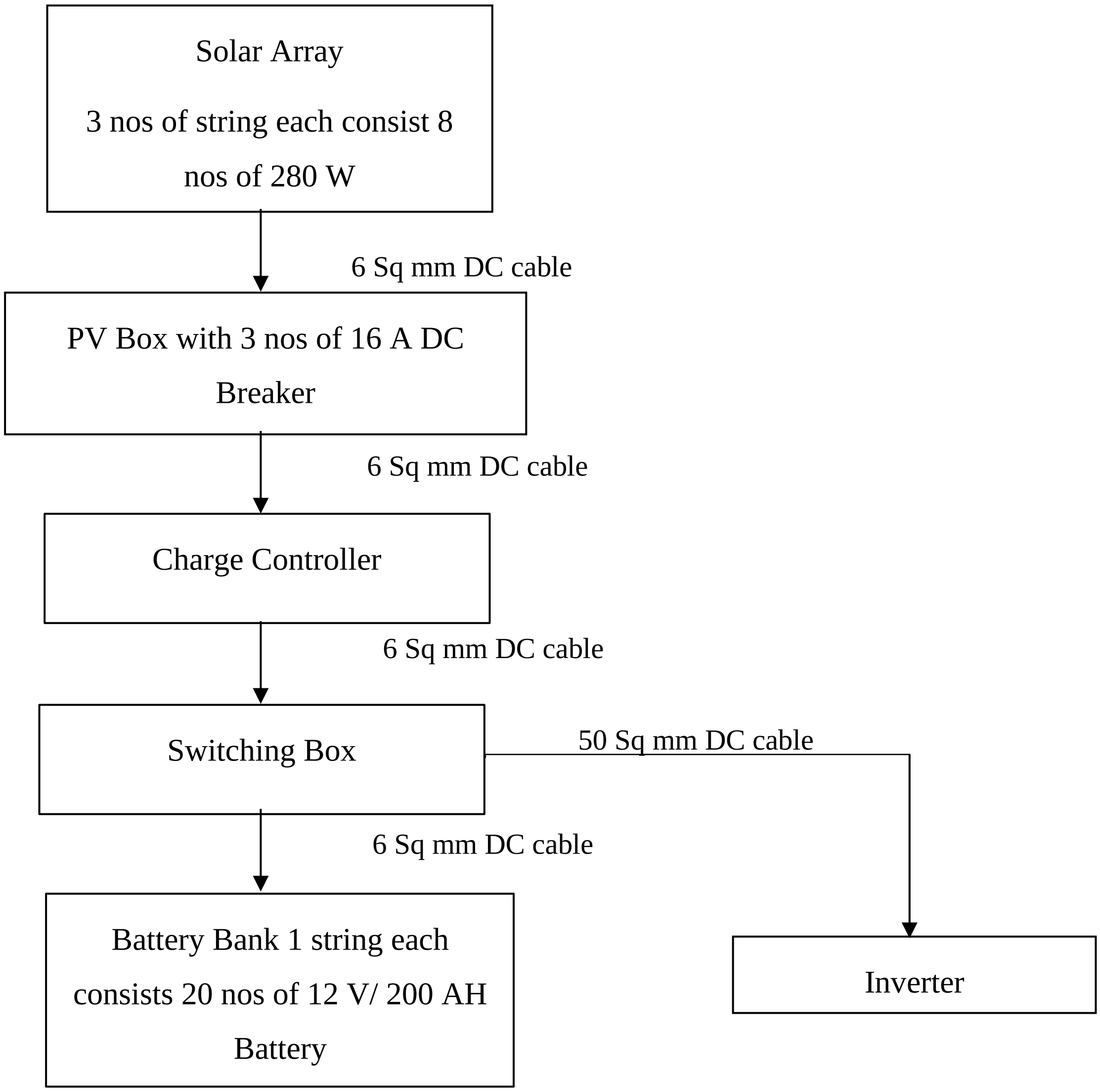


Figure 2.4: Block Diagram for Off Grid PV System (Solar System**)**

1. Solar Array:

Typically, a solar PV array, or collection of connected solar panels, is set up in a field of arrays, either stationary or with a device to follow the sun's position. The layout and mechanical design of the array, including the tilt angle of the panels, height of the panels, clearance between the panels, etc., are examined while taking the local climate, ease of maintenance, etc., into mind.

2. PV Box:

A PV box is an equipment that is used to transform solar panel electrical energy into a form that can be used to power appliances. The PV Box performs the DC power concentration, the DC/AC conversion and the AC voltage elevation to the required voltage level.

3. **Charge controllers**:

In order to safeguard against electrical overload, overcharging, and other situations that may lower the battery's performance or longevity, it restricts the pace at which electric current is added to or extracted from electric batteries. It also prevents deep discharging

4. **Switching Box:**

It is device in the path which takes control over either sending the electricity from module to Inverter for complete AC conversion or allows the electricity from the module to store in battery bank in the DC form.

5. **Battery Bank:**

A battery bank is a group of batteries that are connected together to provide a higher voltage or current than a single battery.

6. **Inverter:**

It is a particular kind of power device that transforms the variable direct current (DC) output of a photovoltaic solar panel into a utility frequency alternating current (AC), enabling the use of typical AC-powered equipment.

7. **Connectors:**

There are various types of connectors or conventional non-connector junction boxes used in the solar photovoltaic sector. Its selection is very precise to prevent misconnection. Thus, connectors can be considered among the distinguishing features of PV system

2.1.2.2 Losses in Solar PV Module

Various loss mechanisms hinder the conversion efficiency of the cell due to the inherent physical processes and available input. The energy injected into the grid accounts for only 76.2% of the total incident solar energy (Ekici & Kopru, 2017). Choosing the right material, using the right processing technology, and adjusting other cell characteristics can control the other category of losses.

a) **Soiling loss:**

As the name implies, this loss results from the accumulation of dust and grime on the PV modules' surface, making it a meteorological and geographic component. The number of losses highly depends on the cleaning frequency and the rainfall. According to Solar Energy Atlas of Nepal (SOLARGIS, 2021), the soiling loss account to 4 to 8% with the uncertainty of +/-1.5%. Based on similar research of the Northern India, the soiling rate integrated into their study is 4% (Kumar et al. 2019).

b) Thermal losses:

Due to the encapsulation of the PV module, alteration takes place for heat into and out of the module, which may result in increasing temperature. The PV module's operation is impacted by the rise in temperature since the reduced voltage lowers output power. Similar to this, rising temperatures are linked to a number of PV module failure or degradation scenarios because they increase the strains associated with thermal expansion.

The following variables influence the heating of modules:

i. the brightness of the incident sun
ii. reflection of the module’s top surface
iii. the electrical operating point of the module
iv. packing density of solar cells

The thermal loss factor by U-value identifies the thermal behavior. This can be broken down into a constant component (Uc) and a factor (Uv) that is related to the wind speed (v), where v is the wind speed in m/s and Uc and Uv are measured in W/m^2 K and K, respectively).

The following U values are taken into account when using common meteo values, such as those in the US TMY2 data (often 4-5m/sec on average in continental-not-coastal) for free-standing systems:

Uv=1.2 W/m^2 K/m/s and Uc=25 W/m^2 K

This is equivalent to U = 28.6 W/m^2 K with an average wind speed of 3 m/s.

c) DC wiring loss:

DC wiring losses are those that happen as a result of the wire material's resistance value and lower the quantity of direct current (DC) energy that solar panels produce before the energy is transformed into alternating current (AC) by the inverter. The widely known NREL research "Performance Parameters for Grid-Connected systems" suggests a 2% loss for DC wiring.

d) Light-Induced Degradation (LID):

The first few days of a solar cell's exposure to the sun are when deterioration occurs. The silicon used in PV modules is known to be doped with either n-type or p-type boron. The performance of the modules is primarily impacted by the reaction between silicon impurities and doped p-type boron or gallium when the modules are exposed to sunlight.

According to the All-India survey, the value of LID can be estimated to 2.5% (Chattopadhyay, Dubey, and Kuthanazhi 2016).

a) Module quality and module mismatch loss:

The term "module quality loss," also known as "module rating loss" or "module nameplate loss," refers to the discrepancy between a module's declared power and its performance at STC. Modular mismatch loss, which results in a fixed percentage reduction in the system's DC power output, is brought on by minute variations in the electrical properties of the installed modules. According to a study conducted in the city of Patna in India and the city of Cardiff in the UK, the module quality loss and module mismatch loss account to 1.5% and 2% respectively (Georgitsioti n.d.).

b) Incident Angle Modifier (IAM) loss:

Because the amount if solar radiation incident on a slanted module surface also depends on angle between the module and the sun, it happens because of the tilt and orientation of the panels. Reflex ions on the glass cover, which grow with incidence angle, are also accounted for.

2.1.2.3 Solar Panel Simulation

The basic principle to studying solar energy collection by the building i.e., of solar power and photovoltaic power potential assessment, use of simulation tools and the combined use of solar and meteorological models and measurements were done to improve the knowledge of solar resources and potential of photovoltaics by utilizing a comprehensive valley-wide dataset for enhancing accuracy. This aids to forecast solar power and grid management.

PV Syst:

PY Syst is an energy modeling tool that aids in determining how much solar energy can be converted from a site or location into electrical energy. The latest version PV Syst 7.2 was used for this study.

The fundamental operation of photovoltaic systems serves as the foundation for PV Syst.The simulation take in considerations of interaction the solar cells with the environment including location, temperature, spectrum radiance and others. The software utilizes the wide range of the physical models and their data, evaluating the accurate data that allows user to optimize the solar panel system with the best option possible.

Meteonorm:

Using more than 30 different weather factors, Meteonorm creates precise and realistic normal years for any location on Earth. It has data going back to 2012 and is updated often from more than 8000 weather stations.

P50 & P90 approach:

A 50% chance of exceedance is the best estimate or median value. Since the multi-year distribution of solar radiation resembles a normal distribution, the summaries for the yearly and monthly sun irradiation are close to average.

Similarly, a conservative estimate using the assumption of a 90% likelihood of exceedance can be utilized. (SOLARGIS,2021).

2.1.3 Electricity

As per research, buildings have a significant role in energy consumption, accounting for around one-third of the energy used in cities. Large public buildings are the main energy consumers, although this consumption can be noticeably reduced by using energy management strategies. (Park et al., 2011). The energy efficiency of ICT hardware has been in concern for world, and the energy efficiency for this sector is improving, however, the overall energy used for ICT is still increasing. The efficiency improvements of individual devices are being outrun by the rising demand for ICT products and services. While this is going on, the global per-person ICT electricity consumption surpassed 100 kWh/year in 2007 (nearly doubling if entertainment equipment is included), and it's only going up from there. (Aebischer & Hilty, 2015). Thus, the growth of the computing energy including all other electrical appliances integrated for ICT would dramatically alter future energy demand. ICT may be able to save anywhere between 10% and 20% of the energy used worldwide, according to reports from ACEEE.

A. National Grid-Connected Electricity

The primary source of energy in any building is the national grid in Nepal. In Nepal, the distribution of electricity is effectively owned and controlled by the NEA, which also oversees the networks and services involved. It distributes single-phase electricity to household and three-phase electricity to the commercial and non-commercial sectors based on the demand. It is necessary for the owner to install Time of Day (ToD) meter for three-phase electricity in the building. It has also been mandated by the government to use Automatic Power Factor Correction (APFC) panel when the power factor is lower than prescribed.

Single-Phase and Three Phase Supply

The electricity from the sub-stations is stepped down through local transformers and supplied to nearby buildings as a single-phase or three-phase supply (50 cycles per second at 220 volts between the phase and the neutral). Then the supply is 230 volts between a phase and a neutral and it is 400 ($= \sqrt{3} \times 230$) volts for line voltages.

In a single-phase supply, there shall be one live-phase wire and a neutral wire.

In a three-phase supply, there shall be three live phases and a neutral for star-connection.

The cost of electricity depends on the factor as:

A. Connected Load

B. Demand unit

Maximum Demand tariff:

The Energy Charge and Demand Charge are the two components of the Maximum Demand Tariff. The energy fee is based on the monthly kWh energy usage, whereas the demand charge is based on the peak KVA demand. In general, it can be inferred that, in this tariff, the energy consumed is charged on the basis of maximum demand. Maximum Demand is measured using a maximum demand meter and is stated in KVA. Throughout a 30-minute period, the demand is averaged. As a result, there are 48 demand values per day, with the maximum demand for a given month being the highest demand value that month.

Understanding Demand Charge:

The owners of three-phase should pay a monthly fee known as the "demand charge" to cover the expense of maintaining the infrastructure needed by the electric company to supply electricity to your building. The demand charge is higher when the building has high usage of electricity in comparison to normal functioning months. The demand charge amount on each monthly account depends on when your energy use, as measured in KVA, peaked. This rate is applicable to three months once the meter has been set up.

TOD meter:

A TOD meter is an electronic device used to measure and record energy consumption at different times of the day. It is used to track the usage of electricity throughout the day in order to better understand energy consumption patterns. This data can then be used to create more efficient energy plans and reduce overall energy costs. By analyzing the data, one can observe deviations in energy consumption.

2.1.4 HVAC Load

HVAC load can simply be defines as the amount of heating and/or cooling essential for maintaining the required temperature as per the human comfort in a building or the space within it. It can also be used to refer to the quantity of heat per unit of time that is required to heat or cool a given space in order to maintain it at a comfortable temperature. Estimation of HVAC loads of any buildings adapted for cooling in summer and heating in winter is crucial for the accuracy of the design and the appropriate choice of equipment to meet the desired thermal space.(Hashim et al. 2018)

A) Heating Load Calculation

The effective and accurate calculation the heating loads for buildings is a great challenge. To determine the necessary heating capacity, a heating load calculation is performed to account the amount of heat that is typically lost from the building especially during the winter. Peak heating demand often occurs before daybreak throughout the winter, and weather conditions are rather stable throughout the season.

i) Heat Transfer Loss

Building heat transfer loss(Q) is the sum of heat loss due to transfer from outer walls glazing surface, partition walls doors, windows etc. heat loss depend in the area, (A), U-value and temperature difference (TD) between the outside region and conditioned region which is given as:

$$Q = A \times U \times TD$$

ii) Ventilation and Infiltration Heat Loss

The uncontrolled heat loss from air infiltration occurs through building joints and gaps around doors and windows. Wind and pressure differences between the outside and inside of the house have an impact on this value because they induce air to flow inside the house, which results in heat loss when the air leaves the room.

Ventilation replaces the inside conditioned air with the outside fresh air and thus extra heat is required to condition it. Sensible and Latent heat added due to ventilation is given as:

$Qs = 1.1 \times n \times CFM \times \Delta T$

$Q_L = 0.68 \times n \times CFM \times \Delta W$

Where,

Q_s = Sensible Heat

Q_l= Latent Heat

N= number of occupants

CFM= fresh air supplied to each person in cubic feet per minute

ΔT = Change in temperature

ΔW= Difference in moisture content

B) Cooling Load Calculation

Cooling load is amount of heat to be removed by the system from a conditioned space in order to keep it at a specified dry bulb temperature and humidity.

There are two types of cooling loads:

i) Sensible Cooling load
ii) Latent Cooling load

Cooling load calculation methodologies take into account heat transfer by conduction, convection, and radiation

ASHRAE handbook of fundamentals refers to the following six modes of entry for heat gains:

i) Solar radiation through transparent surfaces.
ii) Heat conduction through exterior walls and roofs.
iii) Heat conduction through ceilings, floors, and interior partitions.
iv) Heat generated in the space by occupants, lights, and appliances.
v) Energy transfer through direct-with-space ventilation and infiltration of outdoor air.
vi) Miscellaneous heats gains.

CLTD (Cooling Load Temperature Difference) Method

With the release of ASHRAE GRP-158, the Cooling and Heating Load Calculation Manual, ASHRAE 1979, the cooling load temperature difference / cooling load factor (CLTD/CLF) approach has been widely used to calculate cooling loads (Spitler, McQuiston, and Lindsey 1993)

The CLTD approach uses solar load factors for solar gain through windows, temperature differential for walls and roofs, and cooling load factor for interior heat sources. The CLTD varies with time and depends on the building's specifications as well as the surroundings.

As the highest cooling load occurs during the day and the outside conditions change considerably throughout the day due to solar radiation, the unsteady state process must be taken into account when estimating cooling loads. Additionally, all internal sources contribute to the cooling loads. Ignoring them would result in an underestimation of the necessary cooling capacity; a potential inability to keep the desired indoor conditions.

i) Conduction through walls, roofs

The heat transfer rate through walls, roof, floor, doors, glass etc. is given by:

$Q = A \times U \times CLTD$ ((ASHRAE 2001))

Where, U = Overall heat transfer coefficient

A = Area of wall or ceiling or glass

Through experimentation, the ASHRAE assigned reference CLTD value for an indoor temperature of 78°F and outdoor average temperature of 85°F for July 21 taken at latitude of 40°N. For HVAC design at other regions with different indoor and outdoor temperature correction in CLTD should be made(Hashim et al. 2018). The corrected $CLTD_c$ is given as

CLTDc={(CLTD+LM) *K+(78-TR) +(TM-85)} *F(ASHRAE, 1997)

Where,

LM is correction factor for latitude and longitude and backward value by wall direction.

K is correction coefficient for ceiling color =1 for the light roof;

F is coefficient of ventilation between the surface and the secondary roof = 1 (if no ventilation);

TR is internal design air temperature

T_o is external design air temperature rate

$TM=T_o$-(Daily range/2)

Heat gain, usually heat gain per unit time Q is calculated in the following way (through walls, doors, roofs, and windows):

$Q=U*A*CLTD_c$

ii) Heat Gain Through Glass

About 8% of solar radiation that hits an unshaded window is usually reflected back outside, between 5 and 50% of the energy is absorbed by the glass, and the remaining energy is transmitted directly indoors and contributes to the cooling load.(Ahmed and Soomro 2017)

The heat gain components through glass consists of solar radiation and conduction.

Total heat gain = Solar heat gain + Conduction heat gain

Conduction heat gain = $U_g.A_g.CLTD_c$ (ASHRAE, 1997)

where: $U_{g=}$ overall heat transfer coefficient of the glass

A_g= Area of the glass

$CLTD_c$: Correct cooling load temperature difference for glass.

The correction of the CLTD is as follow;

$CLTD_c$ = CLTD + (78– TR) + (TM – 85)

And,

Solar heat gain = A_g. [SHG_{max} x SC x CLF]

Where

SHG_{max}: Maximum solar heat gain in W/m^2

SC: Shading coefficient

CLF: Cooling load factor for glass

Shading coefficient (SC) is the ratio of the solar heat gain through any given type of glass to that through unshaded clear glass (reference glass)

iii) Heat Generated through occupants

The rate at which thermal energy is emitted by the inhabitants of the building varies with their degree of activity. For the sensible portion of the heat released, a cooling load factor has been developed to account for the lag in time between occupancy and the observed cooling load. Hence, the sensible cooling load attributable to persons is,

Qs = N x G_s x CLF_s (ASHRAE, 1997)

Where, Q_s = sensible cooling load due to occupants (W)

N = number of occupants

G_s = sensible heat gain depending on activity and time from entry (W)

CLF_s = cooling load factor (dimensionless) for people.

Latent heat is added in the form of sweat. The latent heat gain from occupants can be calculated as:

Q_L = N x G_L (ASHRAE, 1997)

Where

Q_L: latent heat gain from occupants

N: number of occupants

G_L: latent heat gain from occupants depending on a activity and time from entry (W)

iv) Heat Generated by Lighting

The heat addition due to lighting is given as

Q = 3.4 × W × BF × CLF (ASHRAE, 1997)

Where,

W = lighting capacity (watts)

BF = Ballast Factor

CLF = cooling Load Factor for lighting

BF accounts for heat loss in the ballast in fluorescent lamps. It is usually taken 1.25 for fluorescent lamps. CLF accounts for heat storage effects in the walls of room.

v) Heat Addition Due to Infiltration and Ventilation

Heat is added in the conditioned room in the form of both sensible heat and latent heat when air gets infiltrated or is brought inside from ventilation. The process of calculating heat gain through ventilation is same as that of heating load calculation.

C) Multi VRF System HVAC Unit

The ASHRAE defines Variable Refrigerant flow (VRF) ‘‘to ability of HVAC system to regulator and control the amount of refrigerant flow to each of the indoor units/evaporators, then enable to use multiple evaporators of differing capacities and configurations, individualized comfort control, simultaneous heating and cooling in different zones with heat recovery from one zone to another (ASHRAE Journal)

The VRF systems classified according to the number and type of compressor were used. (Alahmer and Alsaqoor 2018). There are three types of units:

(i) single variable speed compressor; a single, large capacity scroll compressor;
(ii) variable speed compressor; fixed speed compressor having two compressor systems, the inverter-driven compressor always begins and ramps up until it achieves its full capacity, while the fixed-speed compressor starts and the inverter driven compressor ramps down, and
(iii) multiple variable speed compressors with outdoor units having multiple inverter-driven twin rotary scroll compressors

Multi VRF systems are flexible heating and cooling units that may be designed to fit any size business operation. This is due to the fact that they maximize building design options by simultaneously providing energy-efficient heating as well as cooling to several zones.

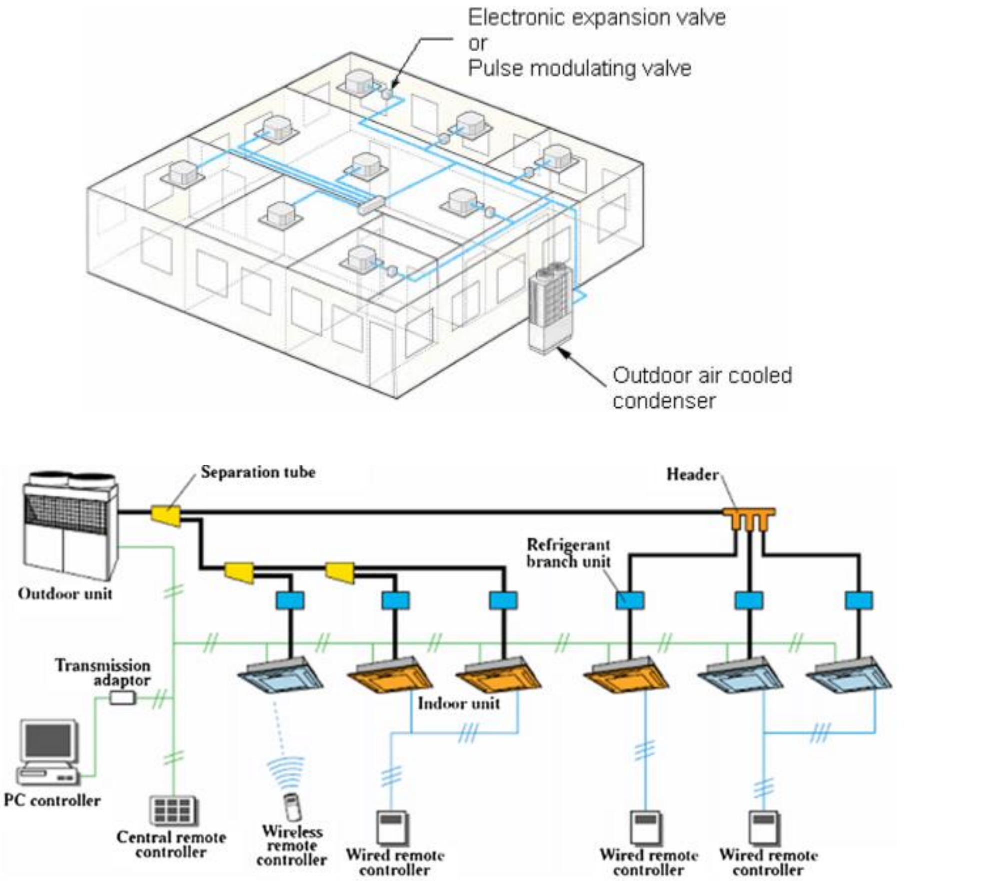


Figure 2.5: Schematic of a VRF System

(Source:(Alahmer and Alsaqoor 2018))

D) Critical thickness of insulation

The use of adequate insulation in pipe networks is certainly the most efficient technique to conserve energy. It is often thought of as a single investment that pays for itself many times over the lifetime of the pipe network (Kayfeci, 2014). More insulation thickness equals less heat transmission from a thermodynamic perspective, nonetheless, this growth should be carefully managed because it has an optimum value at which the sum of its technical, financial, and climatic (TFC) parameters selected by the system have a negligible specific cost (Malka et al., 2022), thus, it becomes necessary to find critical thickness of insulation from the thermodynamic point of view. Likewise, for desirable cooling and heating by HVAC system, the system has to be given more work by electricity in expense to the energy lost due to heat transfer from the refrigerant pipe network system encountered due to thickness below or above the critical thickness of insulation. Critical insulation thickness is the guiding factor to economic insulation thickness which is defined as the thickness of insulation that, when installed on a surface, will result in an annual cost of combined insulation and energy. In a study for the insulation of HVAC refrigerant line piping, the findings show that when the thickness is less than the required insulation thickness, the investment saving decreases by 21.45%, but the operating cost increases by 11%, where operating cost is ultimately more expensive than the initial investment cost. Similar to this, choosing an insulation thickness greater than the required insulation thickness is not justifiable because the amount of energy saved (and hence reduced electricity expenses) is negligible (Girip et al., 2021). Thus, these studies provide bases to consider critical thickness while retrofitting insulation material which lays foundation for optimum thickness.

The heat transfer equation of the piping network can be determined as (Yildiz & Ali Ersöz, 2015):

$$\dot{q} = \frac{\Delta T}{\frac{1}{h_i A_{s,i}} + \frac{\ln\left(\frac{r_0}{r_i}\right)}{2\pi L_{pipe} k_{pipe}} + \frac{\ln\left(\frac{r_{ins}}{r_0}\right)}{2\pi L_{pipe} k_{ins}} + \frac{1}{h_0 A_0}}$$

According to the classical concept (Holman, 2010), the manipulation of the above expression can be done to determine r_{ins} as:

$$\frac{d\dot{q}}{dr_{ins}} = \frac{d}{dr_{ins}}\left\{\frac{\Delta T}{\frac{1}{h_i 2\pi L_P} + \frac{\ln\left(\frac{r_0}{r_i}\right)}{2\pi L_p k_p} + \frac{\ln\left(\frac{r_{ins}}{r_0}\right)}{2\pi L_p k_{ins}} + \frac{1}{h_0 2\pi L r_{ins}}}\right\}$$

$$\text{or, } 0 = \frac{d}{dr_{ins}}\left(\frac{\ln(r_{ins})}{k_{ins}} - \frac{\ln(r_0)}{k_{ins}} + \frac{1}{h_0 r_{ins}}\right)$$

which on further solving yields:

$$r_{ins} = \frac{k_{ins}}{h_0}$$

So, we need to find the Convective heat transfer of air(h_o).

According to Dodbida and Fujita, 2015 the superficial air velocity is variable and ranges from 1.1 to 2.8 m/sec.

According to ISRO, 2010 and Bastian E. Rapp, 2017, the Prandtl Number of the air is 0.7.

According to Yildiz and Eröz, 2015,

$$Nu_0 = 0.3 + \frac{k_{air}\sqrt{Re} \cdot P_r^{1/3}}{[1 + (0.4 / P_r)^{1/3}]^{1/4}}\left[1 + (Re/ 282000)^{5/8}\right]^{4/5}$$

By same literature,

$$h_0 = Nu_0 \cdot \frac{k_{air}}{D_{pipe}}$$

According to Kosky and Wise, 2013, Convective heat transfer coefficient for free air is 2.5-25 W/m^2K

According to research of Abujaband Abusafa, 2011 result show that the optimum insulation thickness for pipe diameters from 12.7- 50.8mm is 11-13mm for flexible foam insulation

2.1.5. Windows

All apertures in the building envelope, such as curtain walls, windows, doors, and skylights, are referred to as fenestration systems. Fenestration is typically seen as an attractive element, but it also has an impact on how well a structure performs. For instance, strategically placing windows can boost natural lighting, minimizing the need for artificial lighting and saving electricity. Additionally, fenestration can be utilized for passive solar heating to lighten the burden on space heating systems.

