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Climate Change Resiliency of Energy Efficient Residential Building in Its Life Cycle: A Case Study at Godawari Nepal

by

Shisab Pant

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The thesis titled **"CLIMATE CHANGE RESILIENCY OF ENERGY EFFICIENT RESIDENTIAL BUILDING IN IT'S LIFE CYCLE: A CASE STUDY AT GODAWARI NEPAL"** prepared and submitted by **Shisab Pant** in partial fulfilment of the requirements for the degree of Master of Science (M. Sc.) in Climate Change and Development has been examined by us and is accepted for the award of M. Sc. in Climate Change and Development by Tribhuvan University.

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DECLARATION

I hereby declare that this study titled "**CLIMATE CHANGE RESILIENCY OF ENERGY EFFICIENT RESIDENTIAL BUILDING IN IT'S LIFE CYCLE: A CASE STUDY AT GODAWARI NEPAL**" is based on my original research work. Related works on the topic by other researchers have been duly acknowledged. I owe all the liabilities relating to the accuracy and authenticity of the data and any other information included hereunder.

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ABSTRACT

Adaptive solutions that encourage environmental resilience and sustainability in all sectors including building construction—are necessary due to the continuous effects of climate change, especially in vulnerable countries like Nepal. Using a case study methodology, this study investigates the climate change resilience of energy-efficient (EE) residential structures throughout their life cycle in Godawari Municipality, Lalitpur. The research area, which consists of 62 similar structures created utilizing EE techniques appropriate for the local requirements, is located in a temperate climate zone. The study evaluates the effects of shifting climate scenarios from 2025 to 2075 on thermal performance, energy demand, and emissions.

The approach combines construction materials analysis, building modeling tools, and climate projection models. The IPCC's Shared Socioeconomic Pathways (SSP245 and SSP585) used the NorESM2-MM General Circulation Model (GCM) to forecast six key climatic variables: max and minimum temperature, wind speed, relative humidity, precipitation, and solar radiation. In order to analyze thermal comfort and energy consumption for heating and cooling over the building's 50-year lifespan, these downscaled and bias-corrected estimates were used as input for thermal simulation in Ecotect 2011 software as weather file.

The findings show that EE buildings perform noticeably better than traditional structures in terms of lowering emissions and conserving energy while preserving interior thermal comfort in the face of rising outdoor temperatures. Because of their better orientation, insulation, and passive solar design, EE buildings have lower yearly heating and cooling loads as determined by degree-day analysis. Lifecycle emissions from energy-efficient buildings were lower (7.64 tCO_2e) than those from conventional buildings (14.68 tCO_2e). For EE buildings, the heating load was 1045.3 MJ, while for standard buildings, it was 1735.8 MJ. The number of hours of thermal discomfort decreased from 2792 to 1654. Additionally, UNFCCC's AMS-III.Z technique was used to compare hollow bricks with other wall materials in order to quantify construction-time emissions. Emissions from hollow brick construction amounted to 55.8 tCO_2e for 62 buildings. To guarantee empirical robustness, the study additionally verified thermal simulations using field data and public questionnaires.

As per study, temporary climate change may result in lower heating loads, sustained increases in temperature and humidity may significantly raise cooling needs, underscoring the necessity of flexible building design techniques. Furthermore, EE buildings' flexibility in responding to changing circumstances highlights how crucial they are to Nepal's national goal of having net-zero carbon emissions by 2045. The study concludes by confirming that incorporating energy-efficient measures into residential buildings can greatly improve sustainability and climate resilience. With Nepal's urbanization accelerating, especially in planned housing expansions and post-earthquake reconstruction, this research provides a crucial guide for creating low-emission, climate-adaptive buildings that meet both national and international climate targets.

Abbreviations

ADB: Asian development Bank
ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers
CBS: Central Bureau of Statistics
CMIP: Coupled Model Intercomparison Projects
CSEB: Compact Stablished Earthen Block
EE: Energy Efficiency/efficient
GCM: Global Climate Model
GIS: Geographic Information System
GHG: Greenhouse Gases
GRI: Global Reporting Initiative
IPCC: Intergovernmental Panel on Climate Change and Development
ISO: International Organization for Standardization
LCA: Lifecycle Assessment
LEAP: Low Emission
NASA: National Aeronautics and Space Administration
NSE: Nash-Sutcliffe efficiency
NSO: National Statistics Office
PBIAS: Percent Bias
QM: Quantile Mapping
RSR: Root Mean Square Deviation Ratio
SDG: Sustainable Development Goal
SDSM: Statistical Downscaling Model
SSP: Shared Socioeconomic Pathways
UN: United Nation
UNEP: United Nations Environment Programme
UNFCCC: United Nation Framework for Climate Change Conference
WACCM: Whole Atmosphere Community Climate Model
WB: World Bank
WECS: Water and Energy Commission Secretariat

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CHAPTER ONE: INTRODUCTION

7.1 Background

The natural climate system of the earth consisting of its own components has continuously evolved with time under the influence of its own internal dynamics. Natural external forcing and anthropogenic forcing are highly influencing the atmospheric composition and ultimately earth's climate. In a nutshell climate change is a statistically significant change in the mean state i.e. variability of climate over a period of some decades (Cubasch et al., 2013). Mainly after the industrial evolution in 17th and 18th Century, world have entered a new geological era, the "Anthropocene", in which human activities impact the earth on a scale relatable to that of a natural forcing (Urry, 2015). To face humanity's greatest ever challenges, we must undertake intensive mitigation and adaptation strategies that will make earth sustainable for the future generation also. Until now, sustainable development and smart cities have mainly focused on using ICT and digital services but it has been extremely late if we don't started the action against climate change immediately (Bibri, 2019;Caragliu & Del Bo, 2023;Yigitcanlar et al., 2018).

As the climate change impacts become more intense, diverse, and unpredictable, countries like Nepal poses a very high risk, which is ranked as 10th most vulnerable country due to climate change in the world by the Long-Term Climate Risk Index (*Global Climate Risk Index ... 16th Edition (2021)*, 2021a), and 80% of the people in Nepal are susceptible to the high risk of climate-induced hazards like flood, landslide, heat stress, and drought (MoHA., 2018). It is anticipated that the temperature on the Tibetan Plateau would rise by 2.5 °C by 2050 and 5 °C by 2100 A.D., while the temperature on the Indian subcontinent will soar by approximately 3.5 to 5.5 °C by that same year (International Centre for Integrated Mountain Development, 2009). According to a recent World Bank and Asian Development Bank report, by 2050, climate change will cost Nepal 2.2% of its yearly gross domestic product (WBG and ADB, 2021). Rapid and haphazard urbanization have a great role in making people more vulnerable to the impact of Climate change (UNFCCC, 2017). To limit the changing climatic conditions and overcome the impact of climate change on people inside building or building itself, efficient and effective design and selection of construction materials and practices are necessary. Hence the energy efficient building concept is gradually fostering in Nepalese society, but the energy used and emission along with capacity to cope with the changing climate by such building in its lifecycle needs to study in detail.

The Intergovernmental Panel on Climate Change (IPCC)'s latest (i.e. 6th) Assessment Report has indicated out the human influence that has unequivocally warmed the atmosphere, ocean, and land, by an increase in well-mixed Greenhouse Gas (Calvin et al., 2023b). The climate change and global warming has considerable effect on the future performance of buildings, particularly their energy performance (Krelling et al., 2023; Santamouris, 2014). The concern in literature of climate change impacts on building energy consumption is rising, driven by the urgency to implement adaptation measures including the multitude of prediction methodologies, future scenarios, as well as climate zones investigated, results in a wide range of expected changes (Campagna & Fiorito, 2022). Climate change, driven by human-induced GHG emissions, demands urgent global action, enhanced energy efficiency, including emission reduction, and sustainable practices for which building sectors can play crucial role (Baglivo et al., 2024). Eco-friendly building materials must be chosen and designs must be efficient and effective in order to mitigate the effects of climate change and limit its effects.

Calculating and estimating a building's carbon footprint is a difficult task. Among the basic methods for quantifying carbon emissions are the hybrid approach, the input-output analysis method, and the process analysis method (Liu et al., 2020). The input-output method is used to quantify the direct and indirect emissions of large supply chains using the geographical area for system boundary; the hybrid method combines the benefits of both approaches to obtain a comprehensive understanding of emissions from the entire supply chain; and the process analysis method, which is widely used in engineering and construction technologies, uses inputs as materials/energy and outputs as emissions/waste for each process of the whole lifecycle (Fenner et al., 2018). Around the world, life cycle assessment, or LCA, is frequently used to examine the energy consumption and carbon emissions from various buildings with various design options, taking into account life cycle spans that vary from 50 to 120 years depending on the local context (Ilgın et al., 2024). In Nepalese context, since the life cycle of concrete is assume as 50 yrs, the building lifecycle is also considered as 50 years for the research propose (GM, 2025). LCA of the building in Norway shows that an increase in the use of wood instead of concrete in the building reduced the energy requirement of the building leading to GHG reductions (Moschetti et al., 2019). The growing awareness of climate change impacts and the need for sustainable development have led to increased interest in energy-efficient buildings. These buildings aim to reduce energy consumption and greenhouse gas emissions while maintaining comfortable living conditions. Godawari, a rapidly developing suburban area in Nepal, presents an excellent case for studying the thermal comfort, life cycle emission and climate change resiliency of energy-efficient residential buildings.

7.2 Problem Statement

The rural to urban and Mountain/hills to Terai migration in Nepal is at its peak and Kathmandu valley is a dreamland for those who wants to migrate from different part of Nepal. Building construction is keeping pace with population growth. Building construction in Nepal has expanded by 22.82% in the past ten years alone as a result of growing urbanization, rural-urban migration, and post-earthquake reconstruction (NSO, 2023). As the number of building projects in Nepal rises, traditional vernacular architecture and sustainable building materials are being replaced by composite materials, contemporary design, and foreign technology (Rijal, 2012). Buildings with RCC roofs and cement-bonded brick/stone walls increased from 28.74% and 22.48%, respectively, to 52.17% and 37.76% during the ten-year period from 2011 to 2021 (CBS, 2012; NSO, 2023). As per National Planning Commission report, the Nepal earthquake in 2015 completely damaged 498,852 houses (NPC, 2015) which were replaced by cement concrete buildings during reconstruction. So, the newly built houses need to adopt climate friendly technology. Energy efficient building is considered as one of the climate's friendly technologies but the climate change resiliency of such types of building also needs to be investigated in detail. In many cases, the positive impacts of climate change on energy efficiency of the building in winter might be short-term and could be offset by the increased energy consumption in summer (Jalali et al., 2023). Despite the increasing implementation of energy-efficient buildings, there is a lack of comprehensive studies evaluating their overall environmental impact and resiliency against climate change in the context of Nepal. Understanding these aspects is crucial for promoting sustainable construction practices and ensuring the long-term benefits of energy-efficient buildings.

7.3 Significance of Research

This research delves into how energy-efficient residential buildings in Godawari, Nepal, can withstand the growing impacts of climate change, offering crucial insight at a time when the country ranks among the world's most climate-vulnerable. As Nepal experiences rapid urbanization and a shift towards modern construction materials, this study explores whether new energy-efficient buildings can truly deliver long-term sustainability and comfort. By simulating future climate conditions using IPCC climate scenarios and analyzing thermal comfort, energy consumption, and emissions over a building's 50-year lifespan, the study provides a holistic view of building performance in a warming world. It emphasizes the potential of well-designed buildings to reduce carbon footprints while ensuring indoor comfort, even as external temperatures and weather patterns shift dramatically. Grounded in a real case study from Godawari, where 62 identical buildings are being developed, the research bridges the gap between global climate models and local urban planning. Ultimately, it not only supports Nepal's commitment to achieving net-zero emissions by 2045 but also advocates for smarter construction practices that align environmental sustainability with everyday livability.

7.4 Research Objectives

2.1.1 General Objective:

The general objective of my research is to find out the climate change resiliency of the energy efficient residential building at temperate climatic zone in Nepal.

2.1.2 Specific Objectives:

- To predict 6 climate variables which impact building performance (i.e. max and min. temperature, wind speed, RH, precipitation and global solar radiation) in the future (2025-2075)
- To evaluate the thermal comfort of the energy efficient building against projected climate variables.
- To calculate lifecycle energy use and emission of normal and energy efficient buildings in study areas to maintain thermal comfort.
- To compare construction time emission of different types of construction materials using AMS-III. Z methodology approved by UNFCCC.

7.5 Scope and Limitations of Research

The overall scope of this study was to find out the impact of climate change in the study area and to study resiliency of EE building against such climatic factors. This research has predicted climate variables as per IPCC-AR6 reports for the lifetime of the building (i.e. 2025-2075) for the study area. The five parameters which have major impact in building were used to create a weather file for each 10 years of both (SSP245 and SSP585) scenarios. Such weather files were feed in a Building model at ecotech-2011 and performed thermal analysis. Thermal discomfort hours were calculated and equivalent external energy requirements to maintain thermal comfort were also calculated. By using an Energy calculator, the energy demand has been converted in term of equivalent CO_2 emission.

The following are the limitations of this research.

- Only one GCM i.e. NorESM2-MM has been used for all variables.
- Only one building modeling software has been used.
- Building envelopes (Wall, windows/door and roof) were conserved as energy efficient parameters of building.
- The weather file was prepared using the default value of daily data of Kathmandu for all other parameters than the 6 parameters that we assumed.
- The thermal comfort range for the whole year was analyzed instead of separate value for summer and winter season.
- Electricity induced in Nepal was considered as only energy source for heating and cooling.
- The energy used for only heating and cooling of buildings have analyzed for the energy and emission calculation.

CHAPTER TWO: LITERATURE REVIEW

By the end of 2022, there were 8 billion people on the planet; this number is expected to rise to 8.5 billion by 2030, 9.7 billion by 2050, and 10.4 billion by 2100 (United Nation). Humans need shelter for living from the time of early evolution. The type of shelter may vary depending on climate, economic condition of people, technology and the level of comfort they want. Given the escalating threat of extreme climatic events driven by the GHG effect, nations are globally grappling with mitigation of carbon footprint and sustainable development through technological advancements and policy initiatives (Ilgın, 2022). The Paris Agreement (2015) set forth a framework aimed at limiting global temperature rise to well below 2 °C from pre-industrialization era (IEA,2011). Achieving this necessitates a GHG emissions reduction of an estimated 77% from the building sector by 2050 (Ilgın et al., 2024). In today's context, more than half of the world's population live in cities (UNFCCC, 2017), and it has been forecasted that by the end of 2050, 70% of the people in earth will live in cities, making cities more critical to achieving SDG (GRI, UN Global Compact and WBCSD, 2015). Up to 80% of energy use, 75% of garbage, and carbon emissions worldwide occur in urban settings (UNEP, 2022), where building sector alone account for 40 % of global GHG emission (Wisdom Ebirim et al., 2024).

Climate change has tangible impacts on how we live and how our houses operate in the coming future (Barbala et al., 2024). Nepalese with the lifetime goal of having their own house at urban cities have 66.08% of its total population resides in urban areas, accounting for 67.19% of the total buildings in the country (CBS, 2021). We spent around 90 % of our lifetime inside the house (Klepeis et al., 2001b). Both the regional weather system and the country's uneven terrain have an impact on Nepal's extraordinarily complicated and variable climate. Improving the buildings' internal and outdoor thermal environments using a multidisciplinary approach is essential to creating an urban microclimate and achieving thermal comfort (Brown, 2011). In Middle east countries Iran, traditional architectural design was supposed to very superior techniques to cope with hot and arid climate (Almansuri et al., 2009). Likewise, Nepalese traditional architecture technique is also one of the climate resilient techniques but due to Nepal's vulnerability from earthquake point of view, new construction technology needs to introduce which can resist earthquake as well as extreme climatic condition (Manandhar et al., 2016). To maintain thermal comfort by modifying the building to the energy efficient, new concept in design and alternate material used during construction have started recently in Nepal. The EE building technology to withstand climate change resiliency has been studied in this research.

General circulation models (GCMs) simulate the Earth's climate by complex mathematical equations that describe atmospheric and oceanic interactions and provide us the future possible climatic conditions based on different scenarios (Tamang et al., 2023). IPCC is continuously upgrading GCM's under Coupled Model Intercomparison Projects (CMIP) and The most recent version, CMIP-6, includes cutting-edge GCMs with more experiments to address a greater spectrum of scientific topics (Narsey et al., 2020; Gusain et al., 2020 2020). Regional Changes of Surface Air Temperature can be studied as per SSP scenarios in which SSP 2:4.5 denotes present temperature rise rate and SSP 5:8.5 is the extreme temperature rise rate till 2100 (Nazarenko et al., 2022). Downscaling techniques like dynamic and statistical downscaling models are used to produce higher climate resolution from the GCM data (Rastogi et al., 2022). Since, using average climate data from the past three decades has been generally considered a sufficient representation of a climate and creation of climate 'normal' (Owen 2021, ch.14, sect.6). Stronger biases in GCMs simulation of surface temperatures are identified as per IPCC reports (Dibike et al., 2008) for which bias correction is necessary with reference to observed DHM data.

2.1 Climate Change

Climate change is defined by UNFCCC as "a change in climate that is additional to natural climate variability observed over the comparable time periods and that is attributed directly or indirectly to human activity that alters the composition of global atmosphere." Long-term (usually more than 30 yrs.) changes in temperature and weather patterns are referred to as climate change. Significant volcanic eruption or variation in sun's activity could be the cause of such changes. But since the industrialization i.e. 1800's, human activity preliminary the burning of fossil fuels like coal, oil, and gas has been the main driver of climate change. As a result of burning fossil fuels, greenhouse gases are released into the atmosphere, enveloping the earth like a blanket and trapping solar heat, raising global temperature. (Intergovernmental Panel on Climate Change (IPCC), 2023)

2.1.1 Climate System

The climates of different regions of the world differ. In certain regions of the world, it rains almost daily and is very hot. They have a humid tropical climate. Others have snowfall and years round cold. Their climate is polar. There is numerous climate that contribute to earth's biodiversity and geological legacy between the frigid poles and the steaming tropics.

A region's climate is determined by its climate system. The atmosphere, hydrosphere, cryosphere, land surface and biosphere are five main parts of a climate system. Among them, the atmosphere varies the most due to the changes of composition and movement of gases that surround the earth. Changes to the hydrosphere occur far more slowly than changes to the atmosphere. Two examples are variation in salinity and temperature. Another component of the climate that is generally stable is the cryosphere. Glaciers and icesheet reflect the light from sun and permafrost and ice's thermal conductivity have a significant impact on temperature. Additionally, the cryosphere aids in controlling thermohaline circulation. This "ocean conveyer belt" has a significant impact on biodiversity and marine ecosystem.(Henry et al., 2014)

2.1.2 Climate Topography

Climate topology refers to the spatial distribution of climate zones across different geographical regions, influenced by factors such as latitude, altitude, ocean currents, and topographical features. It plays a crucial role in shaping local weather patterns, biodiversity, and human activities. One of the key factors in climate topology is latitude, which determines solar radiation levels. The equator receives the most direct sunlight, resulting in tropical climates, while the poles experience colder conditions due to oblique sunlight angles. Altitude also significantly impacts climate, with higher elevations generally experiencing lower temperatures and increased precipitation variability.

Topographical features, such as mountain ranges and valleys, create microclimates. For instance, mountains force moist air to rise, cool, and condense, causing precipitation on the windward side while leaving the leeward side dry in a phenomenon known as the rain shadow effect. Coastal regions are further influenced by ocean currents, which regulate temperatures and humidity. Understanding climate topology is essential for agriculture, urban planning, and environmental conservation. It helps predict weather patterns, assess climate change impacts, and guides sustainable land use. As global temperatures rise, studying climate topology becomes increasingly important for mitigating risks and adapting to shifting environmental conditions.

2.1.3 Climate Features and Variables

Climate features and variables define the characteristics of a region's climate and influence weather patterns, ecosystems, and human activities. These include temperature, precipitation, humidity, wind patterns, atmospheric pressure, and solar radiation. Additional factors like cloud cover, ocean currents, and greenhouse gas concentrations also play crucial roles in climate regulation. Though temperature and precipitation are two aspects of region's climate that people are most familiar with, variation in daily, nightly, and seasonal pattern also contribute to the identification of distinct climates. Moreover, climate is greatly influenced by a region's elevation, latitude, land use pattern, and distance from freshwater or the ocean. Understanding these variables helps scientists predict climate trends, assess environmental impacts, and develop strategies for adaptation and mitigation in response to climate change. The following climate variables were studied in this study which have an impeccable role in determining building performance.

A. Precipitation

Precipitation is a key climate variable that includes rain, snow, sleet, and hail. It plays a crucial role in regulating temperature, water availability, and ecosystem dynamics. The amount, frequency, and intensity of precipitation vary based on factors such as latitude, altitude, atmospheric pressure, and ocean currents. Precipitation patterns are influenced by large-scale climate systems, such as monsoons, El Niño-Southern Oscillation (ENSO), and jet streams. Coastal and mountainous regions often experience higher precipitation due to moist air rising and cooling, leading to condensation and rainfall. In contrast, deserts receive minimal precipitation due to persistent high-pressure systems and dry air masses. Changes in precipitation patterns can significantly impact agriculture, water resources, and biodiversity. Climate change is altering global precipitation trends, increasing extreme weather events like heavy rainfall and prolonged droughts. Understanding precipitation as a climate variable is essential for water management, disaster preparedness, and environmental conservation efforts worldwide.

B. Temperature

Temperature is a fundamental climate variable that influences weather patterns, ecosystems, and human activities. It is primarily determined by latitude, altitude, solar radiation, and proximity to water bodies. Regions near the equator experience higher temperatures due to direct sunlight, while polar areas remain cold due to lower solar angles. Altitude also plays a significant role, as temperatures generally decrease with increasing elevation. Large water bodies, such as oceans and lakes, moderate temperature fluctuations by absorbing and releasing heat more slowly than land. Atmospheric conditions, including cloud cover and greenhouse gas concentrations, further influence temperature variations. Temperature affects evaporation rates, precipitation patterns, and the distribution of plant and animal species. Climate change is causing a rise in global temperatures, leading to more frequent heatwaves, melting ice caps, and shifting weather patterns. Monitoring temperature trends is essential for predicting climate changes, managing resources, and developing adaptation strategies.

C. Relative Humidity

Relative humidity is a crucial climate variable that measures the amount of moisture in the air compared to the maximum amount it can hold at a given temperature. It is expressed as a percentage and plays a key role in weather patterns, human comfort, and ecosystem balance. Temperature directly influences relative humidity; warmer air can hold more moisture, while cooler air holds less. When air reaches 100% relative humidity, it becomes saturated, leading to condensation, cloud formation, and precipitation. High humidity levels contribute to muggy conditions, reducing the body's ability to cool through evaporation, while low humidity can cause dryness and increased evaporation rates. Relative humidity is affected by geographical location, altitude, and seasonal changes. Coastal areas generally have higher humidity due to oceanic moisture, whereas deserts experience low humidity. Monitoring relative humidity is essential for weather forecasting, agriculture, and managing climate impacts on health and infrastructure.

D. Global Solar Radiation

Global solar radiation is a key climate variable that represents the total amount of sunlight reaching the Earth's surface. It is the primary energy source driving weather patterns, temperature variations, and ecosystem functions. Solar radiation intensity varies based on latitude, time of year, atmospheric conditions, and cloud cover. Regions near the equator receive higher solar radiation due to direct sunlight, while polar areas receive less due to the lower sun angle. Atmospheric components like clouds, aerosols, and greenhouse gases influence the amount of solar radiation reaching the surface by absorbing, reflecting, or scattering sunlight. Solar radiation affects evaporation, photosynthesis, and climate systems, influencing temperature and precipitation patterns. Variations in solar radiation contribute to seasonal changes and long-term climate trends. Understanding global solar radiation is crucial for studying climate change, optimizing renewable energy production, and assessing agricultural productivity in different regions.

E. Wind Speed

Wind speed is a crucial climate variable that measures the movement of air in the atmosphere. It is influenced by differences in atmospheric pressure, the Earth's rotation, surface friction, and temperature variations. Wind plays a significant role in weather patterns, ocean currents, and the distribution of heat and moisture across the planet. Regions with strong pressure gradients experience higher wind speeds, while areas with minimal pressure differences have calmer conditions. Wind speeds are generally higher over oceans and flat landscapes due to reduced friction, whereas mountainous regions can create turbulence and variable wind patterns. Seasonal and global wind systems, such as trade winds, westerlies, and jet streams, impact climate and weather. High wind speeds can cause extreme weather events, such as hurricanes and tornadoes, while steady winds are essential for wind energy generation. Monitoring wind speed helps improve weather forecasting, aviation safety, and renewable energy planning.

2.1.4 Global Circulation Models (GCM)

General Circulation Models (GCMs) are complex computer-based models used to simulate the Earth's climate system. They incorporate mathematical equations that represent atmospheric, oceanic, and land surface processes to study climate behavior and predict future climate changes. GCMs help scientists understand interactions between key climate variables such as temperature, precipitation, wind patterns, and greenhouse gas concentrations. GCMs divide the Earth into a three-dimensional grid, with each grid cell representing a specific region. Within these cells, equations simulate physical processes like radiation balance, cloud formation, and heat transfer. Advanced GCMs also integrate ocean circulation, sea ice dynamics, and land surface changes to improve accuracy. These models are essential for studying climate change, projecting temperature and precipitation trends, and assessing the impacts of human activities on global climate.

While GCMs have limitations due to computational constraints and uncertainties in climate feedback mechanisms, continuous improvements in data collection and model resolution enhance their predictive capabilities. Governments and researchers use GCMs to develop climate policies, mitigation strategies, and adaptation plans to address global warming and its effects.