The architecture of the building and the glazing property become more significant throughout time as the usage of glass panels and structures in buildings grows and spreads. This is further supported by the growing trend in buildings to frequently use relatively extensive glass areas. (Jelle 2013)

a) Space Heating and Cooling Factor

(Edeisy and Cecere 2017) studied the effect of retrofit glazing in existing housing apartments and found that replacing a single clear glass with a double-glazing reduced cooling load by 14%.

b) Lighting Factor

Building with ordinary glasses consumes as much as 37% more energy than the suitably selected glazing technology. (Foroughi et al. 26). Similarly, buildings with single(clear) glass facade leads to increased glare in the building and hence occupants perfer using window curtains or blinds and the use of artificial lighting (Somasundaram et al. 2020) Using natural light to illuminate a building's interior could contribute to lower energy use and a more hygienic indoor environment. Sunlight falling on 1000 square centimetres of horizontal glass during a sunny day can produce efficiency that is nearly twice that of a fluorescent lamp (Al-Obaidi, Ismail, and Rahman 2014)The productivity and well-being of tenants are improved, and the energy required for artificial lighting is reduced by natural light, which is clean lighting energy as it flows through glazing materials(Al-Obaidi et al. 2014) The simulation result shows that the proper utilization of the daylighting has potential to reduce artificial lighting consumption from 50% - 80% (Bodart and De Herde 2002)

Type of Glazing

Glazing can be defined as an instalment of glass within a structure or frame.

i) Static Window Glazing

Static glazing is defined as glazing with a single fixed thermal and optical property, such as solar heat gain coefficient, thermal transmittance, or visible transmittance.

ii) Dynamic-Window Glazing

With dynamic glazing, the interior of the glass is made darker using electrochromic technology. With the use of this technology, a thin coating can transform from clear to colored when a tiny DC voltage is introduced. The most widely utilized glazing technology is electrochromic (EC) glazing. It has been the most robust commercial activity in Japan, Europe, and the USA for the past 20 years. (Lampert 1984)

iii) Innovative Glazing

It is termed as the glazing technology that makes the use of some suitable materials in between the fenestration. Some of the most popular technologies used widely are:

c) Aerogel Glazing
d) Phase Changing Material
e) Vacuum Glazing
f) Prismatic Glazing

2.2 Server room standards

The data centers are found to be consuming huge energy in the global trend because of the need for cooling, due to server and storage devices, and also, they are in operation almost all time. The leading commercial, scientific, and technological organizations around the world rely on them for computing services that are essential to their everyday operations. Cooling infrastructure only for the data center consumes 50 percent of the energy (Churazova, 2018).

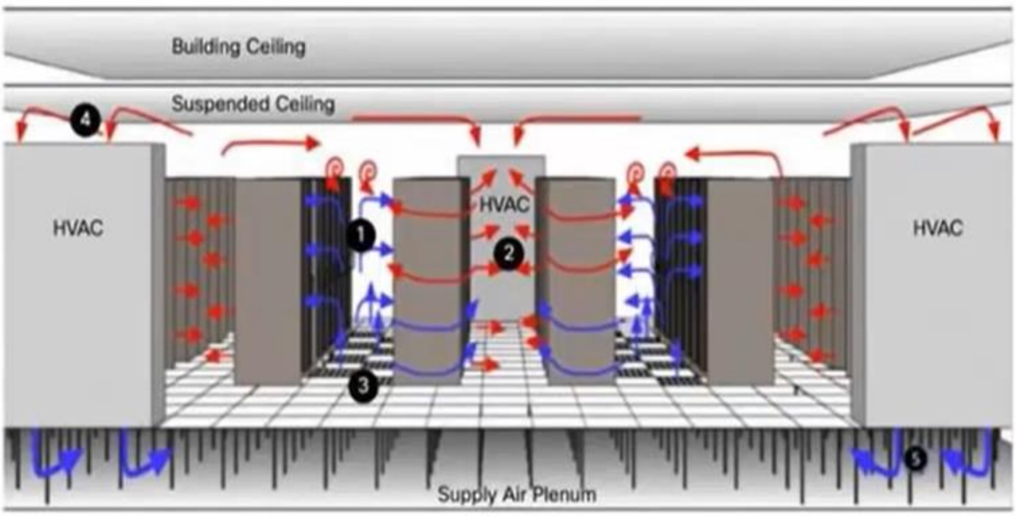


Figure 2.6: ASHRAE 90.4 standards for data center

(Source: Churazova, 2018)

ASHRAE data center standards, ASHRAE 90.4 defines the HVAC standard for energy efficiency standards for data centers for the purposes of design, building, the development of an operation and maintenance plan, and the use of renewable energy sources. By specifically addressing the distinctive energy needs of data centers as opposed to normal buildings, this ASHRAE data center standard incorporates the more important features to the operation of data centers. The major design considerations set by this standard are:

1. The use of raised floor for cooling system where the cool air enters through the perforations in the floor.

2. Specific type of air handler must be used which is Computer Room Air Control (CRAC) units that determine specific flow for hot and cool air streams.

3. In order to conserve energy and the operating cost, the cool air is passed through front of server racks by which the hot air is ejected from the rear side of the racks.

4. For enhancing cooling efficiency, the lowered ceiling configuration is to be used.

Table 2.2: Figure 2.6 Index

Location	**Description**
Point 1	IT equipment inlet
Point 2	IT equipment exhaust
Point 3	Floor tile supply temperature
Point 4	HVAC unit return air temperature
Point 5	CRAC unit supply temperature

The above design results in a 23% reduction in the average temperature estimated for each rack and a 63% reduction in energy used for data center cooling (Churazova, 2018).

About ANSYS Fluent

It is an effective computational fluid dynamics (CFD) tool for simulating heat transfer and fluid flow. One of ANSYS Fluent's primary strengths is its capacity to utilize cutting-edge numerical techniques to resolve difficult fluid flow issues. The governing equations of fluid flow are discretized by the program using a number of approaches, such as the finite volume, finite element, and finite difference methods. All things considered, ANSYS Fluent is a robust and adaptable CFD software suite that is frequently used in both business and academics to simulate a variety of fluid flow issues. For engineers and scientists working in fluid mechanics and related subjects, its cutting-edge numerical capabilities, user-friendly interface, and customization options make it a must-have tool.

2.3 Passive Design Study

2.3.1. Bio Climatic Chart

A bioclimatic chart is a psychometric chart used to show, analyze, and simplify climatic information from the perspective of human comfort for any given region. (Lakhe et al., 2017). It offers information on the climate in the area and recommends suitable passive design techniques that can help cut down on energy use and enhance thermal comfort inside the building. A series of curves or lines that indicate various parameters, including temperature, humidity, and solar radiation, make up the bioclimatic chart in most cases. The best passive design approaches for a specific construction site can be identified using these curves, which are based on local climatic data. For instance, the chart might show the ideal structure orientation, the right amount of insulation, the best shading strategy, and the ideal window-to-wall proportion.

The principles of bioclimatic design, which stress the use of natural ventilation, passive solar heating and cooling, and the use of local materials to optimize building performance in the local climate, serve as the foundation for the bioclimatic chart. Bioclimatic design can reduce energy use, minimize the need for mechanical heating and cooling systems, and enhance thermal comfort inside buildings by taking into account the local climate and creating responsive buildings. A bioclimatic chart's ability to assist builders and designers in optimizing a building's design based on its particular location and climate is one of its advantages. This can help the building have less of an effect on the environment, make the interior more comfortable, and use less energy overall.

In conclusion, a bioclimatic chart is a useful instrument for architects and designers who want to create sustainable, energy-efficient structures that are sensitive to the local climate. By utilizing the data in the chart, architects and designers can optimize the design of structures to lower energy use, increase thermal comfort, and use mechanical heating and cooling systems less frequently.

2.3.2 Mahoney Table

The Mahoney tables present the results of thermal comfort analysis using primarily temperature and humidity data, as well as design guidelines recommendations. The design guidelines from Mahoney table provides appropriate information at strategic decision stages to help make better use of energy in building design and development in order to incorporate passive solar energy considerations in design (Upadhyay et al., 2006).

A climatic analysis instrument known as the Mahoney table is used in passive building design to assist architects and designers in better understanding the local climate and enhancing building design for increased energy efficiency and comfort. The tool's creator and creator of the table, John Mahoney, created it in the 1970s. The Mahoney table, which provides information on the appropriate passive design strategies for a specific building site, is usually based on climatic data such as temperature, humidity, solar radiation, and wind speed. The table usually consists of a number of rows and columns, where the rows correspond to various passive design strategies and the columns to various climate zones.

The table's cells each contain data on the performance of a specific passive design approach in a specific climate zone. For instance, based on the amount of solar radiation present in a given climate zone, a cell may suggest whether a specific passive solar design strategy is suitable for that zone. Based on a building's location and climate, the Mahoney table can be used to determine the suitable passive design approaches. For instance, the table might advise using passive cooling techniques in a hot and dry environment, such as natural ventilation, shading, and the use of thermal mass to absorb and release heat. The table might advise using passive sun heating techniques in cold climates, such as south-facing windows

There are three groups of tables altogether.

i) Table 1: The weather data including wind, rain, temperature, precipitation, and humidity along with respective comfort matching categorized into different groups.

ii) Table 2: Data Analysis Table (Diagnosis)

iii) **Table 3:** Recommended specifications

2.4.Building Energy Simulation

Energy Simulation in building sector i.e. Building Energy Simulation is the computerized technique which involves the process of evaluation of energy performance of the building based on the input parameters. The use of simulation software is essential to depict the whole building performance and make necessary changes to adopt the energy efficiency methods. Whether to construct a new structure or to make changes in real world application, of the existing building, the simulation serves as the strong method to help the owner and designer to integrate the most appropriate alternative based on the result. For instance, one of the energy saving measures in the building these days is cavity wall. If the building with single layer non insulating walls is to be retrofitted with cavity wall the effect of the later can be first analyzed to evaluate enough saving through simulation. Based on the result, retrofitting is to be undertaken.

2.4.1 SketchUp

Architects, engineers, and designers can develop and visualize building designs in a 3D environment using SketchUp, a well-liked 3D modeling program used in the construction industry. Building design pros now frequently use SketchUp because of its simple interface, intuitive tools, and extensive 3D modeling capabilities. Making incredibly accurate 3D models of structures and their surroundings is one of SketchUp's advantages. This enables architects and designers to try out various design concepts before beginning construction to see how they will appear in the real world.

SketchUp users can also quickly and easily share their designs with customers, stakeholders, and other team members, which can speed up the design process and guarantee that everyone is on the same page. The extensive library of pre-built 3D models, textures, and materials that SketchUp offers is another advantage. These resources can expedite the design process and guarantee that designs are correct and realistic. Additionally, SketchUp has a sizable user base that has produced a ton of plugins and expansions that can further the program's functionalities, including energy analysis tools, daylighting analysis tools, and more. Using SketchUp's 3D modeling tools, precise building drawings can be produced and exported to other software applications like AutoCAD or Revit. This can speed up the building process and guarantee that plans are precise and feasible.

In conclusion, SketchUp is a potent 3D modeling program that can significantly improve the process of designing buildings. It is a useful instrument for architects, engineers, and designers in the building design industry due to its simplicity of use, extensive 3D modeling capabilities, and capacity to produce extremely detailed models and construction drawings.

2.4.2 Openstudio-Energyplus

The US Department of Energy created the open-source, free software program OpenStudio to enable EnergyPlus building energy simulation. A simulation software called EnergyPlus models the energy consumption of buildings and the related lighting, ventilation, heating, and air-conditioning systems. Building energy models are made simpler for architects, engineers, and building energy analysts thanks to OpenStudio's user-friendly interface for EnergyPlus. A variety of built-in HVAC and lighting systems, as well as sophisticated features for modeling complicated energy systems, such as radiant heating and cooling systems, are just a few of the many features that OpenStudio offers to support building energy simulation. To speed up the modeling process, OpenStudio also has a collection of pre-made building elements, materials, and weather data sets.

The capability of OpenStudio to analyze the energy performance of buildings at different levels of detail is one of its main advantages. It can simulate both the total energy use of a building and the energy use of its various systems, such as lighting and HVAC. As a result, building systems can be optimized and possible energy-saving opportunities can be found. A variety of output reports and visualization tools are also included in OpenStudio to aid users in understanding the outcomes of their models. Reports on energy use and costs, system and zone-by-zone energy use breakdowns, and representations of building energy use and thermal comfort are a few of these.

In conclusion, OpenStudio is a strong and adaptable building energy simulation tool that can assist architects, engineers, and building energy analysts in maximizing the energy efficiency of buildings. It is a useful instrument for energy modeling and building performance analysis due to its user-friendly interface and extensive feature set.

CHAPTER THREE: METHODOLOGY

3.1 Project Framework

The project was carried out following the framework as presented in Figure 3.1

3.1.1 Problem Identification and Project Questions

Based on the stated problem and objectives of the project, the following questions are generated to carry out effective auditing of the selected site;

i. What is the good target for energy consumption for the building?
ii. Considering the age of the building, what is its current energy status?
iii. If the building was made or operated differently, how would the required equipment capacity and energy consumption change?
iv. Is there any potential area of energy-saving? If yes, what would be their effect on the performance of the building?

3.1.2 Scenario Analysis

The data collection was initial process. The data may include various information to summarize the present status of the building.

The sources of data were:

i. Building Construction Manual
ii. ASHRAE Manual
iii. Department of Hydrology and Meteorology
iv. Utility Bills

A number of measures were adopted to extract the data related to building energy its usage pattern and the current status. For finding out the first-hand attitudes of the students and staffs towards the facilities available in the ICTC Building, primary data were needed. Several methods can be used to collect primary data such as:

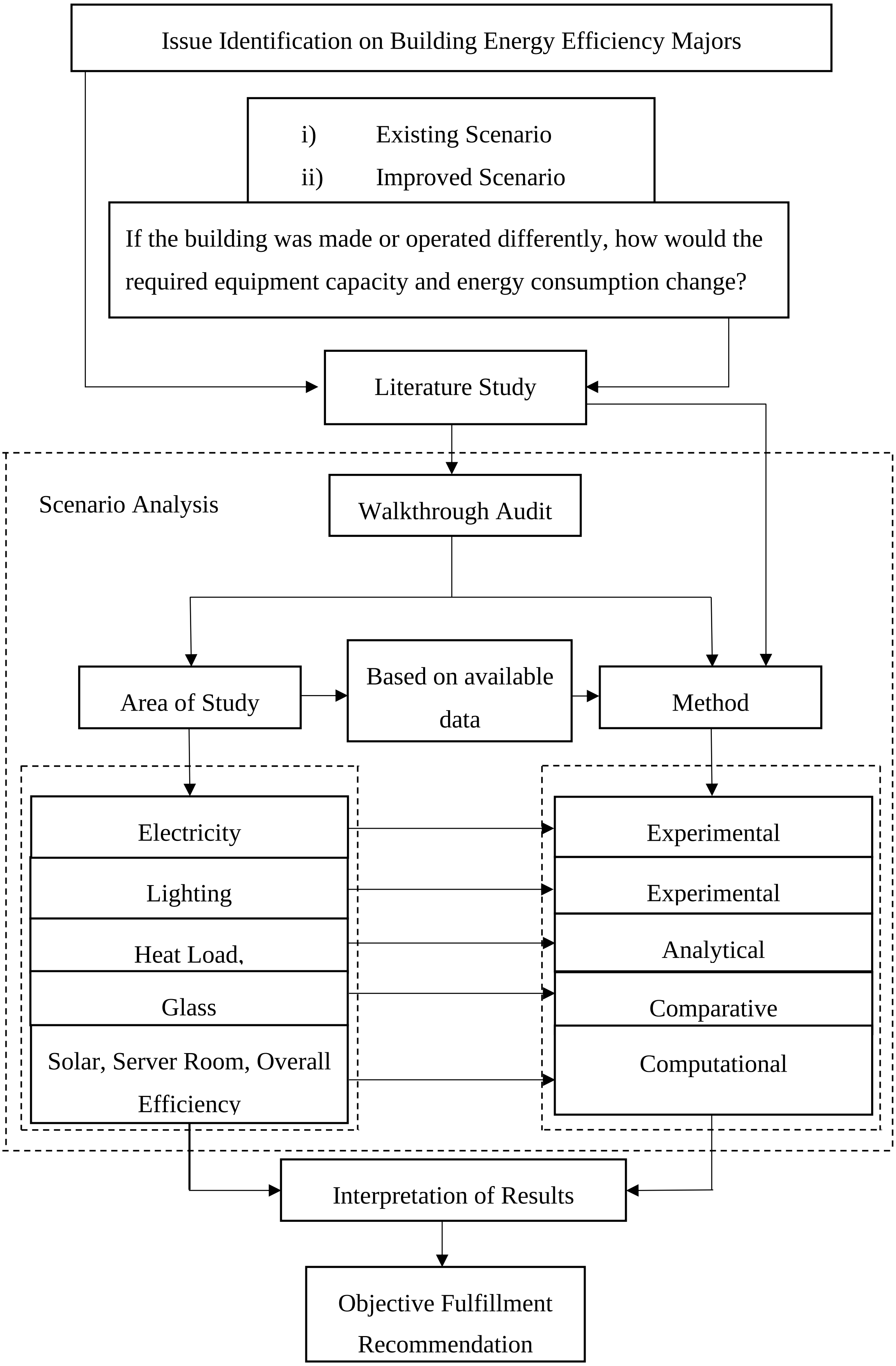


Figure3.1: Project Framework

i) Questionnaire

The questionnaire surveys were performed in the month of September and November, during the building occupancy for NMCLE and IOE Entrance exams. Following factors were considered as part of conducting the study:

a. Defining the genre of study

b. Setting the forms of questions

c. Defining ways of administering a questionnaire

d. Developing an attitudinal scale

ii) Interview

The staffs of ICT building were interviewed both verbally and selective.

iii) Walkthrough Audit

Walkthrough is the initial phase of an audit process, where a company's activities and processes are inspected and examined to further evaluate whether or not controls are in place. This information is then used to decide the scope of the following procedures. It is often referred to the familiarization visit to the facility before proceeding with a proper audit procedure. The walkthrough report is prepared referenced from "Energy Efficiency Planning and Management Guide, Canada"

Then based on the collected information the entire scenario was analyzed adopting the suitable method. Each section of the study was studied separately to create that necessary base case (Explained in later section). The result and the details discussion are presented in Chapter Four

3.1.3 Interpretation of Result

The interpretation the acquired result are done based on the available standards and past studies aiding to the fulfillment of the objectives. Also cost analysis and payback period were determined based on the verification and validation of energy-saving potential after assessing the comparison of the base scenario and the best scenario. Conclusion and Recommendation were then presented in Chapter Five

3.2 Work Category

The measurement and analysis have further been categorized based on the nature of the work as:

i. Lighting: LED retrofitted lighting
ii. Solar Energy
iii. Cooling and Heating Load
iv. Insulation thickness
v. Server orientation
vi. Electricity
vii. Building Simulation

3.1.1. Lighting

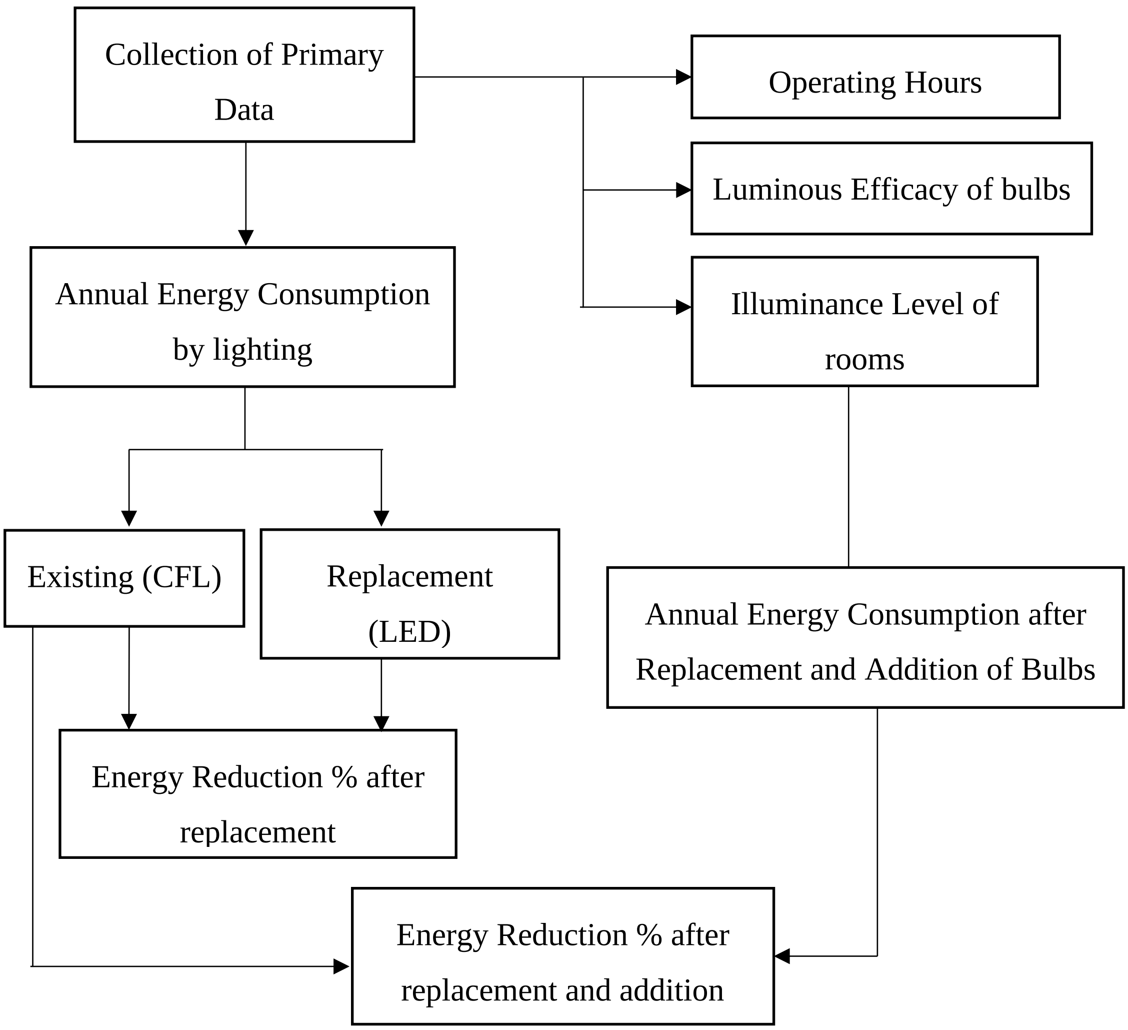


Figure 3.2: Flowchart for lighting analysis

The number of operating hours was obtained after interviewing the staffs and students. It has been found that the average operating hours (OH) for this building to be 2.5 hours/ day, 6 days/ week and 50 weeks/year resulting to annual operating hours be 750 hours.

The luminous efficacy for CFL and LED lighting are set 70 lm/W and 100 lm/W based on the literature review.

Procedure:

Safety instructions for Luxmeter:

a. Turn the on/off switch to the desired measuring range.

b. Remove the protective cap from the light sensor and hold it ensuring that the light reach the light sensor vertically. Avoid shadows of your own body in the direction of sensor.

c. According to Japanese Industrial Standard (JIS), the height of the measured surface shall be within 85 cm from the floor

3.1.2 Solar Energy

3.1.2.1 Data Collection

The data collected for the solar study were secondary type from the sources: DHM, Meteonorm- weather file, project completion report of the building and from the relevant past studies for finding out the Global Solar Radiation received by building, sunshine hours of the location, dimension and material type of window glass, name-plate power, model, brand, dimension, inclination angle and azimuthal angle of PV, and values of percent losses in the PV system.

3.1.2.2 Work Category

The further jobs were carried out specifically on the solar panel and the windows.:

i) Solar Panel Simulation

ii) Windows

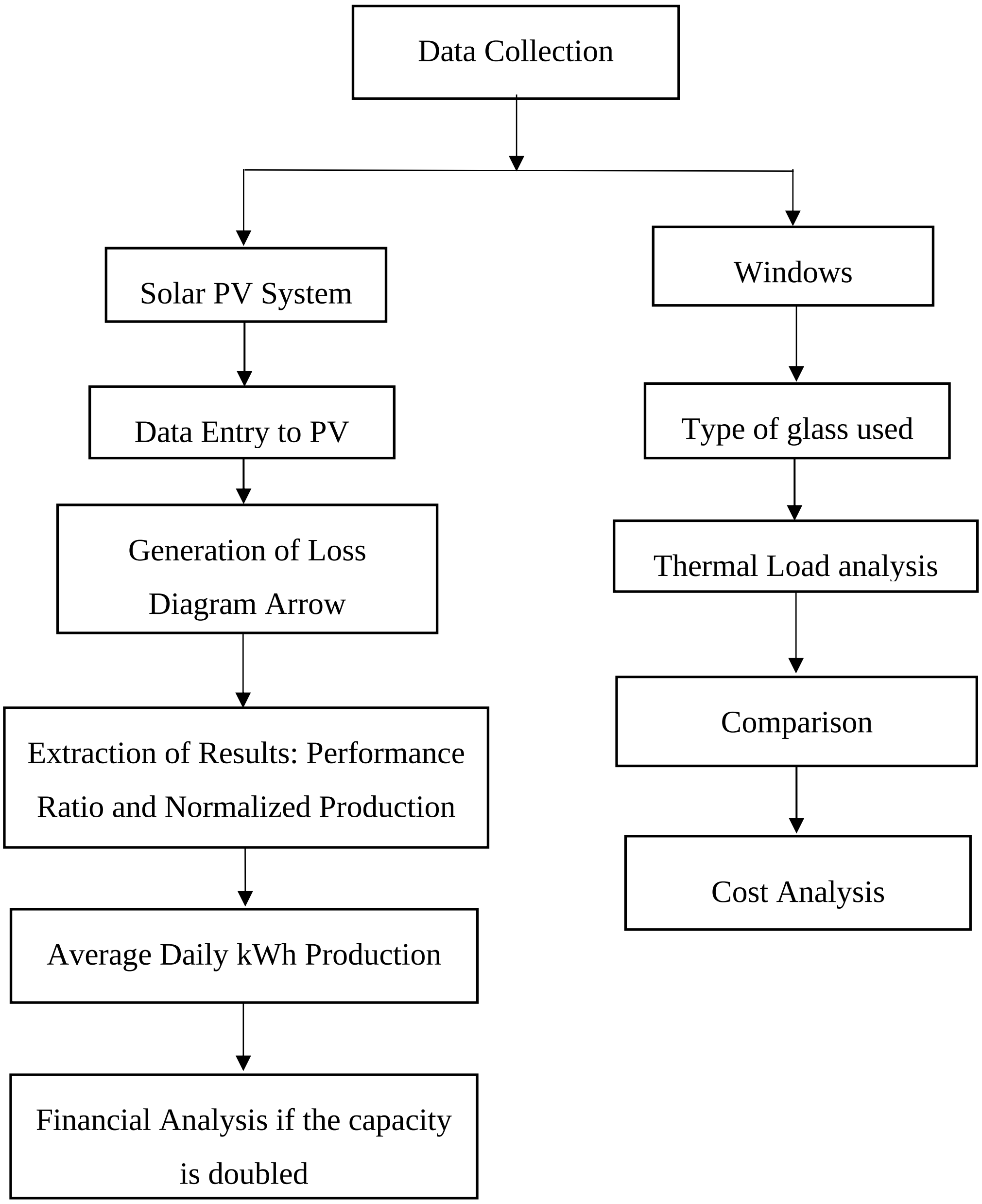


Figure 3.3: Workflow for solar energy study

A. Solar Panel Simulation

The existing PV installation is simulated with a reference to literature with a four-step procedure as (Kumar et al. 2019):

i) The initial phase involves gathering data about the installation site, the anticipated PV capacity, the type of installation, etc.

ii) The second phase involves simulation modeling using the PV Syst program to estimate energy performance.

iii) In the third phase, an analysis of the arrow diagram produced by PV Syst is used to assess the energy performance decline caused by the losses.

iv) Finally, examination of PV system performance characteristics, such as energy delivered and performance ratio, are done in the fourth step.

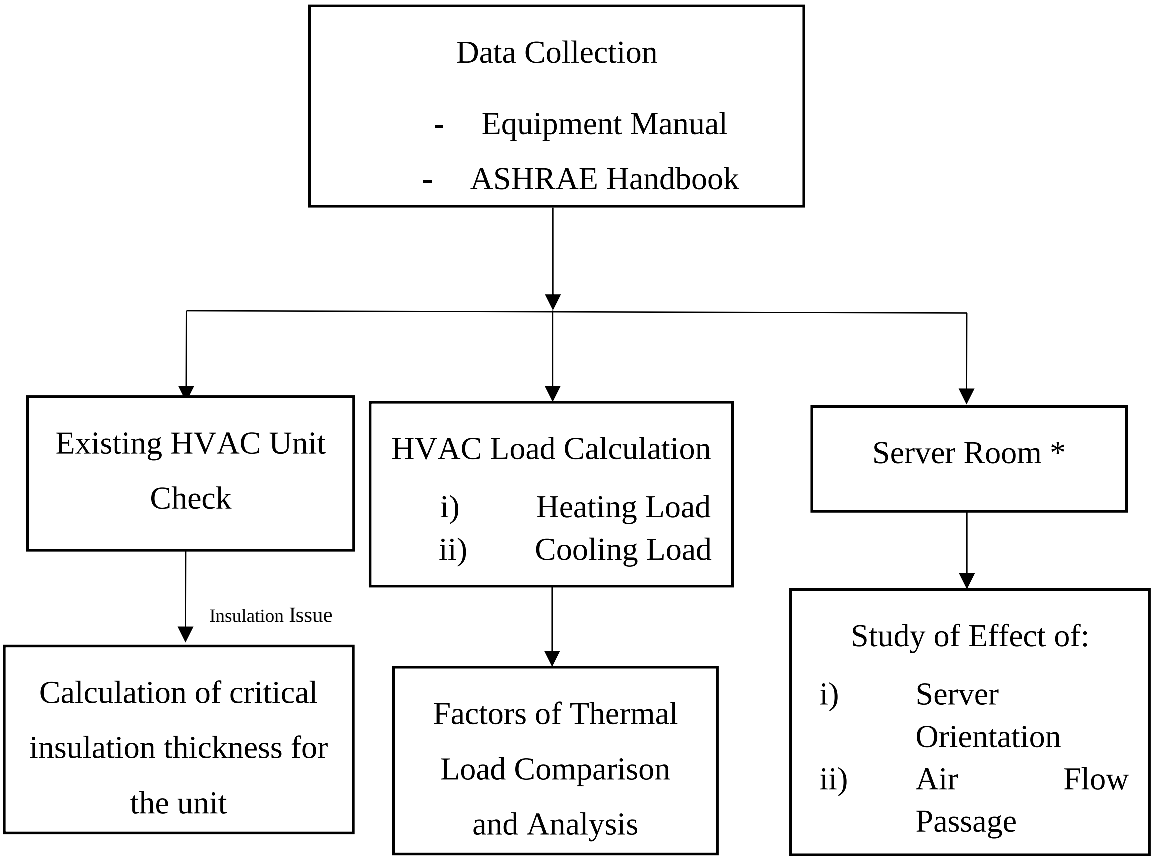
B. Windows

Windows play a major load in the HVAC load of any building. In this part, the study of glass type will be thoroughly done.

The physical properties of the glass were extracted through the building manual(glass type), ASHRAE Handbook(U values, CLF and CLTD) and the dimension was taken manually.

Comparative study existing glass with double glazed glass for the building to explore potential energy saving along with cost analysis.

3.1.3 HVAC



Index: * Separate Detailed Flow Chart

Figure 3.4: HVAC study Workflow

3.1.3.1 Data Collection

The primary step in performing the study on HVAC units includes data collection about the specifications of the units where cooling capacity, heating capacity, connecting pipe diameters, etc. are extracted for each separate model.

Similarly, for the load calculation, the required data were extracted from the ASHARE handbook and the building construction manual of ICTC.

3.1.3.2 Insulation Thickness Calculation

Figure 3.5: Existing Torn Insulation

Based on our walk-through audit, the condition of insulation for the refrigerant pipe network is damaged which requires retrofitting. From the literature considered, it is suggested to find critical insulation thickness to reduce both installation and operating costs. The use of thermal insulation in the HVAC system has been identified as an important energy conservation measure in this study and intending to design insulation in a cost-effective, environmentally friendly, and energy-saving manner. To solve this problem the critical thickness of the insulation is calculated.

A comparative analysis is to be performed whether the existing thickness is in compliance to the critical insulation thickness by experimental measurement.

3.1.3.3 Thermal Load Calculation

The climatic data was based Department of Hydrology and Meteorology station Tribhuvan International Airport at latitude of 27.7°E, longitude 85.2°N and elevation of 4388 ft. As the climatic data for the given site i.e. ICT Pulchowk was not available, the data of airport which is nearer to was taken.

The indoor and outdoor conditions for Pulchowk are summarized below.

Summer

Indoor: 75°F and RH 50% (within Human Comfort)

Outdoor: 88°F and RH 73 % (Weather data from DHM)

Winter

Indoor: 70°F and RH 50%

Outdoor: 33°F and RH 65.2%

Calculating the exact thermal load of the building is of great challenge. A number of assumptions were made to made to make the calculation quick and efficient.:

i) The heat exchange through the air infiltration was neglected.
ii) Not all electrical equipment were considered.
iii) The number of occupants was taken constant i.e building at full capacity during working hours.
iv) The heat exchange through the window frame and the blinds (if any) were not considered.
v) The building envelope heat exchange was only considered.

To evaluate the maximum thermal (heating and cooling) load in the building, the load for the operating hours of the building were calculated i.e 10am – 5pm. Each contributing component of the thermal load is calculated separately as follows:

i) Wall

CLTD data for wall group D for time 10am to 5 pm are obtained from the ASHRAE Handbook. U value is calculated as per the wall construction combination i.e 1.04Btu/hr

ii) Ceiling

The ceiling for the top i.e the 4th floor was only considered for the roof is exposed to environment. Ceiling of each floor of the building is made of up 10" concrete slab with 0.5'' plaster on both sides. The calculated U- value was 0.64 Btu/ft^2 ^{o}F[Appendix D]

iii) Glass

The building has 0.25" single pane type glass. The U value from Data book is taken as 1.04 Btu/ft^2 ^{o}F

Similarly, the CLTD value was referenced from the ASHRAE fundamental handbook for different time.

iv) Lighting

To determine heat gain through internal light, power ratings of lights were determined. For BF, the typical value of 1.25 has been assumed for fluorescent lighting. It recommended that value of 1 can be used for day operation. So, CLF value as 1 has been assigned.

v) Occupants

The sensible and Latent heat gain was taken as per ASHRAE Standard referred to normal office work activity.

vi) Computers

Heat gain through the computers placed in different zone of conditioned space is taken as 250 Btu per hour (ASHRAE Handbook 1997). This includes the heat given off by monitor, CPU fan and additional equipments. The number of was taken summing all the computers run in office hour excluding the break.

vii)Ventilation

For our purpose it was neglected that the infiltrated air has no any effect and only take ventilated air as the volume of infiltrated air is very less in comparison with the ventilated air.

3.1.3.4 Server room standard

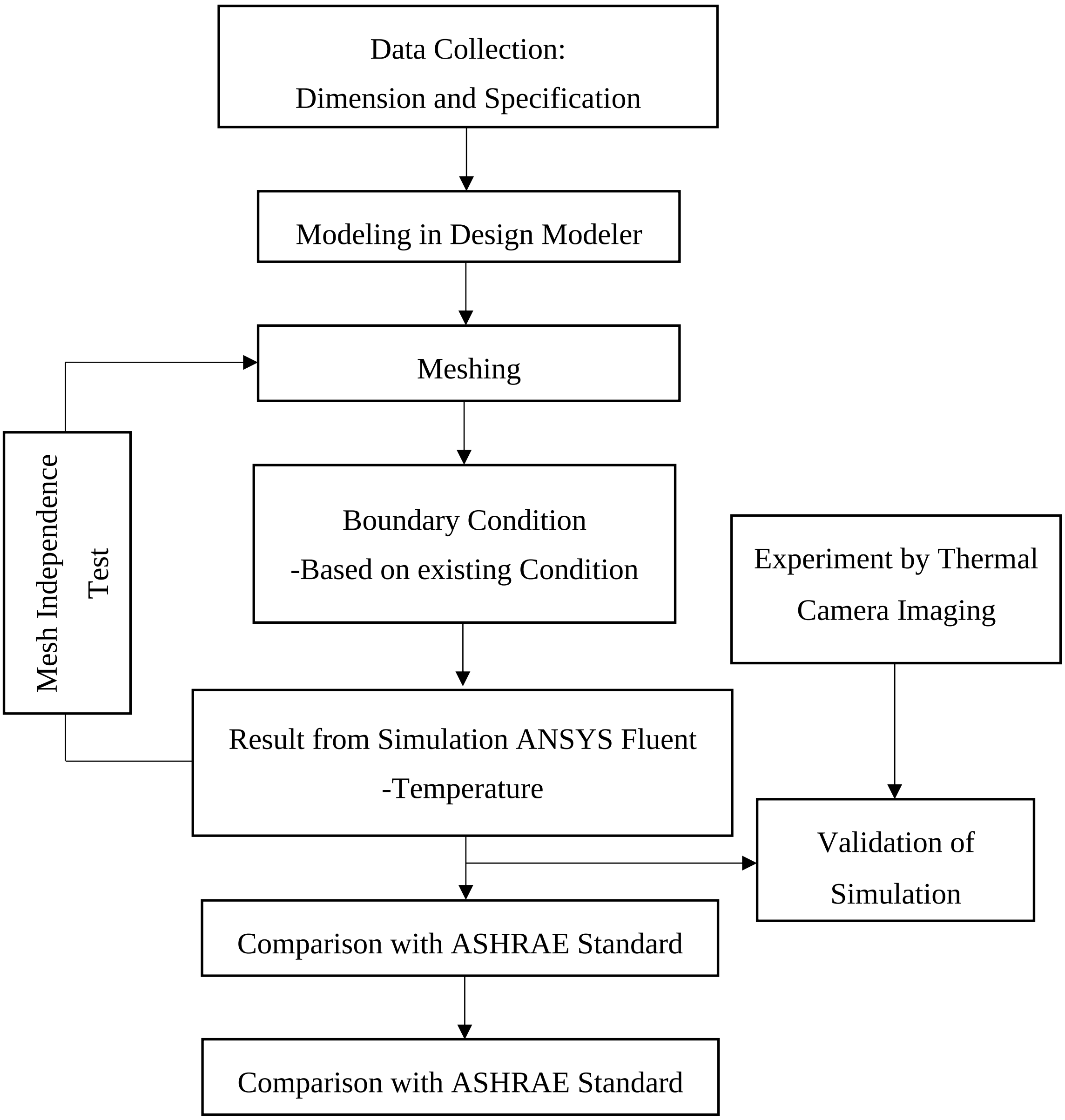


Figure 3.6: Methodology adopted to compare with ASHRAE standard

Modeling

1. The modelling was done in design modeler.
2. Dimensions of server room was measured and were replicated in the model.
3. The server was modeled in the rectangular block replicating its outer case.

Meshing

1. Ansys CFD meshing was used for discretizing the system (meshing)

2. Mesh size of 0.12 m in the body and local meshing of 0.03m for servers, inlets and outlets. Smaller mesh size is to capture the phenomenon more accurately.

Solving

Ansys Fluent was used for solving the fluid flow.

Table 3.1: Parameters Details for simulation

Property	**Value**
Time	Steady state
Model	SST k-omega, Energy (to simulate temperature)
Boundary Conditions 1. Inlet 2. Outlet 3. Light 4. Server exam 5. Server office 6. Window	 1. 0.6392 kg/s 2. Pressure Outlet 3. 15 W/m^2 4. 50 W/m^2 5. 30 W/m^2 6. 15.85 C

Then the simulation was run until convergence up to 4^{th} power of continuity.

Model Description:

RANS (Reynolds-averaged Navier-Stokes) models are relatively computationally efficient and can provide accurate results for a range of flow regimes, including those found in indoor environments. The k-omega model is a two-equation RANS turbulence model that solves for the turbulent kinetic energy (k) and the specific dissipation rate (omega) of turbulence. It is specifically designed to handle the adverse pressure gradient and wall proximity effects that occur in high Reynolds number flows, and also capture the thermal plumes more efficiently, making it a more suitable choice for these types of flows (Liu et. al., 2022).

Mesh Independence Test:

Mesh independence test was done to ensure that the numerical solution is insensitive to the dimensions or resolution of the discrete mesh used to define the domain of interest.

3.1.4 Passive Design Study

3.1.4.1 Bioclimatic chart

The Climate Consultant software v6.0 was used to generate the bioclimatic chart. The EPW data was used for the Kathmandu Valley. Once the location and climate data are provided, it automatically generates a bioclimatic chart. After the chart was created, the information needed to determine the suitable passive design strategies for the building and the local climate was analyzed. The graph usually displays a number of variables, including temperature, humidity, and solar radiation, from which the building's best passive design strategies can be selected. The building's design can be modified to increase thermal comfort and energy efficiency based on the bioclimatic chart's data. For instance, if the graphic indicates that summertime solar radiation levels are high, we might want to use shading techniques like overhangs or shading devices to lower the building's solar heat gain.

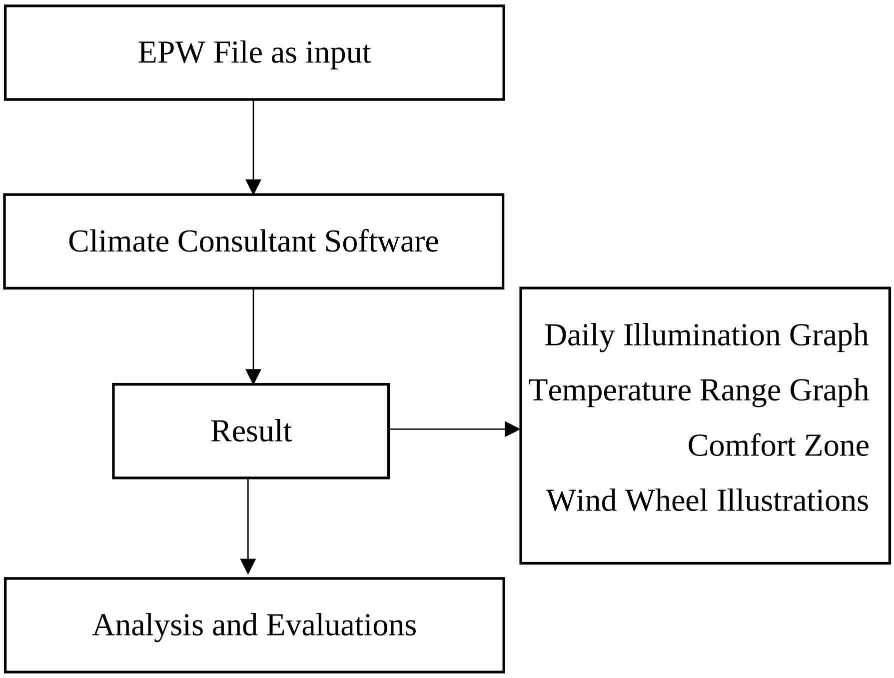


Figure 3.7: Use of Bioclimatic Chart

Finally, we received graphs, charts, and indicators pertaining to several factors. They contain a graph showing daily hourly illumination, a graph showing average dry bulb, humidity, and comfort zone, a graph showing temperature range and comfort zone, a wind wheel illustration, a graph showing hourly average daylight illuminations, a chart showing sun shading, etc.

3.1.4.2 Mahoney Table

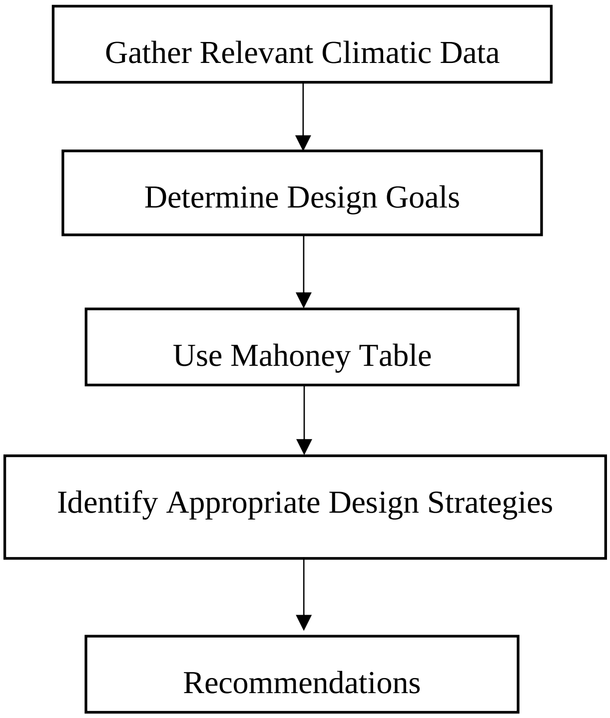


Figure 3.8: Passive Design Strategy Approach

Data on the climate in the area where the structure is being designed must first be gathered. This information ought to cover the following: temperature, humidity, breeze direction and speed, solar radiation, and precipitation. The next step is to decide on the ideal indoor temperature range, humidity levels, and other building construction objectives. We should compare the climate statistics for the location with the design objectives using the Mahoney Table to determine the best passive design approaches. Based on the climate data, the Mahoney Table usually uses a series of shading coefficients and thermal performance values to suggest suitable passive design strategies. The building design can now incorporate the suggested passive design methods. The use of passive sun heating, shading devices, natural ventilation, and thermal mass are a few examples of possible solutions. We can assess the structure's design to make sure that the suggested inactive design techniques are applied correctly and serve the intended design purposes.

The following are detailed descriptions of the project site's climatic features:

i) Temperature
ii) Precipitation
iii) Wind

iv) Humidity

v) Solar Radiation

vi) Sun Position and Solar Path Diagram

3.1.5 Building Energy Simulation

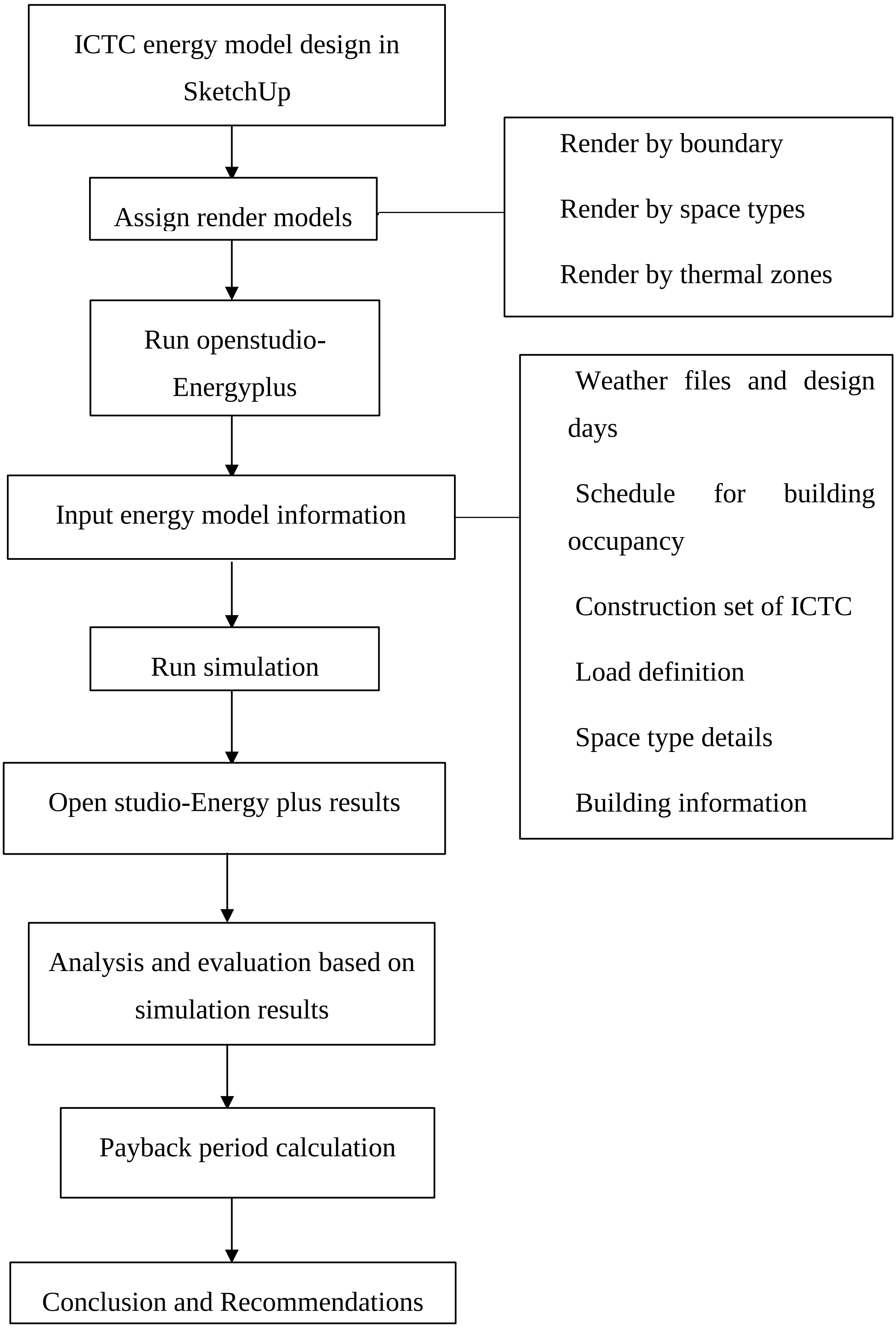


Figure 3.9.: Building Simulation Procedure

The energy model is initially created in SketchUp. Following that, the render modes must be assigned. Boundaries, different space kinds, and heat zones were used to render the model. There should be an openstudio-EnergyPlus program. We must enter a variety of data into the openstudio program, including weather files, design days, a building occupancy calendar, an ICTC construction set, load definition, space type specifics, building fundamentals, HVAC system, etc. Analysis and evaluation can be done utilizing the simulation findings afterward. Calculating the payback period of various energy reduction potential is crucial in building audits. The conclusion and suggested changes will then be given.

3.1.5.1 Scenario development

A) Building Operating Characteristics

The majority of the commercial office floor space that CBECS examined was occupied between 40 and 60 hours per week. The ASHRAE 189.1-2009 user's manual includes information on typical occupancies, HVAC, lighting, and other devices. It was expected that the building would exhibit normal office occupancy patterns, with the peak usage occurring from Sunday through Friday between 10 a.m. and 8 p.m. There would be expected to be a restricted occupancy from 10 a.m. until midnight for housekeeping reasons.Holiday and weekend occupancy was expected to be around 5% of peak occupancy, while working days were predicted to be 50% of peak occupancy from 10 a.m. to 5 p.m. and 30% of peak occupancy from 5 p.m. to 8 p.m.

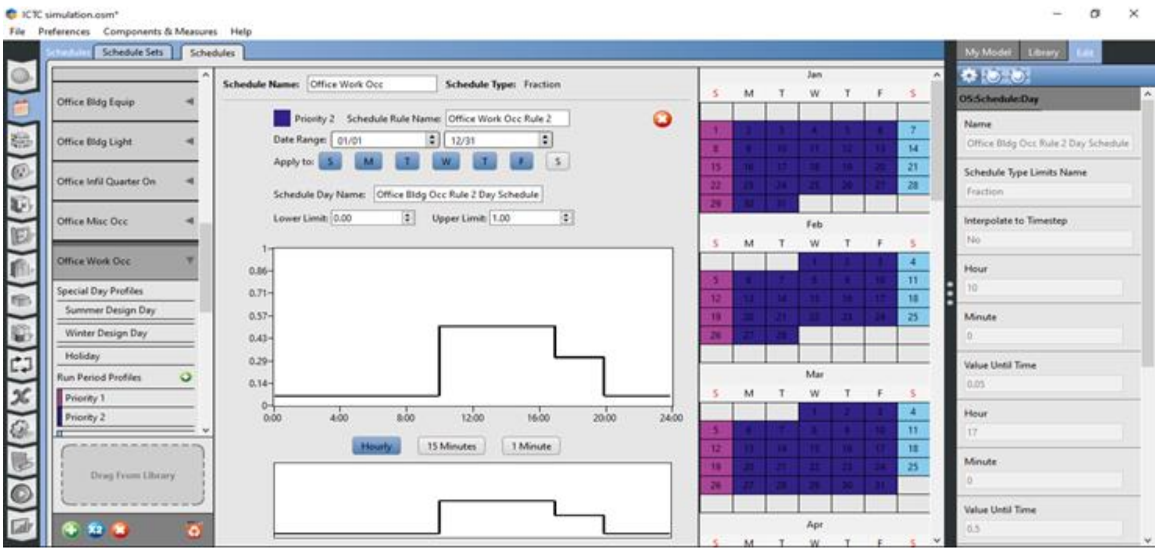


Figure 3.10. Graph Showing Schedules for office work occupancy

B) Baseline Building Envelope Characteristics

The majority of opaque structures were made of walls, window panes, slab-on-grade floors, and built-up roofing with insulation sandwiched between the roofing tiles, it became apparent after the structure was examined. The structure was thought to be 10 feet tall from floor to floor. An isometric perspective of the building's Sketch Up model is shown below.

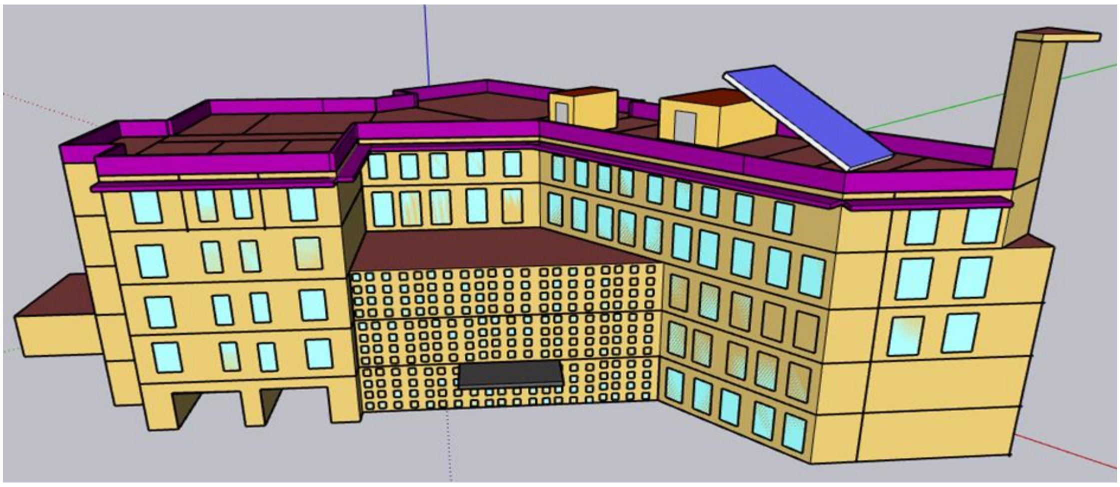


Figure 3.11: Showing Energy Model of ICTC building

C) Render modes

Different render modes in SketchUp were designed to help get a better sense of how building design meets different requirements and criteria. Here are different render modes of the ICTC building.

1) Parametric view of Energy Model

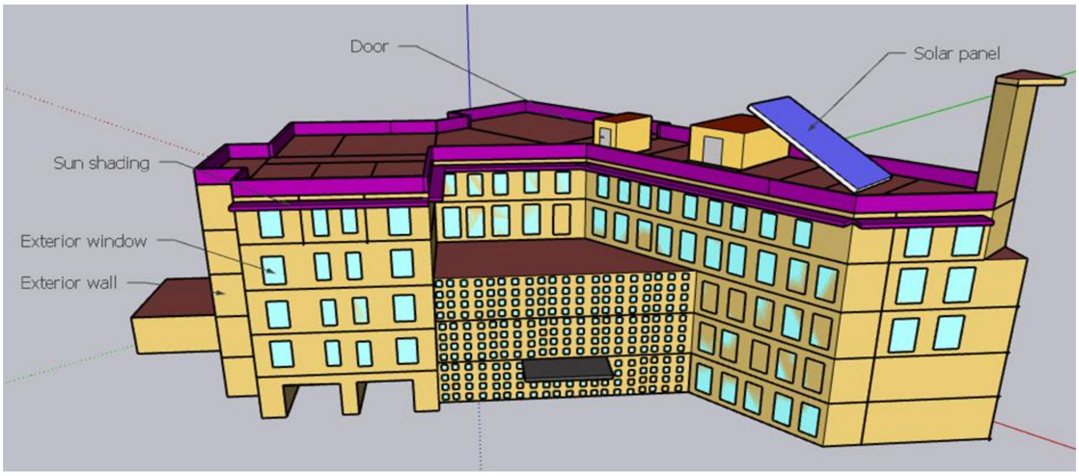


Figure 3.12: Parametric View of Energy Model

This mode enables the view of the structure model with various applied parameters,including size, area, volume, and others. To satisfy requirements, this mode is helpful for analyzing and optimizing design parameters.

2) Different Floor Level of Energy Model

We can view the building model in this setting with its various levels and floors. It's useful for comprehending the relationships and interactions between the various layers.

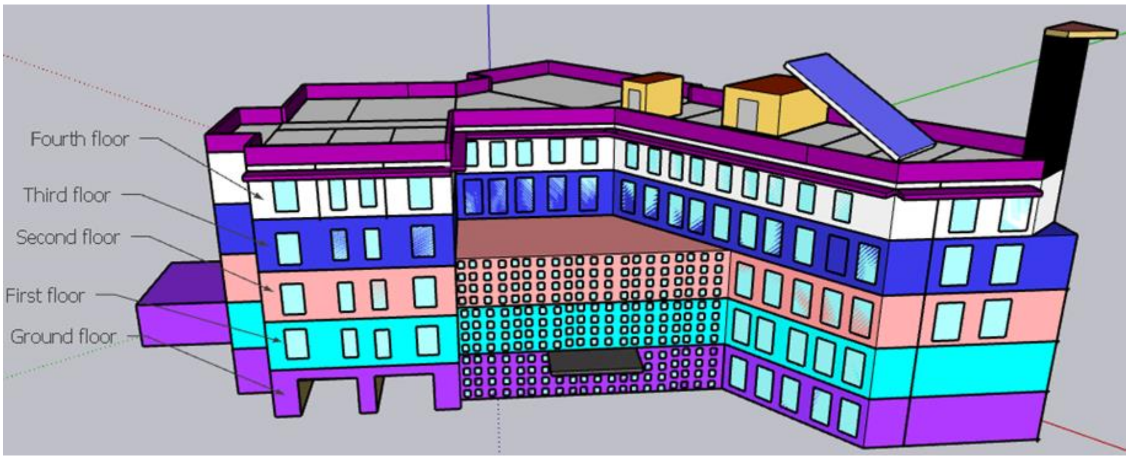


Figure 3.13: Different floor level of energy model

3) Different Space type of Energy Model

This mode allows one to see the building model with different spaces and functions, such as offices, living areas, kitchens, and bathrooms. It's useful for understanding how different spaces relate to each other and how they function within the building.