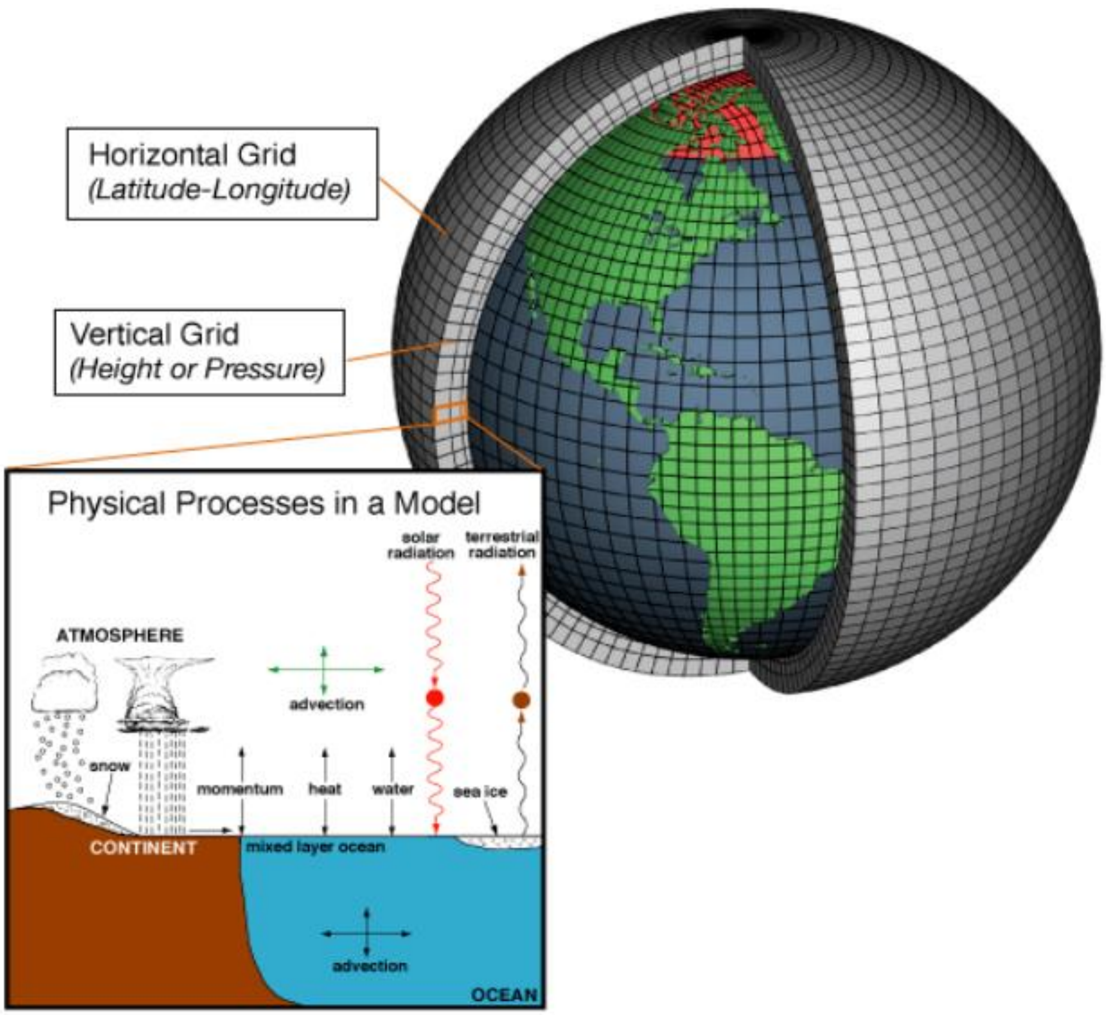


Figure 1: Visualization of GCM Model Working, Source: NOAA (Retrieved on 2025-02)

2.1.5 Climate Change Projection and Scenarios

The various climate futures depicted by the pathways are all through to be feasible given the amount of GHG released in the years to come. The common climate change projection based on IPCC reports are as follows:

- Trends and Variability

- Representative Concentration Pathways
- Shared Socioeconomic Pathways

The Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6) presents comprehensive climate projections based on five Shared Socio-economic Pathways (SSPs), each reflecting different greenhouse gas emission trajectories and socio-economic developments.

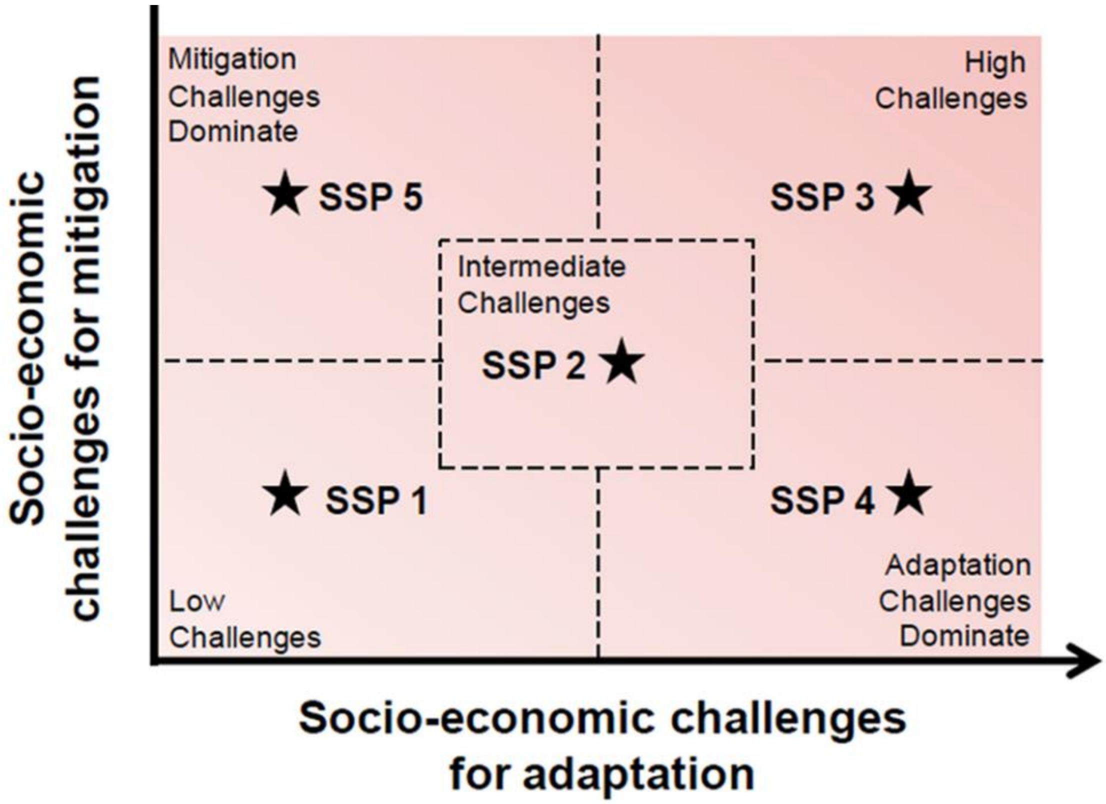


Figure 2: SSP Scenarios as per IPCC AR6

This figure represents the classification of Shared Socioeconomic Pathways (SSPs) based on socio-economic challenges for climate adaptation and mitigation. The following considerations were carried out for the preparation of SSP over RCP.

- GDP and population
- Energy demand
- Land use
- Technology
- Personal transport

- Fossil Fuel resources
- Adaptation
- Air pollutant emission

The x-axis represents socio-economic challenges for adaptation, ranging from low challenges (left) to high challenges (right). The y-axis represents socio-economic challenges for mitigation, ranging from low challenges (bottom) to high challenges (top). The figure categorizes five SSPs:

- **SSP1 (Sustainability - Low Challenges):** Located in the bottom-left, indicating low challenges for both adaptation and mitigation. It represents a sustainable development pathway with global cooperation, technological advancement, and climate-friendly policies. These scenarios envision sustainable development with significant emission reductions, aiming to limit global temperature rise to well below 2°C compared to pre-industrial levels.
- **SSP2 (Middle of the Road - Intermediate Challenges):** Positioned centrally, indicating moderate challenges for both adaptation and mitigation. It represents a world where socio-economic trends follow historical patterns with gradual progress. It is an intermediate scenario, projecting a global temperature increase of approximately 2.7°C by 2100.
- **SSP3 (Regional Rivalry - High Challenges for Both):** Located in the top-right, representing high challenges for both adaptation and mitigation due to regional conflicts, weak international cooperation, and limited sustainability efforts.
- **SSP4 (Inequality - High Adaptation Challenges, Low Mitigation Challenges):** Found in the bottom-right, indicating high adaptation challenges but lower mitigation challenges due to significant socio-economic disparities and uneven technological advancements.
- **SSP5 (Fossil-Fueled Development - High Mitigation Challenges, Low Adaptation Challenges):** Positioned in the top-left, showing low adaptation challenges but high mitigation challenges, as rapid economic growth relies heavily on fossil fuels. High-emission scenarios associated with minimal climate initiatives, potentially leading to temperature rises of 3.6°C and 4.4°C by 2100, respectively.

Projected Climate Outcomes:

- **Near-Term Warming:** There's a more than 50% likelihood that global temperatures will surpass 1.5°C between 2021 and 2040 across various scenarios. Under a high-emission pathway, this threshold could be reached even sooner, between 2018 and 2037.

- **Long-Term Warming:** By 2100, global temperature increases could range from 1.5°C to 5°C, depending on the emission scenario. The intermediate SSP2-4.5 scenario suggests a rise of about 3°C by the century's end.

These projections underscore the urgency for substantial and immediate greenhouse gas emission reductions to mitigate severe climate impacts. The AR6 report emphasizes that limiting global warming to 1.5°C or 2°C necessitates rapid and far-reaching transitions in energy, land use, urban infrastructure, and industrial systems. In summary, the AR6 IPCC report highlights that future climate conditions are contingent upon present-day policy decisions and societal actions, stressing the critical need for global collaboration to achieve climate stabilization goals.

2.1.6 Climate Change Resiliency

Climate change resiliency refers to the ability of systems, communities, or structures to anticipate, prepare for, respond to, and recover from adverse impacts of climate change. This includes coping with extreme weather events, temperature rise, climate indued hazards, and shifting climate patterns while maintaining functionality and minimizing damage.

In terms of buildings, climate change resiliency means designing and constructing structures that can withstand and adapt to climate-related stresses. This includes incorporating flood-resistant materials, improved insulation, natural ventilation, renewable energy systems, and flexible layouts. Resilient buildings ensure occupant safety, reduce maintenance and recovery costs, and contribute to long-term sustainability in the face of climate uncertainty.

2.2 Energy

Energy is a crucial determinant of a country's economic condition and future, not only a gauge of its status and level of progress. It is linked with geopolitics as an instrument that influences the global economy and offers insight into a nation's entire potential. Therefore, it is impossible to overstate the importance of creating an expanded energy database. It helps with planning and strategy to guarantee sustainable development of energy power sources and to avoid future blackouts. Systematic energy assessments and the creation of robust databases are necessary before Nepal's development program can be implemented. These components form the foundation for financial investment in the energy sector, future infrastructure development, and strategic management. They help to shift to renewable materials and provide an indication of how sustainable power use will look like in the future. The Energy Synopsis Report, economic report and other reports and serves as a working manual in terms of compiling the various analyses and gives the stakeholders the essential information that is necessary for decision-making to ensure that Nepal gets a stable, sustainable, and secure energy system.

The country's total energy consumption in 2008/2009 was 401 PJ, with fuelwood accounting for the majority of that amount (i.e., 77.7%), according to Nepal's 2010 energy summary report. Animal dung and agricultural residue contributed 4% and 6%, respectively, to the energy mix in addition to fuelwood. About 8% of all energy was used for petroleum fuels, compared to 4% for coal and electricity combined. 87% of the overall consumption came from conventional sources, with the remaining 12% coming from commercial sources and 1% from renewable sources (Energy Synopsis Report-2010, WECS).

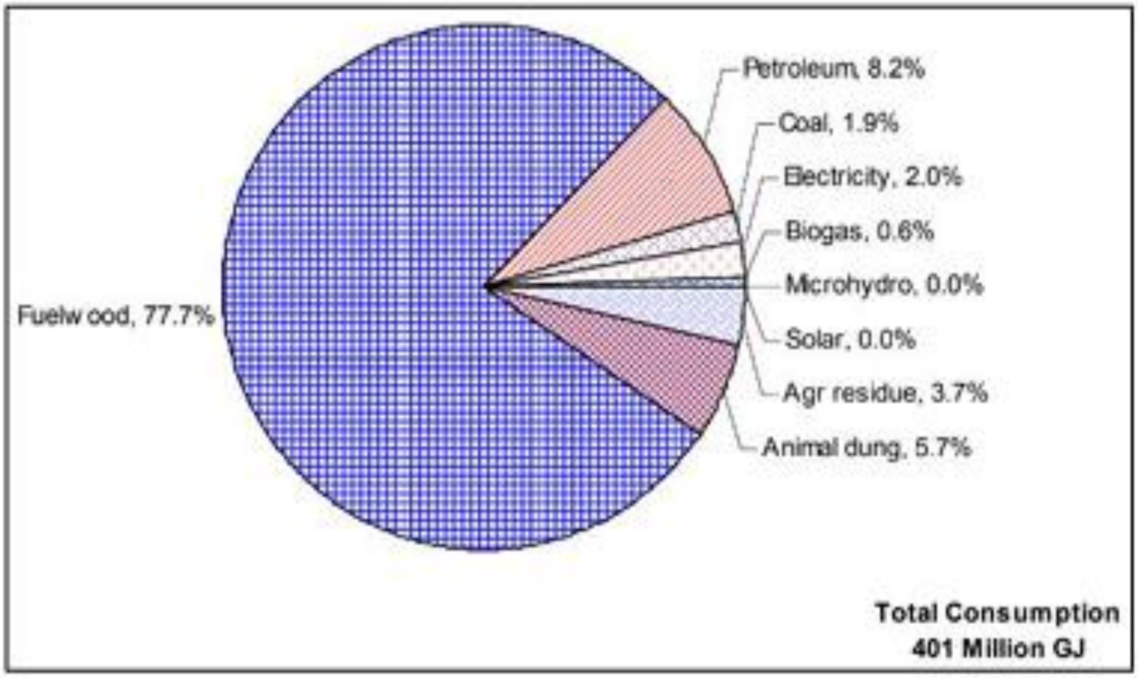


Figure 3: Energy Consumption Sources in Nepal in 2010, Source: Energy Synopsis Report-2010, WECS

Since 2010, the country's energy use has varied over the years. Fuelwood consumption is decreasing yearly, and hydroelectricity is being used more frequently in recent years.

In 2019, 589 PJ, or 62% of total energy consumption, came from fuelwood, while 3.1% and 3.2% came from animal dung and agricultural leftovers, respectively. Petroleum products also accounted for 15.4%. Of the total energy used, 6.9% came from coal, 3.3% from LPG, and 3.9% from electricity. Renewable energy sources made up 2.1% of the energy mix. Traditional, commercial, and renewable energy sources made up 68.3%, 29.6%, and 2.14% of the total energy distribution, respectively. The overall energy consumption dropped little to 566 PJ in 2020. With an increase to 64.9% of the entire mix, fuelwood continued to be the most common energy source. Animal manure and agricultural waste were among the other sources that stayed largely constant. However, coal and LPG saw slight rises, while petroleum fuels fell to 10.8%. Renewable energy sources climbed to 2.6%, while electricity consumption increased little to 4.1%. 71.3% of the total mix came from traditional sources, 26.2% from commercial sources, and 2.6% from renewable sources, which was the same as the previous year. Nepal's overall energy consumption rose to 626 PJ in 2021. Despite dropping to 60.4% of the entire mix, fuelwood continued to be the main energy source. Coal rose to 9.3%, while petroleum fuel slightly declined to 14.3%. The amount of power and LPG used stayed largely constant. The percentage of renewable energy sources in the mix increased little to 2.4%. Traditional sources accounted for 66.3% of the energy distribution, followed by commercial sources (31.3%) and renewable sources (2.4%). The dynamic character of Nepal's energy environment across time is highlighted by these variations in energy demand and source distribution. An extensive summary of Nepal's energy supplies and general consumption conditions may be found in the 2023 Energy Synopsis Report. 64.17% of overall energy consumption is attributed to traditional energy use. Nepal Electricity Authority (NEA) played a pivotal role in the commercial energy sector, achieving an installed hydropower capacity of 626.7 MW and generating 3,242.5 GWh of energy by 2022 (Energy Synopsis Report-2023, WECS).

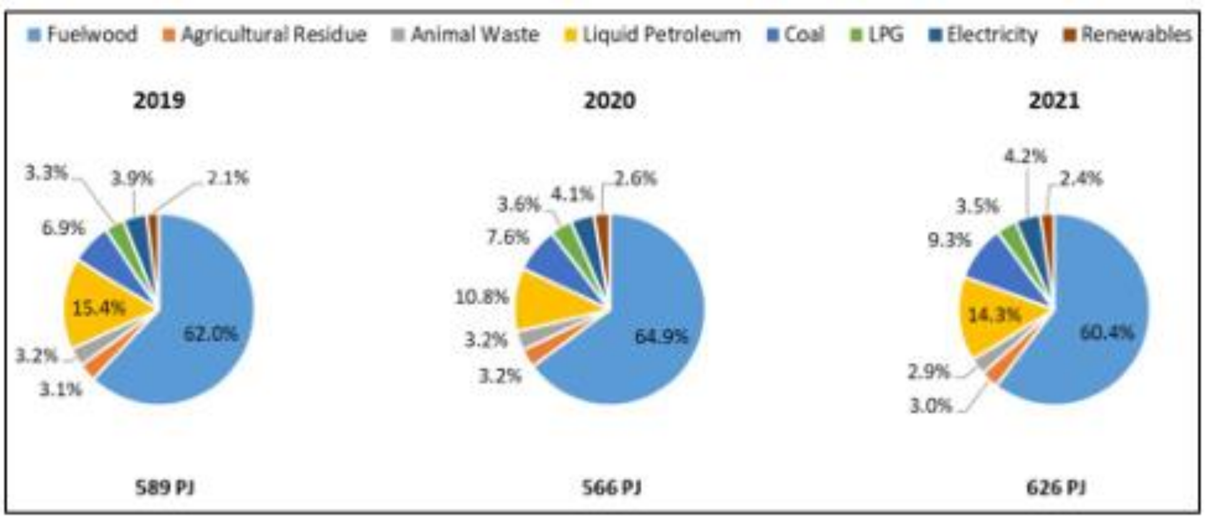


Figure 4: Energy Consumption Sources in Nepal, Source: Energy Synopsis Report 2022, WECS

Compared to F.Y. 2077/78, electricity production rose by 14.61%, with 1,709 MW of added capacity coming from Independent Power Producers (IPP). While coal production primarily supports the brick manufacturing industry, the petroleum sector, run by the Nepal Oil Corporation (NOC), has fluctuations in the sales of gasoline, diesel, kerosene, and LPG. Use of other commercial fuels accounts for 28.35% and electricity for 4.96%. With solar PV systems alone having a theoretical capacity of 2,100 MW, contemporary renewable energy sources including wind, biogas, micro/pico hydro plants, and solar PV systems are becoming attractive alternatives. The total amount of energy used in fiscal year 2078–2079 was 639.97 PJ. Other than grid electricity, renewable energy makes up 2.52% of the energy mix and is trending upward.

2.2.1 Energy Used in Household

There are 6,666,937 households in Nepal overall, with an average household (HH) size of 4.37 people per HH, according to the CBS (2021). According to the research, most homes used wood for cooking, with LPG (44.3%), electricity (0.5%), cow dung (2.9%), biogas (1.2%), and kerosene (0.05%) coming in second and third, respectively. 0.1% of cooking fuel came from other sources. Electricity was responsible for 92.2% illumination, with kerosene (0.6%), solar (6.6%), biogas (0.03%), and other sources (0.6%) following.

Given Figure 5 is a donut chart representing energy consumption across different categories. Each section is color-coded and labeled with percentages to indicate the share of total energy use for various purposes. The largest portion, at 61.0%, is dedicated to cooking (represented in yellow), making it the dominant energy consumer. Heating follows, accounting for 14.2% of total energy use (green), while water heating is next at 12.9% (blue). Other significant energy uses include cooling at 0.2%, lighting at 0.8%, water pumping at 0.1%, electric appliances at 0.4%, and other uses at 10.5% (red). The chart is sourced from WECS, 2014, indicating that this data is based on research conducted in that year. The dominance of cooking in energy consumption suggests that a large portion of energy resources is allocated to meal preparation, possibly due to traditional cooking methods that require high energy input. The relatively low percentages for electric appliances and lighting indicate limited reliance on modern electrical devices, which may reflect energy access limitations or efficiency in usage. The presence of water pumping, though minimal, highlights the need for energy in water management. This visualization provides insight into how energy is distributed across different household and industrial functions.

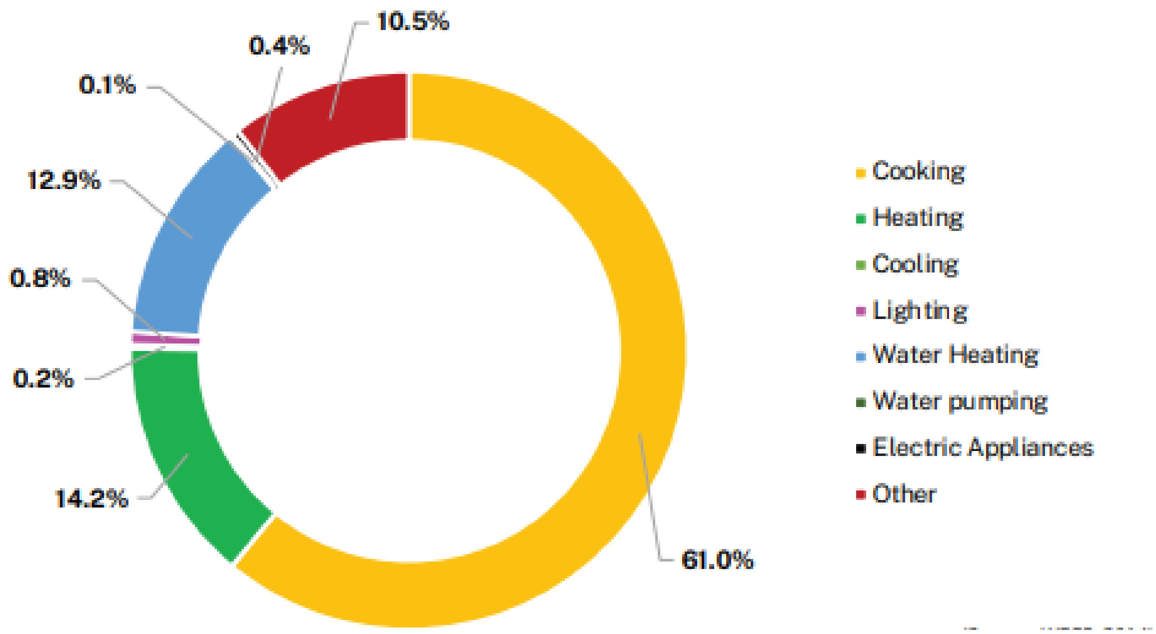


Figure 5: Energy Consumption in Nepalese Houses, Source: WECS, 2014

2.2.2 Energy Efficient Building

An energy-efficient building minimizes energy consumption while maintaining comfort and functionality. It uses smart design, insulation, natural lighting, efficient appliances, and renewable energy sources to reduce waste and environmental impact. These buildings aim to lower utility costs and greenhouse gas emissions, promoting sustainability and long-term energy conservation.

The following building parameters have a special role in maintaining buildings energy efficiency.

I. Location

The location of a building plays a crucial role in determining its energy performance. In this study, the site is situated in Godawari, Lalitpur, a temperate climatic zone of Nepal, which offers a balanced mix of warm summers and cool winters. This setting allows for the effective use of passive solar heating in winter and natural ventilation in summer. The building is positioned to take advantage of local topography, minimizing exposure to harsh winds while maximizing access to sunlight. Vegetation and surrounding landscapes are also considered to provide natural shading and insulation, enhancing thermal comfort and reducing energy demands.

II. Orientation

Proper orientation is key to optimizing natural light, ventilation, and thermal performance. The building in this study is oriented with the longer façade facing south to maximize solar gain during winter while minimizing exposure to intense western sun in summer. Windows are strategically placed to harness daylight and enable cross-ventilation, reducing reliance on artificial lighting and mechanical cooling. Roof slopes and overhangs are designed to allow winter sun in while blocking high-angle summer sun. This passive solar design ensures year-round energy efficiency, helping maintain a stable indoor temperature and significantly lowering the building's overall energy consumption.

III. Uses and Occupancy

The building's intended use and occupancy pattern are essential in designing for energy efficiency. In this study, the residential building is designed for a family of 4–6 members with typical daily activities such as cooking, resting, and working from home. Understanding occupancy helps optimize space layout, lighting needs, ventilation, and appliance usage. Energy demand is managed by aligning peak occupancy periods with natural lighting and ventilation availability. Occupant behavior, such as use of appliances and temperature preferences, influences internal heat gains and energy usage. Incorporating smart control systems and user-friendly designs ensures efficient resource use while maintaining thermal comfort and livability.

IV. Roof

An energy-efficient roof is crucial for regulating indoor temperatures and reducing external heat gain. In this study, the roof is designed using high thermal insulation materials such as polyurethane foam or rigid insulation boards that minimize heat flow. Reflective roofing surfaces are used to deflect solar radiation, thereby reducing cooling loads in summer. Proper sealing and moisture barriers prevent heat loss during winter while avoiding condensation issues. Additionally, adequate roof ventilation is integrated to balance heat buildup. These elements collectively reduce reliance on artificial heating and cooling systems, leading to lower energy consumption and improved indoor thermal comfort year-round.

V. Openings

Energy-efficient doors and windows play a vital role in reducing thermal exchange between indoor and outdoor environments. The study utilizes double-glazed, low-emissivity (Low-E) glass windows with airtight uPVC frames to reduce heat loss in winter and heat gain in summer. These windows significantly enhance insulation and reduce unwanted air infiltration. Doors are designed with insulated cores and tight seals to prevent drafts. The best natural lighting and ventilation are ensured by carefully placing windows, which lessens the need for artificial lighting and air conditioning. Combined, these features improve energy performance, reduce utility bills, and contribute to maintaining a comfortable indoor climate.

VI. Wall

The building's walls are constructed using energy-efficient materials that offer superior thermal resistance. In this case, cavity walls with internal insulation—such as extruded polystyrene (XPS) or rock wool—are used to minimize heat transfer. These walls act as thermal barriers, reducing the need for mechanical heating or cooling. External wall finishes incorporate light-colored or reflective coatings to reduce solar heat absorption. The construction also includes vapor barriers and airtight layers to prevent moisture intrusion and maintain indoor air quality. Together, these wall features significantly enhance thermal comfort, decrease energy demands, and ensure long-term building performance under changing climate conditions.

2.3 Thermal Comfort

ASHRAE defines thermal comfort as "that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation". Heat conduction, convection, radiation, evaporative heat loss, and relative air motion all have an impact on thermal comfort. What one person deems comfortable may be too hot or chilly for another since it is a subjective sense of contentment with the thermal environment that is experienced through physiological sensations that differ from person to person (ASHRAE, 2017). The interior environment has long been studied, but in the last ten years, as study on unstable and irregular settings has grown, scientists have progressively discovered that many systems are still flawed and merit further investigation (Xie et al., 2020)

Thermal comfort is simply about how good you feel in space when it comes to temperature. Our bodies work best when our core temperature stays within a tight range around 37°C so we constantly try to balance the heat we generate and the heat we lose. We exchange heat in several ways: through the warmth or coolness of surrounding surfaces (radiation), the movement of air (convection), and by sweating (evaporation). Clothing also plays a role because it can either trap heat or help us cool off. In short, thermal comfort isn't just about the thermostat, it's a mix of the environment around you and how your body, your clothes, and your activity level interact with it.