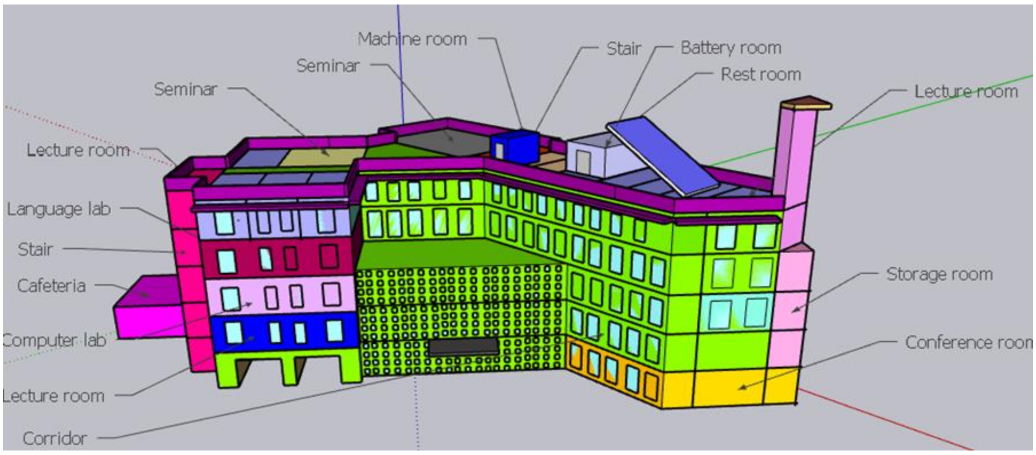


Figure: 3.14: Different space types of Energy Model

4) Different conditioned zone

This mode allows one to see the building model with different conditioned zones, such as heating, cooling, and ventilation zones. It's helpful for understanding how the building's HVAC systems are designed and how they interact with different spaces.

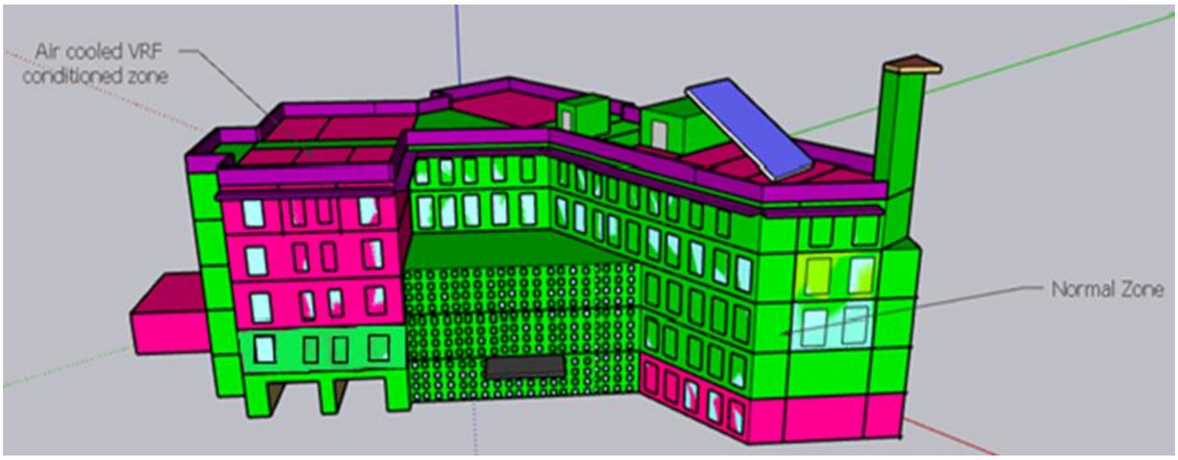


Figure 3.15: Different conditioned zone

According to our case study of the ICTC building, the following factors affect the energy impact:

i. Cavity wall

ii. Window glasses

iii. Electrical equipment definition

iv. Light definition

The inputs for the baseline energy model of the case study project by zone and Standard Space in accordance with ASHRAE Standard 189.1-2009, including the definition of Summary of the People, lighting power intensity, and plug load intensity.

D) Comparative Energy Model

The energy model does not accurately reflect the current situation. Comparative research is required for the goal, so an equivalent model was created by changing the standard model to include energy efficiency measures (EEMs) for a better model instance. The measures intended to lower the internal heating and cooling loads should also be compared.

The literature review's sources were used to develop the EEMs concepts. The following categories were used to categorize all EEMs:

- Cavity wall
- Double glazing window
- Lighting measures
- Electric load measures

Although any combination of EEMs may accomplish the same task, the purpose of this study was not to identify the most effective mix. However, a valid modification in an existing structure will be tested. For that reason, two distinct models—the base case model and the improved case model—were created in order to compare the simulation results for the design strategy, criteria, and potential for energy savings.

The measurements of energy efficiency used in the comparative research model can be explained using the headings below.

E). Building Envelope Building Element Assembly

Improving the thermal performance of the wall and window assembly was explored to reduce heating and cooling loads. The cavity wall was made in the external wall. The improved model maintained the same window area as the baseline mode, but window constructions were improved in terms of U-factor. Double-pane low emissivity glass was modeled in the improved model case.

Table 3.2: Showing EEMs for building envelope

Building Element	Remarks For Improved Assembly
Exterior wall	Cavity wall having wall air space resistance (0.15 m^2K/W)
Window	Double glazing glass having overall U value of 0.46 was installed in place of single glazing window

i. Reduced Lighting Intensity

LED lights were found to be more prevalent than fluorescent fixture types after an examination of the literature. All occupied spaces were modeled with occupancy sensors to detect occupancy.The lighting power intensity of the enhanced model and the baseline model are contrasted in the table below.

Table 3.3: Lighting intensity for the normal model and the improved model

Zone/Standard Space Type	Normal Lights Intensity (W/ m^2)	Improved Lights Intensity (W/ m^2)
MDF server room	8.18	3.93
Administration room	8.08	3.88
Stair	4.29	2.06
Toilet	3.31	1.59
Meeting room	4.26	2.04
Conference room	3.9	1.87
Storage room	6.29	3.02
Corridor	2.65	1.27
Cafeteria	5.1	2.45
Lecture room	5.04	2.41
Computer lab	5.08	2.43
Seminar	5.1	2.45
Language lab	5.08	2.44
Generator room	8.18	3.93
Machine room	15.15	7.27
Battery room	5.1	2.45

ii. Electric Loads Measures

After the walk-through audit of the site, it was found that the old version of desktop was present there. In order to conserve energy, all the old versions of the desktop were replaced by the latest desktop in the energy model for the feasibility study.

The table below presents the normal and improved case intensity of electrical plug and process load.

Table 3.4: Electrical intensity for normal case and improved case

Zone/Standard Space Type	Normal Case Electrical Intensity (W/m^2)	Improved Case electrical Intensity (W/m^2)
MDF server room	28.3	12.17
Administration room	17.52	7.53
Stair	-	-
Toilet	0.75	0.75
Meeting room	37.23	16
Conference room	17.07	7.34
Storage room	-	-
Corridor	0.75	0.75
Cafeteria	5	5
Lecture room	44.08	28.68
Computer lab	66.7	26.68
Seminar	33.48	14.4
Language lab	44.47	19.12
Generator room	13.5	13.5
Machine room	2.91	2.91
Battery room	122.45	122.45

3.2 Instruments

An energy audit by default comprises a sequential and repeated process of data measurement of various instruments confined in the building. So, several devices are to be employed to complete the task. Some of them include:

i) Measuring Tape

ii) Infrared Thermal Camera

iii) Luxmeter

iv) Vernier Caliper

CHAPTER FOUR: FINDINGS AND ANALYSIS

4.1 Questionanaire

4.1.1 Result

Table 4.1: Questionnaire Result

Question	1	2	3	4	5	6	7	8
Count 5	20	7	5	5	2	8	7	18
Count 4	30	15	19	9	10	23	13	25
Count 3	3	25	24	6	13	11	26	4
Count 2	0	5	5	28	25	8	4	5
Count 1	0	1	0	5	3	3	3	1

The available population sample size was 53 administered both by email and by public-questionnaire.

- 37.73% strongly agreed that "The building includes well operating electronic equipment", while 56.6% agreed for the same and remaining 5.67% being neutral.
- 47.17% were neutral about liking the fact that building is south facing for solar heat, while 28.3% agreed that they like the building is south facing for solar heat with minority strongly agreeing and disagreeing.
- 45.28% are neutral about liking the fact building is south facing for sunlight, while 35.85% agreed that they like the building is south facing for solar heat with 9.44% both strongly agreeing and disagreeing.
- 52.83% disagreed that "Heat radiation was coming out from computers and devices", while 9.43% strongly disagreed for the same.

- 47.16% disagreed that "The building needs additional lighting bulbs" while 24.52% were neutral and 18.86% agreed that additional lighting bulbs are required.
- 43.4% disagreed that "The temperature inside the room was not comfortable", 20.75% being neutral, 15% strongly disagreed, while 15% responded agreeing the statement and the remaining strongly agreeing.
- 24.5% agreed that they give preference to operating Air Conditioning over non-operating state, while 49% were neutral.
- 47.16% strongly agreed that they would like to give other such higher academic exams in the buildings like ICTC, and 33.96% agreed for the same.

4.1.2 Analysis:

i. Many of the responses to the questions, "The building includes well operating electronic equipment." and "You would like to give other such higher academic exams in the buildings like ICTC." are perceived by the respondents in a similar trend. It can be inferred that respondents, in majority, view the building to be electronically well-infrastructured and the building bears huge potentialities for the use in future.

ii. The contradictory responses between two similar questions "You like that the building is south facing for solar heat" and "You like that the building is south facing for sunlight." can indicate that occupants may not always like both sunlight and heat at a same time. This hints for study of types of glass for fenestration system.

iii. A majority of respondents disagreed that "Heat radiation was coming out from computers and devices". Thus, it can be understood that majorly used computers need no replacement. However, this should be ascertained by studying energy consumption before making any financial analysis of the entire project.

iv. Some important figures show that the building needs additional lighting system. Thus, a systematic experiment can be done to learn illumination level in the building for the analysis of energy efficiency.

v. Likewise, some important figures do reflect respondents prefer operating Air Conditioning over non-operating state. Since HVAC system can be the most energy consuming unit in a building, further analysis to understand future energy consumption based on preference to human comfort can be set as one of the major objectives of this project.

4.2 Building Energy Simulation

The comparative energy model represented a study that compared various energy-saving techniques to better the annual energy end-use for typical building scenarios. Normal buildings and improved buildings were simulated using the two energy models. While the improved case model altered in terms of its envelope characteristics, lighting load intensity, electrical load reduction for simulation results to study the efficiency of annual operational performance of strategies as energy efficiency measures on building utility in the hope of increasing energy efficiency.

4.2.1 Normal Case Scenario

For the normal case, the annual energy consumption of heating, cooling, lighting, interior equipment, and the water system were found to be 20.45%, 40.58%, 13.66%, 24.42%, and 0.89%, respectively.

The cooling load is found to be greater than the heating load because of factors like climate, building design, building occupancy, equipment, and appliances. The Kathmandu Valley has a warm and humid climate during the summer months. This means that more cooling is required to maintain comfortable indoor temperatures during this time, resulting in a higher cooling load. There is less use of overhang projections. Also, ICTC buildings have a large number of equipment and appliances, such as computers, printers, and lighting systems, which generate heat and increase the cooling load. The building is heavily occupied during exams, which results in higher levels of body heat and other heat-generating activities, which contribute to a higher cooling load. The number of electrical equipment like computers, printers, servers, etc. is higher but concentrated in a small area. These are the old versions and produce a lot of heat. These contribute to the overall heating of the building.

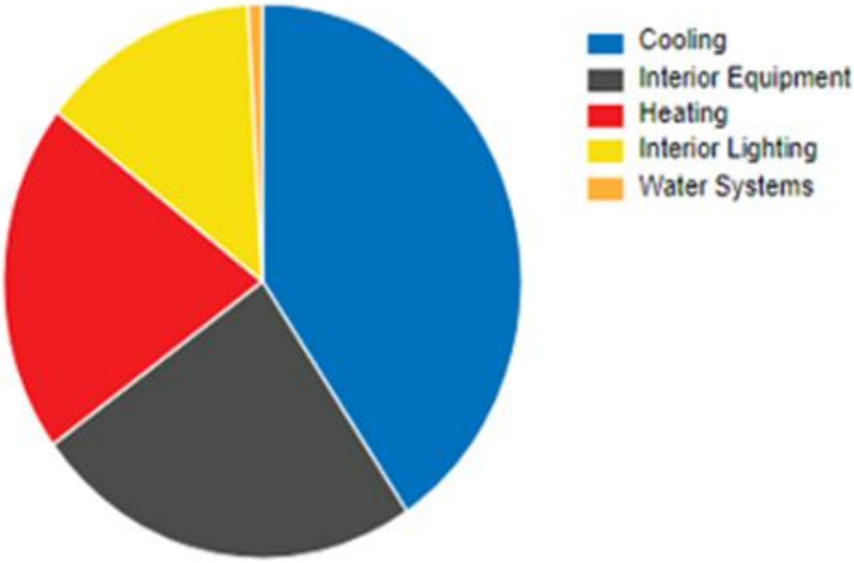


Figure 4.1: Annual energy consumption for improved case scenario

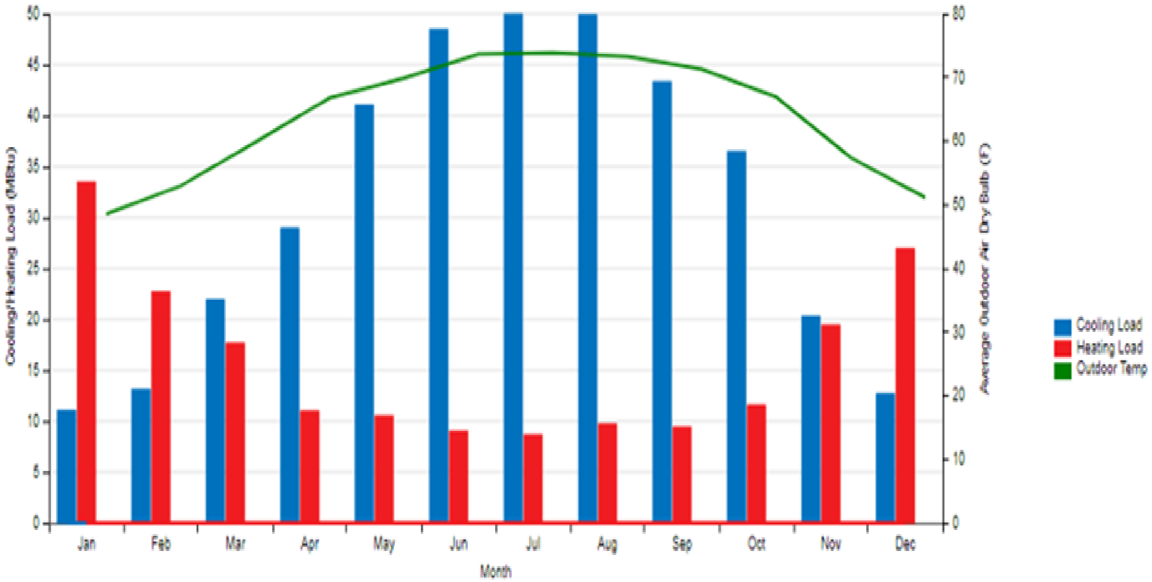


Figure 4.2: HVAC load profile for normal case scenario

4.2.2 Improved case scenario

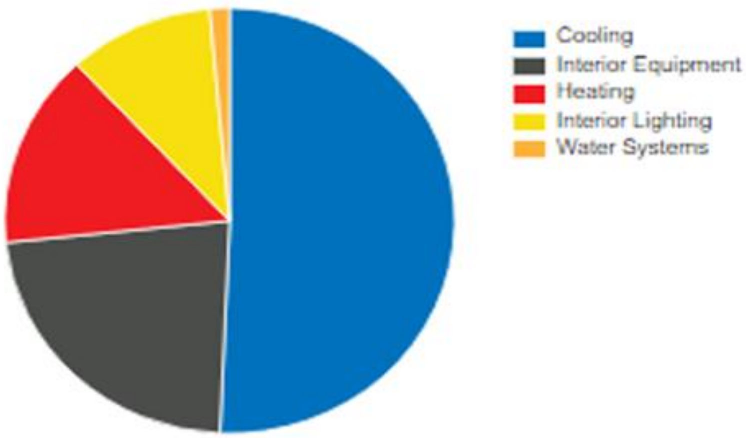


Figure 4.3: Annual energy consumption for improved case scenario

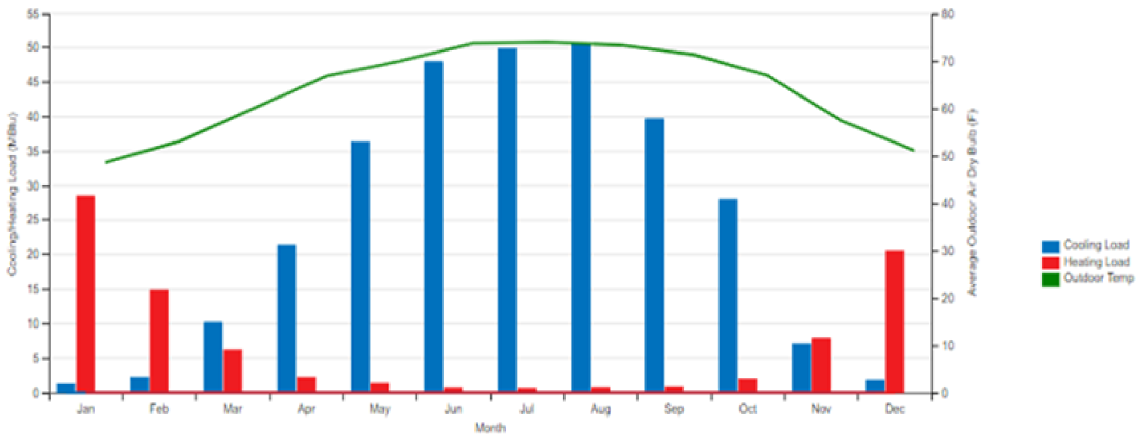


Figure 4.4: HVAC load profile for improved case scenario

For the improved case, the annual energy consumption of heating, cooling, lighting, interior equipment, and the water system were found to be 14.74%, 50.69%, 10.46%, 22.68%, and 1.43%, respectively.

In an improved case, Cavity walls and double-glazing windows reduce thermal load by improving the thermal insulation of a building, which can lead to lower heating and cooling demands. Efficient lighting measures and replacement of old versions of desktop contribute to the significant amount of energy saving. These measures help to conserve a significant amount of energy. However, there is significant heating load at extreme months because of cold weather and significant cooling load in mid seasons because of hot climate.

4.2.3 Comparative analysis

Table 4.2: Comparison of Annual Energy Consumption for two cases

Component	**Normal Building Case Model** (kWh)	**Improved Normal Building Case Model** (kWh)	**Percentage improvement**
Heating (kWh)	55,680.841	25,244	54.66%
Cooling (kWh)	110,495.28	86,790.12	21.45%
Interior lighting (kWh)	37,207.77	17,917.83	51.84%
Interior Equipment (kWh)	66,478.18	38,821.04	41.6%
Water system (kWh)	2429.849	2429.849	0%
Total(kWh)	272286.65	171202.83	37.12%

For the comparative analysis, the energy model was simulated for both normal and improved case scenarios. The building can be made 37.12% more energy efficient by using energy conservation opportunities like cavity walls, double glazing windows, efficient lights, and efficient electric equipment. The percentage improvements for heating, cooling, interior lighting, and interior equipment were found to be 54.66%, 21.45%, 51.84%, and 41.6%, respectively. By reducing the amount of heat transfer through the walls and windows and lowering the energy needed to keep a comfortable indoor temperature, cavity walls and double-glazed windows help to enhance a building's heating and cooling load. LED bulbs and modern desktops are designed to be more energy-efficient than their predecessors resulting in significant energy savings.

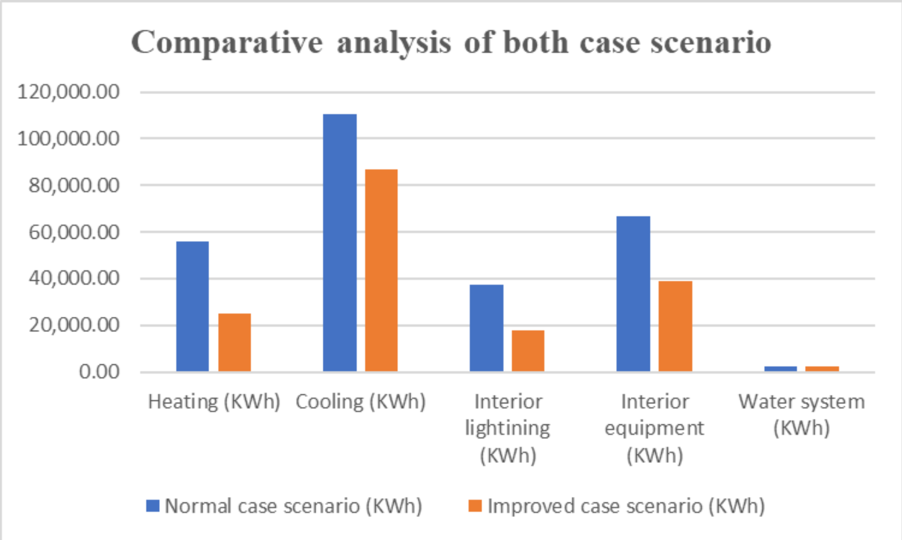


Figure 4.5: Comparison of Normal and Improved case scenario

4.2.4 Energy saving and payback period

Table 4.3: Energy saving for various energy conservation measures

Measures	Annual energy demand conservation
Cavity wall	13.11%
Double glazing window	6.78%
Light definition	7.08%
Electric equipment definition	10.15%

Table 4.4: Payback period calculation of various energy conservation measures

Measures	Total investment (in NRs)	Annual energy saving (in KWh)	Payback period (in yrs)
Cavity wall	2,12,69,170	35,696.78	48.65

Double glazing window	19,37,504	18,478.78	8.56
Light definition	4,42,200	19,289.94	1.87
Electric equipment definition	1,96,63,000	27,657.14	58.03

The percentage improvement in annual energy consumption by cavity wall, double glazing window, light definition, electric equipment definition was found to be 13.11%, 6.78%, 7.08%, and 10.15% respectively.

The payback period for the cavity wall was found to be 48.65 years which is relatively high. It is because the glasses are installed in the south direction and the other side of the building has walls. Because of which it receives comparatively less solar intensity. The surface area of walls is larger and have a complex design, which makes high cavity instalment cost.

The payback period of the double-glazing window is obtained to be 8.56 years. The window-to-wall ratio of the ICTC building is high, with most of the windows facing south direction. South-facing windows in Kathmandu can generate a high amount of heat due to solar radiation. During the winter months, when the sun is low in the sky, the angle of incidence of the sun's rays is such that they strike the south-facing windows at a more direct angle, which can result in a significant amount of solar heat gain. In addition, during the summer season, the sun's rays intensify in the south direction.

All the CFL bulbs were replaced by the LED light for efficient lighting. The payback period for the LED was found to be 1.87 years which is good enough. This is because of less electricity consumption to produce the same amount of light as incandescent or fluorescent bulbs, resulting in lower energy bills. Also LED lighting has a cheaper price along with longer lifespan than traditional lighting, which reduces the need for frequent bulb replacements and maintenance costs. This can result in lower overall costs over time.

For efficient electric energy consumption, all the old versions of desktop computers were replaced by the new ones. The payback period of the electric equipment was found to be 58.03 years. This is because there are a huge number of desktops. So, the replacement of that will require huge investment. Also, the usage rates on the desktop are quite low. It is only used during examinations.

4.3 Lighting System

4.3.1 Observation:

The number of operating hours was obtained after interviewing the staffs and students. It has been found that the average operating hours (OH) for this building to be 2.5 hours/ day, 6 days/ week and 50 weeks/year resulting to annual operating hours be 750 hours.

The luminous efficacy for CFL and LED lighting are set 70 lm/W and 100 lm/W based on the literature review.

Table 4.5.: Lux Meter Reading

TYPE	**No.**	**Values from Standards (Lux)**	**Observed Range in Lux**			
			With natural lighting		**With lighting**	
Computer Lab	12	300	Lab 1	176.3	Lab 1	101.8*
			Lab 2	313.7	Lab 2	150.5*
			Lab 3	7226	Lab 3	227.5*
			Lab 4	255.3	Lab 4	105.7*
			Lab 5	338.8	Lab 5	522
			Lab 6	250.5	Lab 6	477.5
			Lab 7	NA	Lab 7	NA
			Lab 8	310.3	Lab 8	296.2*
			Lab 9	408.2	Lab 9	375
			Lab 10	273.2	Lab 10	281.2*
			Lab 11	10428	Lab 11	1113
			Lab 12	382.5	Lab 12	NA
Corridor	3	70	457-23183.83		483	
Conference Room	1	500	NA		196*	
Meeting Hall	1	300	522.83			
Administration	1	500	35		232.167	
Battery Room	1	150	150.33		268.667	
Generator Room	1	200	83		142.17*	

Index: *not in compliance to standard

Not every room was found to be in compliance to the illuminance level stated by standards, thus annual energy consumption after replacement and addition of lighting was also found from the same equation (ii) based on addition lux required to rooms and use of luminous efficacy of lights as the area of both rooms and photo-diode of the luxmeter being constant.

Table 4.6: Lighting Detail Analysis

Type of Existing lighting (CFL)			
	S.N.	Numbers	Watts
	1	136	2*36
	2	354	3*36
	3	140	36
Annual existing EC	39798 kWh		
Total energy consumed in year 2078	81610 kWh		
Contribution of light	48.76% of total electricity		
LED Lumen equivalence to 36 W CFL	17 W		
Type of Replacement lighting (LED)	S.N.	Numbers	Watts
	1	136	2*17
	2	354	3*17
	3	140	17
Annual replacement EC	18793.5 kWh		
Energy Reduction percentage by LED replacement	52. 78%		
Energy Reduction percentage by LED replacement as per literature	51- 53%		

Table 4.7 : Additional Lighting Details

ADDITIONAL LIGHTING TO MEET STANDARD					
Type	CFL (Watt)	Lumen (70 lm/W for CFL)	Current Lux	Additional lumen required to meet standard	Corresponding LED Watt required (100 lm/W for LED)
Conference room	1296	90720	196	140708	1407.08
Lab 1	648	45360	101.8	88313.87	883.1
Lab 2	792	55440	150.5	55071.6	550.7
Lab 3	1080	75600	227.5	4043	40.43
Lab 4	792	55440	105.7	101960.13	1019.6
Lab 8	2592	181440	296.2	2451.89	24
Lab 10	864	60480	281.2	4043	40.43
Administration room	1080	75600	232.17	87213.83	872.13
Generator room	288	20160	142.17	8200	82
Additional Watt required to meet the room illuminance standard					5119.94 W
Annual EC after replacement and addition			22633,5 kWh		
Energy Reduction percentage by LED replacement and addition			43.13 %		

4.2.2. Analysis

All the building rooms were facilitated by Linear CFLs. From the above table, it can be inferred that not all rooms were sufficiently illuminated. Some require instant additional lighting. However, based on the literature study, LEDs can facilitate energy-efficient lighting. There are several advantages of energy-efficient lighting because it is usually the lowest life-cycle cost option. It reduces peak loading, lowers customer bills, and reduces mercury and the volume of material being sent to the landfill. It is suggested to replace the bulbs as the building occupancy is also found in the early morning and late evening, during active days.

To conclude, Energy reduction by LED for the building is 52.78 %. The result of simulation in section 4.2 also agree with this analytical evaluation with the saving of

51.84%. If the additional LED lighting is included to meet the illuminance level of facilities, then the percentage saving reduces to 43.13%.