There are two sets of factors that affect this comfort:

1. **Environmental factors**

    - **Air Temperature (Dry Bulb Temperature):** This is what we normally think of as the room's temperature.
    - **Relative Humidity:** How much moisture is in the air. High humidity makes it harder for sweat to evaporate, so you might feel hotter, while low humidity allows sweat to evaporate more easily, making you feel cooler.

- **Mean Radiant Temperature (MRT):** This measures the average temperature of all the surfaces around you (i.e. walls, ceilings, etc.) and influences how much heat you gain or lose through radiation.
- **Air Movement:** A gentle breeze can help cool you by carrying away sweat and increasing heat loss, though too much movement in a cold room might make you feel chilly.

2. **Personal factors**

- **Clothing (Clo Value):** What you wear changes how much heat your body retains. More layers keep you warm in cold weather but can make you overheat when it's hot.
- **Metabolic Rate:** This is the heat your body produces through its activities. When you're active, your body makes more heat, which changes what you find

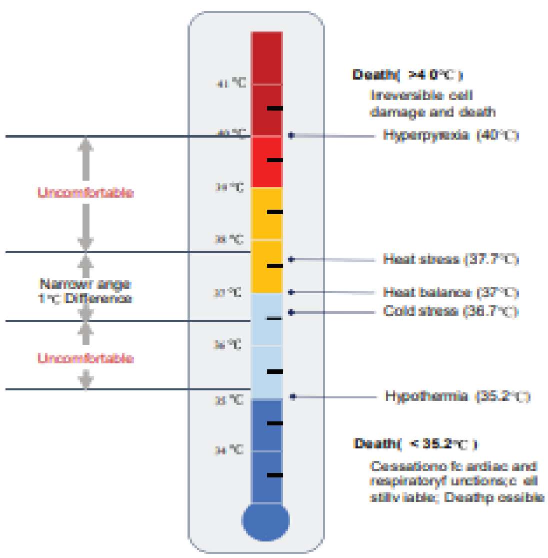


Figure 6: Comfort Band of Human Body, Source: EE Design Guidelines (BEEN)

3. **Operative temperature**

Finally, the idea of an "operative temperature" combines the effects of both air temperature and the heat coming from surrounding surfaces into one overall "feeling" of warmth or coolness.

2.3.1 Thermal comfort models and indices

A. The heat balance model

A mathematical model based on physics is presented via the heat balance approach. When the body's heat production and loss are precisely equal, thermal comfort is established. Figure 6 shows the model of heat balance. The heat balancing method takes a biological approach to thermal comfort:

- If the heat generation rate > heat loss rate, person will feel warm/hot
- If heat generation rate < heat loss rate, person will feel cool/cold
- If heat generation rate = heat loss rate, person will experience thermal comfort.

A building's intended range of thermal comfort can be determined by taking into account the level of personal control provided within the indoor environment as well as the comfort expectations of its users. One of the two thermal comfort models—the adaptive comfort model or the heat balance model—is used to determine the range of desirable comfort.

PMV & PPD: Using the 7-point thermal sensation scale and the human body's heat balance, the Predicted Mean Vote (PMV) index forecasts the average number of votes cast by a sizable sample. "Cold," "cool," "slightly cool," "neutral," "slightly warm," "warm," and "hot" are the categories that correlate to the sensory scale, which is stated from -3 to +3. When the body's internal heat generation and external heat loss are equal, thermal equilibrium is achieved. PMV can be computed for various combinations of air temperature, mean radiant temperature, air velocity, air humidity, garment insulation, and metabolic rate (ISO:7730, 2005). The PPD, or Predicted Percentage of Dissatisfied, can be ascertained once the PMV has been computed. A quantifiable estimate of the proportion of thermally dissatisfied individuals who feel either too warm or too chilly is established by the PPD index.

B. Adaptive thermal comfort model

Humans are naturally able to adapt to the weather by changing their activities, posture, attire, and window-opening and closing techniques, which reduce pain. In addition, people prefer a wider range of temperatures in a room, which is impacted by the outside weather during the day. In order to recognize the impact of behavioral and psychological changes on the human body, the adaptive thermal comfort model was created. The adaptive thermal comfort model considers the occupants' behavioral, psychological, and physiological characteristics as well as how these affects how thermal comfort is perceived. ASHRAE 55 specifies acceptable temperatures for naturally conditioned areas that are occupant controlled. For naturally ventilated areas, ASHRAE 55 recommends acceptable temperature conditions based on an adaptive comfort model. This method defines acceptable thermal environments only for occupant-controlled naturally conditioned spaces that meet all the below mentioned criterias:

- No mechanical cooling or heating system (e.g., refrigerated air conditioning, radiant cooling, or desiccant cooling) was in operation.
- Representative occupants have metabolic rates ranging from 1.0 to 1.3 met. They are free to adapt their clothing to the indoor and/or outdoor thermal conditions within a range between 0.5 to 1.0 Clo.
- The prevailing means outdoor temperature is greater than 10°C and less than 33.5°C.

2.1.3 Indoor Relative Humidity

Regression analysis may be helpful in elucidating the connection between indoor relative humidity and indoor air temperature. The link between the recorded indoor relative humidity and the midsummer indoor air temperature is depicted in Figure 7. The regression equations for the corresponding climatic areas are as follows (Gautam, 2021).

Cold: $RH_i = -1.46T_i + 79.3$ ***(n = 6048, R2 = 0.089, S.E. = 0.060, p……….i***

Temperate: $RH_i = -1.78T_i + 97.4$ ***(n = 24784, R2 = 0.053, S.E. = 0.046, p…….ii***

Sub-tropical: $RH_i = -2.49T_i + 133.1$ ***(n = 22320, R2 = 0.332, S.E. = 0.024, p……..iii***

where, RH_i denotes the indoor relative humidity, T_i denotes the indoor air temperature, n denotes the number of data, S.E. denotes the standard error of the regression coefficient and p denotes the significance level of the regression coefficient.

As may be shown, there is a negative correlation between interior air temperature and indoor relative humidity.

As may be shown, there is a negative correlation between interior air temperature and indoor relative humidity. Compared to cold and temperate climates, subtropical regions have a significantly greater coefficient of determination. As indoor air temperature rises, there is a tendency for indoor relative humidity to decrease. The data plots for cold and temperate locations are located within the 14.0 °C to 21.0 °C range of indoor air temperature. Assuming the indoor air temperature is 18 °C, the regression lines in equations I and II indicate that relative humidity (RHi) becomes 53% for cold regions and 65% for temperate regions; this means that the regional difference of indoor relative humidity (ΔRHi) is 12%. Similarly, there exist data plots for temperate and sub-tropical regions within the 21–35 °C range of indoor air temperature. Assuming the indoor air temperature is 28.0 °C, the regression line in equations ii and iii indicates that RHi becomes 48% for temperate regions and 63% for sub-tropical regions, meaning that there is a 15% regional difference in indoor relative humidity (ΔRHi)(Gautam, 2021). However, it is challenging to determine the degree of thermal environment by looking at the relative humidity only.

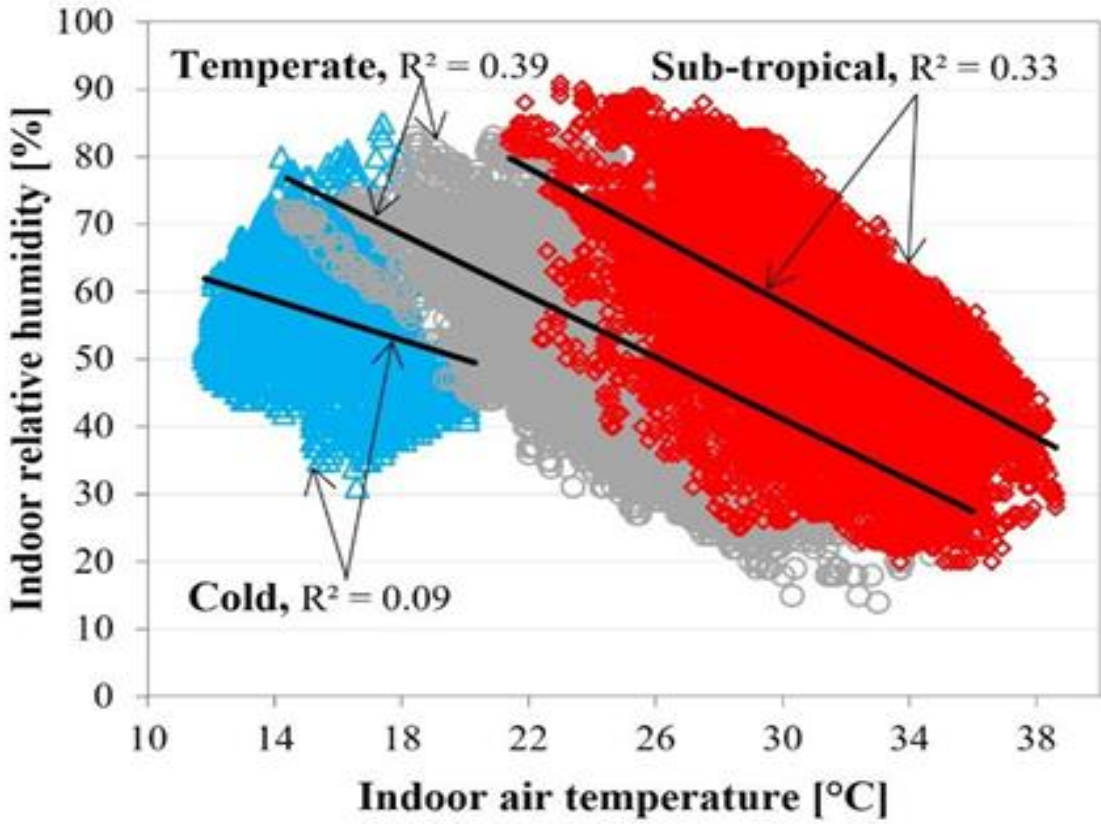


Figure 7: Relationship Between Indoor air temperature and RH

2.1.4 Thermal Comfort range in Case of Kathmandu

There are three distinct seasons in Kathmandu's climate: the cool dry season, which runs from November to March, the hot dry season, and the warm rainy season. The coldest months are January, February, and December. It is distinguished by a low nighttime temperature of roughly 3°C on average (Table 1). The climate of Kathmandu during May and June is typically hot and dry. During the summer months, the average maximum air temperature reaches around 30°C, while the minimum is around 20°C. This season is characterized by hot days and warm nights. Generally, the monsoon season is warm and wet, and it lasts from June to August (Bajracharya, 2014).

Table 1: Climatic data of Kathmandu (Source: Meteorological Department, Government of Nepal)

1	Climatic feature	Composite climate	
2	Landscape	Relatively flat	
3	Vegetation	Abundant vegetation	
4	Solar radiation	Intense in summer & Diffused in monsoon	
5	Ambient temperature:		
	Summer	Day	mean maximum 30°C
	Night		mean minimum 20°C
	Winter	Day	mean maximum 19°C
	Night		mean minimum 3°C
	Diurnal variation	> 10°C	
6	Relative humidity	78% (Monsoon) & 50-60% (Summer & Winter)	
7	Precipitation	>1000 mm per year	
8	Winds	Variable	
9	Sky conditions	Clear sky (Summer) & Generally overcast (Monsoon)	

The indoor temperature (Tin) is the most significant physical factor influencing thermal comfort in residential buildings in Kathmandu Valley. Modern building designs in Kathmandu Valley have increasingly shifted toward the use of concrete and glass, materials that exacerbate thermal discomfort in both summer (SM) and winter (WT). For most people, a comfortable range for Relative Humidity (RH) is between 30 and 70%, while a pleasant Dry Bulb Temperature (DBT) is between 20 and 26°C. Thermal discomfort may result, though, if one or both of the parameters are very high or low. Therefore, it is essential to take into account both elements at the same time. In conclusion, though the temperature required for comfort is as low as 17.6 ◦C and as high as 31.2 ◦C in naturally ventilated buildings in the world (Lamsal et al., 2023), for kathmandu lowest temperature considered comfortable might be nearly 18°C during winter and highest to 26°C in summer from Nicol graph and nearly 15°C during winter and highest to 26°C in summer from (Aqilah et al., 2022; Bajracharya, 2014). Similarly, the RH of study area i.e. temperate region has ranges from 15% at 26°C to 70% at 15°C and hence identified as average 60% ((Gautam, 2021) for our research. The relationship between indoor comfort temperature and outdoor temperature can be used to compare buildings in Kathmandu. Figure 8 shows an example of the monthly mean temperature of Kathmandu and compares indoor comfort temperature of Nicol graph.

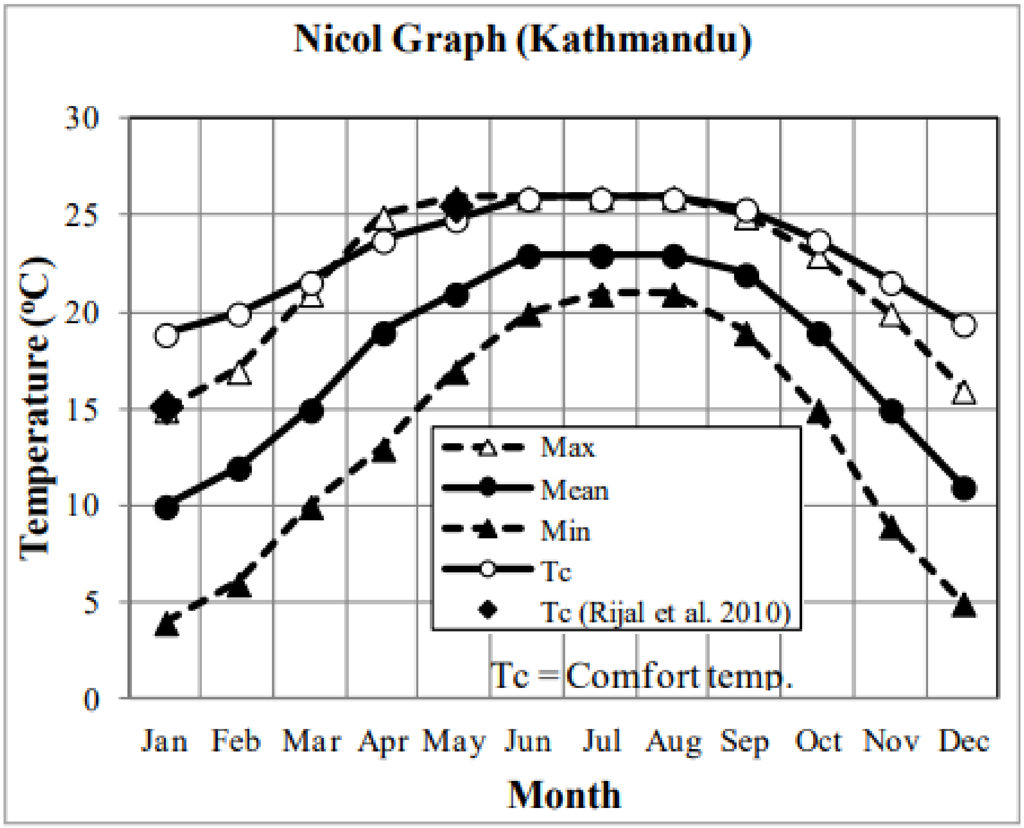


Figure 8: Thermal comfort temperature (Tc) and Outdoor air temperatures (Tout) for residential buildings of Kathmandu, Nepal (Bajracharya, 2014)

2.1.3 Challenges in Maintaining Thermal Comfort

There are many challenges in maintaining thermal comfort in Kathmandu Valley's residential buildings due to several factors like as mentioned below:

- **Climatic Extremes:** as per Collins and Hartley indicate the World Health Organization's (WHO) bedroom temperature limit of 16**°C**, because of a decreasing resistance to respiratory infections once below this temperature (Peeters et al., 2009). The study shows that both traditional and modern buildings struggle to provide adequate comfort during these periods without significant energy consumption.

- **Inadequate Building Design:** Due to the valley's climate, which experiences both hot summers and cold winters, thermal comfort in buildings is important but often neglected. Most residential buildings lack adequate insulation, making homes uncomfortable during extreme weather conditions and increasing energy consumption for heating (HT) and cooling (CL). Thermal comfort in residential buildings shows a strong dependency on weather data, more specifically on recent outdoor temperatures (Peeters et al., 2009).

- **Inadequate Space and Ventilation:** Overcrowding is another major issue due to Kathmandu's population density. Buildings are often constructed close together, reducing natural ventilation and sunlight. Poor ventilation increases health risks, especially in densely populated residential buildings where airflow is restricted.
- **Failure to Follow Building Codes:** While Nepal has building codes aimed improving construction quality and safety, enforcement remains inconsistent. Many homeowners and builders either lack awareness of these codes or choose to ignore them to cut costs, leading to the construction of unsafe or substandard buildings.

The study demonstrates that indoor thermal comfort in residential buildings in Kathmandu Valley is significantly influenced by both climatic conditions and building characteristics. Traditional homes, while offering some natural thermal regulation, often fail to provide adequate comfort during extreme weather. Modern buildings, though structurally advanced, frequently suffer from poor thermal performance due to inappropriate design choices. To achieve better thermal comfort in Kathmandu Valley, a balanced approach that integrates both passive and active design strategies while also considering energy efficiency is essential.

2.2 Emission

The phrase 'global warming' has become familiar to many people as one of the most important issues of our day. A more accurate but longer phrase to use is 'human induced climate change'. Methane and Carbon dioxide are the two main greenhouse gases responsible for climate change. These arise, for example when fuel is burnt to run a car or coal is burned to heat a building. Destroying forests and clearing land can also release carbon dioxide. Methane emissions are mainly produced by oil and gas industry and agriculture. Energy, manufacturing, transportation, construction, land use and agriculture are the main industries that emit GHG gases.(UNEP, 2023).

Buildings are a huge part of our daily lives, but they're also responsible for a big chunk of global carbon emissions. From the energy used to make construction materials to the power needed to heat and cool our homes, the impact adds up fast. The good news? By choosing energy-efficient and resource-efficient materials, we can cut down on emissions while making buildings more sustainable and cost-effective. Imagine a home that stays warm in winter and cool in summer without cranking up the heater or AC. That's what insulated concrete, high-performance glass, and reflective roofing can do. Materials like aerogels and vacuum-insulated panels provide even better insulation, reducing the need for energy-hungry heating and cooling systems. Plus, adding solar panels and energy-efficient lighting helps buildings rely more on clean energy instead of fossil fuels. Traditional building materials like cement and steel are major carbon culprits. But there are greener alternatives, like bamboo, reclaimed wood, and recycled steel, which require less energy to produce. Even concrete can be made eco-friendlier by replacing a portion of it with fly ash or geopolymer blends, significantly cutting emissions. By making smarter choices, buildings can use 30–50% less energy and slash their carbon footprint by up to 40%. That means lower energy bills, cleaner air, and a big step toward fighting climate change. More cities and businesses are embracing green building certifications like LEED and BREEAM, proving that sustainable construction isn't just good for the planet and it's good for people too. At the end of the day, the way we build shapes the future. Choosing energy-efficient, low-impact materials today means healthier homes, stronger communities, and a cleaner world for generations to come.

2.2.1 Net Zero Emission

Nepal has committed to achieving net-zero carbon emissions by 2045 as part of its efforts to combat climate change. This ambitious target, set in Nepal's Second Nationally Determined Contribution (NDC) under the Paris Agreement, aims to balance greenhouse gas emissions with carbon absorption, primarily through forest conservation and clean energy initiatives. As a country highly vulnerable to climate change, Nepal has prioritized sustainability by promoting hydropower, electric mobility, and reforestation. With over 40% of its land covered by forests, Nepal plays a crucial role in carbon sequestration. The government is also investing in renewable energy sources, particularly hydropower, to replace fossil fuels. By 2030, Nepal aims to increase the share of clean energy in its energy mix to 15% and ensure that 90% of all vehicles sold are electric by 2030. Challenges such as financial constraints, technological gaps, and dependency on imported fossil fuels remain. However, Nepal seeks international support, including climate finance and technology transfer, to meet its goal. If successful, Nepal's net-zero strategy will not only contribute to global climate efforts but also enhance energy security, reduce air pollution, and support sustainable economic growth.

The building sector plays a crucial role in Nepal's journey toward net-zero emissions. Energy-efficient building designs, green construction materials, and renewable energy integration are key strategies. The adoption of solar panels, improved insulation, and passive heating and cooling systems can significantly reduce energy consumption. The government is promoting green building codes and policies to ensure sustainability in new constructions. Retrofitting existing buildings with energy-efficient technologies will also help lower emissions. Encouraging the use of locally sourced, low-carbon materials and enhancing waste management in construction will further contribute to Nepal's climate goals while fostering a resilient and sustainable urban future.

2.2.2 Clean Development mechanism for Construction time Emission

The clean development mechanism (CDM) can be defined as component of the Kyoto Protocol that allows industrial countries to receive credits for helping developing countries to reduce their carbon emissions. CDM under the United Nation Framework Convention on Climate Change (UNFCCC) allows emission-reduction projects in developing countries to earn certified emission reduction (CER) credits, each equivalent to one tone of CO2. These CERs can be traded and sold, and used by industrialized countries to meet a part of their emission reduction targets under the Kyoto Protocol, 1997. The mechanism stimulates emission reductions and global sustainable development while giving industrialized countries some flexibility in how they meet their emission reduction limitation targets. This baseline emission and project emission value mainly differ based on the materials used during the construction period. For our study area, hollow brick has been used as construction materials for all 62 households, each of which have an approximate wall area of 400 m^2 and carpet area of 244 m^2 requiring a total of 12400000 bricks in.

CHAPTER THREE: APPROACH AND METHODOLOGY

3.1 Area of Research

Godawari Municipality lies at the center of Lalitpur District at central Nepal. The Municipality first established in 2014, has total area of 96.11 Sq. K.M. and population of 78310 (CBS,2021). The study area lies on ward no. 3 of the municipality has R.L. of around 1400 m. from MSL between 27.6°North latitude and 85.37°East longitude and hence can be categorized under the temperate bio-climatic regions. There are 62 identical buildings (housing) under construction by the Bhumi Developers, which are designed to make energy efficient using the best suited techniques for this climate. The building selected for analysis is facing Southwest and have occupancy of 5/6 members. The floor area of each building block is 244 sqm. The details of the project area are as shown in the figure below.

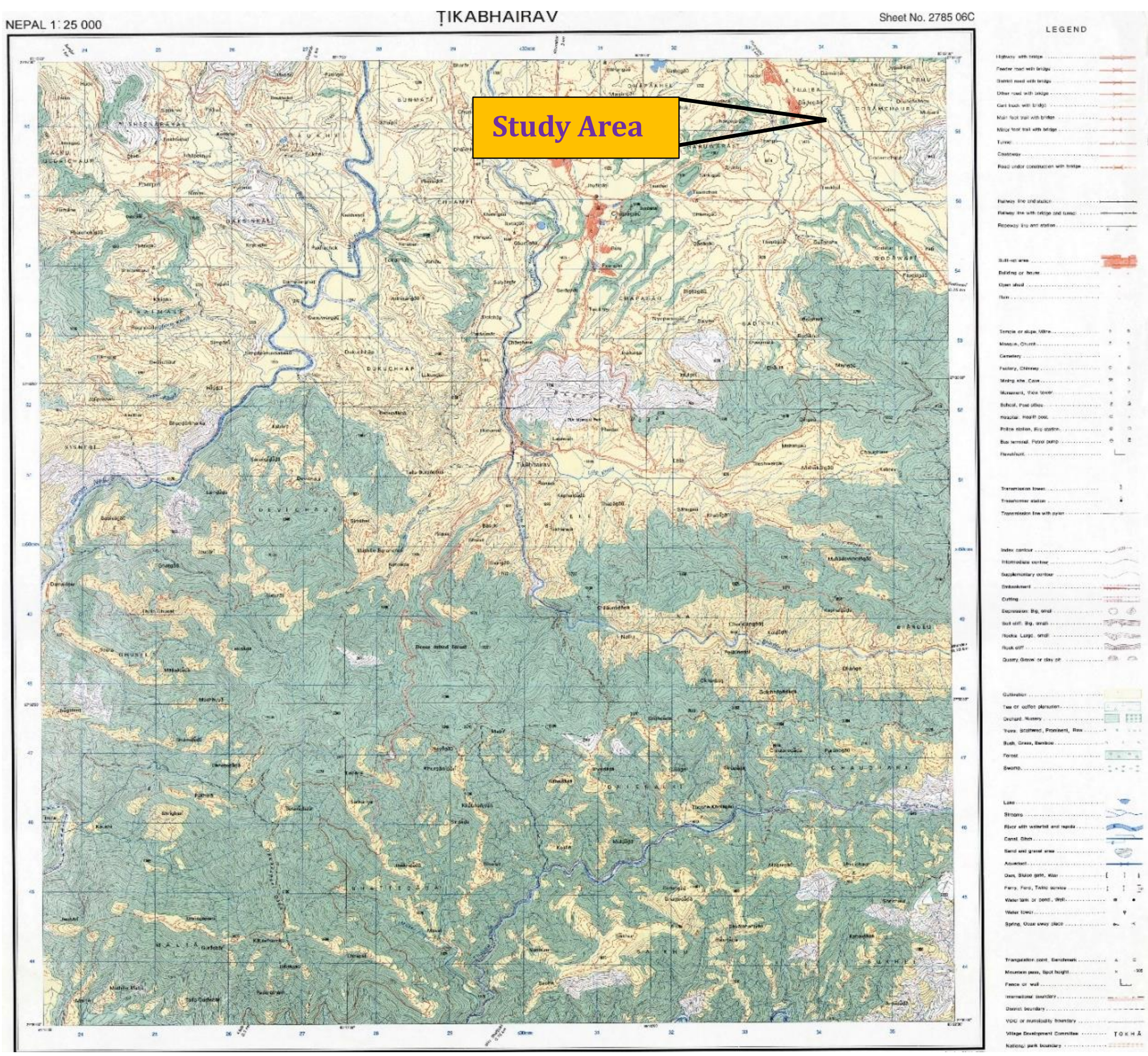


Figure 9: Topographic Map of Study Area

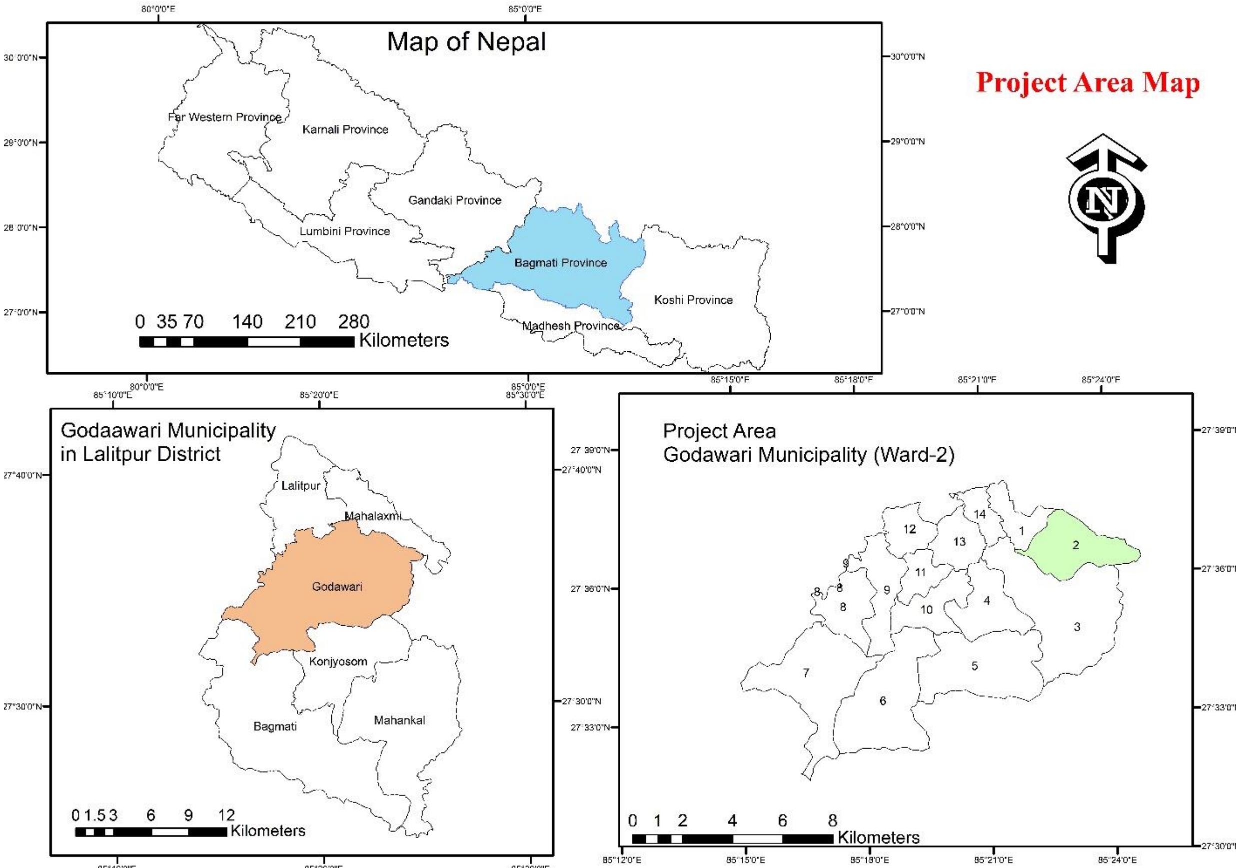


Figure 10: Location Map of Study Area

3.2 Research Approach

The research is for finding out the climate change resiliency of energy efficient building in the Godawari, Nepal. The study begins with extensive data collection, including meteorological records from local stations, building design details from Bhumi Developers, and global climate model (GCM) data download, bias correction based on observed DHM data and projections of corrected future weather data. Public surveys and in-situ measurement further enrich the dataset. Climate data has been processed using the Python script and R-Climdex for bias correction and future climate projections, which are then used as inputs for simulation tools. The energy-efficient building has modeled using Eco-tect 2011 software, incorporating real-world materials and projected climate conditions to evaluate energy demand and thermal performance. The most important impact categories, which should be considered during emission calculation in building's lifecycle are resource use, human health, and ecological considerations (K.C. et al., 2024). We have used emission calculator to calculate emission required to maintain thermal comfort and then compare that emission to conventional ones from literature review. Finally, the results are analyzed to identify environmental impacts, assess thermal comfort under future climate scenarios, and evaluate the resiliency of energy-efficient designs. This comprehensive approach ensures a thorough understanding of sustainable building practices in the context of climate change.

By recognizing that climate change and its effects on buildings are objective realities that can be measured and examined, this study takes a realist ontological position. The project, which is informed by a positivist epistemology, uses simulation tools, climate models, and empirical data to produce knowledge about energy-efficient buildings and their resilience to future climate scenarios. The validity and reproducibility of results are guaranteed by quantitative techniques such as thermal simulations and bias correction. The conceptual foundation of the research is further enhanced by the etymologies of important terms like sustainability (sustinere, to uphold), efficiency (efficientia, effective operation), and resilience (from the Latin resilire, to spring again). Together, these linguistic and philosophical foundations fortify the methodological approach and enable a thorough, data-driven assessment of climate change-resilient building techniques.

3.3 Research Methodology

The study follows a case study approach, integrating quantitative and qualitative analysis to assess environmental impacts across a building's lifespan for maintaining a building's thermal comfort. Primary data includes material inventories, energy consumption, and construction practices, while secondary data is gathered from literature and databases. The figure below presents a structured research methodology framework for assessing the climate change resiliency of energy-efficient residential buildings. The process starts with Survey & Data Collection, which includes field station measurements and literature review to gather baseline information. These inputs support simulation and observation, which aid in verifying the study's accuracy. Climate projections are integrated using General Circulation Models (GCMs) and processed through a weather data tool. The final step involves energy requirement and emission calculation. This structured approach enables data-driven insights into sustainable and resilient building designs. The findings guide sustainable building strategies for increased resilience.

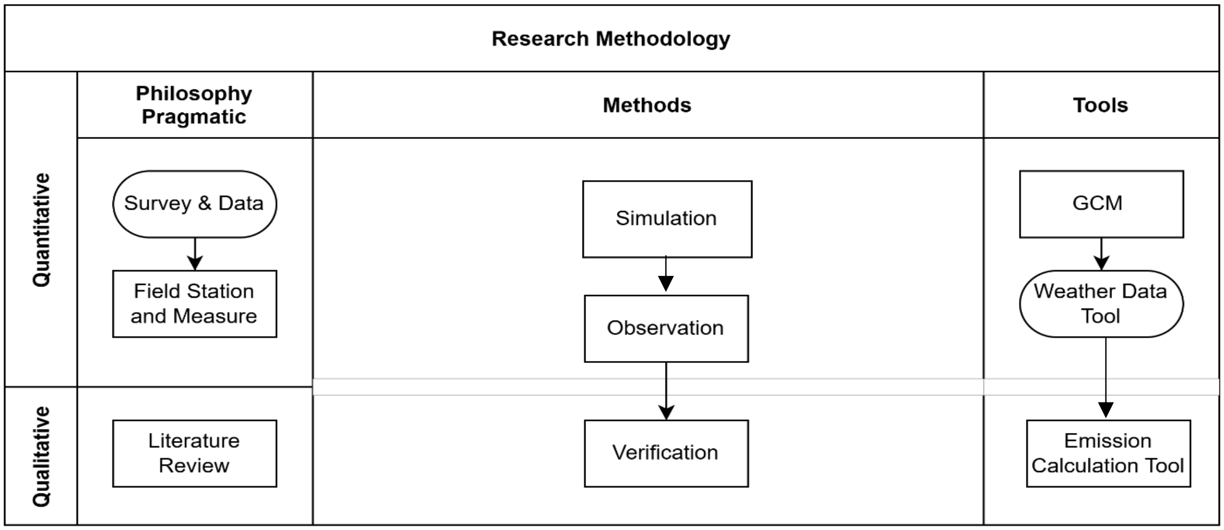


Figure 11: Flowchart of Research Methodology

The following Tools and techniques has been used to achieve the objectives by following the abovementioned methodologies.

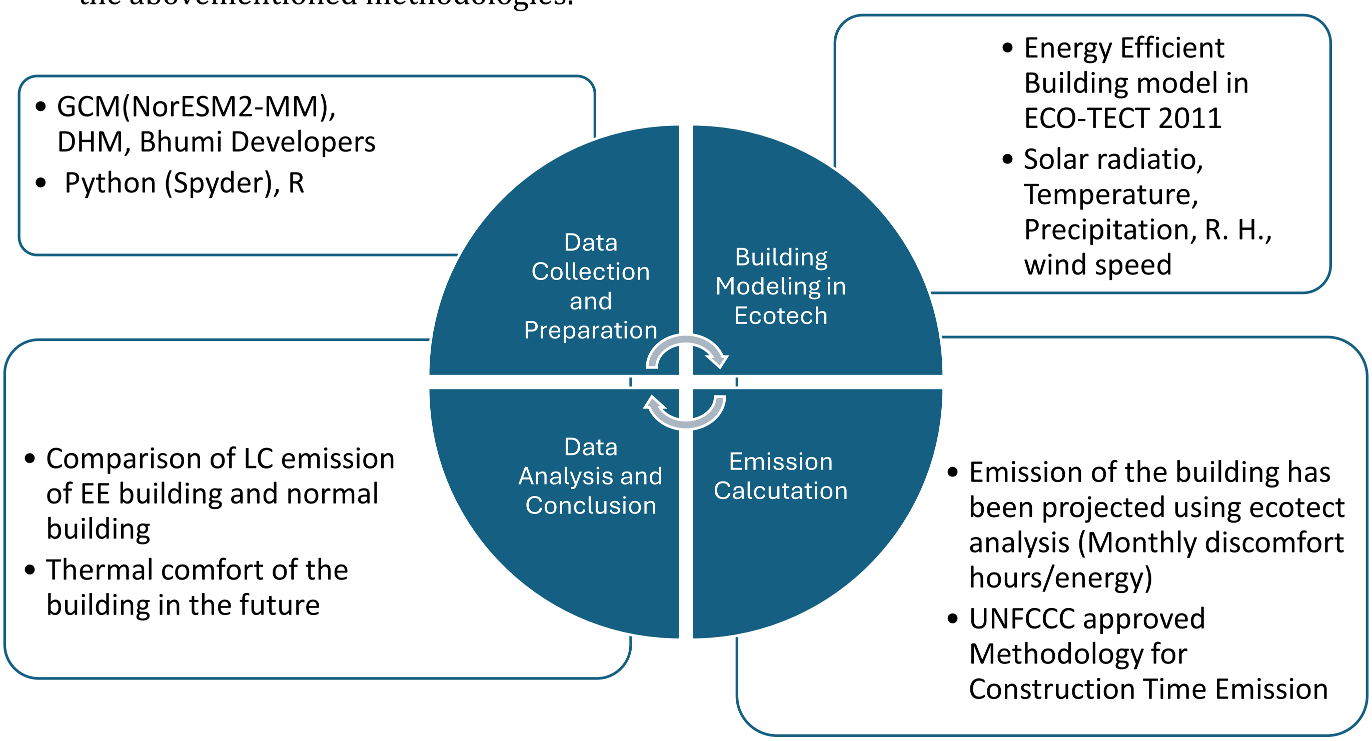


Figure 12: Research Tools and Techniques

3.3.1 Data Collection and Preparation of Weather data

The collection of data is one of the crucial stages in research. Bhumi Developers, the owner of the property, had provided the details of the building including the detailed design, technology used, and materials proposed to be used. The open source downscaled GCM data has been used from NASA earth exchange. Some questionnaire surveys for public perception and in field real data collection have been conducted in the study area for the result validation. Other required data during the research time has been used by the authorized source without violation of any national/international laws and rules. The proper handling of the data has been done through advanced software and modeling tools.

A. DHM Data

The meteorological data of stn. no. 1029 (Khumaltar) and 1030 (TIA) were purchased from the DHM, Climatology Section, Babarmahal Kathmandu, as these are the only nearby stations having most of the climate variables for climatic analysis required in this study. The following meteorological indicators has been analyzed from DHM.

1. Global solar radiation
2. Temperature
3. Precipitation (rainfall)
4. Relative Humidity
5. Wind speed

The following data were collected from the following metrological stations.

Table 2: DHM data Collection

S.N.	**Parameters**	**GCM Code**	**Station**		**Data Range**	**Remarks**
			1029 (Khumaltar)	1030 (TIA)		
1	Precipitation	ppt	Y	Y	1980-2014	
2	Minimum temperature	Tmin	Y	Y	1980-2014	
3	Maximum temperature	Tmax	Y	Y	1980-2014	
4	Relative Humidity	hurs	N	Y	2000-2008	
5	Global Solar radiation	srad	Y	N	2019-2025	
6	Wind Speed	Wspeed	Y	Y	2000-2008	

B. GCM Selection

Selecting the best General Circulation Model (GCM), requires evaluating models based on their ability to simulate regional climate patterns, topography, and historical data accuracy. Given Nepal's complex terrain and monsoonal influence, high-resolution models like CMIP6, MRI-AGCM, and RegCM are preferred. Bias correction techniques and downscaling methods enhance their reliability. GCMs should effectively capture temperature variations, precipitation extremes, and seasonal shifts crucial for water resources, agriculture, and disaster preparedness. Multi-model ensemble approaches improve predictions, reducing uncertainties. The selection must align with Nepal's climatic conditions to ensure accurate climate projections and informed policymaking.

Different GCM are suitable for analysis of different climate variables. Since thermal comfort which we particularly wanted to study has been largely based on the temperature, we focused on temperature and selected NorESM2-MM GCM for our analysis which has best GCM for thermal analysis in Tibet and Nepal also. (Raila et al., 2022; Shiru et al., 2022)

C. GCM Data Download

The NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6) dataset represents a significant advancement in climate modeling, providing high-resolution, bias-corrected climate projections that bridge the gap between coarse-scale global models and the need for local-scale climate impact studies. By leveraging the latest advancements in the Coupled Model Intercomparison Project Phase 6 (CMIP6) and applying the Bias-Correction Spatial Disaggregation (BCSD) methodology, this dataset enhances the accuracy and usability of climate projections for researchers and policymakers alike. One of the most crucial aspects of this dataset is its ability to support localized climate assessments, helping communities, urban planners, and environmental researchers anticipate future climate scenarios with greater precision. The dataset, covering multiple Shared Socioeconomic Pathways (SSPs), allows for comparative analyses of different emission trajectories, offering valuable insights into potential mitigation and adaptation strategies.

Despite its strengths, the dataset is not without limitations. The BCSD method assumes that past spatial climate patterns will remain consistent under future climate change, an assumption that may not fully capture the complexities of evolving climate systems. Additionally, while the dataset improves spatial resolution, it does not inherently correct trends within individual General Circulation Models (GCMs), meaning care must be taken when interpreting future projections. Looking forward, continued improvements in downscaling methodologies, enhanced observational datasets, and integration with emerging machine learning techniques could further refine the accuracy and applicability of downscaled climate data. As climate change accelerates, datasets like NEX-GDDP-CMIP6 will remain vital tools in climate research, enabling informed decision-making to address the challenges of a warming planet. For researchers and policymakers, the dataset stands as both a resource and a call to action an opportunity to use science to guide resilient and sustainable futures. (Thrasher et al., 2022)

Data analysis in the research proposal will involve collecting, processing, and interpreting data to uncover patterns and insights. The goal is to derive meaningful conclusions that support the research requirement, within scope and objective and contribute to the field's knowledge base. The following software tools have been employed to ensure accuracy and reliability along with other on-time statistical approaches. The SSP2:4.5 and SSP5:8.5 scenarios have been analyzed during the study. These models provide high-resolution data and have extensive user communities, making them ideal for detailed climate studies and projections in Nepal's diverse and complex topography. Furthermore, the weather data generated by such a method has been used to ecotect-2011 for calculating building energy requirements and thermal comfortability.

D. Bias Correction

Bias correction can be defined as the process of scaling climate model outputs to account for their systematic errors which improves their matching to real time observations by using different techniques (Zhang et al., 2024). Errors in climate models can be caused by a range of factors such as limited spatial resolution (large grid sizes), simplified thermodynamic processes and physics or incomplete understanding of the global climate system. The bias correction method Quantile mapping (QM) using Qmap package in R has been used in our research:

The Bias-Correction step “corrects” the bias of the GCM data through comparisons performed against the observed historical data of the respective station. For each climate variable in a given day, the algorithm generates the cumulative distribution function (CDF) for the GMFD data and for the retrospective GCM simulations, respectively, by pooling and sorting the corresponding source values (day of year +/- 15 days) over the period from 1980 through 2014. It then compares the two CDFs at various probability thresholds to establish a quantile map between the GCM data and the historical climate data. Based on this map, GCM values in any CDF quantile (e.g., p=90%) can be translated to corresponding GMFD values in the same CDF quantile. Assuming that the CDF of the GCM simulations is stable across the retrospective and the prospective periods, to “correct” the projected future climate variations the algorithm simply looks up the probability quantile associated with the predicted climate values from the estimated GCM CDF, identifies the corresponding observed climate values at the same probability quantile in the GMFD, CDF, and then accepts the latter as the adjusted climate predictions. The climate projections adjusted in this way have the same CDF as the observed historical data; therefore, the possible biases in the statistical structure (the variance, in particular) of the original GCM outputs are removed by this procedure. At the end of the Bias-Correction step, the previously extracted temperature climate trends are added back to the adjusted GCM climate fields. The bias-corrected value of different parameters for the baseline period from the selected GCM has been compared with the observed DHM data of station number 1029 and 1030 to evaluate the performance metrics RMSE, PBIAS, and NSE from which bias corrected value has been calculated for each variable (Dawadi et al., 2022).

2. RMSE (Root Mean Square Error):

RMSE measures the average magnitude of error between predicted and observed values. It squares the errors, averages them, and then takes the square root, emphasizing larger errors. It is widely used to evaluate model performance, with lower values indicating better accuracy and predictive reliability.

$$\mathbf{RMSE = \sqrt{[\ (1/n) \times \Sigma(P_i - O_i)^2\ ]}}$$

Where:

Pi = predicted value

Oi= observed value

n = number of observations

3. 2. PBIAS (Percent Bias):

PBIAS quantifies the average tendency of predicted values to be larger or smaller than observed data. It expresses model bias as a percentage, helping assess over- or underestimation. Negative values indicate overestimation, while positive values suggest underestimation. An ideal PBIAS is close to zero.

Mathematically,

$$\mathbf{PBIAS = 100 \times [\ \Sigma(P_i - O_i)\ /\ \Sigma O_i\ ]}$$

Where:

P_i= predicted value

O_i= observed value

4. NSE (Nash–Sutcliffe Efficiency):

NSE evaluates predictive skill by comparing observed and simulated data variance. It ranges from ∞ to 1, with 1 being perfect agreement. Values above 0.5 generally indicate acceptable model performance. NSE emphasizes how well a model captures variability relative to the means of observed data. This can be presented as:

$$\mathbf{NSE = 1 - [\ \Sigma(O_i - P_i)^2\ /\ \Sigma(O_i - \bar{O})^2\ ]}$$

where,

P_i= predicted value

O_i= observed value

O^- = mean of observed values

E. Preparation of Weather Data

The bias corrected data has been used to prepare the weather data in the format that is acceptable in ecotect-2011. The values for the parameters that has been extracted from GCM (i.e. Tmax, Tmin, RH, Wspeed, Solar Radiation and precipitation) and their dependent parameters have been calculated for each days and used in hourly weather data format but the other parameters value have been used from standard weather file of Kathmandu for the thermal analysis.

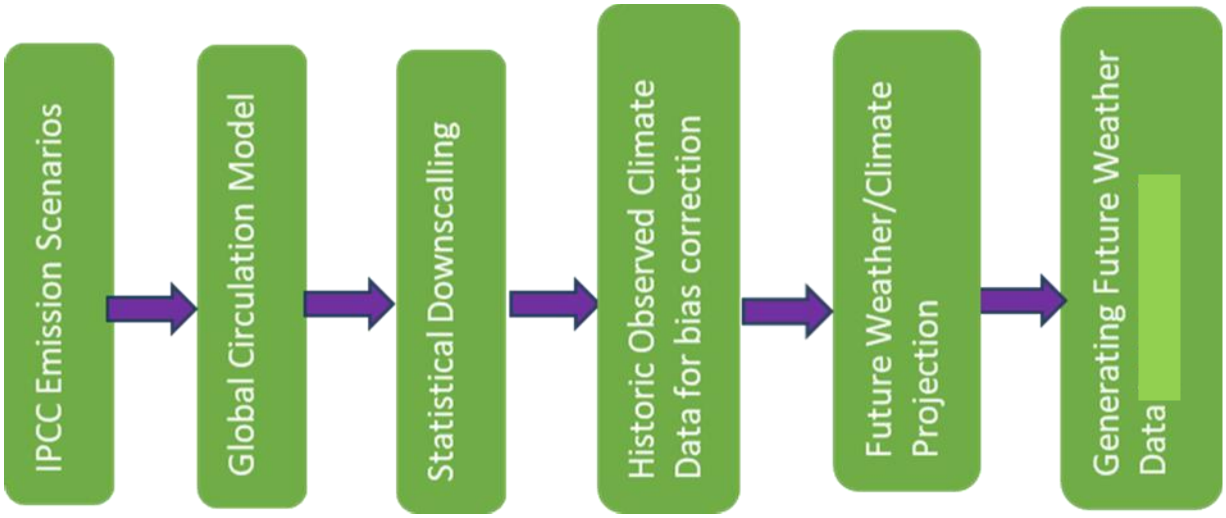


Figure 13: Process of future weather data generation

3.3.2 Building Modeling in ECO-TECT

Eco-tect 2011, a powerful building performance simulation software, facilitates this assessment by analyzing various parameters such as energy consumption, material usage, and emissions. Autodesk Ecotect Analysis is a building environment analysis tool that allows designers to simulate building performance while designing performance while designing a building. It analyses and interacts with the building function. It gives the options to choose various materials and finishes with varying properties. Using Eco-tect 2011, we can model energy-efficient buildings to optimize design for reduced energy use and lower greenhouse gas emissions. The software allows for detailed simulations of different building materials and systems, providing insights into their environmental impacts over the building's lifecycle. By providing different weather data predicted from GCM model during design process, Eco-tect 2011 provides the heatmap of the building which already has minimum environmental footprint and maximum energy efficiency. This approach provides thermal comfort for the energy-efficient buildings due to various weather data input.

The buildings used for modeling have following salient fractures.

Table 3: Salient Features of the Modeled Building

Parameters	Normal building	Energy Efficient Building
Purpose of Building	Residential	Residential
Location	Godawori, Lalitpur	Godawari, Lalitpur
Co-ordinate	27.6N, 85.4 E	27.6N, 85.4 E
MSL height (m.)	1456 m.	1456 m.
Orientation/Facing	Southwest (-130° N)	Southwest (-130° N)
Plinth Area	169 Sqm.	169 Sqm.
Total Carpet Area	244 Sqm.	244 Sqm.
Total Floor Area for thermal analysis	442.257 Sqm.	442.257 Sqm.
No of. Zone	14	14
Total Zone Area	1926.644 Sqm.	1926.644 Sqm.
Total Zone Volume	617.818 cum	617.818 cum
Total Window Area	54 Sqm.	54 Sqm.
Wall construction materials	**Normal Brick**	**Hollow Brick with 15% less mass and volume than normal brick**
Windows materials	**Single glazed aluminum framed window**	**Double glazed (5 mm. argon filled) aluminum framed window**
Ceiling Materials	**Plaster and normal tile**	**Plaster, tile and CRI paints**
No. of people	6	6
External Wall Thickness	230 mm.	230 mm.
Internal wall thickness	115 mm.	115 mm.
No. of storey	2.5	2.5
Ventilation and HVAC (95% efficiency)	Mixed Model System	Mixed Model System

Clothing factor	1.5	1.5
Relative Humidity	60%	60%
Thermal Comfort Band	15∘C-26∘C	15∘C -26∘C
Air Speed	0.5 m/s	0.5 m/s
Operation Hours of each zone	10-24 Hrs.	10-24 Hrs.
Lighting Indes	300 lux	300 lux

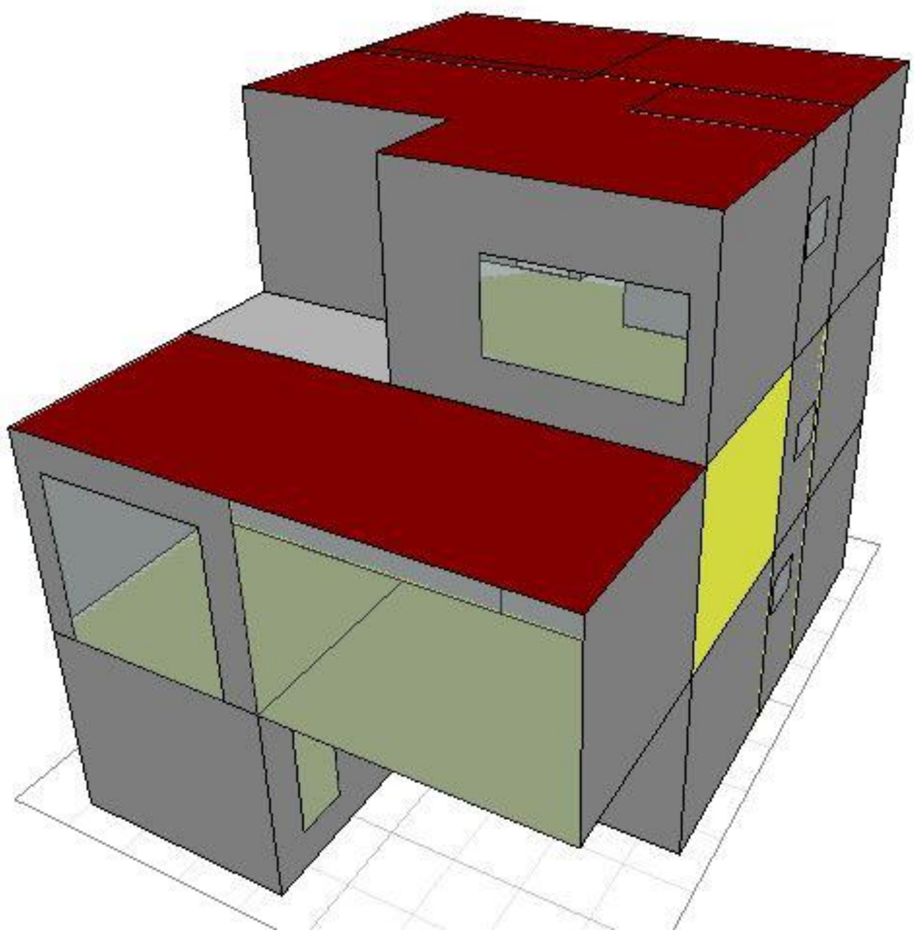


Figure 14: EE Building Model in Ecotech

3.3.3 Emission Calculation from Heating and Cooling

Emission calculators have been used to calculate the emission from the external energy in the building. The energy demand to maintain thermal comfort in ecotect 2011, assuming mixed HVAC system (95% efficiency) have been calculated and then the energy has been converted to the emission based on type of fuel used in Nepal and their emission coefficient. The software provides a comprehensive set of features, allowing users to input data, perform impact assessments, and generate reports. For our research, it has been assumed that electricity induced in Nepal is sole fuel source used for heating and cooling which have emission coefficient of 64.98 gCO2-eq/ kWh (K.C. et al., 2024).