4.4 Solar Panel

4.4.1 Findings

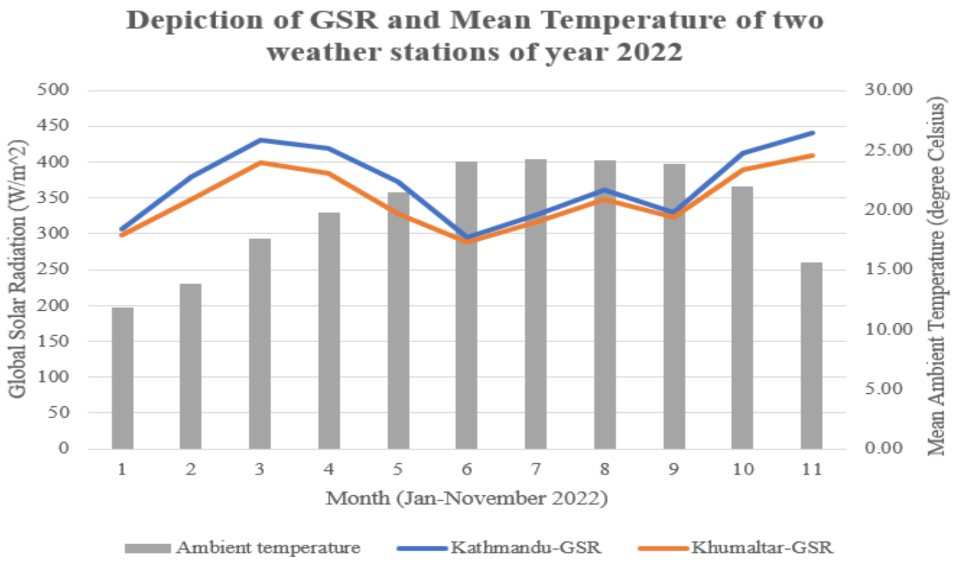


Figure 4.6: Depiction of GSR and Mean Temperature of two weather stations of year 2022

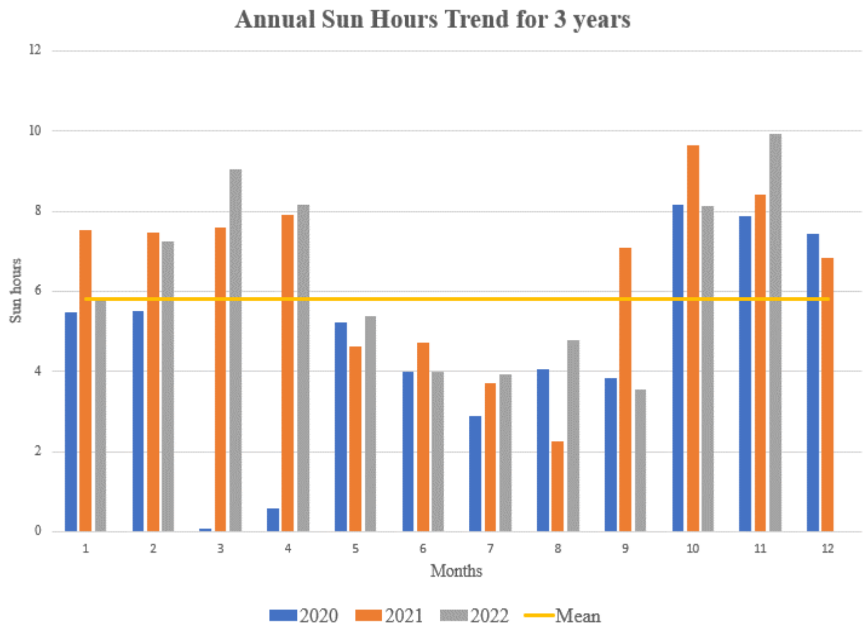


Figure 4.7: Annual Sun Hour Trend obtained from Khumaltar Station

(Source : DHM)

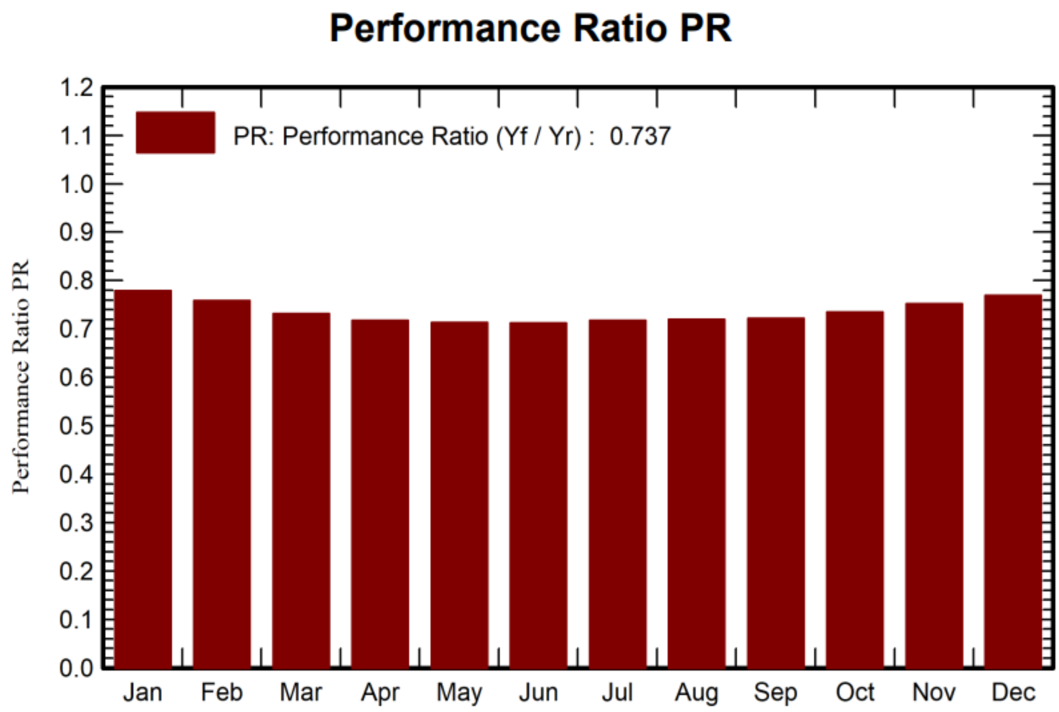


Figure 4.8: Performance Ratio Result from PV Syst Report

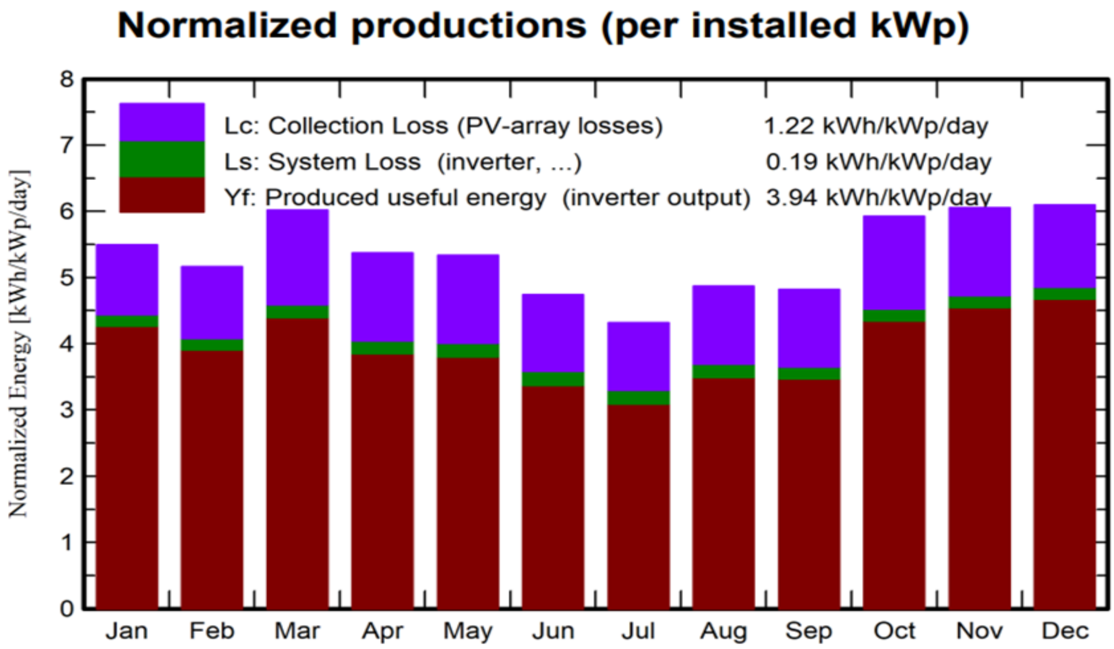


Figure 4.9: Normalized Productions Result from PV Syst Report obtained from PV Syst

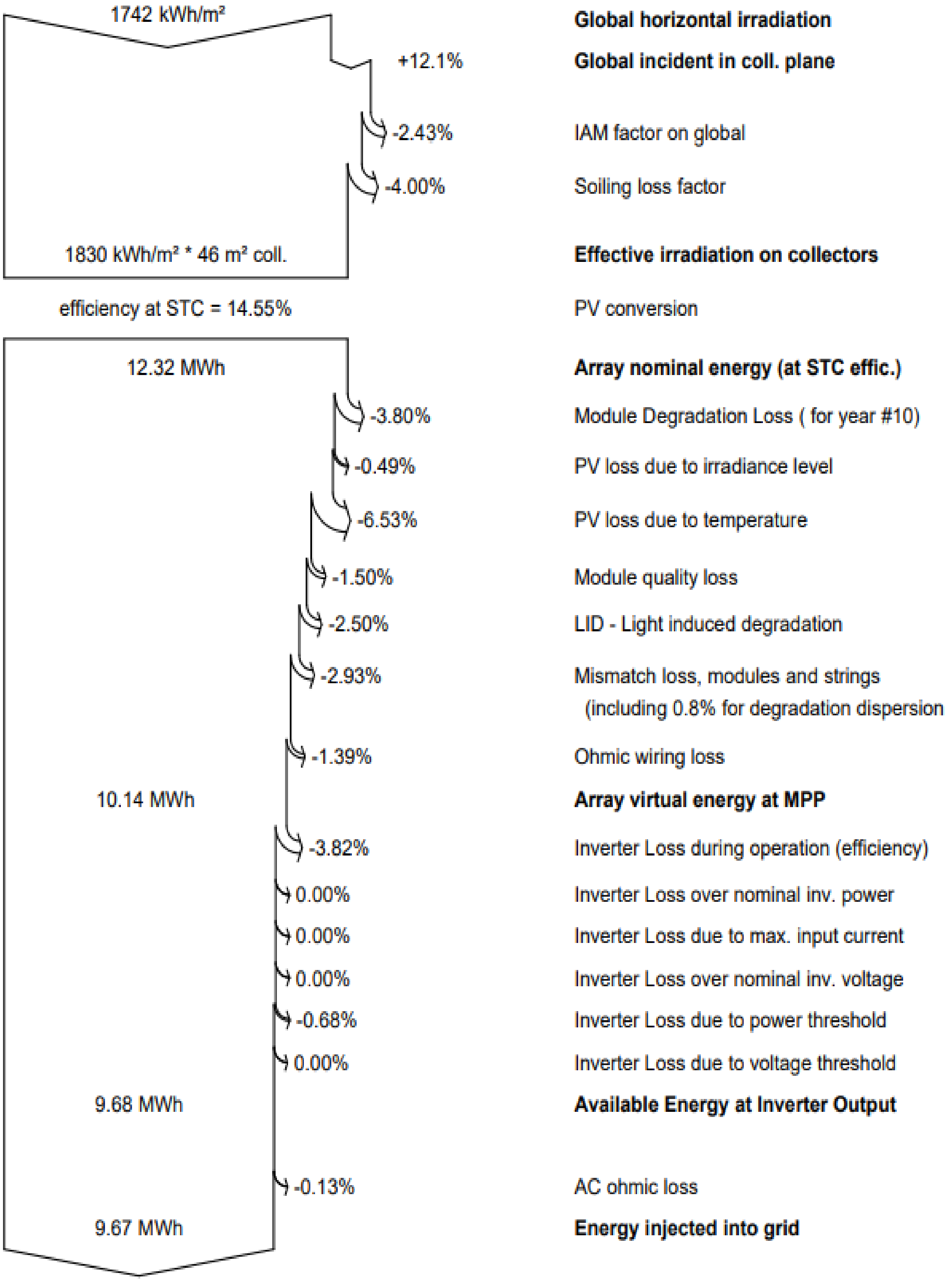


Figure 4.11: Loss Diagram

Obtained from PV Syst

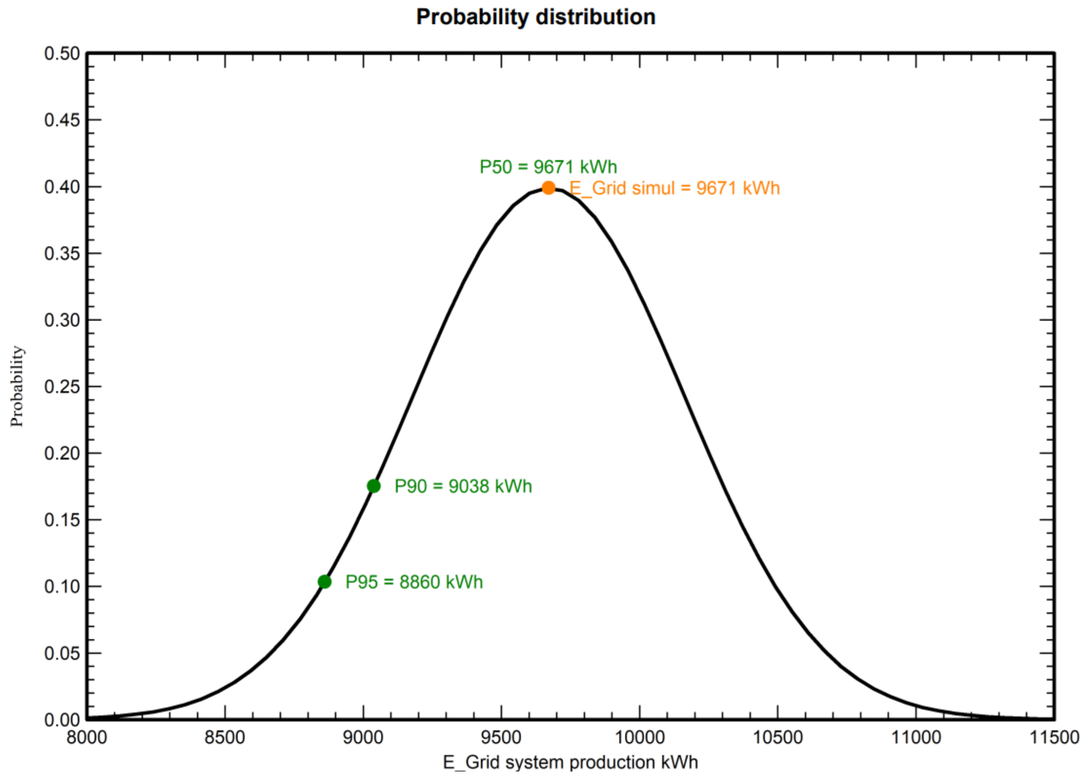


Figure 4.10: Probability Distribution of the production

Obtained from PV Syst

Table 4.8: Overall Module Degradation Loss

Result:	
From PV Syst Simulation:	Relevance to the literature as:
The module degradation rate from this study found to be 3.8%	Degradation Rate is estimated to lie from 0.6% to 5% based on the Indian study where the range was obtained by carrying out secondary data research(Kumar et al. 2019)

Table 4.9: System Performance Ratio for fix mounted PV module

Result from Simulation	Reference to literature (SOLARGIS, 2021)
ICTC- 73.67%	Dharan- 75.5%
	Jumla- 79.3%

	Kathmandu- 77.4%
	Lumle- 79.5%
	Nepalgunj- 74.7%

4.4.2 Analysis

- Figure 4.7 depicts that the daily mean sun hours received by the solar panel is 5.8 hours in case of Lalitpur Area.
- The normalized production as demonstrated from Figure 4.9 shows that units of electricity produced on monthly basis. On further analysis, the system produces an average of 26.5 kWh daily.
- Although it is challenging to anticipate with accuracy potential energy losses in a PV system, understanding the baset-case situation is essential. The predicted energy losses in a 6.72 KW roof-integrated PV system using the PV Syst simulation approach throughout one year is shown in arrow diagram(Figure 4.11). The total predicted energy loss was observed to be 17.29% out of which the highest loss factor is due to the temperature which is 6.53%.
- According to the Figure 4.10, the system has probability of 50%, 90% and 95% for producing 9671 kWh, 9038kWh and 8860kWh respectively based on normal probability distribution.
- Table 4.8 and table 4.9 shows that the obtained results are in accordance to the literatures considered.
- The output from solar by the analytical method and from simulation have quite similar values with a 2.5% deviation. Hence, it can be concluded that the values obtained from simulation can be validated.

4.4.3 Analytical study of solar panel

The peak sun hours obtained from the climate consultant software are used here. Then the output of the solar panel was calculated by using a solar panel table (Arora et al., 2016)

Table 4.10: Monthly Energy Production

Month	Peak Sun (hr)	Array Size (kWp)	Output (kWh)	Inverter Output (kWh)
Jan	4.75	6.72	957.6	729.69
Feb	6.49	6.72	1308.384	996.99
Mar	5.51	6.72	1110.816	864.44
Apr	5.63	6.72	1135.008	864.88
May	4.3	6.72	866.88	660.56
Jun	5.14	6.72	1036.224	789.6
Jul	5.62	6.72	1132.992	863.34
Aug	4.59	6.72	925.344	705.11
Sep	4.68	6.72	943.488	718.94
Oct	6.57	6.72	1324.512	1009.28
Nov	4.12	6.72	830.592	632.9
Dec	4.01	6.72	808.416	616.01
Total			12308.256	9433.76

Estimated output from simulation = 9670 kWh/year
Estimated output by analytical method = 9433.76 kwh/year

Here, the output from solar by the analytical method and from simulation have quite similar values with a 2.5% difference. Hence, it can be concluded that the values obtained from simulation can be validated.

4.4.4 Financial Analysis

Table 4.11: Solar Panel Financial Analysis

Parameter	Unit	Value
Normal Time Tariff rate (T2)	Rs	12.25
Total NEA electricity consumed in 2078 BS	kWh/year	81,610

Estimated yield from PV system	kWh/year	9,670
Yearly energy saving	%	11.85
Yearly saving in existing case	Rs	1,18,457
Estimated yield if PV system is doubled	kWh/year	19,340
Yearly energy saving if doubled	%	23.7
Yearly saving if PV system is doubled	Rs	2,36,915

Simple Payback period of New Installed Solar Panel Set

Installation Cost= Rs. 9,84,520

Saving per year = Rs. 1,18,457

Simple Payback period = $\frac{\text{Installation Cost}}{\text{Annual Saving}}$= 8.311 years

4.5 Electricity

4.5.1 Observations and Findings

Table 4.12: Power Factor observation from TOD meter

Phases	For Building Active Hours	For Building Passive Hours
Phase 1	0.998	0.7264
Phase 2	0.9974	0.9527
Phase 3	0.999	0.9432

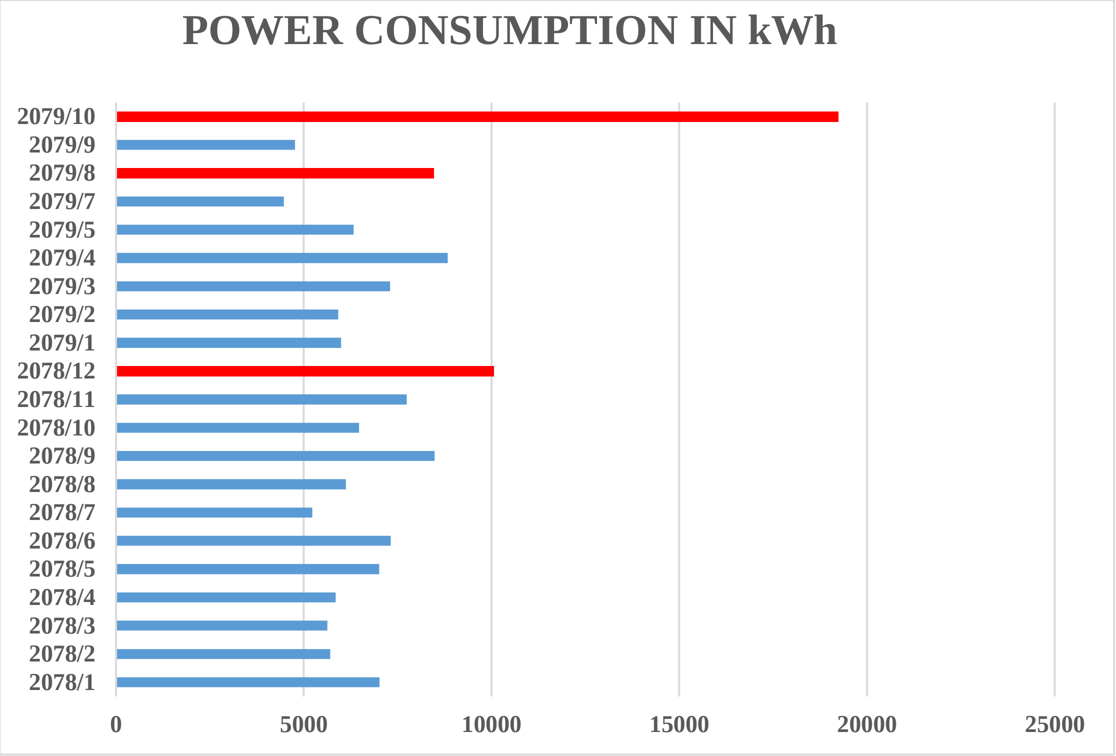


Figure 4.113: Power Consumption from 2078 Baisakh to 2079 Jestha

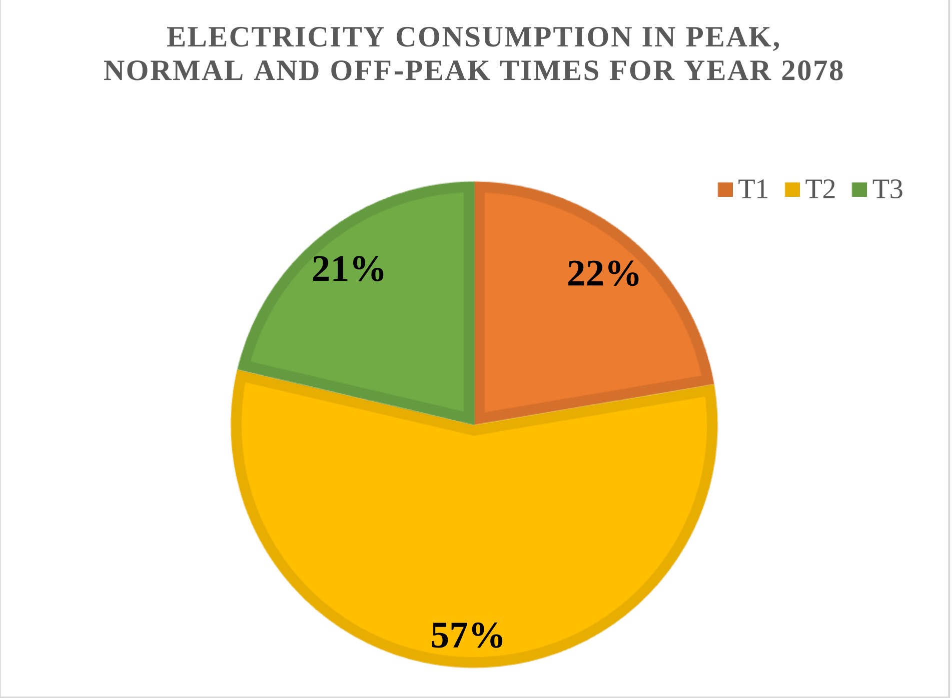


Figure 4.13: Electricity Consumption in Peak(T1), Normal(T2) and Off Peak Time(T3)of year 2078 BS

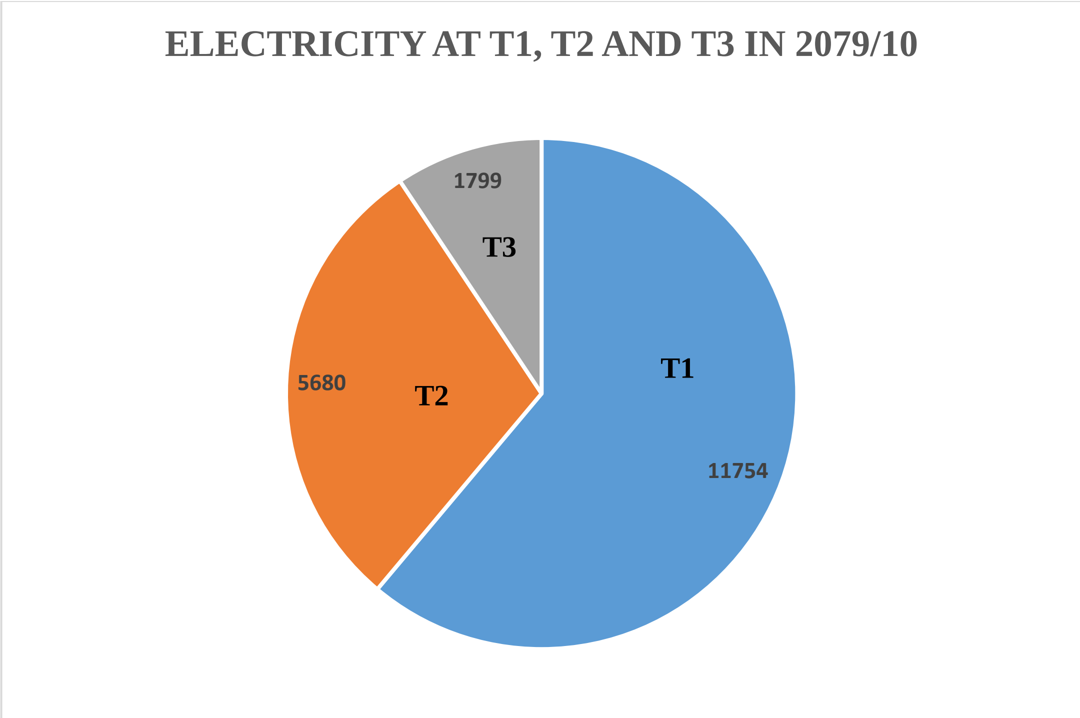


Figure 4.14: Electricity Consumption in Peak(T1), Normal(T2) and Off Peak Time(T3) of Magh,2079

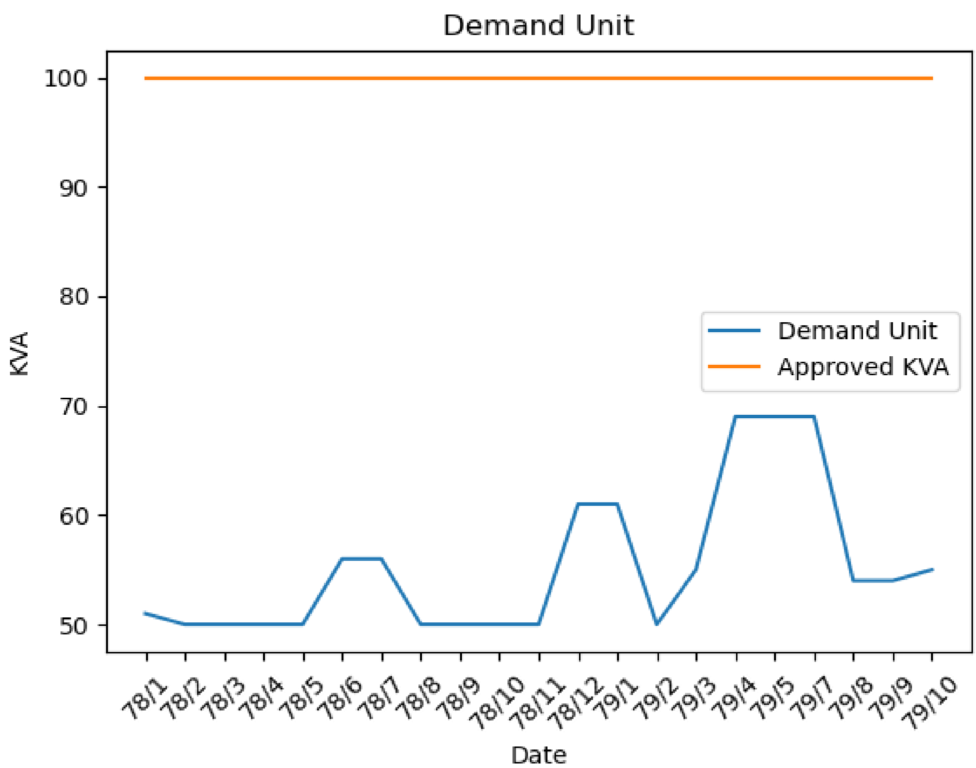


Figure 4.15: Maximum Demand

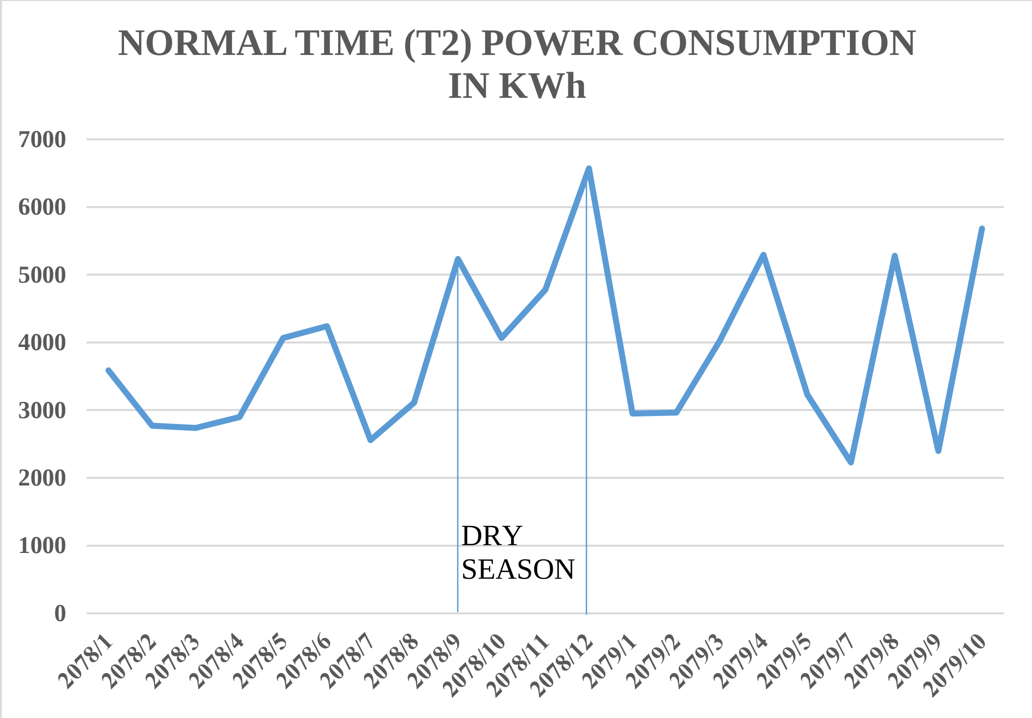


Figure 4.16: Power Consumption in Normal Time

4.5.2 Analysis

- As can be observed from the Table 4.12, power factor of the building electricity is close to unity in every phase for active hours when maximum devices are operated. Likewise, in passive hours the power factor in a phase account to around 0.7-0.8. This is because power correction is done by the use of APFC when the consumption is high in order to neutralize the phase angle to the resistive mode by addition of capacitors. This is also a good practice to be safe from additional penalty for electricity bill payment.
- The Figure 4.15 demonstrates the electricity consumption monthly in kWh. The highest recording is found for the month 10 of 2079 BS. On further study, it is known that the building has highest occupancy throughout the year for conducting exams in which ICT devices like computers, public administration system etc. were mostly used including the use of Air Conditioning and Lighting systems accounting for the highest electricity consumption during such months.
- The pie chart from the figure 4.13 depicts that the building is scheduled for operation mostly in the normal time (T2). However, the most recent data shows that the electricity consumption was highest at peak time (T1) in the month of Magh- 2079.from pie chart figure 4.14

- The demand charge is evaluated for three months interval. This can also be seen from the figure 4.15 where can also be inferred that the demand charge has not been applicable for three-months from the starting of the first month of the year in the case of ICTC Building. The approved load is 100 KVA, however, the highest recorded demand is 69 KVA so far. This provides a scope for study of reducing transformer approved load against high charge for high approved load, whereby, use of diesel generator can be done in maximum load condition to safeguard against penalty.
- According to the figure 4.16, the mostly electricity consumed months have been scheduled to suffer higher tariff due to dry season of hydropower. This provides a basis that building has not been properly scheduled for preventing additional electricity costs.

4.6 HVAC Load

4.6.1 Result

From the collected data, the building heating load and cooling load was calculated. Among a list of data calculated from 10 am to 5 pm, the maximum values are:

Table 4.13: Thermal Load Contribution by Various Factors

S.No	**Factor**	**Load (TR)**
1	Walls	10.7056
2	Ceiling	13.78866
3	Glass (Conduction)	18.13079
4	Glass (Solar)	22.258
5	Internal Lights	2.883
6	Computers	9.24338
7	Occupants	15.4577
8	Ventilation	29.14

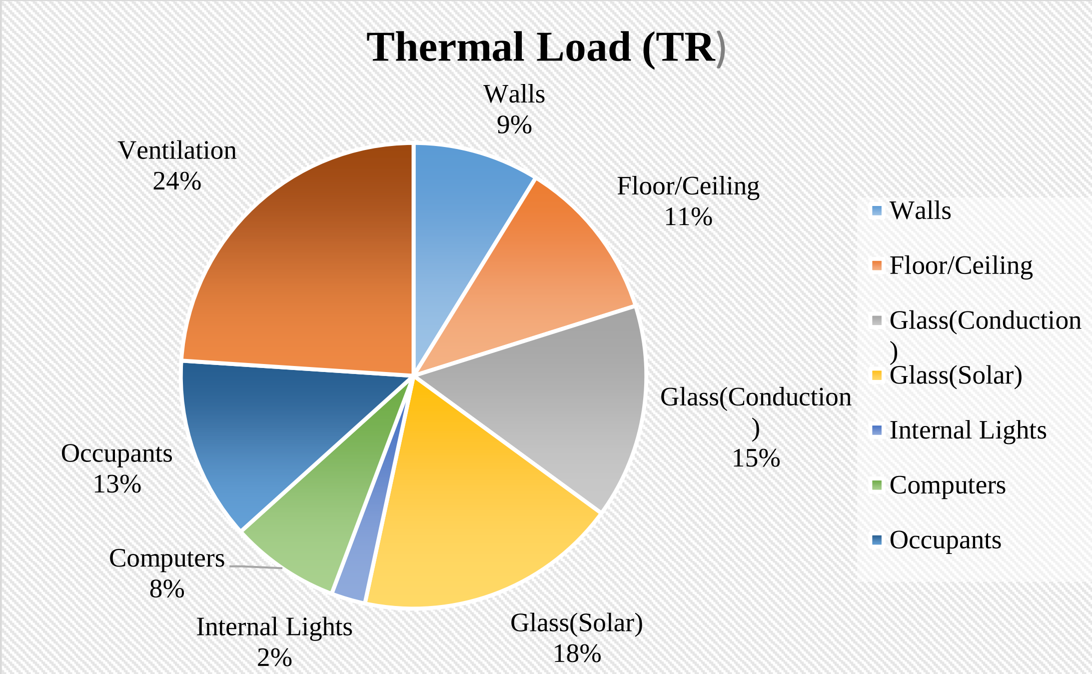


Figure 4.17: Thermal Load Distribution in the building

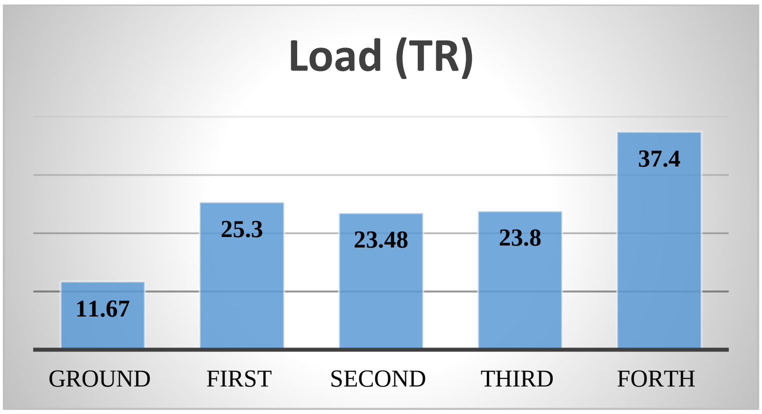


Figure 4.18: Floor wise Load Distribution in building

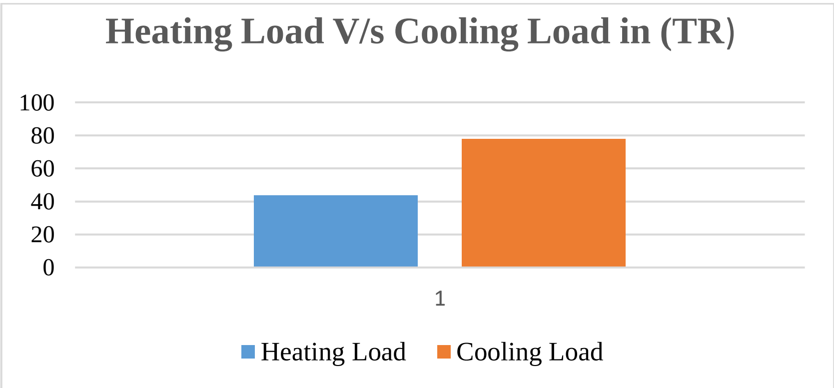


Figure 4.19: Heating and Cooling Load of the building

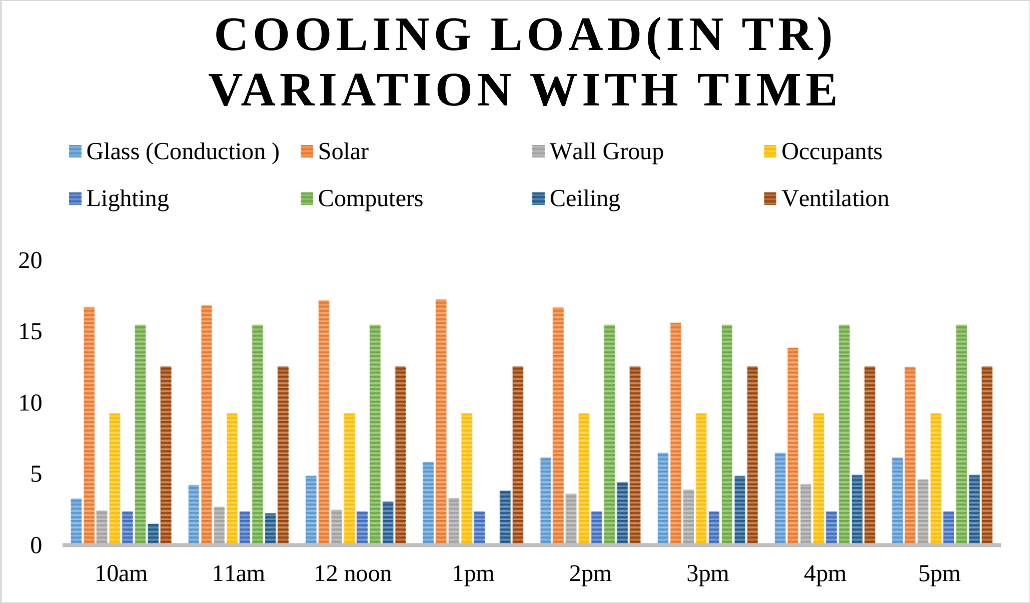


Figure 4.20: Cooling Load Variation with time

4.6.2 Analysis

1. The building uses the Multi VRF system for efficient space heating and cooling.
2. The calculation of cooling and heating load separately showed that the cooling load is dominant in the building. Despite this fact the cooling capacity of the installed HVAC is lower than the heating capacity.
3. Floor wise load distribution shows that thermal load is higher in 1st floor compared to the ground and 2nd floor. However, that particular floor is not equipped with any indoor unit.
4. The cooling load is dominant in the building and the major cooling load factor is radiation through glass.

   The thermal load obtained from simulation of the building in section 4.2 also shows that cooling load is dominant in the building and thus the measures for decreasing the heat gain from the building should be adopted.

5. The thermal load of the 4th floor is highest among all. However, the installed capacity of indoor unit is lowest of all on 4th floor
6. The HVAC unit is rarely used but anytime available only for Server room. The system has not been used optimally.

4.7 Critical Thickness of insulation

Table 4.14: Input values for insulation thickness calculation

Type of insulation	Flexible foam insulation
Average velocity of air	2.1 m/s
Density of air	1.225 kg/m3
Dynamic viscosity of air	1.79 *10^(-5) Pa.s
Thermal conductivity of air	0.027 W/ (mK)
Reynold's number	1825
Nusselt number	1.2
Convective heat transfer coefficient of air	2.6 W/m^2 K
Outer radius of pipe	6.35 mm
Inner radius of pipe	5.4 mm
Outer radius of insulation	(6.35+t) mm where t is thickness
Thickness of insulation	10.957mm ~ 11 mm

Analysis:

The convective heat transfer coefficient is found to be 2.6 W/m^2 K in this study. The data thus obtained is in given range of the relevant past studies where the value ranges from 2.5-10. The critical insulation thickness of flexible foam material for the piping system of the liquid refrigerant line of the HVAC system is found to be 11 mm. Choosing the thickness below 11 mm is highly not recommended for saving energy encountered due to heat loss.

This critical thickness is in relevance to required optimum thickness as well ,because the study for same refrigerant piping system finds for pipe diameters 12.7 to 50.8 mm the required optimum thickness insulation is 11 to 13 mm for flexible foam insulation based on the literature review.

4.8 Windows

From the calculation in Section 4.6.1 it is clear that window pane alone contributes to 33% (15% through conduction and 18% through solar transmission) of the total thermal load in the building. This very situation has ultimately led to the conclusion that glass is one of the major contributors of the heat gain in the building. HVAC being the major energy load factor to the building, the study of glass became the interest of study.

4.8.1 Analysis

The benefits of window systems are best understood in terms of energy. consumption, visual comfort requirements, and thermal comfort standard are carefully considered during the building design stage correct control strategy. The design of ICTC in terms of natural light use is optimally provided that the building is south-faced. However, the use of single-pane glass has obstructed leasing its maximum potential. The drawbacks of the use of single-pane glass in ICTC include the:

i) Increased Cooling Load
ii) Use of extra shades or blinds to control glaring
iii) Use of additional lighting load in the east-facing rooms.

The best alternative to reduce the artificial lighting load and cooling load is the installment of the double-glazing window with proper glazing material.

For given existing condition, the most favorable option is static double glazed 6mm glass. The installation of double-glazed glass is even possible in the current frames of the fenestration system in the building. It saves the cost of new aluminum frames.

Glazing Type: 6 mm clear glass, air space: 12 mm, inner pane: 6 mm clear glass

4.8.2. Comparison with Double Glazed Glass

i) Thermal Factor

Table 4.15: Comparison in cooling load between double pane and single pane glass.

		Cooling Load			
		Double Pane		**Single Pane**	
S. N	**Room**	**Conduction**	**Transmission**	**Conduction**	**Transmission**
1	MDF Server	115.8626196	1425.143846	873.167568	2528.62611
2	Administration	592.6818618	2916.063563	1786.635178	5173.958041
3	Conference	1247.751288	2915.862518	3761.337216	5173.601328
4	Meeting -I	289.656549	11037.19379	873.167568	5786.003808
5	Lab 1,5,9	2615.82145	1425.143846	7885.374806	2528.62611
6	Lab 2,6,10	2834.177926	12870.1452	8543.608819	22835.43887
7	Lab 3,7,11	2272.689846	13944.48441	6851.007072	24741.63394
8	Lab 4,8,12	2116.720935	10236.35317	6380.83992	15171.02816
9	Seminar 1	871.9404834	33583.66704	2628.458269	46109.54447
10	Meeting -II	946.2113934	4290.048399	2852.347389	7611.812957
11	Office	757.563282	4655.469898	2283.669024	8260.178627
12	Office	705.573645	3412.117722	2126.94664	5057.009387
13	Lobby	4281.717962	11194.55568	12907.20777	15369.84816
14	Front Face	5958.755109	26838.64753	17962.6241	39776.84932
Btu/hr		**25607.12435**	**140744.8966**	**77716.39133**	**206124.1593**
TR		**2.133841672**	**11.72827223**	**6.47610689**	**17.17632619**
kWh		**7.50942063**	**41.27416323**	**22.7907306**	**60.44696753**

From the table above it is clear that the cooling load in the building through glass can be reduced as by 42.9%. by the uses of static double-glazing glass. Similarly the heating load is reduced by 55%. A study conducted by (Forughian and Taheri Shahr Aiini 2017) concluded the reduction by almost 50%.

Under similar condition of other load factor, the replacement of glass alone can reduce the cooling load of the building by almost 13.5%. (Forughian and Taheri Shahr Aiini 2017)also stated the overall building thermal load reduction by 12.5% with double glazed glass.

Cooling Load of buiding with static double-glazing glass: - 62.31

Heating Load of building with static double-glazing glass: 36.4242 TR

ii) Light Factor

The lighting supporting factor of the window can heavily affect type of the glazing to be chosen. In the new constructions, it is essential for the designer to consider both light and thermal comfort and potential savings.

However, in case of ICTC the effect of glass is dominant on the HVAC load of the building. The potential saving of the energy through light can be covered by replacement of the highly efficient bulbs mentioned in section 4.2.2

The use of double of glazed static glass has less effect on light control. However, compared to single glazed glass, the visible light transmittance is lower and thus aids to the reduction of glaring in the direct sun facing rooms.

So, Double pane glass can be suitable option for ICTC in energy management opportunities.

4.9 Server room standard

4.9.1 Results

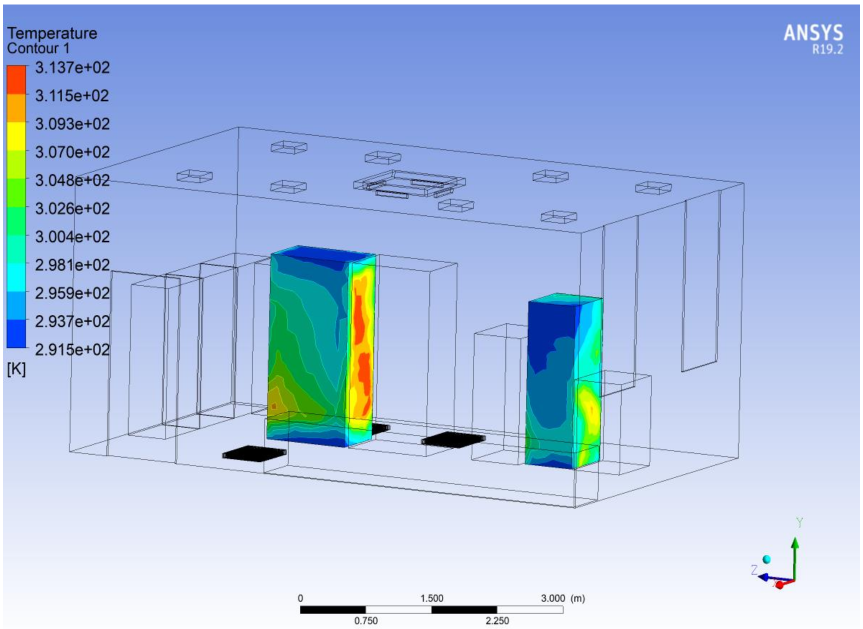


Figure 4.21. Temperature contour from simulation results

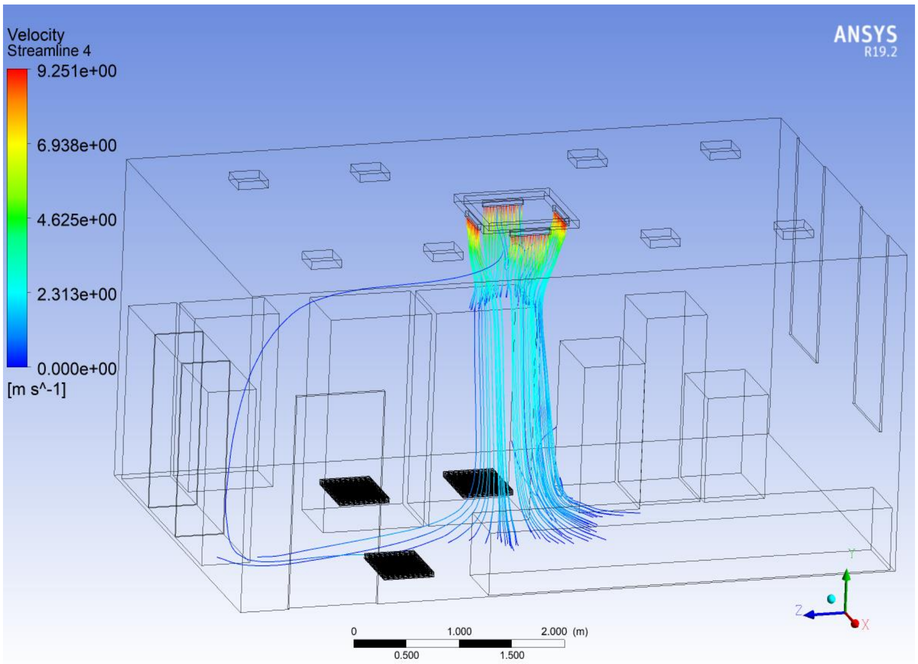


Figure 4.22: Velocity streamlines from inlet obtained from simulation results

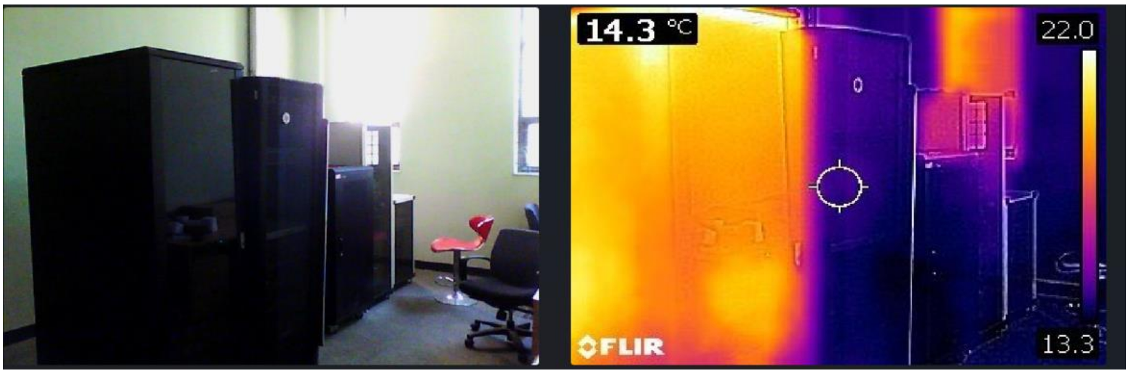


Figure **4.23.**: Thermal imaging of server room

Table 4.13: ASHRAE Temperature Limits

Property	**ASHRAE Recommended value**
Lower temperature	18 ^{o}Celsius
Upper temperature	27 ^{o}Celsius

4.9.2 Analysis

- The above simulation is obtained after mesh independence test whereby mesh element size is 0.12 corresponding to average surface area of Exam-server 300.9 K.

- The temperature contour of front part of the server and that from thermal imagining depicts the average temperature of 293 K i.e., 20 ^{o}C. This verifies the results of existing state by thermal imagining versus the simulation as the boundary condition have been experimentally measured and set in the simulation software.
- The temperature contour (Figure 4.21) shows that there are certain heat spots in the region of server cooling fan whose temperature surpasses the upper temperature limit set by ASHRAE standard. It can also be inferred that the server cooling fan intake the heated air as lack of access to the cold stream as a result of formation of heat spots.
- The velocity contour (Figure 4.22) shows that due to poor server orientation and nearby blockages, the flow is not being directed towards either of server.
- It is suggested to follow ASHRAE server cooling standard as discussed in the literature review i.e. application of CRAC units, raised floor configuration with perforations for cold stream inlet and lowered ceiling configuration by which energy savings of 63% for the data center cooling system can be achieved.

4.10 Passive Design Study

4.10.1 Bioclimatic chart

Findings

The bioclimatic chart was plotted for various months based on the mean monthly maximum temperature, mean monthly minimum temperature, and their relative humidity. The highest amount of solar radiation recommended by the remedy when the cooling condition is at its worst, the bioclimatic chart correlates to the minimum temperature and minimum humidity. The highest wind speed recommended by the bioclimatic chart's corrective measure corresponds to the maximum temperature and maximum humidity when the heating state is at its worst.

Installing the climatic energy plus weather file on the climate consultant program for this research, the bioclimatic charts obtained for design strategies are presented in the figures below.

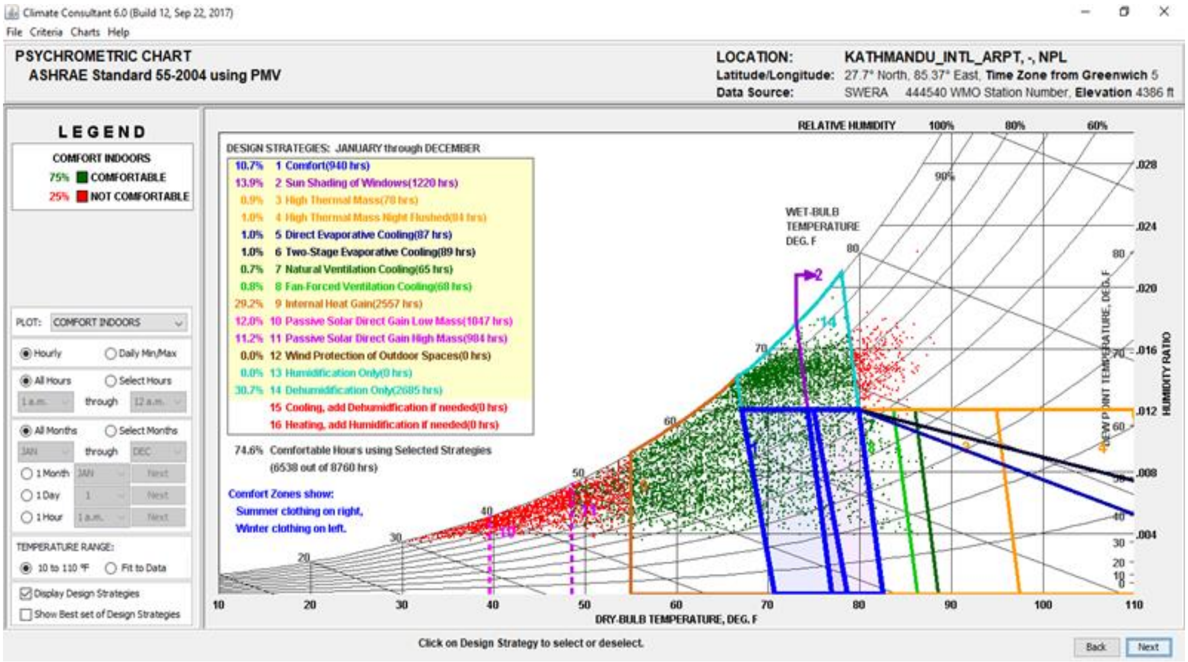


Figure 4.24 : Bioclimatic Chart Showing Passive Design Strategy on Project Site

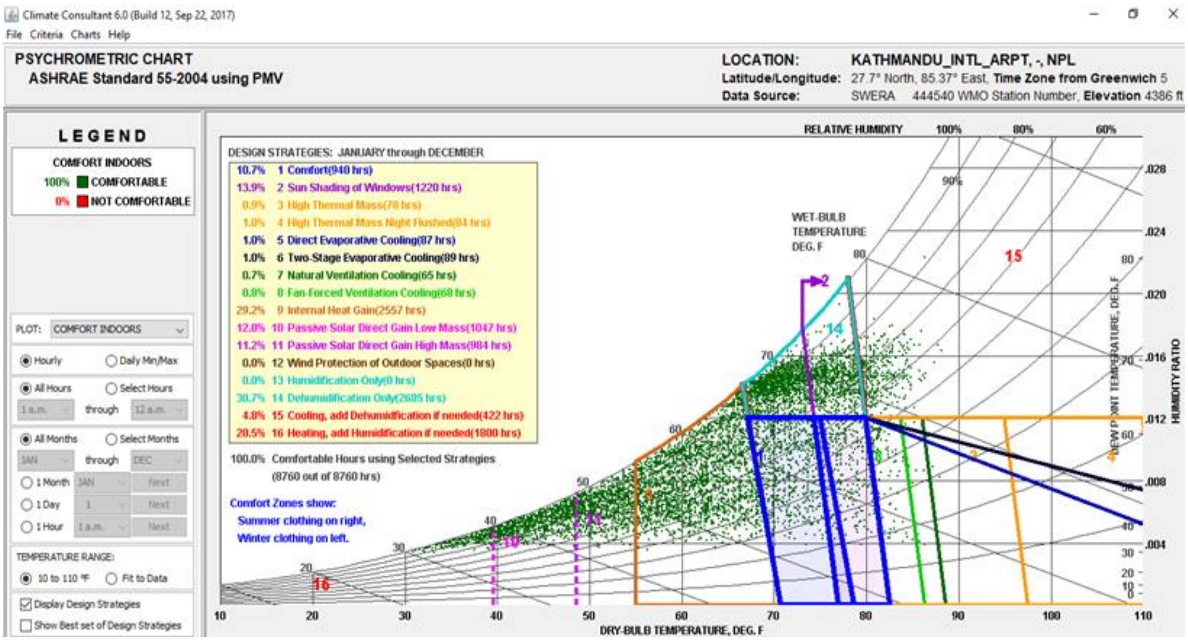


Figure 4.25: Bioclimatic Chart Showing Effective Design Strategy on Project Site

4.10.1.1 Analysis

Figure 4.24 shows that the energy for heating and cooling demand is completely ignored in passive solar buildings because this demand is met by passive solar energy but it may not be an effective solution to maintain indoor comfort in the context. For example, analyzing the graph result imparting passive design strategies only offers 6538 hours of indoor comfort out of 8760 hours satisfying 74.6% comfort hour throughout the year in the context. Figure 4.25 shows that incorporating simple means of effective heating and cooling complete comfort hours throughout the year. Throughout the year, it can be summarized in detail as follows:

- The comfort hour throughout the year is about 940 hours and it covers 10.7 % out of 8760 total annual hours to maintain comfort indoors.
- The window sun shading is effective for 1220 hours and covers 13.9% of the total annual hour to maintain indoor comfort.
- The direct and two-stage evaporative cooling is effective for approximately 176 hours accounting for 2%.
- Natural ventilation accounts for 0.7% within 65 hours.
- The thermal mass of the building is effective for approximately 172 hours and accounts for 1.9% of the total annual hours required to maintain indoor comfort.
- Fan forced ventilation for cooling is required for approximately 68 hours, accounting for 0.8% of the total annual hours required to maintain indoor comfort.
- Internal heat gain is possible for approximately 2557 hours, accounting for 29.2% of the total annual hours required to maintain indoor comfort.
- Passive solar direct gain is possible for approximately 2031 hours, accounting for 23.2% of the total annual hours required to maintain indoor comfort.
- Active strategies with heating and dehumidification are possible for approximately 1800 hours, accounting for 20.5% of the total annual hours required to maintain indoor comfort.
- Effective cooling and dehumidification may be required for approximately 422 hours, accounting for 4.8% of the total annual hour requirement to maintain indoor comfort.
- Passive strategy of dehumidification accounts for 30.7% with 2685 hours.
- The wind protection of outdoor spaces and humidification are not required.