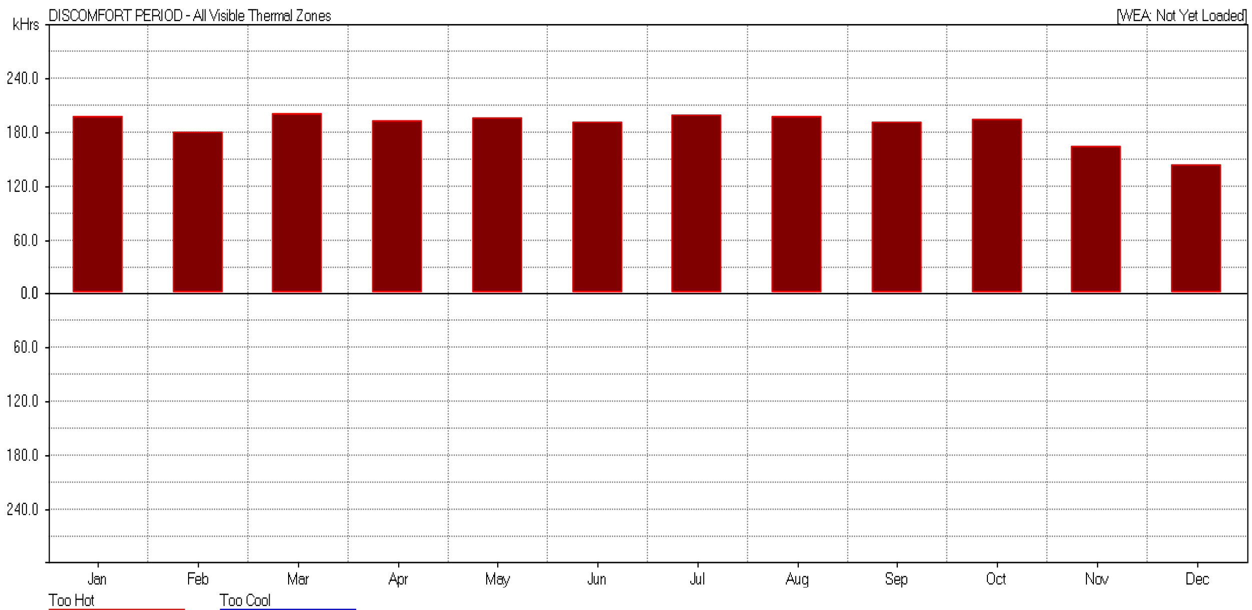


Figure 15: Sample of Monthly Energy Requirement to maintain thermal comfort in Ecotect

3.3.4 Construction Time Emission Calculation

The methodology was chosen as per the guidelines of UNFCCC clean development mechanism (CDM Methodology booklet, 14th edition, 2022). The methodology adopted for this project is AMS-III.Z which is small scale methodology for Fuel Switch, process improvement and energy efficiency in brick manufacture.

Baseline emission and Project emission:

The baseline emissions are the fossil fuel and NRB consumption related emissions associated with the system(s), which were or would have otherwise been used, in the brick production facilities in the absence of the project activity. For projects involving the installation of systems in a new facility or a capacity addition in an existing system, the average annual baseline fossil fuel consumption value and the baseline brick production rate shall be determined as that which would have been consumed and produced, respectively, under an appropriate baseline scenario. The baseline emission in this project was calculated as follows:

$$[BE]_y = [[SEC]_{BL} \times EF]_{BL} \times P_{(PJ,y)}$$

Where:

$[BE]_y$ =The baseline emissions from fossil fuels or NRB displaced by the project activity in t CO_2e in project period

$[SEC]_{BL}$=Specific energy consumption of brick production in the baseline, TJ per unit volume or mass unit (kg or m^3)

$[EF]_{BL}$ = The emission factor of baseline fuel(s), in t CO_2/TJ

$P_{(PJ,y)}$ = The net production of the facility in year y, in kg or m^3

Project Emission:

The project emissions is calculated as follows:

$$[PE]_y=[PE]_{(elec,y)}+[PE]_{(fuel,y)}+[PE]_{(cultivation,y)}+[PE]_{(CH_4,y)}$$

Where:

$[PE]_y$ = Project emissions in year y (t CO_2)

$[PE]_{(elec,y)}$ = Project emissions due to electricity consumption in year y (t CO_2)

$[PE]_{(fuel,y)}$ = Project emissions due to fossil fuel or NRB consumption in year y (t CO_2)

$[PE]_{(cultivation,y)}$ = Project emissions from cultivation of biomass in a dedicated plantation in year y (t CO_2e)

$[PE]_{(CH_4,y)}$ = Project emissions due to the production of charcoal in kilns not equipped with a methane recovery and destruction facility in year y (t CO_2e)

We have analyzed normal brick, hollow brick (15% hole) (Central material testing lab, IOE, 2079), stone and CSEB as the different construction materials.

3.3.5 Data Analysis

Data analysis involves systematically processing collected information to identify patterns, trends, and relationships. It includes data cleaning, normalization, and statistical analysis to ensure accuracy and reliability. Descriptive statistics summarize key variables, while inferential analysis explores correlations and predictions. Advanced techniques like bias correction, time series analysis, and regression modeling help refine projections. Simulation tools and machine learning algorithms enhance predictive accuracy, particularly in climate-related studies. Data visualization through graphs and charts aids interpretation. The process ensures informed decision-making, validating research findings and supporting evidence-based conclusions for sustainable solutions in various fields, including climate resilience and energy efficiency.

Table 4: DHM Data Availability

S. N.	Parameters	GCM Code	Station		Past Data Range	Remarks
			1029 (Khumaltar)	1030 (TIA)		
1	Precipitation	ppt	Y	Y	1980-2014	
2	Minimum temperature	Tmin	Y	Y	1980-2014	
3	Maximum temperature	Tmax	Y	Y	1980-2014	
4	Relative Humidity	hurs	N	Y	2000-2008	
5	Global Solar radition	srad	Y	N	2019-2025	
6	Wind Speed	Wspeed	Y	Y	2000-2008	

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Bias Correction Outputs

The bias correction results using the script in R has represented in the graph as shown below. These graphs present the results of bias correction applied to climate data, adjusting systematic errors in raw model outputs. It compares observed and corrected values, ensuring more accurate climate projections. The corrected dataset aligns closely with observed data, improving reliability for future climate simulations and impact assessments. The following variables were analyzed from the following meteorological stations.

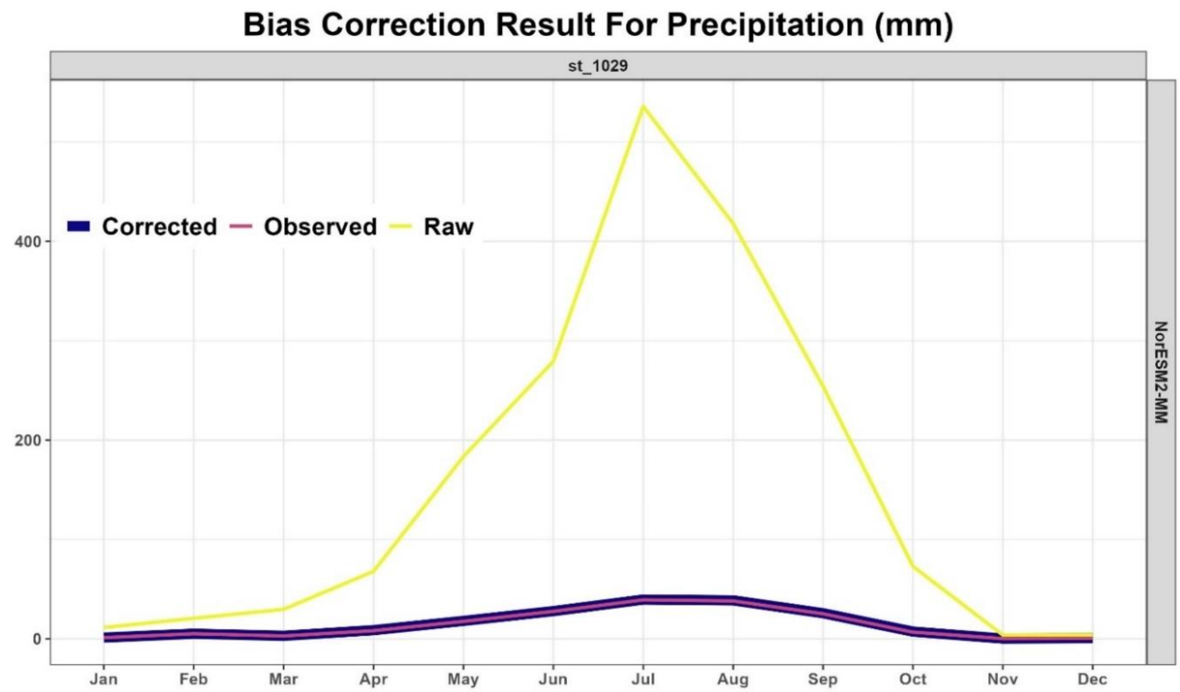
The statistical indicators (NSE, PBIAS, and R2) at two stations (st_1029 and st_1030) are compared in the table before and after correction for several climate factors (PPT, RADS, RH, Tmax, and Tmin). Following adjustment, notable gains are seen, with PBIAS nearing zero and NSE values rising to 1 from extremely negative values (e.g., -229.31 for precipitation at st_1029), indicating less bias. In general, R2 values increase to 1, indicating stronger association. All things considered, the adjustment significantly improves model performance and data reliability, which are essential for evaluations and studies pertaining to climate change.

Table 5: Summary of Bias Correction

S.N.	Statistical indicator	Pre-Correction	Post-Correction	Station	Variables
1	NSE	-229.31	1	st_1029	PPT
2	PBIAS	-993.33	-2	st_1029	PPT
3	R2	0.97	1	st_1029	PPT
4	NSE	0.81	0.98	st_1030	PPT
5	PBIAS	-24.35	-9.47	st_1030	PPT
6	R2	0.99	0.99	st_1030	PPT
7	NSE	-7.44	1	st_1029	RADS
8	PBIAS	-37.69	0.05	st_1029	RADS
9	R2	0.72	1	st_1029	RADS
10	NSE	-0.77	1	st_1030	RH
11	PBIAS	-1.41	0.08	st_1030	RH
12	R2	0.43	1	st_1030	RH
13	NSE	0.42	1	st_1030	Tmax
14	PBIAS	10.21	0.01	st_1030	Tmax
15	R2	0.98	1	st_1030	Tmax

4.1.1 Precipitation (ppt)

The precipitation trend graph illustrates variations in rainfall patterns over time, comparing historical observations with projected values under different climate scenarios. It highlights seasonal fluctuations, extreme rainfall events, and long-term changes. Increasing or erratic rainfall trends suggest potential risks such as flooding or water scarcity, impacting building design and water management strategies for resilient infrastructure.



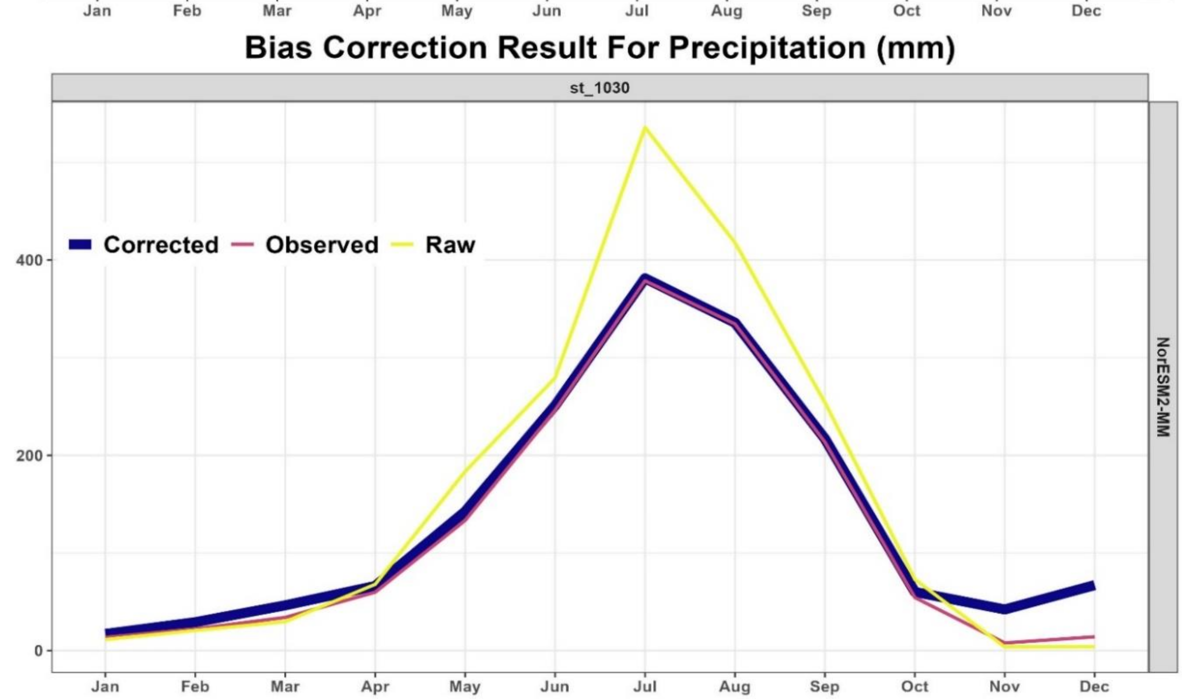
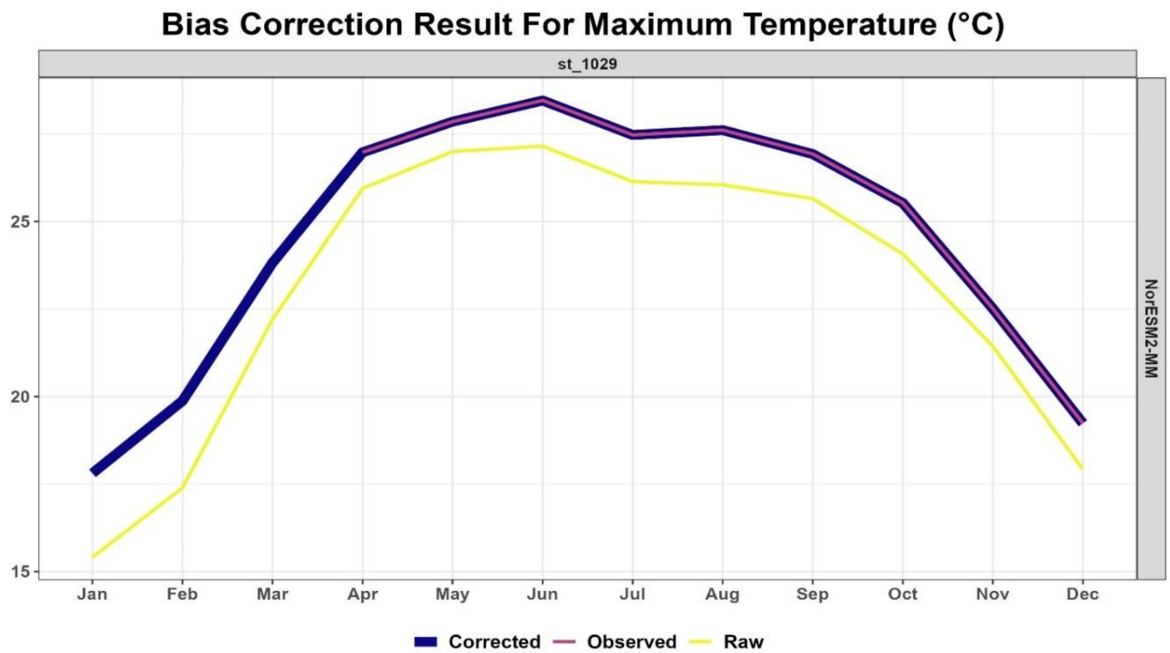


Figure 16: Bias Correction Result for Precipitation

4.1.2 Maximum Temperature (Tmax)

The Tmax trend graph displays the long-term variation in maximum daily temperatures, indicating potential heat stress on buildings and urban environments. A rising Tmax trend suggests increased cooling demand and possible material degradation due to prolonged exposure to high temperatures. This trend emphasizes the importance of heat-resistant construction materials and energy-efficient cooling strategies.



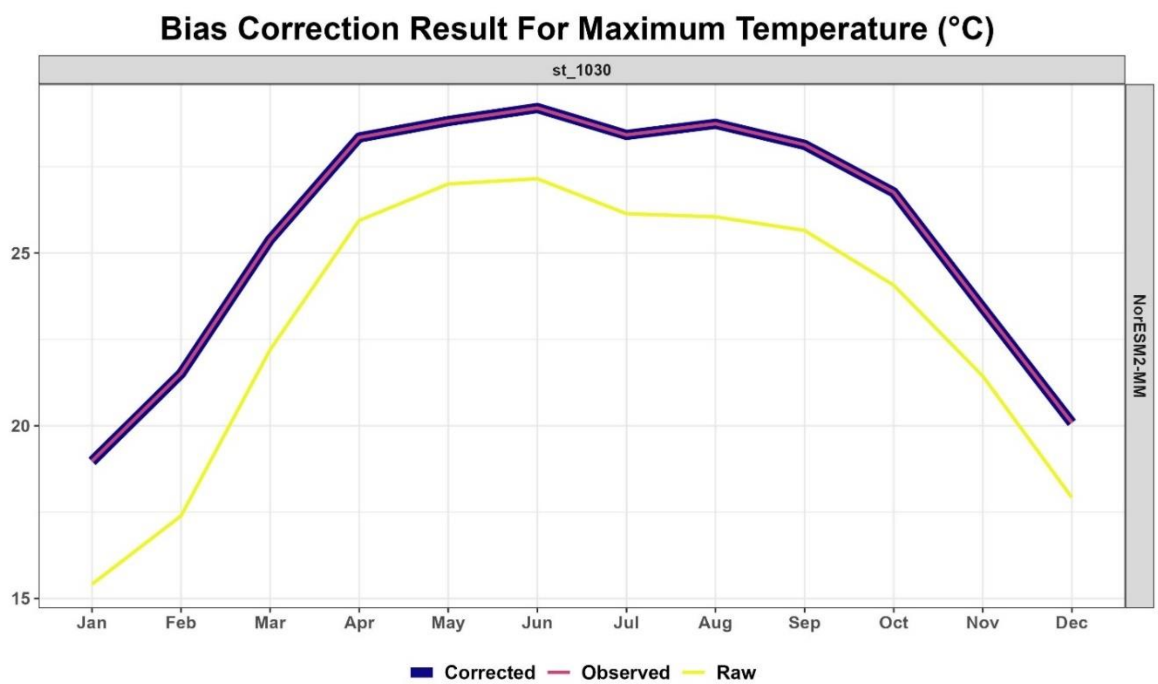


Figure 17: Bias Corrected Result for Tmax.

4.1.3 Minimum Temperature (Tmin)

This graph shows the variation in minimum daily temperatures over different periods. An increasing trend suggests warmer nights due to climate change, which can impact energy consumption for cooling and thermal comfort. Understanding Tmin trends is crucial for designing buildings with passive cooling strategies, insulation, and ventilation to enhance indoor comfort while reducing energy demand.

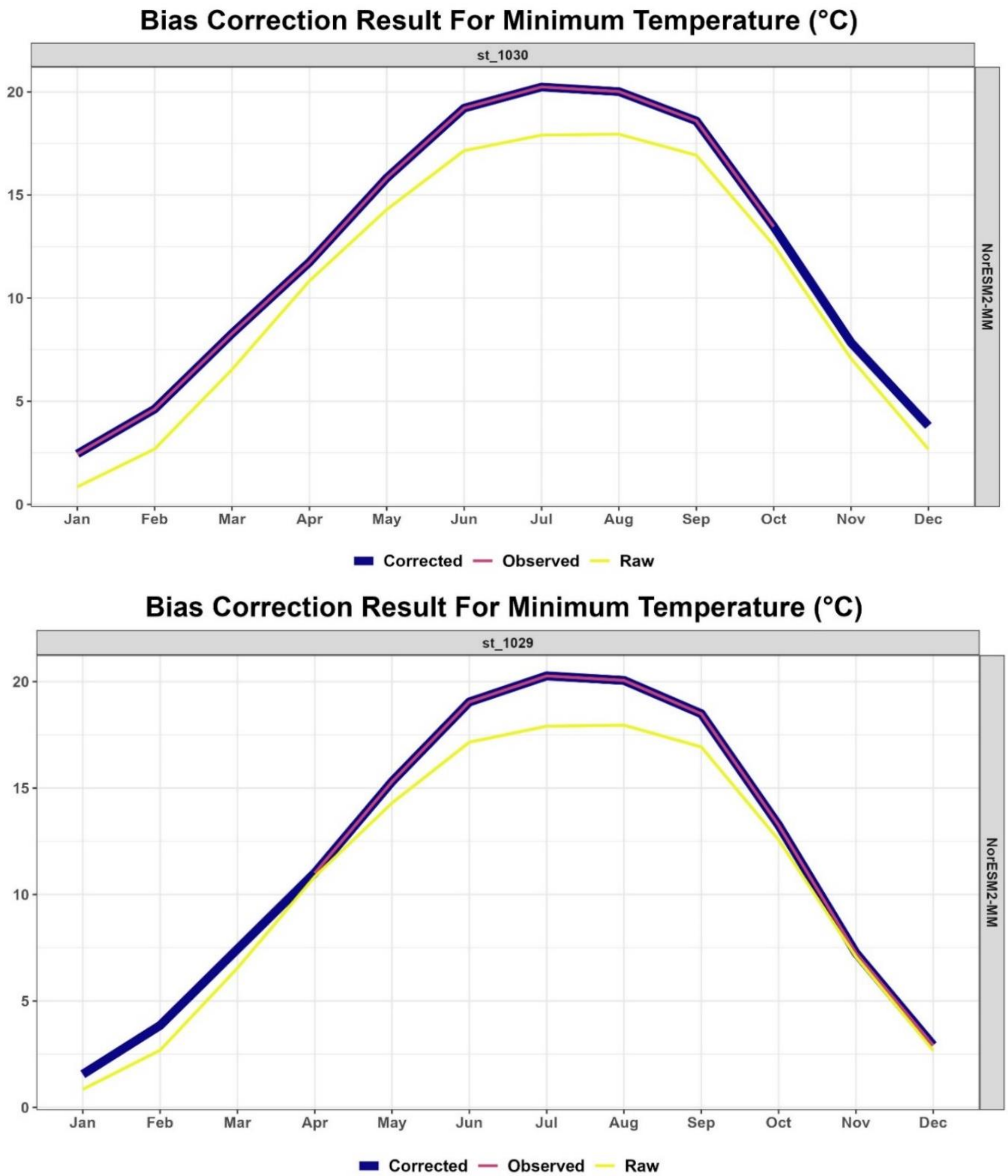


Figure 18: Bias Corrected Graph for Tmin

4.1.4 Wind Speed (Wspeed)

The wind speed graph highlights variations in wind patterns, which influence building ventilation, energy efficiency, and structural integrity. Changes in wind speed may impact natural ventilation strategies and wind energy potential. Higher wind speeds may also require reinforced structural designs to withstand increased aerodynamic loads on buildings.

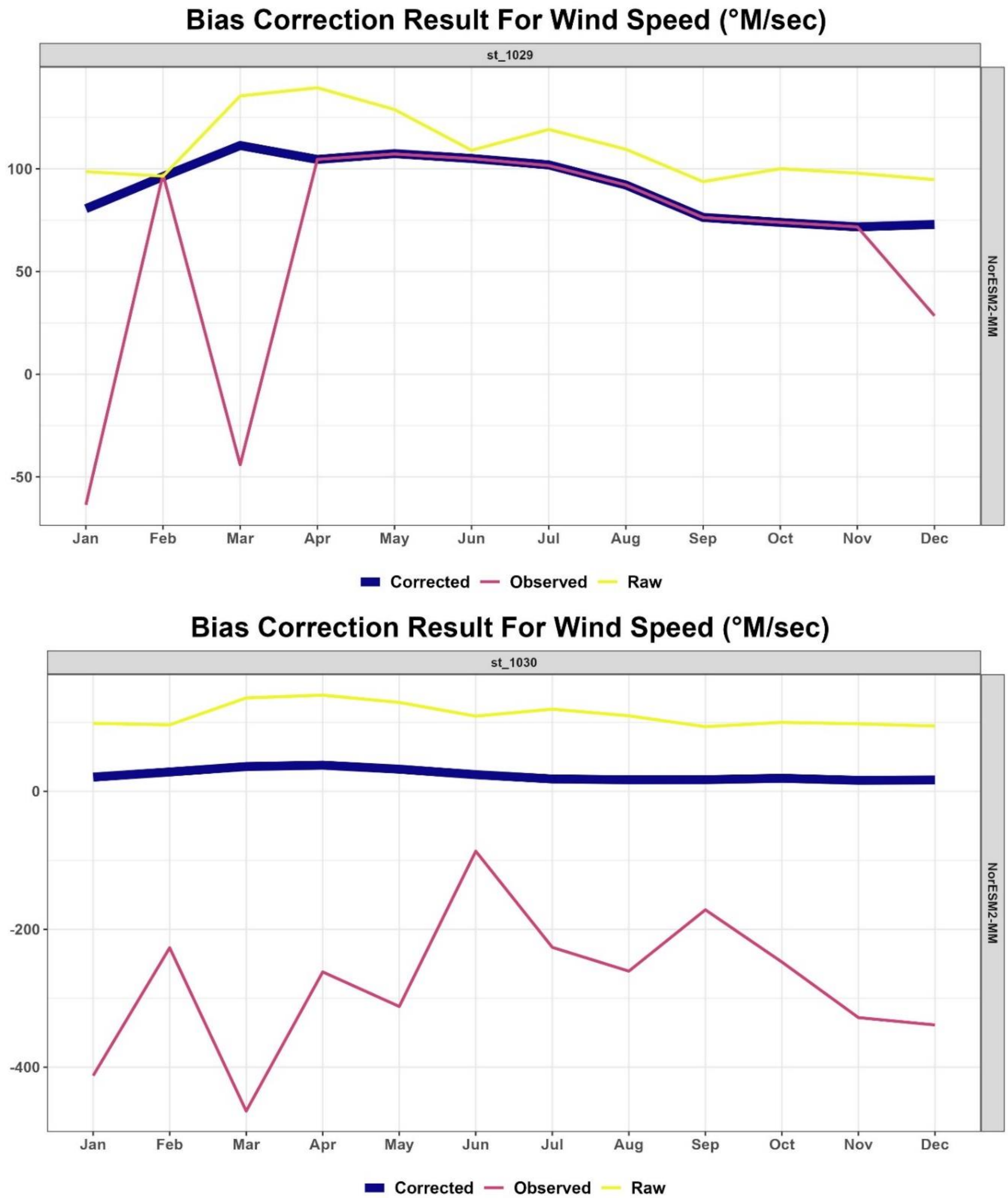


Figure 19: Bias Corrected Graph for Wspeed

4.1.5 Relative Humidity (R.H.)

This graph presents the trend of relative humidity (RH) over time, showing seasonal and long-term variations. A rising RH trend can contribute to mold growth, reduced air quality, and increased discomfort in buildings. Conversely, decreasing RH levels may lead to drier conditions, affecting occupant comfort. Understanding RH trends helps in optimizing HVAC systems for indoor climate control.