4.10.2 Mahoney Table

4.10.2.1 Findings and Analysis

The following design criteria were developed based on the findings of a climatic analysis and an examination of Kathmandu Valley traditional architecture from Mahoney table:.

- The Kathmandu Valley has primarily chilly climate conditions, according to the climatic study, and the mahoney table indicates that there may be a chance for passive solar heating in the winter. The Mahoney tables also advise facing structures southward to catch the low-angle winter sun. The best orientation angle is provided by slightly rotating the building toward the west on foggy winter mornings in the Kathmandu Valley due to the westerly wind.
- It is preferable to use solar energy for space heating, but in winter, it is important to ensure that the sun can reach the location without obstruction. A solar envelope should be prepared for the site, which will ensure solar exposure on the building during the specified time. Each plot will be given equal building volume consideration based on its size, allowing it to receive solar exposure.
- The months of June through September are hot and muggy with significant amounts of rain. These months bring about 82% of the annual rainfall to the Kathmandu Valley. For this time span, a permanent ventilation and rain protection arrangement is required. In the Mahoney tables, single-banked construction is advised to ensure cross ventilation. The Kathmandu Valley's traditional design generally does not make good provisions for cross ventilation because the majority of the homes are double banked with small windows in one wall, which goes against this climate suggestion. The structural restrictions are typically the cause of the minimum apertures.
- It is better to use passive solar heating. If the south façade may be utilized for this purpose, Mahoney tables also propose a medium level of openings in the range of 25–40% of the floor area, which is ideal for the direct gain system. The lower levels of the Kathmandu Valley's traditional architecture have very few openings, whereas the opening area on the top floors is almost 20–25%. Traditional windows, however, are not made specifically to gather solar energy. They cannot keep heat inside the room because they have wooden shutters. People now use glass in the shutters, and window

style has significantly evolved. As a result, it is possible to use regular windows as solar windows.

- Openings on the south façade work effectively for both daylight entry and sun shading. The south façade's huge French windows are usually advantageous since they allow for efficient heating of a broad floor area thanks to the vast solar gathering area. Openings on the north façade should be avoided as much as possible since they will cause heat loss because the north side does not get sun radiation during the winter.
- Rain protection is required since the Kathmandu Valley experiences monsoon rain for four months out of the year. Projections are used to shield windows. Traditional structures are shielded by roof projections, which in the summer also aid in shading openings from unwelcome solar radiation.
- Modern buildings in the Kathmandu Valley are built with light outside walls, poor thermal capacities, and quick temporal delays. Contrary to what this assertion implies, historic buildings are made of thick walls with a high thermal capacity and a long time lag. People who previously resided in traditional structures but have since moved into new structures frequently gripe that the new structures are less comfortable than the traditional ones. In the new buildings, people experience cold winters and hot summers, which wasn't an issue in the old ones. Although the Kathmandu Valley is not particularly arid, having heavy walls with a high thermal capacity and a long-time lag will help residents better withstand the eight months of winter.
- For residential buildings, a roof with a 10-hour time lag is advised. When heat is not required, it stops the flow of unneeded heat flux, while allowing the flow of heat at night when the room's temperature drops below a comfortable level. To obtain a desired time lag, proper insulating measures must be considered. Modern structures rarely have roof insulation, which results in poor internal comfort levels.
- A structure should have a raised base and good surface drainage should be maintained in light of the four months of monsoon rain in order to prevent damage from a strong rainstorm.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

Conclusion

An energy audit was carried out in the Information, Communication, and Technology Center (ICTC), Pulchowk Campus, in order to evaluate the patterns of energy use and provide specific recommendations to improve energy consumption efficiency and reduce energy expenditures.

In conclusion, switching from CFLs to LED bulbs can result in yearly lighting energy savings of up to 52%. Similarly, if double glazing is retrofitted onto the glass, the energy consumption can be decreased by roughly 13% of the thermal load. The PVSyst software's simulation of solar panels reveals a decrease in electricity costs of 11.85% when used at full capacity and a reduction of 23.7% when the capacity is doubled. The analytical analysis recommended replacing the damaged insulation with 11mm foam insulation in order for the HVAC system to operate at its best. Replacing electric equipment and installing cavity walls, double-glazed windows, energy-efficient lighting, and other measures can reduce annual energy usage by more than 37.12%.

Recommendations

After completion of this project, the following recommendations can be made for efficient energy conservation in ICTC building:

i. Efficiency study should always be done without neglecting human perception aspects including human comfort parameters, and so questionnaire, and interviews can be effective tools.

ii. Globally, CFL are being switched by LED but the retrofit is suggested to be done to meet certain illumination level as per standards. Lower payback period makes it even more feasible retrofit.

iii. Thermal load of the building should be checked before HVAC installments.

iv. Energy efficient measures should be thought right before starting construction as material properties matter for e.g., that of window and wall.

v. Solar PV system contribute to saving and it should be utilized to its utmost capacity. The day electricity consumption can be fulfilled by solar energy. Utilizing the capacity of the PV system can be an effective way to reduce energy costs and promote sustainable energy development.

vi. Behavioral shift is necessary for reducing electricity consumption. Proper attention can be given to seasonal scheduling and day scheduling for being protected against high-tariff timings.

vii. The user should give attention while taking approval of transformer load which should be in relevance to existing load.

viii. Retrofitting of insulation should be done by best economic and energy saving perspective which is critical thickness of insulation.

ix. Use of Mahogany chart and Bio-Climatic table must be encouraged to find suitable passive design techniques such as shading devices, natural ventilation, daylighting,building insulation, a green roof, that can help cut down on energy use and enhance thermal comfort.

x. ASHRAE server cooling standard is advisable in case of data room which includes server. The server room of the ICTC building should adhere to the ASHRAE server cooling standard, i.e., the use of CRAC units, raised floor design with perforations for cold stream inlet, and lowered ceiling configuration

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APPENDICES

Appendix A : Questionnaire and Interview

Questionnaire

	Table : Attitudinal Scale Development for Questionnaire	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
1	The building includes well operating electronic equipment. (+ve)	5	4	3	2	1
2	You like that the building is south facing for solar heat. (+ve)	5	4	3	2	1
3	You like that the building is south facing for sunlight. (+ve)	5	4	3	2	1
4	Heat radiation was coming out from computers and devices. (+ve)	5	4	3	2	1
5	The building needs additional lighting bulbs. (+ve)	5	4	3	2	1
6	The temperature inside the room was not comfortable. (-ve)	1	2	3	4	5
7	You give preference to operating Air Conditioning (AC) over non-operating state. (+ve)	5	4	3	2	1
8	You would like to give other such higher academic exams in the buildings like ICTC. (+ve)	5	4	3	2	1

Interview

This entire section was filled by Dr. Sanjeev Prasad Pandey

Table 7: ICTC Details

Owner:	DEAN Office, IOE
Building name:	ICTC
Building type:	Institutional
Primary service type:	Exams, Conference
Location:	Pulchowk Engineering Campus
Address:	Pulchowk, Lalitpur
Phone:	01 5524749
Fax no:	
Email	ictc.ioe.edu.np
Specific Problems or Ideas of Interest related to Building Energy Use: -----	--------------------

Table 8: Building's Operating Schedule:

Type	**No of Shift**	**Hours of Operation/Day**	**Days/Year**
Office Hours	10am – 5pm	Usually, 7 hours (Changes as per requirement)	≈ 245 days
BE Entrance	4 shifts /day	≈ 12 hours	12-15 days
NMCLE	As per requirement/schedule		
Others			

Table 9: Energy Management Questions (Yes/No):

Does you Table 5: Questionnaire r organization have a formal written Energy Management Plan?	No
Have you formed Energy Management Team at your organization?	No
Does your organization use life cycle cost analysis to evaluate the economics of Energy Efficient equipment when making new purchase of system?	No
Does your company establish required payback periods for energy efficient improvement projects?	No

Table : Energy Consumption Systems Utilized in Building

SYSTEM	Energy System in Plant (Yes/No)	Primary Energy Source	Secondary Energy Source

Compressed Air	No		
Fans	Yes	Electricity	
Lighting Facilities	Yes	Electricity	Solar
HVAC Facilities	Yes	Electricity	
Material Handling	Yes	Electricity	
Generator	Yes	HSD	
Pumps	Yes	Electricity	
Server	Yes	Electricity	Solar/Generator
Computers	Yes	Electricity	Generator
Solar PV panel	Yes	Sun	

Table: Energy Saving Opportunities:

SYSTEM	Energy Management Opportunities (EMOs) Level (High/Medium/Low)
Compressed Air	-------
Fans	Medium
Lighting Facilities	High
HVAC Facilities	High
Material Handling	Medium
Generator	High
Pumps	Low
Server	High
Computers	Low-Medium
Solar PV panel	High

Table 12: Miscellaneous Questions

How often is the pumped used in a week?	Once
Are the urinals checked daily for any water leak?	No

How often are the computers serviced in a year?	Twice/thrice annually
What sort of servicing is carried for Server?	Periodic/
How often is the server room temperature noted in a day? Is there any sensor?	No
The staffs give preference to lift then walking upstairs?	Lift
How often the electric bulbs are replaced?	Per requirement
Has building interior wall paint ever changed?	Once
What is the number of working staff number during building active days?	20-30
What is the number of working staff member during building passive days?	6
Has the building ever caught fire leading to use of fire hose?	No

Any Energy Efficient project implemented in your organization? No

Appendix B: Weather Data

Table : Monthly Mean Temperature

Month	J	F	M	A	M	J	J	A	S	O	N	D
Monthly mean max.	19.1	21.4	25.3	28.2	28.7	29.1	28.4	28.7	28.1	26.8	23.6	20.2
Monthly mean min.	2.4	4.5	8.2	11.7	15.7	19.1	20.2	19.9	18.5	13.4	7.8	3.7

Monthly mean range	16.7	16.9	17.1	16.5	13	10	8.2	8.8	9.6	13.4	15.8	16.5

(Source: Weatherspark.com)

Table B : Monthly Mean Rainfall and Wind Direction

Rainfall, mm	14.4	18.7	34.2	61	123.6	236.3	363.4	330.8	199.8	51.2	8.3	13.2
Wind, prevailing	SW-NE	SW-NE	SW-NE	SW-NE	S	S	SW-NE	SW-NE	SW-NE	SW-NE	SW-NE	SW-NE
Month	J	F	M	A	M	J	J	A	S	A	N	D

(Source: Weatherspark.com)

Table 4: Monthly Mean Relative Humidity

Average	79	71	61	53	57	73	81	83	82	79	85	80
Month	J	F	M	A	M	J	J	A	S	O	N	D

(Source: Weatherspark.com)

Table: Global Solar Radiation (Source:DHM)

Time	**Time**	**Khumaltar**	**Kathmandu_AWOS_20**
2021	**10**	370.97	392.15
	11	327.27	357.32
	12	282.98	307.66
2022	**1**	297.3	305.73
	2	347.05	378.55
	3	398.49	430.04
	4	383.85	418.91
	5	327.29	372
	6	288.7	295.47
	7	316.18	325.59

	8	348.07	360.98
	9	322.05	329.6
	10	389.47	412.04
	11	408.98	440.14

Table: Temperature data (source: DHM)

	2021		**2022**	
Month	**Max temp**	**Min Temp**	**Max temp**	**Min Temp**
1	19.67	3.955	17.055	4.865
2	21.79	5.775	18.13	5
3	25.475	9.775	27.22	11.78
4	28.135	11.395	29.23	15.64
5	26.435	16.47	27.67	17.07
6	28.225	19.875	28.43	20.04
7	27.865	20.7	29.155	20.965
8	27.745	20.525	29.73	20.7
9	28.335	19.35	28.64	19.725
10	27.195	16.67	26.525	14.55
11	22.435	8.67	25	10.8
12	18.78	4.835		

Table: Sun hours data (source: DHM)

Month	**2020**	**2021**	**2022**
1	5.49	7.54	5.83
2	5.52	7.46	7.24
3	0.08	7.58	9.05
4	0.59	7.91	8.17
5	5.23	4.64	5.38
6	4	4.72	4
7	2.88	3.72	3.94

8	4.07	2.25	4.78
9	3.84	7.1	3.55
10	8.17	9.66	8.12
11	7.88	8.4	9.93
12	7.43	6.85	

Appendix C: Solar Panel Details

Table: Electrical Standards for single module

Solar Module Electrical Characteristics at STC

S.N.	**Parameter**	**Abbreviation**	**Unit**	**Value**
1	Nominal Output	Pmax	Wp	280
2	Voltage at Pmax	Vmp	V	36.3
3	Current at Pmax	Imp	A	7.72
4	Open Circuit Voltage	Voc	V	44.3
5	Short Circuit Voltage	Isc	A	8.36

Table: Solar PV system

Solar Array (LDK Panel:LDK285PBFW))	3 nos of string consist 8 nos of 280 W LDK Panel
PV Combiner Box (NEMA)	1 no of box with 3 nos of 16 A DC breaker
Solar Charge Controller (SUKAM)	1 no of 240 V
Battery Bank (EXIDE)	20 nos 12V/200 AH: all in series to form 240 V bank
Online UPS (KI Power:C15KS)	1 no of 176-300V/ 10 kWac

Table: PV Array Characteristics from PV syst at operating condition (50^o Celsius)

Power	6.03 kWp
Voltage	255 V
Current	24 A
Module area	46.3 m^2
Cell area	42.1m^2

No. of modules	24
Inverter performance ratio (DC:AC)	0.67

Table: Array losses

Parameter	Unit	Value
Thermal loss factor: Uc Uv	 W/m^2K $W/m^2K/m/s$	 25 1.2
Module Quality loss	%	1.5
Module average degradation	%/year	0.4%
DC wiring losses	%	2
Module mismatch losses	%	2

Table: AC wiring loss

Inverter wire section	Copper 50mm diameter
Inverter wire length	25m
Loss fraction to injection point	0.25%

Appendix D: Building Parameters Details

Table: Electricity Bill summary

S.N.	Dated Bill month	T1	T2	T3	Total Consumed Units (kWh)	Demand Unit (KVA)
1	2078/1	1693	3589	1736	7018	51
2	2078/2	1451	2769	1486	5706	50
3	2078/3	1426	2738	1462	5626	50
4	2078/4	1454	2898	1496	5848	50
5	2078/5	1506	4064	1436	7006	50
6	2078/6	1598	4240	1476	7314	56
7	2078/7	1325	2558	1348	5231	56
8	2078/8	1510	3109	1506	6125	50

9	2078/9	1713	5233	1541	8487	50
10	2078/10	1205	4066	1199	6470	50
11	2078/11	1612	4781	1353	7746	50
12	2078/12	1914	6570	1570	10054	61
13	2079/1	1507	2952	1538	5997	61
14	2079/2	1459	2966	1492	5917	50
15	2079/3	1695	4029	1576	7300	55
16	2079/4	1781	5292	1763	8836	69
17	2079/5	1554	3229	1548	6331	69
18	2079/7	1157	2228	1086	4471	69
19	2079/8	1747	5282	1435	8464	54
20	2079/9	1181	2397	1191	4769	54
21	2079/10	11754	5680	1799	19233	55

Existing HVAC Unit in the building

The distribution of the indoor and outdoor using is:

Outdoor Unit					
	Model	**Nos**	**Heating Capacity**	**Cooling Capacity**	**Floor**
1	GMV- Pdm 280W/NaB-M	1	31.5	28	4^{th}
2	GMV- Pdm 670W/NaB-M	2(335W each)	75	67	3^{rd}
3	GMV- Pdm 900W/NaB-M	2(450W each)	100	90	2^{nd}
4	GMV- Pdm 900W/NaB-M	1	50	45	Ground
	Total	6	256.5	230	

Indoor Units	

	Model	Nos	Heating Capacity	Cooling Capacity	Floo r
1	GMV-R125T/Na-K	2	12.5	12.5	4th
2	GMV-R100T/Na-K	6	10.6	10.6	3rd
3	GMV-R100T/Na-K	8	10.6	10.6	2nd
4	GMV-R125T/Na-K	4	12.5	12.5	G

Source: GREE, Multi VRF Service Manual

Tentative building occupancy

Year	**B.E./B.Arch total Application form**	**M.Sc. total Application form**
2076/77	11907	2565
2077/78	12699	--
2078/79	11037	1772

Miscellaneous Exam

Date	**Human load**
2079/03/2022	973
2079/02/12 to 14	1516
2078/10/21 to 22	734
2078/09/22 to 25	2170
2078/04/28 to 29	1156
2077/11/09 to 11	1385
2077/08/12 to 13	844

Electrical parameters in building

Table 19: Light Fixture (Fluorescent)

S.no	Type	Power	Count
a.	FA type	2*36 W	136
b.	FD type	3*36 W	354
c.	Street lamp	150 W	1
d.	Other Fluorescent type	Not available	140

Table 20: Water Pumps (Brand: Kirloskar)

S. N.	Type	Capacity(m3/hr)	Head(m)	Rating (HP)	Nos
1	Supply pump	133	76	7.5	2
2	Supply pump	NA	NA	3	2
3	Submersible pump	15	15	2	2
4	Submersible pump	15	15	2	2

Table 22: Miscellaneous Electrical Parameters in ICTC

LED Display Board	3500 W
Heater (No. 6)	1200 W

Appendix E: Thermal Load

Wall Group

S.No	Description	Thermal Resistance (ft^2 hr ^oF/ Btu)
1	0.5" Plaster	0.09995
2	9" Brick	3.3112
3	0.5" Plaster	0.09995
4	4" Face Brick	1.4716
Total Resistance		4.9827

Overall Heat Transfer Coefficient	0.2 Btu/ft^2 hr ^{o}F

Table: CLTD and LM Values in ^{o}F (ASHRAE Handbook)

Solar Time	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**Correction Factor (LM)**
N	6	6	7	8	10	12	13	15	-2
NE	14	17	20	22	23	23	24	24	0
E	17	22	27	30	32	33	33	32	-1
SE	13	17	12	26	29	31	32	32	-1
S	6	7	9	12	16	20	24	27	-3
SW	8	8	8	10	12	16	21	27	-1
W	9	9	9	10	11	14	18	24	-1
NW	7	7	8	9	10	12	14	18	0

Glass

CLTD value was referenced from the ASHRAE fundamental handbook for different time

Time	10	11	12	13	14	15	16	17
CLTD ^{o}F	4	7	9	12	13	14	14	13

Cooling Load

Conduction Through Glass

Room	Direction	Area (ft^2)	U	CLTD/corr (oF)								Heat Gain							
				10am	11am	12 noon	1pm	2pm	3pm	4pm	5pm	10am	11am	12 noon	1pm	2pm	3pm	4pm	5pm
MDF Server	NE	41.979	1.04	10	13	15	18	19	20	20	19	436.5838	567.5589192	654.8757	785.8508	829.509	873.1676	873.167568	829.50919
Administartion	NE	85.896	1.04	10	13	15	18	19	20	20	19	893.3176	1161.312865	1339.976	1607.972	1697.3	1786.635	1786.63518	1697.30342
Conference	SW and NE	180.83	1.04	10	13	15	18	19	20	20	19	1880.669	2444.86919	2821.003	3385.203	3573.27	3761.337	3761.33722	3573.27036
Meeting -I	NE	41.979	1.04	10	13	15	18	19	20	20	19	436.5838	567.5589192	654.8757	785.8508	829.509	873.1676	873.167568	829.50919
Lab 1,5,9	NE	126.37	1.04	10	13	15	18	19	20	20	19	3942.687	5125.493624	5914.031	7096.837	7491.11	7885.375	7885.37481	7491.10607
Lab 2,6,10	NE	136.92	1.04	10	13	15	18	19	20	20	19	4271.804	5553.345732	6407.707	7689.248	8116.43	8543.609	8543.60882	8116.42838
Lab 3,7,11	N	109.79	1.04	10	13	15	18	19	20	20	19	3425.504	4453.154597	5138.255	6165.906	6508.46	6851.007	6851.00707	6508.45672
Lab 4,8,12	S	102.26	1.04	10	13	15	18	19	20	20	19	3190.42	4147.545948	4785.63	5742.756	6061.8	6380.84	6380.83992	6061.79792
Seminar 1	NE	126.37	1.04	10	13	15	18	19	20	20	19	1314.229	1708.497875	1971.344	2365.612	2497.04	2628.458	2628.45827	2497.03536
Meeting -II	NE	137.13	1.04	10	13	15	18	19	20	20	19	1426.174	1854.025803	2139.261	2567.113	2709.73	2852.347	2852.34739	2709.73002
Office	N	109.79	1.04	10	13	15	18	19	20	20	19	1141.835	1484.384866	1712.752	2055.302	2169.49	2283.669	2283.66902	2169.48557
Office	S	102.26	1.04	10	13	15	18	19	20	20	19	1063.473	1382.515316	1595.21	1914.252	2020.6	2126.947	2126.94664	2020.59931
Lobby		620.54	1.04	10	13	15	18	19	20	20	19	6453.604	8389.685049	9680.406	11616.49	12261.8	12907.21	12907.2078	12261.8474
Front Face	N	863.59	1.04	10	13	15	18	19	20	20	19	8981.312	11675.70566	13471.97	16166.36	17064.5	17962.62	17962.6241	17064.4929
						Total Heat Gain						38858.2	50515.65437	58287.29	69944.75	73830.6	77716.39	77716.3913	73830.5718
						Total Heat Gain in TR						**3.238053**	**4.209469478**	**4.85708**	**5.828496**	**6.1523**	**6.476107**	**6.47610689**	**6.15230155**

Radiation Through Glass

Room	Direction	Area (ft^2)	Solar Heat gain	Solar Cooling Load Factor (ºF)								Heat Gain (Btu/hour)							
				10am	11am	12 noon	1pm	2pm	3pm	4pm	5pm	10am	11am	12 noon	1pm	2pm	3pm	4pm	5pm
MDF Server	NE	41.979	178	0.49	0.41	0.4	0.32	0.29	0.27	0.24	0.21	3441.741	2879.824181	2528.626	2247.668	2036.95	1896.47	1685.75074	1475.0319
Administartion	NE	85.896	178	0.49	0.41	0.4	0.32	0.29	0.27	0.24	0.21	7042.332	5892.563324	5173.958	4599.074	4167.91	3880.469	3449.30536	3018.14219
Conference	NE	85.89	178	0.49	0.41	0.4	0.32	0.29	0.27	0.24	0.21	7041.846	5892.157068	5173.601	4598.757	4167.62	3880.201	3449.06755	3017.93411
	SW	94.32	251	0.15	0.17	0.3	0.4	0.54	0.66	0.73	0.72	3338.079	3783.156336	5786.004	8901.544	12017.1	14687.55	16245.3184	16022.7798
Meeting -I	NE	41.979	178	0.49	0.41	0.4	0.32	0.29	0.27	0.24	0.21	3441.741	2879.824181	2528.626	2247.668	2036.95	1896.47	1685.75074	1475.0319
Lab 1,5,9	NE	126.37	178	0.49	0.41	0.4	0.32	0.29	0.27	0.24	0.21	31081.57	26007.0276	22835.44	20298.17	18395.2	17126.58	15223.6259	13320.6727
Lab 2,6,10	NE	136.92	178	0.49	0.41	0.4	0.32	0.29	0.27	0.24	0.21	33676.11	28177.97199	24741.63	21992.56	19930.8	18556.23	16494.4226	14432.6198
Lab 3,7,11	N	109.79	50	0.88	0.95	1	0.98	0.94	0.88	0.79	0.79	13622.96	14706.60893	15171.03	15171.03	14551.8	13622.96	12229.7064	12229.7064
Lab 4,8,12	S	102.26	246	0.38	0.53	0.7	0.72	0.71	0.63	0.52	0.42	26956.35	37597.01318	46109.54	51075.19	50365.8	44690.79	36887.6356	29793.8595
Seminar 1	NE	126.37	178	0.49	0.41	0.4	0.32	0.29	0.27	0.24	0.21	10360.52	8669.009201	7611.813	6766.056	6131.74	5708.86	5074.54197	4440.22423
Meeting -II	NE	137.13	178	0.49	0.41	0.4	0.32	0.29	0.27	0.24	0.21	11243.02	9407.425658	8260.179	7342.381	6654.03	6195.134	5506.78575	4818.43753
Office	N	109.79	50	0.88	0.95	1	0.98	0.94	0.88	0.79	0.79	4540.988	4902.202977	5057.009	5057.009	4850.6	4540.988	4076.56879	4076.56879
Office	S	102.26	246	0.38	0.53	0.7	0.72	0.71	0.63	0.52	0.42	8985.45	12532.33773	15369.85	17025.06	16788.6	14896.93	12295.8785	9931.2865
Front Face	N	863.59	50	0.88	0.95	1	0.98	0.94	0.88	0.79	0.79	35717.99	38559.19067	39776.85	39776.85	38153.3	35717.99	32065.0112	32065.0112
							Total Heat Gain(Btu/hr)					200490.7	201886.313	206124.2	207099	200248	187297.6	166369.369	150117.306
							Total Heat Gain in TR					**16.70689**	**16.82318647**	**17.17633**	**17.25756**	**16.6867**	**15.60751**	**13.8635596**	**12.5092751**

* Maximum Solar Heat Gain adn Solar Cooling Load Factor Obtained from ASHRAE Handbook