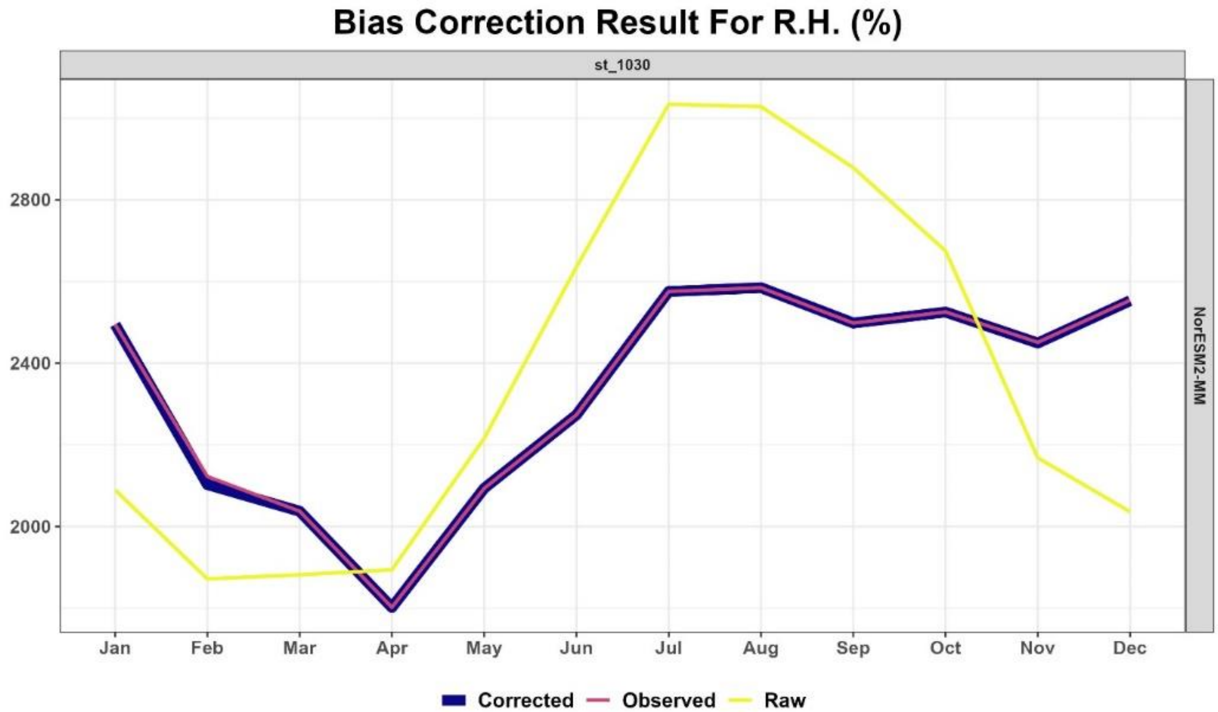


Figure 20: Bias Corrected Graph for R.H.

4.1.6 Global Solar radiation (Rads)

This graph shows the trend of solar radiation over time, influencing the potential for passive solar heating and photovoltaic energy generation. Increasing solar radiation trends may enhance solar energy utilization, supporting sustainable energy solutions. Conversely, lower radiation levels could affect solar power efficiency, emphasizing the need for advanced solar panel technologies and positioning strategies.

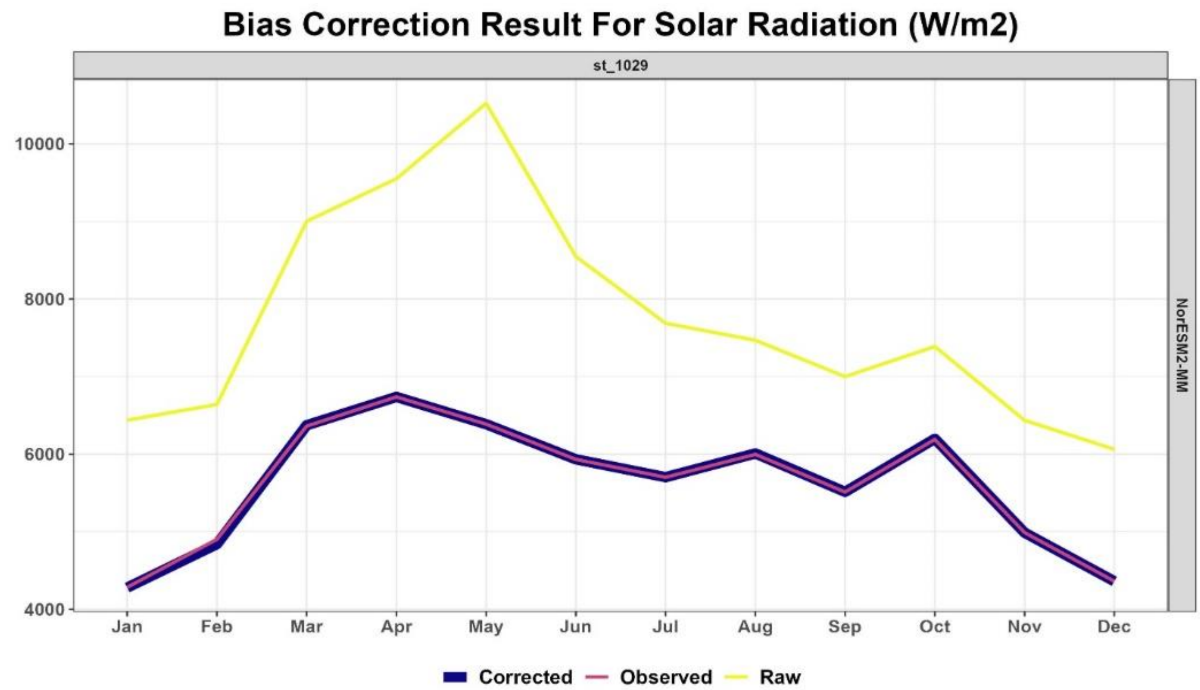


Figure 21: Bias Corrected Graph for Rads

4.2 Climate Variables Projection

4.2.1 Maximum Temperature (Tmax.)

The graph shows the projected trend of maximum temperature (tmax) under the SSP5-8.5 scenario from 2025 to 2075 for two stations: st_1029 and st_1030. Both stations exhibit a clear upward trend in tmax values, indicating a steady rise in future temperatures. Station st_1030 consistently records higher tmax than st_1029, with values rising from around 27°C to over 29°C. Station st_1029 increases from about 24.5°C to 27.5°C. This trend highlights the intensifying heat conditions expected in the future, reinforcing the urgency for climate-resilient building and urban planning strategies.

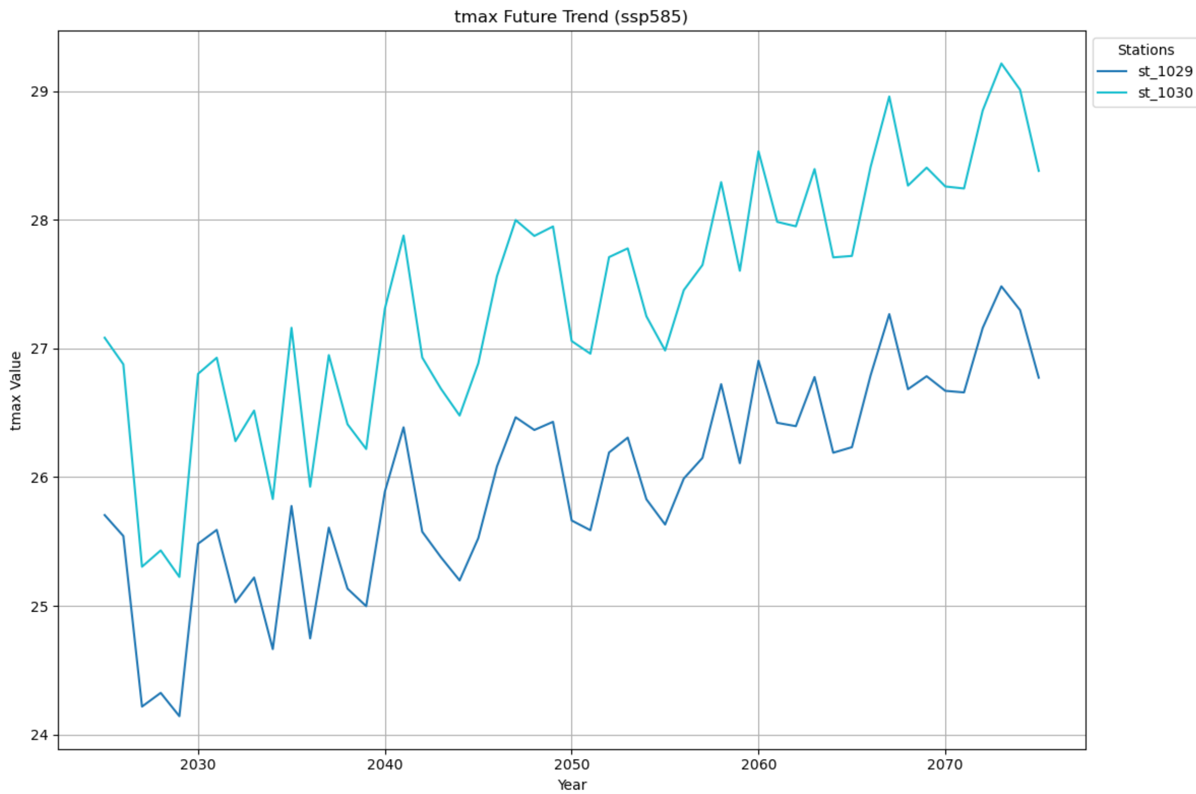


Figure 22: Trend of Max. Temperature in Future as per SSP585

4.2.2 Minimum Temperature (Tmin.)

The graph shows the future trend of minimum temperature (tmin) under the SSP585 scenario for two stations (st_1029 and st_1030). From 2025 to 2075, both stations exhibit a clear upward trend in tmin values, indicating a gradual warming. Station st_1030 consistently shows slightly higher temperatures than st_1029. Seasonal or interannual fluctuations are observed, but the overall trajectory is a steady increase. This suggests a significant rise in minimum temperatures in the future under high-emission scenarios, contributing to climate warming impacts.

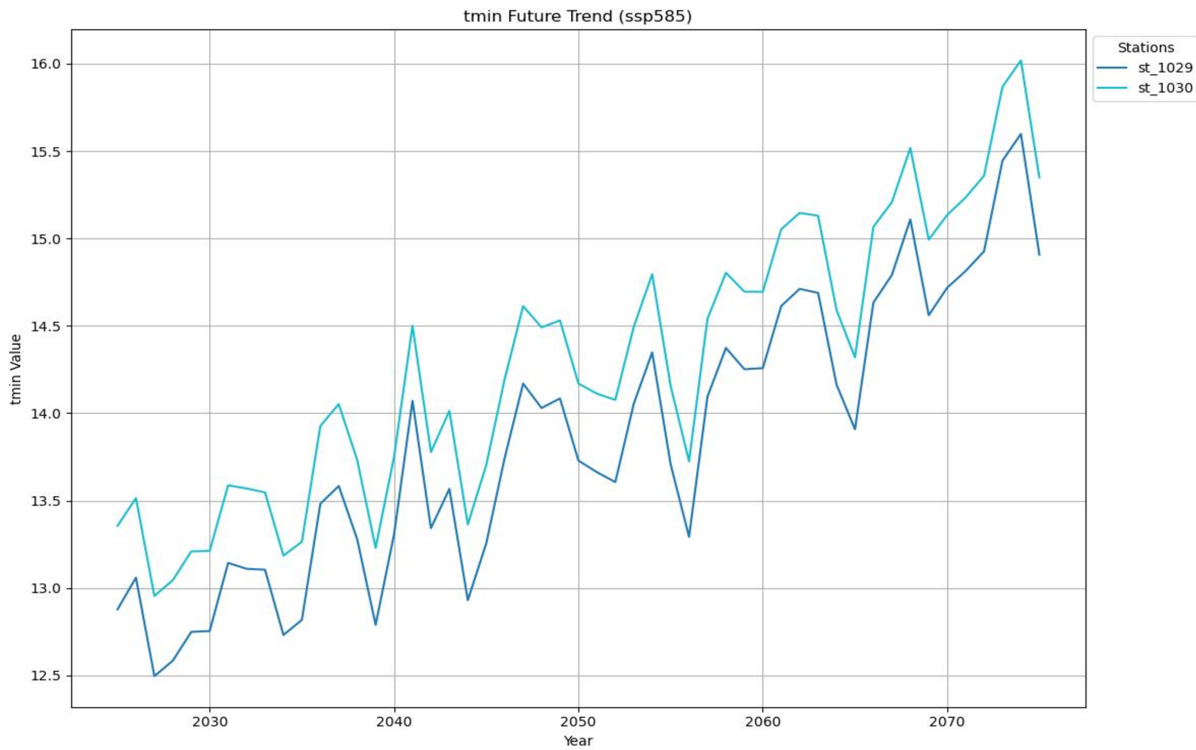


Figure 23: Trend of Minimum Temperature in Future as per SSP585

4.2.3 Relative Humidity (RH)

The graph illustrates the projected future trend of relative humidity (RH) under the SSP5-8.5 climate scenario from 2025 to 2075 at station st_1030. RH values fluctuate significantly over the decades, showing high interannual variability. Peaks above 81% are observed around 2030 and 2040, while notable drops occur below 75% around 2045 and 2060. Despite short-term fluctuations, the overall RH trend remains relatively stable, fluctuating between 75% and 82%, suggesting a persistent humid climate with varying intensities over time.

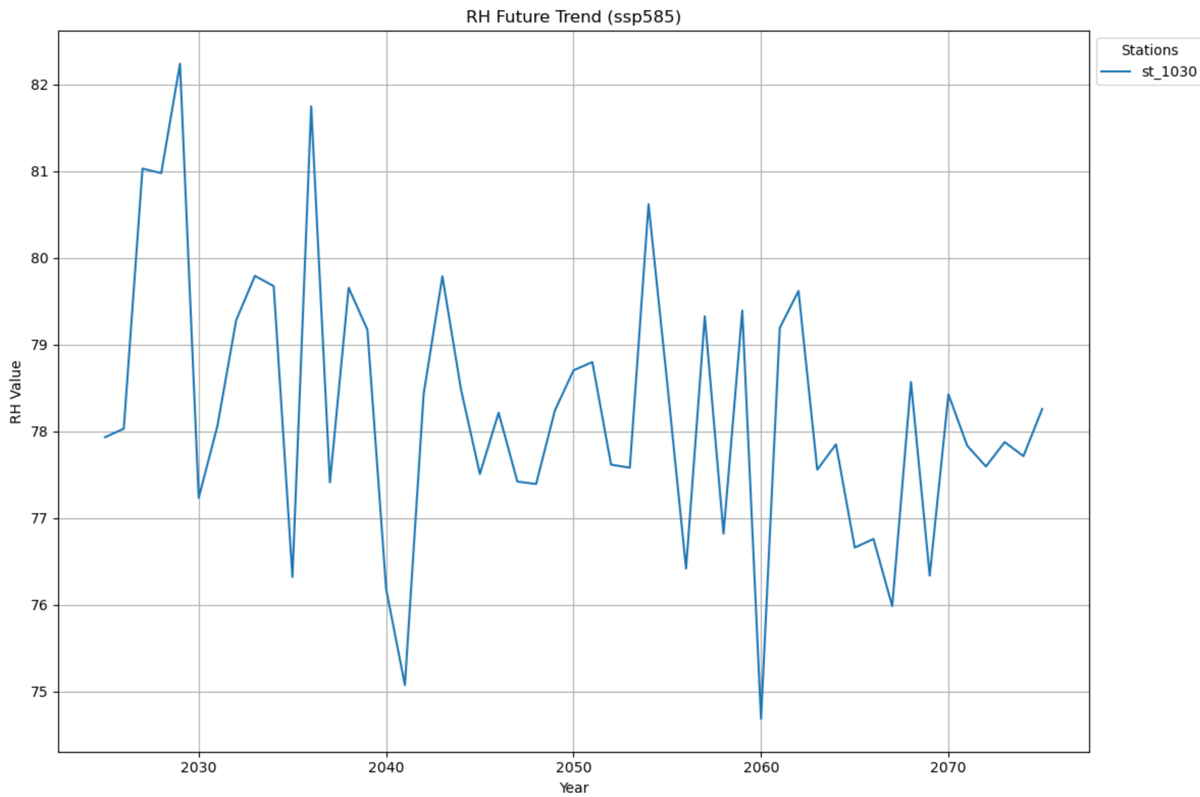


Figure 24: Trend of Relative Humidity in Future as per SSP585

4.3 Building Model

Autodesk Ecotect is a powerful building performance analysis software used for thermal and energy simulations. It allowed architects and engineers to assess a building's energy efficiency by analyzing solar radiation, thermal comfort, shading, and ventilation. The software enabled users to create 3D models and simulate heat gain/loss, daylighting, and HVAC performance. Ecotect integrated with tools like Autodesk Revit, Archicad and EnergyPlus for more detailed simulations. Such simulations are crucial for optimizing building designs to enhance energy efficiency and sustainability.

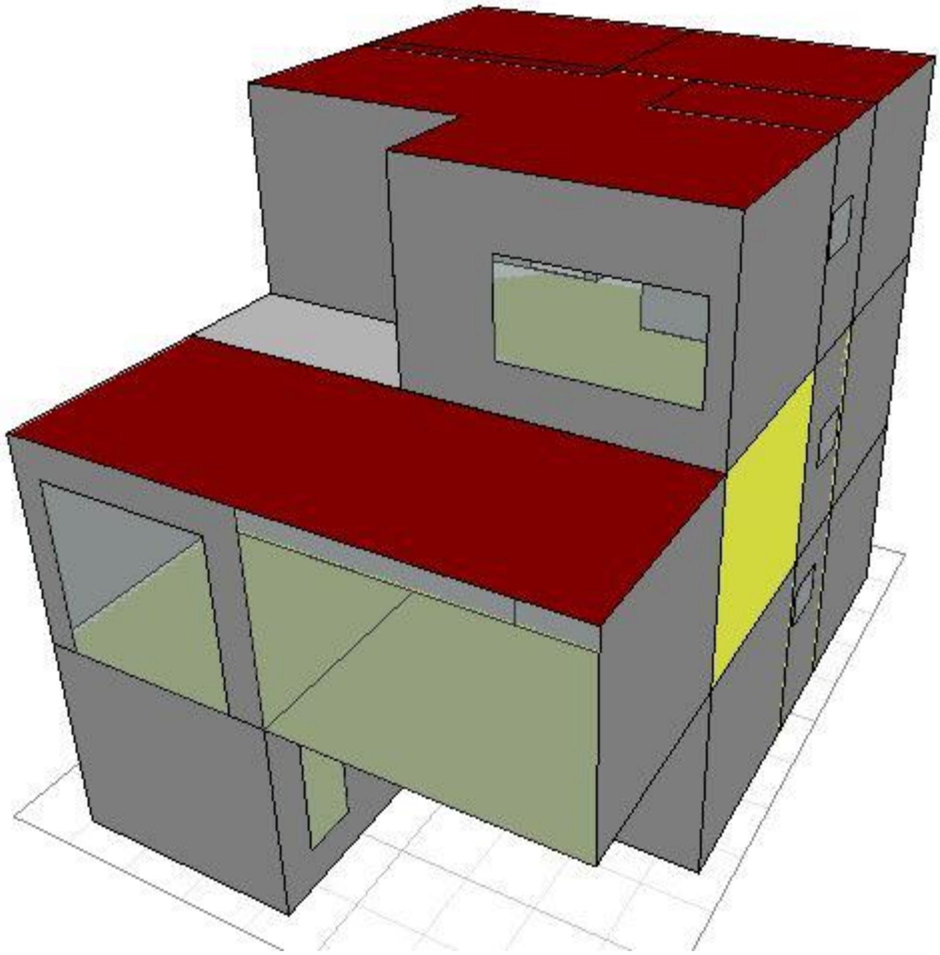


Figure 25: Building Model in Ecotech for Energy/Thermal Simulation

4.4 Thermal Simulation Results

The results contain thermal analysis output under different climate scenarios: SSP245 and SSP585 for the years 2025, 2045, and 2075 for provided building locations using the separate weather data. The different graphs have different explanations about the future scenario but the common conclusion from all of the results is there will be no thermal discomfort in the analyzed houses due to high temperatures, given the other than 6 parameters that we kept as default have little or no impact in building performance. The following results from thermal comfort have been analyzed.

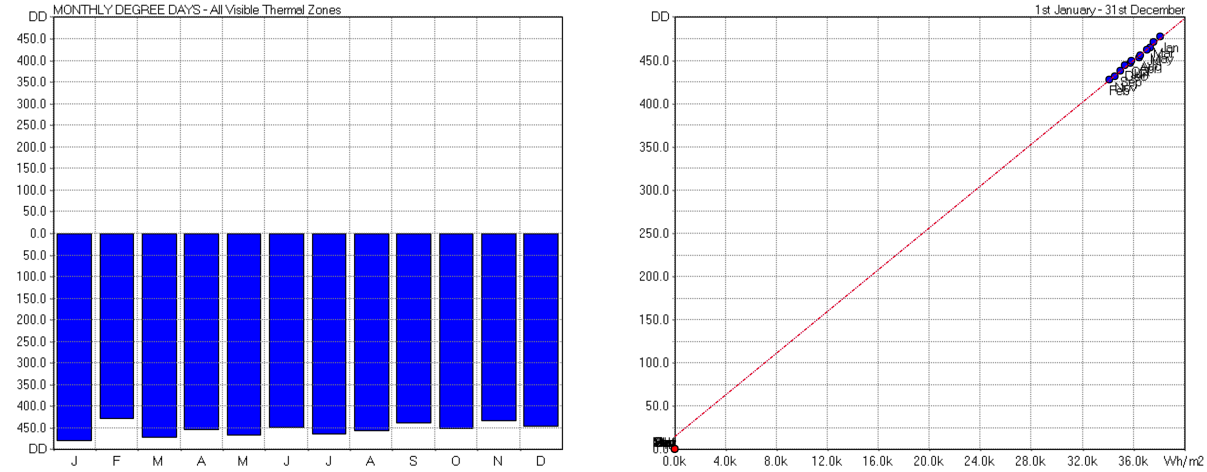


Figure 26: Monthly Degree Days

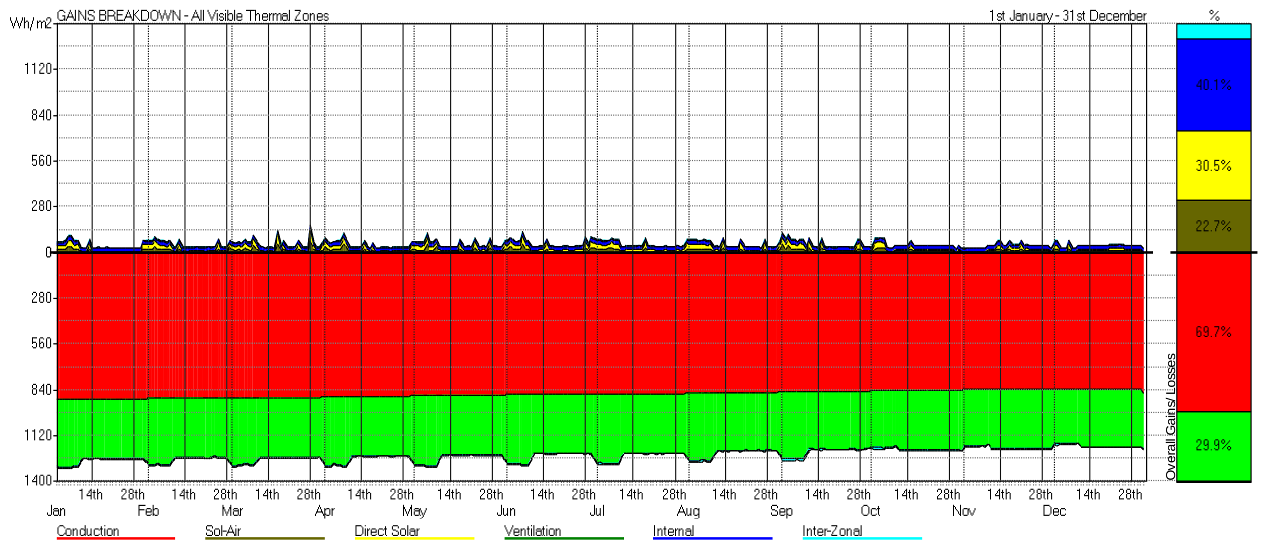


Figure 27: Gains Breakdown

The first figure, i.e. fig. 26 illustrates consistent heating degree days (HDD) across all months, represented by uniform blue bars. This suggests a consistent heating requirement throughout the year, possibly due to location in a high-altitude or cooler climatic zone. The accompanying line plot likely shows cumulative or regression analysis, indicating a linear relationship between degree days and another parameter, with the red dotted line suggesting a trendline or baseline. The second figure presents a detailed breakdown of internal heat gains by source across the months. The red section (69.7%) dominates, likely representing internal gains from occupants or equipment. Green (29.9%) may represent lighting or appliances, while blue, yellow, and other minor segments indicate contributions from solar gains, ventilation, or infiltration. The percentages on the right legend highlight the proportion of total gains from each source. The consistency across the months suggests steady internal heat contributions, with only minor fluctuations.

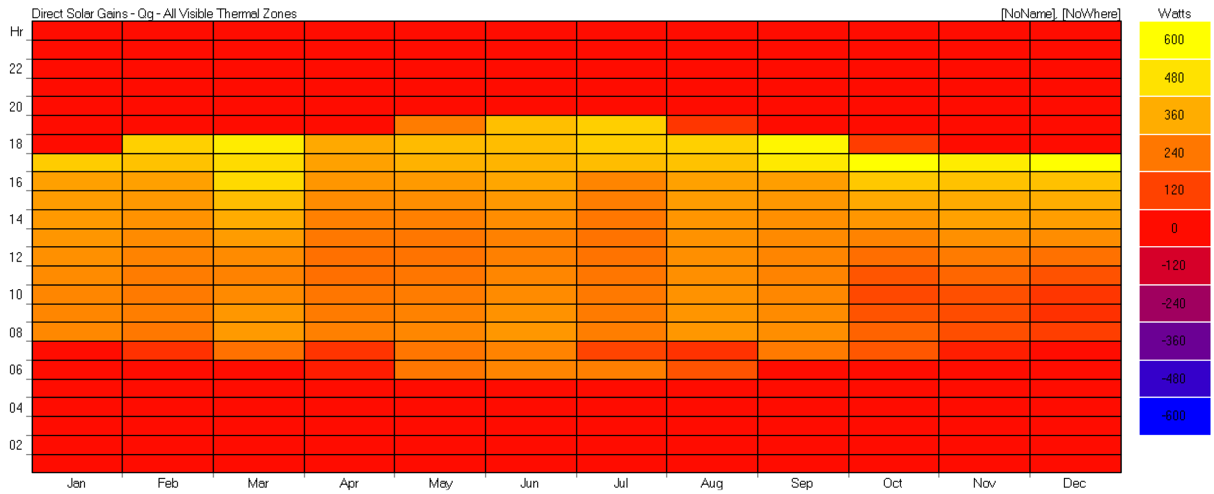


Figure 28: Direct Solar Gains

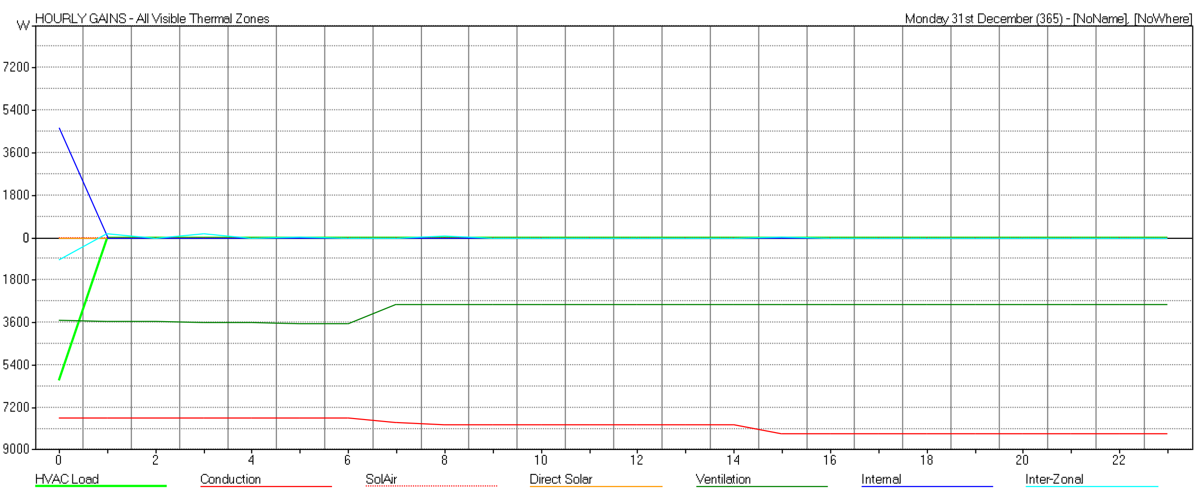


Figure 29: Hourly Gains

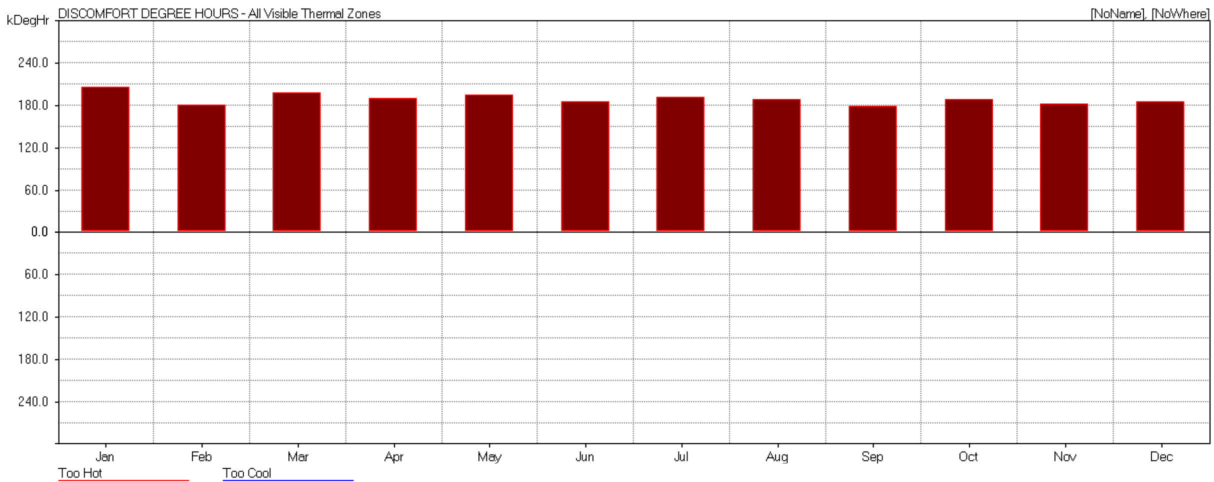


Figure 30: Discomfort Degree Hours

4.4.1 Energy Requirement

A. Energy Efficient Building

Table 6: Heating Load for EE Building

Year	Heating Load (Watt Hrs.)			
	Scenario SSP 245		Scenario SSP 585	
	Whr	MJPYPsqm.	Whr	MJPYPsqm.
2025	2134668.4	8.074	2139341.5	8.092
2035	2108070.5	7.974	2129624.7	8.055
2045	2178219.1	8.239	2136640.6	8.082
2055	2109108.2	7.978	2113322.4	7.994
2065	2118203.3	8.012	2112820.9	7.992
2075	2178219.1	8.239	2141407.6	8.100

B. Normal Building

Table 7: Heating Load for Normal Building

Year	Heating Load			
	Scenario SSP 245		Scenario SSP 585	
	Whr	MJPYPsqm.	Whr	MJPYPsqm.

2025	4840796.3	18.3101	4843876.4	18.3217
2035	4663808.4	17.6406	4687973.2	17.7320
2045	4887774.7	18.4878	4842096.9	18.3150
2055	4660866.5	17.6295	4668402.1	17.6580
2065	4671754.2	17.6707	4664588.4	17.6436
2075	4887745.1	18.4877	4845572.7	18.3281

From the comparison of the above two tables, it has been observed that the heating load for the normal building is around 2.25 times greater than that of EE building in all years and all scenarios whereas there is no cooling load for our study area to maintain assumed thermal comfort band.

Scenario wise Analysis:

Based on emission scenario, energy requirement in SSP 585 scenario has been found way more i.e. 2.25 times more than the normal building which is presented as shown below.

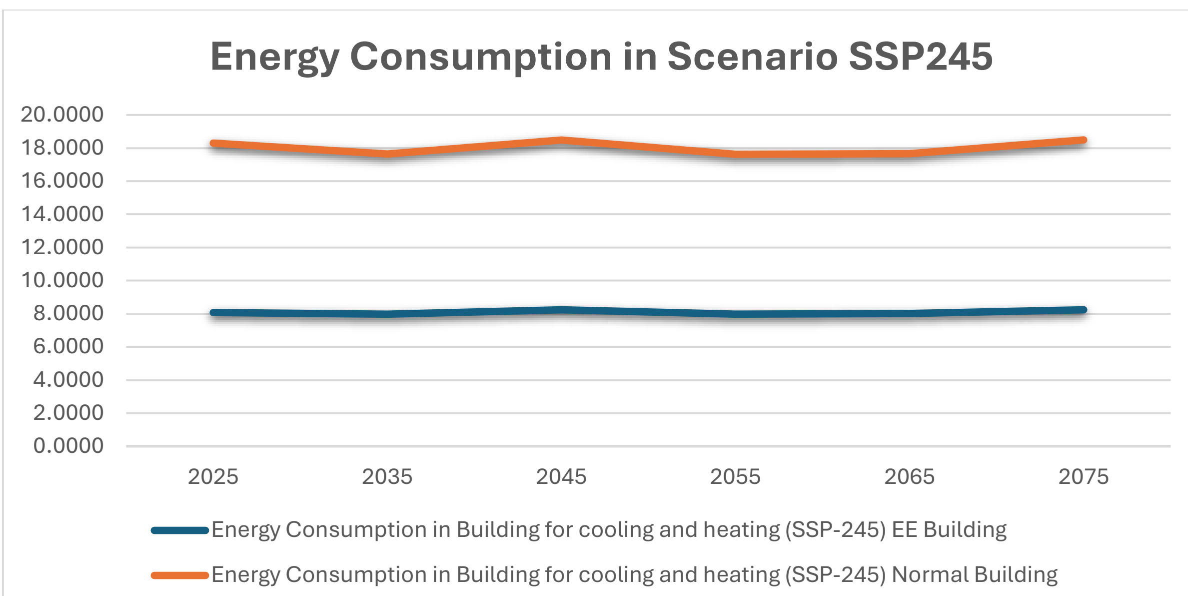


Figure 31: Energy Consumption in SSP245 Scenario

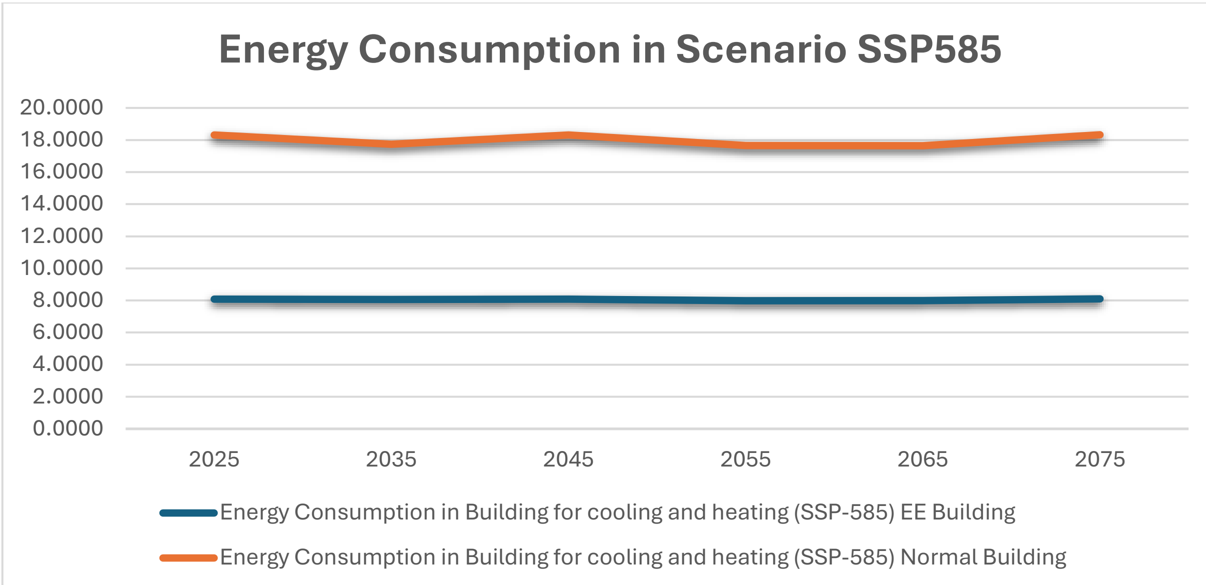


Figure 32: Energy Consumption in SSP245 Scenario

4.4.2 Emission Calculation

Table 8: Lifecycle Emission in EE Building

Year	**Emission (t CO2-eq./KWH)**	
	Scenario SSP 585	**Scenario SSP 245**
2025		
2035	1386987.12	689232.93
2045	1386109.60	1385540.68
2055	1380812.98	1392784.07
2065	1373073.96	1383203.07
2075	1382198.84	1384680.57
Lifecycle Emission	**6909182.49**	**6235441.32**

Table 9: Lifecycle Emission in Normal Building

Year	**Emission (t CO2-eq./KWH)**	
	Scenario SSP 585	**Scenario SSP 245**

2025		
2035	3088046.064	3096897.935
2045	3103309.346	3096319.775
2055	3102353.526	3089961.125
2065	3032168.465	3032288.613
2075	3105881.323	3089851.341
Lifecycle Emission	**15431758.72**	**15405318.79**

The lifecycle emission of EE building has found **6909182.49** t CO_2-eq./KWH and **6235441.32** t CO_2-eq./KWH for SSP 585 and 245 scenario respectively. Whereas the lifecycle emission of normal buildings has been observed as **15431758.72** t CO_2-eq./KWH and **15405318.79** t CO_2-eq./KWH for SSP 245 and 585 scenario respectively.

Table 10: Construction Time Emission of Different Wall Materials

Parameters	**Normal Brick**	**Hollow Brick**	**CSEB**	**Stone Wall**
Total Emission (t CO_2-eq.)	2735.57	2325.23	1276.87	0.00
Emission Reduction per Sqm. (t CO_2-eq. per Sqm.)	0	1.68	5.98	11.21

Table 10 shows the construction time emission for different wall construction materials. The total emission in our study area is 2325.23 t CO2-eq., which is 1.68 t CO_2-eq. per Sqm. less than the usual brick. It has also been observed that there are other efficient wall materials like CSEB and stone walls in terms of construction time emission.

CHAPTER FIVE: CALIBRATION AND VALIDATION OF THE STUDY

The calibration of the hygrometer used in the measurement of the real time temperature and relative humidity in the field was done by the standard pyrometer at DHM, in presence of DHM meteorologist.

The field validation of the study was carried out by observing the real time indoor thermal comfort data (i.e. Temperature and Relative Humidity), while they are staying comfortably inside the houses. This validates the range of thermal comfort that we assumed in our study was correct in the field also.

In the other hand, the energy requirement in unit area of the building for maintaining thermal comfort has been analyzed based on past literature. The specific energy consumption during the operation of the normal building is 2999.30 per square meter i.e 59.99 MJ per square meter per year (K.C. et al., 2024). Since heating and cooling account for 40% energy consumption, makes it **26.996** MJ per square meter per year. In our research too, this value is in the range of 16-18 MJ per square meters per year. The slight variation may be due to the following reasons.

1. Analysis tool and method (i.e. eco vent 3 and ecotect 2011)
2. Exact location of the study within kathmandu
3. Orientation and occupancy of buildings
4. Size and numbers of opening in the building
5. Consideration of detailed weather parameters in our study

CHAPTER SIX: CONCLUSION

This study evaluated the climate change resiliency of energy-efficient residential buildings in Godawari, Nepal, using thermal comfort modeling, and emission analysis. Through bias-corrected climate projections under SSP2-4.5 and SSP5-8.5 scenarios, the research modeled building performance using Ecotect 2011 and assessed thermal comfort and associated energy demands. Results indicate that while energy-efficient buildings significantly reduce lifecycle energy use and emissions compared to conventional ones, their performance is increasingly challenged by future climate variability. The study highlights the importance of adaptive building design, passive strategies, and resilient materials to maintain comfort and reduce environmental impact over time. It further underscores the necessity for localized climate data, policy alignment, and broader adoption of sustainable construction practices in Nepal.

The study highlighted that the use of energy efficient building (i.e. only change in building envelop materials) can reduce the energy requirement for heating and cooling by around 2.25 times whereas there is a significant reduction in operation time emission too. The operation time energy demand and lifecycle emission for energy efficient building is 8.23 MJPYPSqm. and 6235441.32 for SSP245 scenario and 8.1 MJPYPSqm and 6909182.49 t CO_2-eq./KWH for SSP 585 scenario respectively. The construction time emission may vary based on wall materials used and the hollow brick alone can reduce the emission by 1.68 t CO2-eq. per Sqm. As SSP 585 scenario is extreme scenario, the global temperature in this scenario is high. Due to which, energy consumption for the heating in building (as there is only heating load in our case) is high in SSP 245 scenario as well as emission compared to SSP 585 scenario.

In conclusion, improving indoor thermal comfort in Kathmandu Valley requires a comprehensive approach that respects the region's climatic realities while embracing advancements in building technology. By focusing on both building design and occupant behavior, and incorporating energy-efficient solutions, it is possible to enhance the living conditions in the valley’s diverse range of residential buildings, ensuring comfort, sustainability, resilience against future climatic challenges and overall emission reduction.

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CHAPTER SEVEN: ANNEXES

7.1 ANNEX:1 Comment Response Matrix

S.N.	Comments from Experts/ External	Response in Final Report	Page Number in Report
MID-TERM			
1	What is the significance of the research?	Included significance of research topic	14
2	Clarity in objective and interconnection between the objectives	Revised accordingly	15
3	Describe the energy efficient parameters of the building	Wall, Roof, orientation, occupants, and openings were analyzed	28,29
4	Mention f.y. and exact data in the values of the report.	Mentioned	N/A
5	Use Citation for data and values.	Resolved	N/A
6	Thermal comfort depends not only on temperature but also R.H. So RH range also needs to study.	RH was also analyzed for thermal comfort range i.e. 60%	33,34
7	Include ontology, entomology and etymology in methodology.	Included	42

8	Use third person view in the report (passive)	Done	N/A
9	Don't generalize the results	Made specific results and discussion	N/A
10	Do calibration of the instrument used.	Calibrated from DHM	68
11	Why only one building considered?	Analyzed two buildings, one EE and another normal for the same climate and orientation	N/A
FINAL DEFENCE			
1	Attach the detail calculation sheet	Attached in annex 7.6 and 7.7	
2	Attach salient features of comparative buildings	Done	
3	More detail conclusion	Done	
4	State limitation for the Study i.e. other than 6 parameters in weather file have been used as default value for Kathmandu	Done	
5	Do proper citation and references	Done	

7.2 ANNEX: 2 IOEGC PAPER

त्रिभुवन विश्वविद्यालय
Tribhuvan University
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Institute of Engineering
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गोश्वारा पो. नं. २८०, थापाथली, काठमाडौं
फोन: ०१-५३३९७६६

Date: April 21, 2025

To Whom It May Concern:

This is to certify that the paper titled **"Emission Calculation and Economic Analysis of different Construction Materials based on Clean Development Mechanism for an apartment building at Pokhara"** (Submission# **352**) submitted by **Shisab Pant** as the first author, which had been accepted for presentation after the peer-review process, has successfully been presented at the 16th IOE Graduate Conference held during April 18 - 20, 2025. Kindly note that the final revision of the papers and publication process of the conference proceedings is still underway and hence inclusion of the accepted manuscript in the conference proceedings is contingent upon timely response to further edits during the publication process.

Dr. Raj Kumar Chaulagain,
Convener,
16th IOE Graduate Conference

IOE Graduate Conference

Certificate of Participation

THIS CERTIFICATE IS AWARDED TO

Shisab Pant

in recognition of an invaluable contribution as

POSTER PRESENTER

at the 16th IOE Graduate Conference

Organized by Tribhuvan University, IOE, Thapathali Campus in association with IOE, Office of the Dean held from April 18-20, 2025 at Thapathali Campus, Kathmandu, Nepal.

Dr. Raj Kumar Chaulagain
Convener
16th IOE Graduate Conference

Dr. Khem Gyanwali
Campus Chief
Thapathali Campus

Prof. Dr. Sushil Bahadur Bajracharya
Dean
Institute of Engineering

IOE Graduate Conference
[Placeholder for Publication Information]

Emission Calculation and Economic Analysis of different Construction Materials based on Clean Development Mechanism for an apartment building at Pokhara

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Abstract
This paper focuses on the economic aspects of climate change, with a particular emphasis on the economics of mitigation, adaptation, loss, and damage. It delves into greenhouse gas (GHG) emissions and emission reduction contributions, specifically highlighting the significant impact of real estate on global carbon footprints. The study was conducted based on the Framework Convention on Climate Change (UNFCCC)'s approved guidelines of Clean Development Mechanism (CDM) in calculating the emission of Building Construction Materials at Himalaya Homes Apartment, Pokhara. The methodology adopted for this project is AMS-III. Z, which is the small-scale methodology for fuel switch, process improvement, and energy efficiency in brick manufacture. Using this methodology, the baseline emission during the construction phase was found to be 200 T of CO2, and an emission reduction of 107 T of CO2 can be achieved using CSEB whereas 200 T of CO2 emission can be reduced using stone walls as construction materials. After the economic analysis of the project, the CSEB wall is recommended as the best economic material, which gives a benefit/Cost (B/C) value of 1.22, whereas the stone wall was the best material for sustainability which has the highest (200 T) emission reduction. The study proposed the use of alternative construction materials rather than conventional brick to reduce carbon emissions from the building sector. The potential economic benefits of implementing CDM, including CO2 trading and cost savings from sustainable materials are explored. The calculation of operation time emission, analysis of non-marketable benefits and study of other available CDMs using different approved methodologies are some of the limitations in the study. This paper advocates for the urgent need for sustainable practices and adoption of CDM's, particularly in building construction, to mitigate environmental pollution and climate vulnerabilities.

Keywords
Emission, energy efficiency, CDM, AMS-III. Z, CER, UNFCCC

1. Introduction

Climate change economics refers to the study of the economic impacts of climate change, as well as the costs and benefits associated with efforts to mitigate and adapt to it. There has been a significant need for environmental sustainability and climate action in light of rising global temperatures, changing precipitation patterns, loss in biodiversity, decreasing agricultural productivity, and escalating air and water pollution [1]. So, UNFCCC has proposed clean development mechanisms for reducing the impact of climate change due to the development work in our society. In the past few years, the field of the economics of climate change has witnessed substantial growth, with numerous studies and reports shedding light on the complex interactions between energy markets and climate change considerations [2]. In recent times, climate change economists have been particularly interested in how increased energy prices cause corporations and individuals to reduce their consumption of carbon-based fuels. The economics of climate change mainly consist of three major aspects as economics of mitigation, adaptation, and loss and damage which are interrelated and often require integrated approaches to effectively address the challenges of climate change. Mitigation measures (both local and global) provide global benefits to the society, while adaptation is mostly implemented at local and regional levels observing the vulnerability and risk [3]. Balancing the adaptation and mitigation is a modern face of the commons dilemma (or the tragedy of the commons), which occurs when individuals follow their self-interests and deplete a common public resource such as land, water resource, fish, forest, or the environment [4]:[5]. While mitigation efforts aim to reduce the severity of climate change impacts in the long term, adaptation measures are needed to cope with the changes that are already occurring or are inevitable due to past emissions. In other side, despite mitigation and adaptation efforts, some level of loss and damage is expected, underscoring the importance of addressing this aspect within broader climate policy frameworks. From an economic perspective, addressing climate change requires balancing the costs of mitigation and adaptation against the potentially catastrophic economic, social, and environmental consequences of inaction. Furthermore, considering equity and justice is crucial, as vulnerable communities and countries often bear a disproportionate burden of climate impacts despite contributing minimally to greenhouse gas emissions like the community of Nepal as we are affected more intensely despite very minimum carbon footprint. Buildings are big energy consumers all over the world, particularly in places with extreme climatic conditions. Many reports have shown that the real estate sector is one of the major culprits in global GHG emissions. According to the IPCC report in 2010, the buildings sector accounted for 32% of global final energy consumption and 19% of energy-related CO2 emissions [6]. Furthermore, the recent reports published on Forbs (Apr 5, 2022) suggest the real state sector has contributed about 40% of the global carbon footprint. And it is predicted to increase the number of buildings by two-fold at the end of 2060. Nepal, being one of the highly urbanized countries in South Asia, with 12,39,635/- new houses constructed in the last 10 years. The energy demand of the building sector is pretty high equal to around 70% in the case of Nepal. As an important part of climate change building energy efficiency technology is very crucial in building energy savings, urban energy planning, urban strategy creation, and energy policy formulation. The building energy efficiency can be achieved by using active and passive design strategies. The passive building design strategies include the building orientation and layout, proper sunlight and air ventilation, shading, and solar radiation, and certainly the construction materials. The proper selection of building materials can be beneficial to achieve thermal comfort and energy efficiency too in a minimal cost. It is important to know that traditional building construction materials were way more energy efficient, thermally comfortable and had less emission compared to present buildings [7].

2. Objective

This research has primarily two objectives:

1. To find out different construction materials for building wall construction and analyze based on economy and GHG emission

2. To identify the baseline emission of the project and calculate the emission reduction by using different building wall materials based on AMS-III methodology.

3. Scope and Limitation

This study was solely intended to find out the construction time emission from different wall materials and their economic suitability. During the process, only one UNFCCC's methodology (AMS-III. Z) and three economic parameters (IRR, PV, B/C) was studied without a detail sensitivity analysis. The valuation of non-marketable items and market availability study of the materials were not studied in depth. There are many assumptions like the lease rate of land, rate of each unit, GHG selling rate, operation and maintenance rate, etc. based on recent practices around the project site.

4. Study Area

Pokhara Metropolitan City, located in the Kaski district of Gandaki, is the second most populous city in Nepal with 518,452 population and 101,669 households [8]. The city's humid subtropical climate, moderate temperatures, and adequate precipitation make it an ideal place to live. Since the 1990s, Pokhara has seen rapid urbanization, with service-sector industries increasingly contributing to the local economy, surpassing traditional agriculture making Pokhara as an emerging education and healthcare hub for the Gandaki province [9]. Aligned with urbanization new technologies and imported materials have replaced the vernacular architecture and local construction materials of the city [10].