Wall

Room	Direction	Area(ft^2)	U	CLTD/corr								Heat Gain							
				10	11	12	1	2	3	4	5	10am	11am	12 noon	1pm	2pm	3pm	4pm	5pm
MDF Server	NE	123.05	0.2	20	23	26	28	29	29	30	30	492.204	566.0346	639.8652	689.0856	713.696	713.6958	738.306	738.306
Administartion	NE	134.9	0.2	20	23	26	28	29	29	30	30	539.6	620.54	701.48	755.44	782.42	782.42	809.4	809.4
Conference	NE	394	0.2	20	23	26	28	29	29	30	30	1576	1812.4	2048.8	2206.4	2285.2	2285.2	2364	2364
	SW	216.7	0.2	13	13	13	15	17	21	26	32	563.42	563.42	563.42	650.1	736.78	910.14	1126.84	1386.88
	S	448.16	0.2	9	10	12	15	19	23	27	30	806.688	896.32	1075.584	1344.48	1703.01	2061.536	2420.064	2688.96
Meeting -I	NE	64.72	0.2	20	23	26	28	29	29	30	30	258.88	297.712	336.544	362.432	375.376	375.376	388.32	388.32
Lab 1,5,9	NE	585.9	0.2	20	23	26	28	29	29	30	30	7030.8	8085.42	3046.68	9843.12	10194.7	10194.66	10546.2	10546.2
	N	219.82	0.2	10	10	11	12	14	16	17	19	1318.896	1318.896	1450.786	1582.675	1846.45	2110.234	2242.1232	2505.9024
Lab 2,6,10	NE	248.91	0.2	20	23	26	28	29	29	30	30	2986.92	3434.958	3882.996	4181.688	4331.03	4331.034	4480.38	4480.38
Storage Room (2,6,10))	NE	83.62	0.2	20	23	26	28	29	29	30	30	1003.44	1153.956	1304.472	1404.816	1454.99	1454.988	1505.16	1505.16
	SW	448.1	0.2	13	13	13	15	17	21	26	32	3495.18	3495.18	3495.18	4032.9	4570.62	5646.06	6990.36	8603.52
Lab 3,7,11	S	275.7	0.2	9	10	12	15	19	23	27	30	1488.769	1654.188	1985.026	2481.282	3142.96	3804.632	4466.3076	4962.564
Lab 4,8,12	N	275.7	0.2	10	10	11	12	14	16	17	19	1654.188	1654.188	1819.607	1985.026	2315.86	2646.701	2812.1196	3142.9572
Seminar 1	NE	585.9	0.2	20	23	26	28	29	29	30	30	2343.6	2695.14	3046.68	3281.04	3398.22	3398.22	3515.4	3515.4
Meeting -II	NE	219.82	0.2	20	23	26	28	29	29	30	30	879.264	1011.1536	1143.043	1230.97	1274.93	1274.933	1318.896	1318.896
	NE	83.62	0.2	20	23	26	28	29	29	30	30	334.48	384.652	434.824	468.272	484.996	484.996	501.72	501.72
	SW	448.1	0.2	13	13	13	15	17	21	26	32	1165.06	1165.06	1165.06	1344.3	1523.54	1882.02	2330.12	2867.84
Office	N	275.7	0.2	10	10	11	12	14	16	17	19	551.396	551.396	606.5356	661.6752	771.954	882.2336	937.3732	1047.6524
Office	S	275.7	0.2	9	10	12	15	19	23	27	30	496.2564	551.396	661.6752	827.094	1047.65	1268.211	1488.7692	1654.188
								Total Heat Gain (Btu/hr)				28985.04	31912.0102	29408.26	39332.8	42954.4	46507.29	50981.8588	55028.246
								Total Heat Gain (TR)				**2.415324**	**2.65922781**	**2.45059**	**3.277602**	**3.57939**	**3.875452**	**4.24831829**	**4.58550374**

Occupants

	Gs	Gl	N	CLF	Qs	Ql	Qt		Heat Gain							
									10am	**11am**	**12 noon**	**1pm**	**2pm**	**3pm**	**4pm**	**5pm**
Administartion	250	185	5	1	1250	925	2175		2175	2175	2175	2175	2175	2175	2175	2175
Conference	250	185	25	1	6250	4625	10875		10875	10875	10875	10875	10875	10875	10875	10875
Meeting -I	250	185	15	1	3750	2775	6525		6525	6525	6525	6525	6525	6525	6525	6525
Lab 1,5,9	250	185	35	1	8750	6475	15225		15225	15225	15225	15225	15225	15225	15225	15225
Lab 2,6,10	250	185	35	1	8750	6475	15225		15225	17400	17400	17400	17400	17400	17400	17400
Lab 3,7,11	250	185	30	1	7500	5550	13050		13050	13050	13050	13050	13050	13050	13050	13050
Lab 4,8,12	250	185	30	1	7500	5550	13050		13050	13050	13050	13050	13050	13050	13050	13050
Seminar 1	250	185	25	1	6250	4625	10875		10875	10875	10875	10875	10875	10875	10875	10875
Meeting -II	250	185	20	1	5000	3700	8700		8700	8700	8700	8700	8700	8700	8700	8700
Office	250	185	5	1	1250	925	2175		2175	2175	2175	2175	2175	2175	2175	2175
Office	250	185	5	1	1250	925	2175		2175	2250	2250	2250	2250	2250	2250	2250
Lobby	250	185	20	1	5000	3700	8700		8700	8700	8700	8700	8700	8700	8700	8700
								Total Heat Gain	108750	111000	111000	111000	111000	111000	111000	111000
								Total Heat Gain (TR)	**9.062138**	**9.24963**	**9.24963**	**9.24963**	**9.24963**	**9.24963**	**9.24963**	**9.24963**

Index:

G_s - Sensible Heat Gain (referred from ASHRAE Funadamental Handbook)

G_l – Latent Heat Gain

Lighting

									Heat Gain							
	Wattage per bulb	n	BF	CLF	-	F_u	Q		10am	11am	12 noon	1pm	2pm	3pm	4pm	5pm
Administartion	36	16	1.25	1	3.4	0.7	1714		1713.6	1713.6	1713.6	1713.6	1713.6	1713.6	1713.6	1713.6
Conference	36	18	1.25	1	3.4	0.7	1928		1927.8	1927.8	1927.8	1927.8	1927.8	1927.8	1927.8	1927.8
Meeting -I	36	15	1.25	1	3.4	0.7	1607		1606.5	1606.5	1606.5	1606.5	1606.5	1606.5	1606.5	1606.5
Lab 1,5,9	36	38	1.25	1	3.4	0.7	4070		4069.8	4069.8	4069.8	4069.8	4069.8	4069.8	4069.8	4069.8
Lab 2,6,10	36	44	1.25	1	3.4	0.7	4712		4712.4	4712.4	4712.4	4712.4	4712.4	4712.4	4712.4	4712.4
Lab 3,7,11	36	35	1.25	1	3.4	0.7	3749		3748.5	3748.5	3748.5	3748.5	3748.5	3748.5	3748.5	3748.5
Lab 4,8,12	36	32	1.25	1	3.4	0.7	3427		3427.2	3427.2	3427.2	3427.2	3427.2	3427.2	3427.2	3427.2
Seminar 1	36	16	1.25	1	3.4	0.7	1714		1713.6	1713.6	1713.6	1713.6	1713.6	1713.6	1713.6	1713.6
Meeting -II	36	18	1.25	1	3.4	0.7	1928		1927.8	1927.8	1927.8	1927.8	1927.8	1927.8	1927.8	1927.8
Office	36	15	1.25	1	3.4	0.7	1607		1606.5	1606.5	1606.5	1606.5	1606.5	1606.5	1606.5	1606.5
Office	36	15	1.25	1	3.4	0.7	1607		1606.5	1606.5	1606.5	1606.5	1606.5	1606.5	1606.5	1606.5
								Total Heat Gain (Btu/hr)	28060.2	28060.2	28060.2	28060.2	28060.2	28060.2	28060.2	28060.2
								Total Heat Gain (TR)	**2.338256**	**2.338256466**	**2.338256**	**2.338256**	**2.33826**	**2.338256**	**2.33825647**	**2.33825647**

Index:

BF- Ballast Factor

F_u – Usaugae Factor

Ceiling

			CTLD/corr									Heat Gain							
Room	**U value**	**Area**	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**		**10am**	**11am**	**12 noon**	**1pm**	**2pm**	**3pm**	**4pm**	**5pm**
Seminar 1	0.64	295.7	20	30	41	51	59	65	66	66		3784.96	5677.44	7759.168	9651.648	11165.6	12301.12	12490.368	12490.368
Meeting -II	0.64	295.7	20	30	41	51	59	65	66	66		3784.96	5677.44	7759.168	9651.648	11165.6	12301.12	12490.368	12490.368
Office	0.64	295.7	20	30	41	51	59	65	66	66		3784.96	5677.44	7759.168	9651.648	11165.6	12301.12	12490.368	12490.368
Office	0.64	295.7	20	30	41	51	59	65	66	66		3784.96	5677.44	7759.168	9651.648	11165.6	12301.12	12490.368	12490.368
Lobby	0.64	212	20	30	41	51	59	65	66	66		2713.818	4070.7264	5563.326	6920.235	8005.76	8819.907	8955.59808	8955.59808
								Total Heat Gain (Btu/hr)				17853.66	26780.4864	36600	45526.83	52668.3	58024.39	58917.0701	58917.0701
								Total Heat Gain(TR)				**1.487799**	**2.231698273**	**3.049988**	**3.793887**	**4.38901**	**4.835346**	**4.9097362**	**4.9097362**

Computers

					Heat Gain							
Room	**Gain Btu per hour**	**n**	**Qt**		**10am**	**11am**	**12 noon**	**1pm**	**2pm**	**3pm**	**4pm**	**5pm**
Administartion	500	5	2500		2500	2500	2500	0	2500	2500	2500	2500
Conference	500	1	500		500	500	500	0	500	500	500	500
Lab 1,5,9	500	90	45000		45000	45000	45000	0	45000	45000	45000	45000
Lab 2,6,10	500	90	45000		45000	45000	45000	0	45000	45000	45000	45000
Lab 3,7,11	500	90	45000		45000	45000	45000	0	45000	45000	45000	45000
Lab 4,8,12	500	90	45000		45000	45000	45000	0	45000	45000	45000	45000
Others	500	5	2500		2500	2500	2500	0	2500	2500	2500	2500
				Total Heat Gain (Btu/hr)	185500	185500	185500	0	185500	185500	185500	185500
				Total Heat Gain (TR)	**15.45772**	**15.457715**	**15.45772**	**0**	**15.4577**	**15.45772**	**15.457715**	**15.457715**

Ventilation

									Heat Gain							
Room	**n**	**CFM**	**ΔT**	**ΔW**	**Qs**	**Ql**	**Qt**		**10am**	**11am**	**12 noon**	**1pm**	**2pm**	**3pm**	**4pm**	**5pm**
Administartion	5	20	13	6.73	1300	673	1973		1973	1973	1973	1973	1973	1973	1973	1973
Conference	25	20	13	6.73	6500	3365	9865		9865	9865	9865	9865	9865	9865	9865	9865
Meeting -I	15	15	13	6.73	2925	1514.25	4439		4439.25	4439.25	4439.25	4439.25	4439.25	4439.25	4439.25	4439.25
Lab 1,5,9	90	15	13	6.73	17550	9085.5	26636		26635.5	26635.5	26635.5	26635.5	26635.5	26635.5	26635.5	26635.5
Lab 2,6,10	90	15	13	6.73	17550	9085.5	26636		26635.5	26635.5	26635.5	26635.5	26635.5	26635.5	26635.5	26635.5
Lab 3,7,11	90	15	13	6.73	17550	9085.5	26636		26635.5	26635.5	26635.5	26635.5	26635.5	26635.5	26635.5	26635.5
Lab 4,8,12	90	15	13	6.73	17550	9085.5	26636		26635.5	26635.5	26635.5	26635.5	26635.5	26635.5	26635.5	26635.5
Seminar 1	25	20	13	6.73	6500	3365	9865		9865	9865	9865	9865	9865	9865	9865	9865
Meeting -II	20	20	13	6.73	5200	2692	7892		7892	7892	7892	7892	7892	7892	7892	7892
Office	5	20	13	6.73	1300	673	1973		1973	1973	1973	1973	1973	1973	1973	1973
Office	5	20	13	6.73	1300	673	1973		1973	1973	1973	1973	1973	1973	1973	1973
Lobby	20	15	13	6.73	3900	2019	5919		5919	5919	5919	5919	5919	5919	5919	5919
								Total Heat Gain (Btu/hr)	150441.3	150441.25	150441.3	150441.3	150441	150441.3	150441.25	150441.25
								Total Heat Gain(TR)	**12.53627**	**12.53626936**	**12.53627**	**12.53627**	**12.5363**	**12.53627**	**12.5362694**	**12.5362694**

Index;

ΔT – Difference in temperature ; Q_s – Sensible Heat

ΔW - Difference in moisture content ; Q_l – Latent Heat

Heating Load

Windows

Room	U Value	Area (sq.ft)	TD (ºF)	Heat Loss
MDF Server	1.04	41.97921	37	1615.360001
Administartion	1.04	85.895922	37	3305.275079
Conference	1.04	180.83352	37	6958.47385
Meeting -I	1.04	41.97921	37	1615.360001
Lab 1,5,9	1.04	126.368186	37	14587.94339
Lab 2,6,10	1.04	136.916808	37	15805.67632
Lab 3,7,11	1.04	109.79178	37	12674.36308
Lab 4,8,12	1.04	102.25705	37	11804.55385
Seminar 1	1.04	126.368186	37	4862.647797
Meeting -II	1.04	137.132086	37	5276.842669
Office	1.04	109.79178	37	4224.787694
Office	1.04	102.25705	37	3934.851284
Lobby	1.04	620.538835	37	23878.33437
Front Face	1.04	863.587697	37	33230.85458
		Total Heat Loss (Btu/hour)		143775.324
		Total Heat Loss (TR)		**11.98079775**

Walls

	U Value	Area	TD	Heat Loss
MDF Server	0.2	123.051	37	910.5774
Administartion	0.2	134.9	37	998.26
Conference	0.2	1058	37	7829.2
Meeting -I	0.2	64.72	37	478.928
Lab 1,5,9	0.2	805	37	17871
Lab 2,6,10	0.2	780.63	37	17329.986
Lab 3,7,11	0.2	275.816	37	6123.1152
Lab 4,8,12	0.2	275.698	37	6120.4956
Seminar 1	0.2	585.9	37	4335.66
Meeting -II	0.2	780.63	37	5776.662
Office	0.2	275.698	37	2040.1652
Office	0.2	279.698	37	2069.7652
Lobby	0.2	219.8163	37	1626.64062
		Total Heat Loss (Btu/hour)		73510.45522
		Total Heat Loss (TR)		**6.125626233**

Ceiling

	U Value	Area	TD	Heat Loss
Seminar	0.64	848.11	37	20083.2448

Meeting-II	0.64	1504.2	37	35619.456
Office	0.64	986.512	37	23360.60416
Office	0.64	986.512	37	23360.60416
Lobby	0.64	212.027	37	5020.79936
		Total Heat Loss (Btu/hour)		107444.7085
		Total Heat Loss (TR)		**8.953367558**

Ventilation

	n	**CFM**	**ΔT**	**ΔW**	**Qs**	**Ql**	**Qt**
Administartion	5	20	17.3	6.73	1730	673	2403
Conference	25	20	17.3	6.73	8650	3365	12015
Meeting -I	15	15	17.3	6.73	3892.5	1514.25	5406.75
Lab 1,5,9	35	15	17.3	6.73	27247.5	10599.8	37847.25
Lab 2,6,10	40	15	17.3	6.73	31140	12114	43254
Lab 3,7,11	30	15	17.3	6.73	23355	9085.5	32440.5
Lab 4,8,12	30	15	17.3	6.73	23355	9085.5	32440.5
Seminar 1	25	20	17.3	6.73	8650	3365	12015
Meeting -II	20	20	17.3	6.73	6920	2692	9612
Office	5	20	17.3	6.73	1730	673	2403
Office	5	20	17.3	6.73	1730	673	2403
Lobby	20	15	17.3	6.73	5190	2019	7209
				Total Heat Loss (Btu/hour)			199449
				Total Heat Loss (TR)			**16.62008517**

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Appendix: Mesh Independence Result

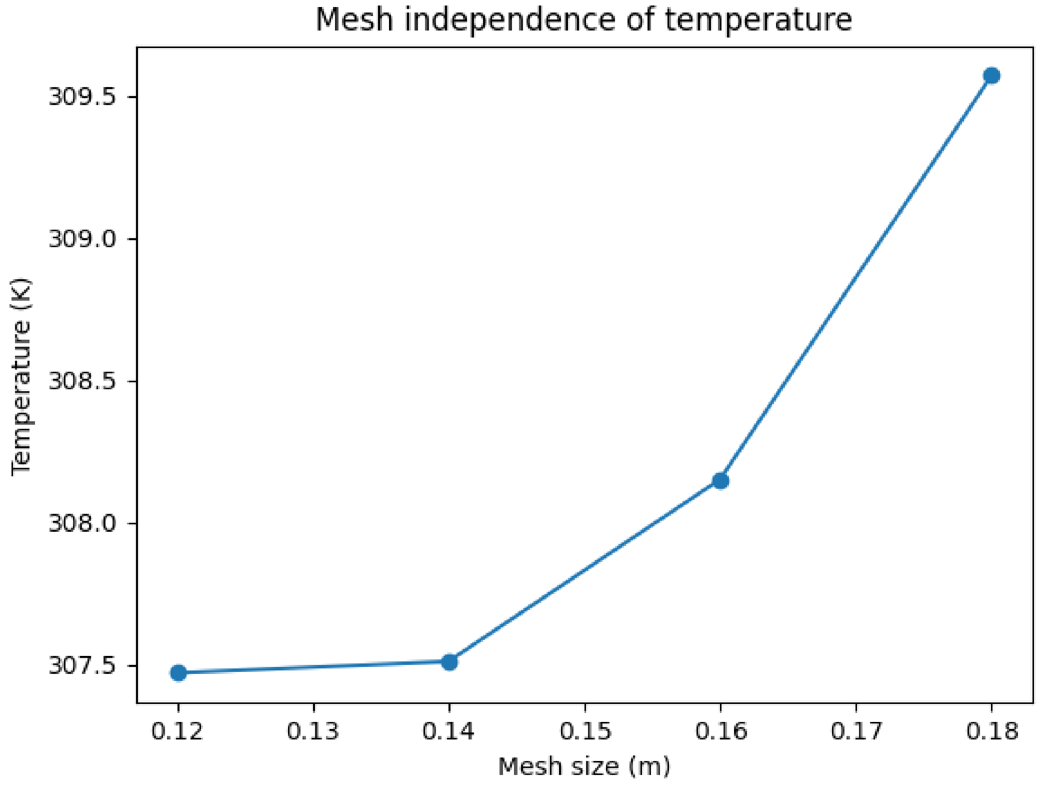

Figure: Results from Mesh Independence test to find appropriate mesh element size

Appendix F: Cost

S.No	Product	Qunatity	Cost (Rs)		Life
1	Double Pane Glass	per sq. feet	Rs. 540	Silk Sewa	15-30 years
2	Solar Panel (280W)	1	Rs. 8000	LDK	25 years
3	Charge Controller(240V)	1	Rs. 26520	SUKAM	15
4	Online UPS(10KW)	1	Rs. 224000	energyNP	15 years
5	Battery (12V)	20	Rs.718000	Exide	5-15 years
6	Combiner Box()	1	Rs.20000	Daystar Solar	
7	Desktop		Rs. 53,000	Dell	5-8 years
8	LED	1	Rs 200	Baltra	1000 hour
10	Cavity wall	Per sq. feet	Rs 17,222	Mero Property	60-80 years

Appendix G: Mahoney Table

TABLE 1

Location	Kathmandu, Nepal
Longitude	85.3240° E
Latitude	27.7172° N
Altitude	1337 m

Air temperature: °C (From 2014 to 2022)

(Source: weatherspark.com)

	J	F	M	A	M	J	J	A	S	O	N	D	High	AMT
Monthly mean max.	19.1	21.4	25.3	28.2	28.7	29.1	28.4	28.7	28.1	26.8	23.6	20.2	29.1	15.75
Monthly mean min.	2.4	4.5	8.2	11.7	15.7	19.1	20.2	19.9	18.5	13.4	7.8	3.7	2.4	26.7
Monthly mean range	16.7	16.9	17.1	16.5	13	10	8.2	8.8	9.6	13.4	15.8	16.5	**Low**	**AMR**

Relative humidity: %

(Source: Weatherspark.com)

Average	79	71	61	53	57	73	81	83	82	79	85	80
Humidity group	4	4	3	3	3	4	4	4	4	4	4	4

Humidity group:	**1**	**If average RH: below 30 %**
	2	**30-50 %**
	3	**50-70%**
	4	**Above 70 %**

Rain and wind

Rainfall, mm	**14.4**	**18.7**	**34.2**	**61**	**123.6**	**236.3**	**363.4**	**330.8**	**199.8**	**51.2**	**8.3**	**13.2**		**1454.9**	**Total**

Wind, prevailing	SW-NE	SW-NE	SW-NE	SW-NE	S	S	SW-NE	SW-NE	SW-NE	SW-NE	SW-NE	SW-NE
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**

		AMT **over 20 °C**		**AMT** **15-20 °C**		**AMT** **below 15 °C**	
Comfort limits		**Day**	**Night**	**Day**	**Night**	**Day**	**Night**

Humidity groups	**1**	**26-34**	**17-25**	**23-32**	**14-23**	**21-30**	**12-21**
	2	**25-31**	**17-24**	**22-30**	**14-22**	**20-27**	**12-20**
	3	**23-29**	**17-23**	**21-28**	**14-21**	**19-26**	**12-19**
	4	**22-27**	**17-21**	**20-25**	**14-20**	**18-24**	**12-18**

TABLE 2-Diagnosis

	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	O	**N**	**D**	
Monthly mean max.	19.1	21.4	25.3	28.2	28.7	29.1	28.4	28.7	28.1	26.8	23.6	20.2	AMT 15.75
Day comfort: upper	25	25	28	28	28	25	25	25	25	25	25	25	
lower	20	20	21	21	21	20	20	20	20	20	20	20	
Monthly mean min.	2.4	4.5	8.2	11.7	15.7	19.1	20.2	19.9	18.5	13.4	7.8	3.7	
Night comfort: upper	20	20	21	21	21	20	20	20	20	20	20	20	
lower	14	14	14	14	14	14	14	14	14	14	14	14	
Thermal stress: day	O	O	O	H	H	H	H	H	H	H	O	O	
night	C	C	C	C	O	O	H	O	O	C	C	C	

Indicators

Humid: H1						*	*	*	*	*	*	*		7	
H2	*	*	*											3	**Total**
H3						*	*	*						3	
Arid: A1			*	*	*									3	
A2														-	
A3														-	
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**			

INDICATORS

Applicable when: **Meaning:**	**Indicator**	**Thermal stress**		**Rainfall**	**Humidity Group**	**Monthly mean range**
		Day	**Night**			
Air movement essential	**H1**	**H**			**4**	
		H			**2.3**	**Less than 10**
Air movement desirable	**H2**	**O**			**4**	
Rain protection necessary	**H3**			**Over 200 mm**		
Thermal capacity necessary	**A1**				**1,2,3**	**More than 10**
Out-door sleeping desirable	**A2**		**H**		**1,2**	
		H	**O**		**1,2**	**More than 10**

Protection from cold	**A3**	**C**				

Table 3: Recommended Specifications

Indicator Totals from Table 2					
H1	**H2**	**H3**	**A1**	**A2**	**A3**
7	3	3	3	-	-

								Layout
			0-10			*	**1**	Orientation north and south (long axis east-west)
			11,12		5-12			
					0-4	*	**2**	Compact courtyard planning

								Spacing
11,12							**3**	Open spacing for breeze penetration
2-10						*	**4**	As 3, but protection form hot and cold wind
0,1							**5**	Compact lay-out of estates

								Air movement
3-12						*	**6**	

1,2			0-5					Rooms single banked, permanent provision for air movement
			6-12				**7**	Double banked rooms, temporary provision for air movement
0	2-12							
	0,1						**8**	No air movement requirement

								Openings
			0,1		0		**9**	Large openings, 40-80%
			11,12		0,1		**10**	Very small openings, 10-20%
Any other conditions						*	**11**	Medium openings, 20-40%

								Walls
			0-2				**12**	Light walls, short time-lag
			3-12			*	**13**	Heavy external and internal walls

								Roofs
			0-5			*	**14**	Light, insulated roofs
			6-12				**15**	Heavy roofs, over 8 h time-lag

								Out-door sleeping
			2-12			*	**16**	Space for out-door sleeping required

								Rain protection
			3-12			*	**17**	Protection from heavy rain necessary

Table 4: Detail Recommendations

Indicator totals from Table 2					
H1	**H2**	**H3**	**A1**	**A2**	**A3**
7	3	3	3	-	-

								Size of opening
			0,1		0		**1**	Large: 40-80%
					1-12	*	**2**	Medium: 25-40%
			2-5					
			6-10				**3**	Small: 15-25%
			11,12		0-3		**4**	Very small: 10-20%
					4-12		**5**	Medium: 25-40%

								Position on openings
3-12						***6**		In north and south at body height on windward side
1-2			0-5					
			6-12			**7**		As above, openings also in internal walls
0	2-12							

								Protection of openings
					0-2	***8**		Exclude direct sunlight
		2-12				*** 9**		Provide protection from rain

								Walls and floors
			0-2			**10**		Light, low thermal capacity
			3-12			***11**		Heavy, over 8 h time-lag

								Roofs
10-12			0-2			**12**		Light, reflective surface, cavity
			3-12			***13**		
0-9			0-5					Light, well insulated
			6-12			**14**		Heavy, over 8 h time-lag

								External features
				1-12		**15**		Spaces for outdoor sleeping
		1-12				***16**		Adequate rainwater drainage

Appendix H: Some Pictures

Figure : Estimation of Azimuthal angle from Google Earth

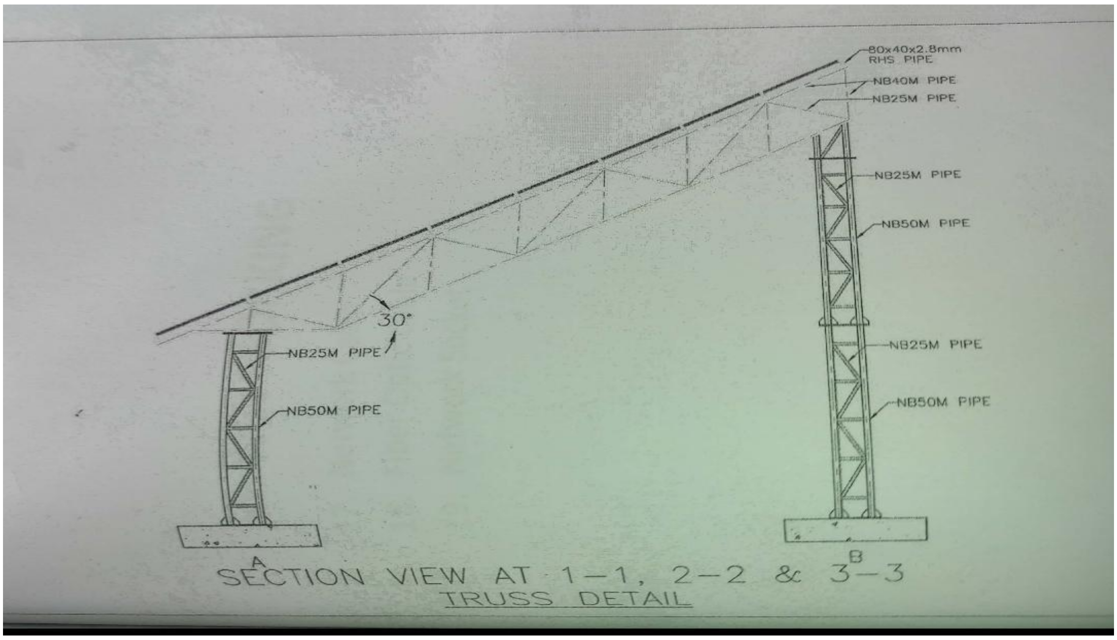

Figure : Tilt angle of the solar PV

(Source: ICTC Project Completion report)

Figure: Thermal Camera Image

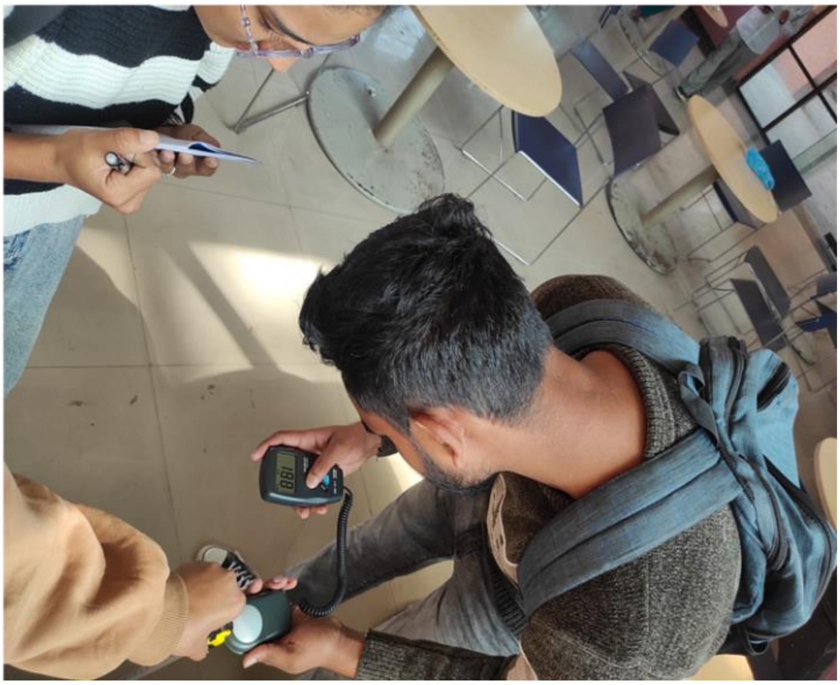

Figure: Luxmeter Reading

STUDY OF ENERGY SCENARIO AND IMPROVEMENT OPPORTUNITIES OF ICT BUILDING, PULCHOWK CAMPUS

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