Figure 1: Traditional Building Model of Pokhara

Our study building, Himalaya Homes Apartment lies at Pokhara Metropolitan City-03, Tersapatti- Kaski, Nepal. The project has a buildup area of 6552.31 SQ.M. having 11 storeys from the basement to 36 m. above ground level. The building have been designed by maintaining 32.33 ground coverage (G.C.) and 3.49 floor area ratio (FAR) in accordance with the Nepal National Building Code (NNBC). The project area has an annual mean temperature of 21.5 °C, max. monthly precipitation of 799.33 mm., relative humidity of 76.83, and CO2 equivalent to 400 ppm. is found in the air at present condition. The apartment is designed for 49 blocks each has floor area of about 1000 sqm. After site visit, questionnaire to focal persons, and related literature review about the project, it is found that in this building, normal brick (230X110X55) is proposed to use as a wall construction material. It is estimated that 9,08,000 bricks will be used to construct the 49-unit apartment. The plan of the apartment chosen for the study is shown in the figure below.

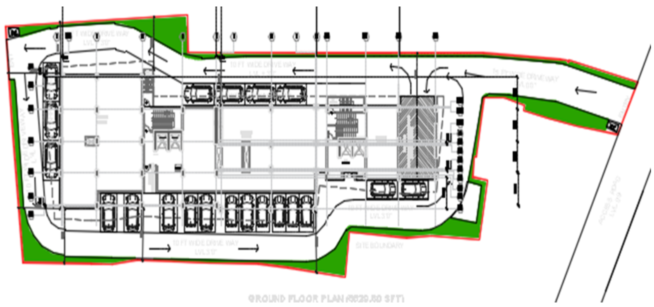

Figure 2: Site Plan of Apartment Building

5. Methodology

The clean development mechanism (CDM) can be defined as a component of the Kyoto Protocol that allows industrial countries to receive credits for helping developing countries to reduce their carbon emissions. CDM under the United Nation Framework Convention on Climate Change (UNFCCC) allows emission-reduction projects in developing countries to earn certified emission reduction (CER) credits, each equivalent to one tone of CO_2. These CERs can be traded and sold, and used by industrialized countries to meet a part of their emission reduction targets under the Kyoto Protocol, 1997. The mechanism stimulates emission reductions and global sustainable development while giving industrialized countries some flexibility in how they meet their emission reduction limitation targets. The methodology was chosen as per the guidelines of UNFCCC clean development mechanism (CDM Methodology booklet, 14th edition, 2022). The methodology adopted for this project is **AMS-III.Z** which is small scale methodology for Fuel Switch, process improvement, and energy efficiency in brick manufacture.

5.1 Baseline Emission

The baseline emissions are the fossil fuel and NRB consumption-related emissions associated with the system(s), which were or would have otherwise been used, in the brick production facilities in the absence of the project activity. For projects involving the installation of systems in a new facility or a capacity addition in an existing system, the average annual baseline fossil fuel consumption value and the baseline brick production rate shall be determined as that which would have been consumed and produced, respectively, under an appropriate baseline scenario. The baseline emission in this project was calculated as follows:

[BE]_y = [[SEC]_BL ×EF]_BL×P_(PJ,y)

Where:

[BE]_y =The baseline emissions from fossil fuels or NRB displaced by the project activity in t CO2e in project period

[SEC]_BL=Specific energy consumption of brick production in the baseline, TJ per unit volume or mass unit (kg or m3)

[EF]_BL = The emission factor of baseline fuel(s), in t CO2/TJ

P_(PJ,y) = The net production of the facility in year y, in kg or m3

5.2 Project Emission:

The project emissions has been calculated as follows:

[PE]y=[PE](elec,y)+[PE](fuel,y)+[PE](cultivation,y)+[PE](CH4,y)

Where:

[PE]y = Project emissions in year y (t CO2)

[PE](elec,y) = Project emissions due to electricity consumption in year y (t CO2)

[PE](fuel,y) = Project emissions due to fossil fuel or NRB consumption in year y (t CO2)

[PE](cultivation,y) = Project emissions from cultivation of biomass in a dedicated plantation in year y (t CO2e)

[PE](CH4,y) = Project emissions due to the production of charcoal in kilns not equipped with a methane recovery and destruction facility in year y (t CO2e)

5.3 Emission Reduction

Stone walls and CSEB walls have been proposed as alternative wall construction materials.

Figure 3: I-Stone and II-CSEB as Wall Construction Materials

Emission reductions (ERy) achieved by the project activity has been calculated as the difference between the baseline emissions and the sum of project emissions and leakage as follows: (ER)y=(BE)y-(PE)y-(LE)y

Where:

(ER)y =Emission reductions in year y (t CO2e)

(BE)y =Baseline emissions in year y (t CO2e)

(PE)y =Project emissions in year y (t CO2)

(LE)y =Leakage emissions in year y (t CO2)

5.4 Economic Analysis

Economic analysis is the systematic evaluation of the costs and benefits associated with a particular decision, policy, or project. It involves assessing the financial implications of various alternatives to determine their feasibility, efficiency, and impact by using methods like cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), and net present value (NPV) calculations. Among these methods, we have used CBA and IRR methods in our research.The Internal Rate of Return (IRR) is the discount rate at which the Net Present Value (NPV) of cash flows becomes zero. The Benefit-Cost (B/C) Ratio Method is a widely used economic analysis technique that evaluates the feasibility of a project or investment by comparing its expected benefits to its associated costs. It is expressed as:

$B/CRatio = \sum(Ct/(1+r)^t)/\sum(Bt/(1+r)^t)$

where:

Bt = Benefits in year t

Ct = Costs in year t

r= Discount rate

t = Time period

For the calculation of IRR i.e. the discount rate (r) that makes the Net Present Value (NPV) of cash flows equal to zero, we used the trial-and-error method in the following formula.

$$NPV = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t} = 0$$

where:

n = Total number of periods

6. Results and Discussion

Stone and CSEB has been proposed as the new wall construction materials instead of normal brick. The project baseline emission i.e.emission from as usual scenario (brickwall) was calculated as 200 T CO2 during the construction stage only. It is estimated that the stone had no emission, but the CSEB block has some emissions due to it's composition [i.e. angular sand aggregate 50%, clayey soil 38%, cement 4%, and water 8%] which was calculated as 7 T CO2 along with 86.3 T CO2 as leakage emission, making it a total of 93.3 T CO2 emission. From above calculation, it has shown that the stone was has least emission and hence highly recommended as wall construction material for reducing global carbon footprint.

By taking reference of the district rate 2081/082 published by Kaski district administration office and using the standard norms approved by the Department of Urban Development and Building Construction (DUDBC), the unit rate of 1 m3 quantity of each of 3 materials was calculated and determined that CSEB has the most economic rate among all 3 construction materisls.

Table 1: Rate of Different Wall Materials

Material Type	Rate ($)	Unit	Economic
Normal Brick Wall	123.76	cum	Least
CSEB Wall	91.44	cum	Best
Quarry Stone Wall	97.44	cum	Better

Source: District Rate Kaski (2081/082) and DUDBC Norms

From the economic analysis, the value of NPV and IRR have determinated as follows.

Table 2: Comparision of NPV and IRR values

Material Type	NPV ($)	IRR (%)	Rank
Normal Brick Wall	161869.1	11	3
Quarry Stone Wall	211138.6	11	2
CSEB wall	241274.4	12	1

Source: Author's Calculation

The results of all of the economic analyses including NPV, IRR, B/C have indicated that the CSEB is the best alternative as a wall construction material.

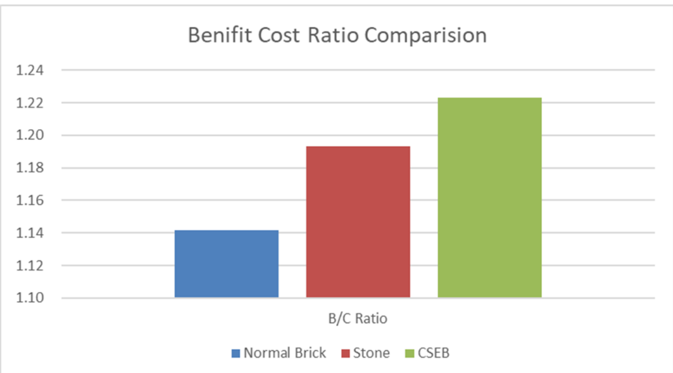

Figure 4: B/C of Different Materials

7. Conclusion and Future Recommendation

AMS-III is a well-verified methodology from UNFCCC as CDM to use in small-scale methodology for fuel switch, process improvement, and energy efficiency in brick manufacture. Using that methodology, it has concluded that the stone wall has the best emission reduction capacity i.e. 200 T eqvt. of CO2. Similarly, based on IRR, PV and B/C methods, CSEB has the best economic rate in the case of our research site with 12% IRR value and B/C ratio of 1.22. We need to select construction materials based on environmental sustainability, market availability, workmanship, economic rate, safety and of course personal comfort. In conclusion, it has been recommend to use either CSEB or stone wall for the construction of this particular project as both have less emission and more economical than brickwall. Moreover, incorporating CDM into Nepal's climate change mitigation efforts offers opportunities for economic development, technology transfer, and emissions reduction. However, realizing these benefits requires overcoming challenges related to financing, capacity-building, and institutional support.

Urbanization comprises of two major components; physical and socio-economic arrangement, where physical includes morphological viewpoints like arrival utilize, engineering, land use plan and vitality, while the socio-economic component includes social or human environmental forms and cost-effective techniques, which ought to be taken into thought amid urban arranging [11]. Hence, not only the direct purchase cost but also the indirect benefits should be considered in the economic analysis along with the materials availability survey. It would be great if the multiple UNFCCC-approved CDM methodologies can be used for the validation of this research. The 200 Ton eq. of CO2 emission from this project in construction time only can obviously increase in overall lifetime. So, the operation and dismantling i.e. lifecycle emission will be useful in carbon trading. The lack of social awareness, political stability, and geopolitical issues are holding our country back from achieving maximum benefit from carbon trading. With the right diplomacy, policies, partnerships, and investments, Nepal can harness the economic opportunities of climate change mitigation while enhancing its resilience to climate impacts and promoting sustainable development.

Acknowledgments

The authors are thankful to the respected personnel who spared their valuable time for making the study successful.

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7.3 ANNEX 3: Himalayan Knowledge Conclave – HKC, 2025 Conference Presentation

Congratulations for Selection of Abstract for HKC 2025 External Inbox ×

GRADUATE CONFERENCE <hkc@nou.edu.np> Apr 1, 2025, 11:38 PM

to aayu.chau222, bcc: me

Dear Presenter,

Congratulations! Your abstract has been selected for HKC- 2025. We would like to request you to follow the attached guidelines and templates for the Oral and Poster Presentation. We will provide 'BEST PRESENTER AWARD' and 'BEST POSTER AWARD' at the event to the participants recommended by the scientific and evaluation committee.

For Oral Presenters: Please prepare and send the slide as per the attached template by 3 **April,2025. Please upload your file in the form below by 3 April,2025.:**

Link: https://forms.gle/hjAy3qk1oUW6fqV5A

For Poster Presenters: Please follow the guideline and bring the printed poster on the day of your presentation. We will provide the stand for the poster .

We will have an online orientation workshop for all the presenters on **April 3,2025 from 6:30 pm** onwards and details about the session will be sent through your mail by tomorrow. The event venue is fixed at NAST, Kathmandu and the detailed schedule will be sent to you sooner.

Once again, congratulations for the selection.

In case of any queries, please mail us at hkc@nou.edu.np


Himalayan Knowledge Conclave

The 11th Graduate Conference-2025

Towards Sustainability: Trends in Education, Technology and Environmental Convergence for Socio-economic Growth

CERTIFICATE OF APPRECIATION

is presented to

SHISAB PANT

for valuable contribution as a Oral Presenter at the 11th Graduate Conference held on April 5-6, 2025, hosted by the Nepal Open University, Manbhawan, Nepal.

Prof. Govinda Singh Bista, PhD
Convener, 11th Graduate Conference
Registrar
Nepal Open University

Asso. Prof. Surendra Shrestha, PhD
Coordinator, 11th Graduate Conference
Dean, FOSHT
Nepal Open University

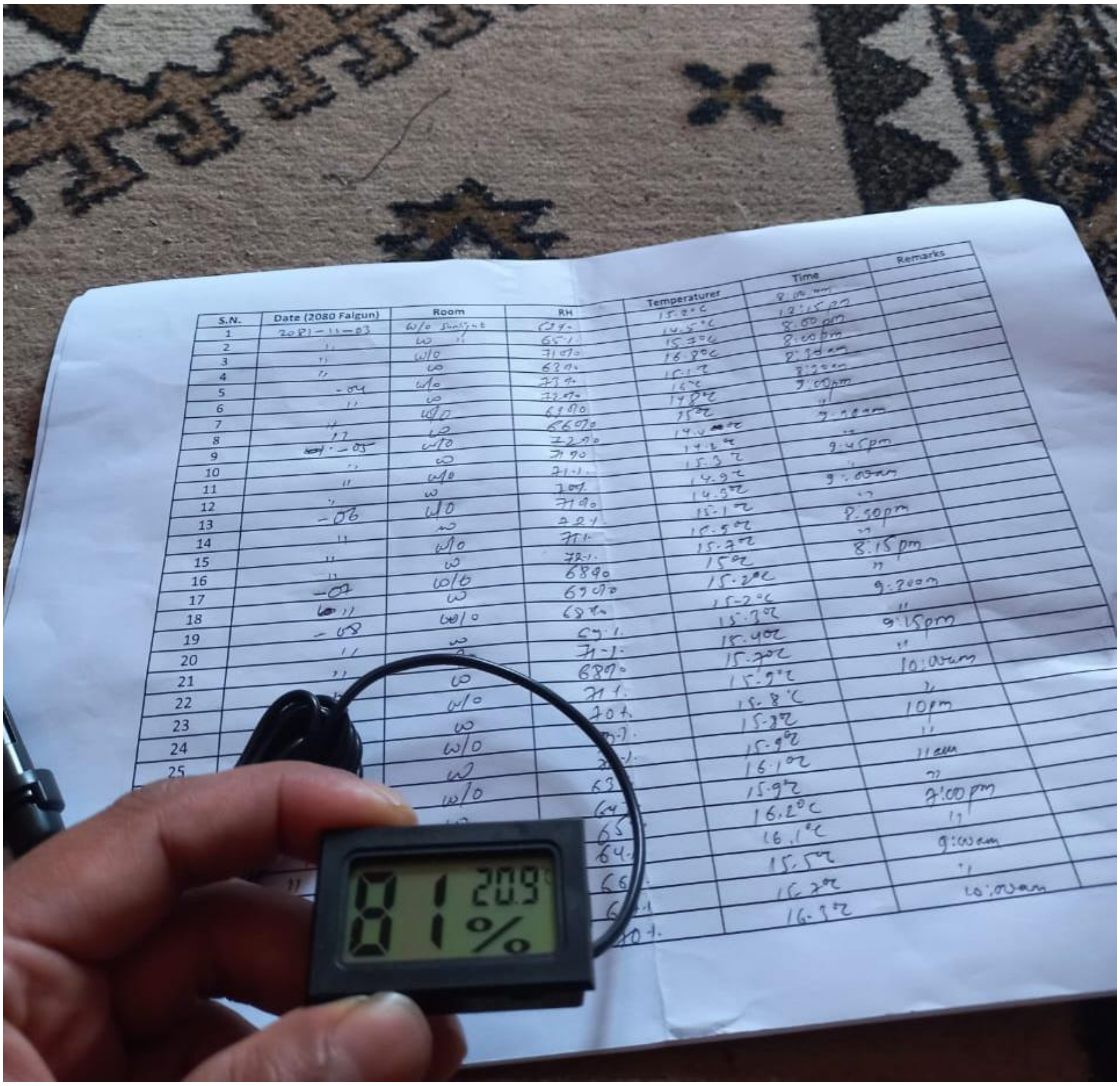
Prof. Shilu Manandhar Bajracharya, PhD
Patron, 11th Graduate Conference
Vice Chancellor
Nepal Open University

Initiating Partners

Organizing Partners

7.4 ANNEX 4: Calibration at DHM

7.5 ANNEX 5: Validation around the HH of study area about the thermal comfort range



7.6 ANNEX 6: U-value Calculation

U Value.Calculation

Envelope Component	Wall
Climatic Zone	Warm Temperate and Temperate
Layer: Outermost to Innermost	
U-value (W/m^2.K)	1.73
R_{total} (m^2.K/W)	0.58
R_{si} (m^2.K/W)	0.13
R_{se} (m^2.K/W)	0.04

Material	Thickness (mm)	k (W/m.K)	R (m^2.K/W)
Cement plaster, Density-1762 kg/m3	20	0.721	0.03
Resource efficient (hollow) brick, Density-1520 kg/r	230	0.631	0.36
Cement plaster, Density-1762 kg/m3	12	0.721	0.02
	125		
	10		

Index			R_{si}	R_{se}		
Wall, Warm Temperate and Temperate	Wall	Warm Temperate and Temperate	0.13	0.04		
Wall, CoolTemperate and Cold	Wall	CoolTemperate and Cold	0.13	0.04		
Roof, Warm Temperate and Temperate	Roof	Warm Temperate and Temperate	0.17	0.04		
Roof, CoolTemperate and Cold	Roof	CoolTemperate and Cold	0.1	0.04		
			t	R		
Air Layer- 5 mmWallWarm Temperate and Temperate	Wall	Warm Temperate and Temperate	5	0.12	Air Layer- 5 mm	
Air Layer- 7 mmWallWarm Temperate and Temperate	Wall	Warm Temperate and Temperate	7	0.12	Air Layer- 7 mm	
Air Layer- 10 mmWallWarm Temperate and Temperate	Wall	Warm Temperate and Temperate	10	0.14	Air Layer- 10 mm	
Air Layer- 15 mmWallWarm Temperate and Temperate	Wall	Warm Temperate and Temperate	15	0.16	Air Layer- 15 mm	
Air Layer- 25 mmWallWarm Temperate and Temperate	Wall	Warm Temperate and Temperate	25	0.18	Air Layer- 25 mm	
Air Layer- 50 mmWallWarm Temperate and Temperate	Wall	Warm Temperate and Temperate	50	0.18	Air Layer- 50 mm	
Air Layer- 100 mmWallWarm Temperate and Temperate	Wall	Warm Temperate and Temperate	100	0.18	Air Layer- 100 mm	
Air Layer- 300 mmWallWarm Temperate and Temperate	Wall	Warm Temperate and Temperate	300	0.18	Air Layer- 300 mm	
Air Layer- 5 mmWallCoolTemperate and Cold	Wall	CoolTemperate and Cold	5	0.12	Air Layer- 5 mm	
Air Layer- 7 mmWallCoolTemperate and Cold	Wall	CoolTemperate and Cold	7	0.12	Air Layer- 7 mm	
Air Layer- 10 mmWallCoolTemperate and Cold	Wall	CoolTemperate and Cold	10	0.14	Air Layer- 10 mm	
Air Layer- 15 mmWallCoolTemperate and Cold	Wall	CoolTemperate and Cold	15	0.16	Air Layer- 15 mm	
Air Layer- 25 mmWallCoolTemperate and Cold	Wall	CoolTemperate and Cold	25	0.18	Air Layer- 25 mm	
Air Layer- 50 mmWallCoolTemperate and Cold	Wall	CoolTemperate and Cold	50	0.18	Air Layer- 50 mm	
Air Layer- 100 mmWallCoolTemperate and Cold	Wall	CoolTemperate and Cold	100	0.18	Air Layer- 100 mm	
Air Layer- 300 mmWallCoolTemperate and Cold	Wall	CoolTemperate and Cold	300	0.18	Air Layer- 300 mm	
Air Layer- 5 mmRoofWarm Temperate and Temperate	Roof	Warm Temperate and Temperate	5	0.10	Air Layer- 5 mm	
Air Layer- 7 mmRoofWarm Temperate and Temperate	Roof	Warm Temperate and Temperate	7	0.12	Air Layer- 7 mm	
Air Layer- 10 mmRoofWarm Temperate and Temperate	Roof	Warm Temperate and Temperate	10	0.14	Air Layer- 10 mm	
Air Layer- 15 mmRoofWarm Temperate and Temperate	Roof	Warm Temperate and Temperate	15	0.16	Air Layer- 15 mm	
Air Layer- 25 mmRoofWarm Temperate and Temperate	Roof	Warm Temperate and Temperate	25	0.18	Air Layer- 25 mm	
Air Layer- 50 mmRoofWarm Temperate and Temperate	Roof	Warm Temperate and Temperate	50	0.20	Air Layer- 50 mm	
Air Layer- 100 mmRoofWarm Temperate and Temperate	Roof	Warm Temperate and Temperate	100	0.20	Air Layer- 100 mm	
Air Layer- 300 mmRoofWarm Temperate and Temperate	Roof	Warm Temperate and Temperate	300	0.21	Air Layer- 300 mm	
Air Layer- 5 mmRoofCoolTemperate and Cold	Roof	CoolTemperate and Cold	5	0.10	Air Layer- 5 mm	
Air Layer- 7 mmRoofCoolTemperate and Cold	Roof	CoolTemperate and Cold	7	0.12	Air Layer- 7 mm	
Air Layer- 10 mmRoofCoolTemperate and Cold	Roof	CoolTemperate and Cold	10	0.14	Air Layer- 10 mm	
Air Layer- 15 mmRoofCoolTemperate and Cold	Roof	CoolTemperate and Cold	15	0.16	Air Layer- 15 mm	
Air Layer- 25 mmRoofCoolTemperate and Cold	Roof	CoolTemperate and Cold	25	0.17	Air Layer- 25 mm	
Air Layer- 50 mmRoofCoolTemperate and Cold	Roof	CoolTemperate and Cold	50	0.17	Air Layer- 50 mm	
Air Layer- 100 mmRoofCoolTemperate and Cold	Roof	CoolTemperate and Cold	100	0.17	Air Layer- 100 mm	
Air Layer- 300 mmRoofCoolTemperate and Cold	Roof	CoolTemperate and Cold	300	0.17	Air Layer- 300 mm	

Index	Index		Density (kg/m3)	Thermal Conducti	Specifi c Heat	R (m2.K/W)
Solid burnt clay brick, Density-1920 kg/m3	Solid burnt clay brick, Density-1920 kg/m3	Solid burnt clay brick	1920	0.980	0.8	
Solid burnt clay brick, Density-1760 kg/m3	Solid burnt clay brick, Density-1760 kg/m3	Solid burnt clay brick	1760	0.850	NA	
Solid burnt clay brick, Density-1600 kg/m3	Solid burnt clay brick, Density-1600 kg/m3	Solid burnt clay brick	1600	0.740	NA	
Solid burnt clay brick, Density-1440 kg/m3	Solid burnt clay brick, Density-1440 kg/m3	Solid burnt clay brick	1440	0.620	NA	
Resource efficient (hollow) brick, Density-1520 kg/m3	Resource efficient (hollow) brick, Density-1520 kg/m3	Resource efficient (hollow) brick	1520	0.631	0.65	
Fly ash brick, Density-1650 kg/m3	Fly ash brick, Density-1650 kg/m3	Fly ash brick	1650	0.856	0.93	
Solid concrete block 25/50, Density-2427 kg/m3	Solid concrete block 25/50, Density-2427 kg/m3	Solid concrete block 25/50	2427	1.396	0.2	
Solid concrete block 30/60, Density-2349 kg/m3	Solid concrete block 30/60, Density-2349 kg/m3	Solid concrete block 30/60	2349	1.411	0.3	
Aerated autoclaved concrete (AAC) block, Density-642 kg/m3	Aerated autoclaved concrete (AAC) block, Density-642 kg/m3	Aerated autoclaved concrete (AAC) bloc	642	0.184	1.24	
Cement stabilized soil block (CSEB), Density-1700 kg/m3	Cement stabilized soil block (CSEB), Density-1700 kg/m3	Cement stabilized soil block (CSEB)	1700	1.026	1.03	
Cement stabilized soil block (CSEB), Density-1800 kg/m3	Cement stabilized soil block (CSEB), Density-1800 kg/m3	Cement stabilized soil block (CSEB)	1800	1.201	1.07	
Cement stabilized soil block (CSEB), Density-1900 kg/m3	Cement stabilized soil block (CSEB), Density-1900 kg/m3	Cement stabilized soil block (CSEB)	1900	1.303	1.07	
Dense concrete, Density-2410 kg/m3	Dense concrete, Density-2410 kg/m3	Dense concrete	2410	1.740	0.88	
Reinforced concrete cement (RCC), Density-2288 kg/m3	Reinforced concrete cement (RCC), Density-2288 kg/m3	Reinforced concrete cement (RCC)	2288	1.580	0.88	
Brick tile, Density-1892 kg/m3	Brick tile, Density-1892 kg/m3	Brick tile	1892	0.798	0.88	
Lime concrete, Density-1646 kg/m3	Lime concrete, Density-1646 kg/m3	Lime concrete	1646	0.730	0.88	
Mud Phuska, Density-1622 kg/m3	Mud Phuska, Density-1622 kg/m3	Mud Phuska	1622	0.519	0.88	
Cement mortar, Density-1648 kg/m3	Cement mortar, Density-1648 kg/m3	Cement mortar	1648	0.719	0.92	
Cement plaster, Density-1762 kg/m3	Cement plaster, Density-1762 kg/m3	Cement plaster	1762	0.721	0.84	
Gypsum plaster, Density-1120 kg/m3	Gypsum plaster, Density-1120 kg/m3	Gypsum plaster	1120	0.512	0.96	
Cellular concrete, Density-704 kg/m3	Cellular concrete, Density-704 kg/m3	Cellular concrete	704	0.188	1.05	
AC sheet, Density-1520 kg/m3	AC sheet, Density-1520 kg/m3	AC sheet	1520	0.245	0.84	
GI sheet, Density-7520 kg/m3	GI sheet, Density-7520 kg/m3	GI sheet	7520	61.060	0.5	
Timber, Density-480 kg/m3	Timber, Density-480 kg/m3	Timber	480	0.072	1.68	
Timber, Density-720 kg/m3	Timber, Density-720 kg/m3	Timber	720	0.144	1.68	
Plywood, Density-640 kg/m3	Plywood, Density-640 kg/m3	Plywood	640	0.174	1.76	
Glass, Density-2350 kg/m3	Glass, Density-2350 kg/m3	Glass	2350	0.814	0.88	
Tar felt (23 kg/m2), Density- kg/m3	Tar felt (23 kg/m2), Density- kg/m3	Tar felt (23 kg/m2)		0.479	0.88	
Expanded polystyrene, Density-16 kg/m3	Expanded polystyrene, Density-16 kg/m3	Expanded polystyrene	16	0.038	134	
Expanded polystyrene, Density-24 kg/m3	Expanded polystyrene, Density-24 kg/m3	Expanded polystyrene	24	0.035	134	
Expanded polystyrene, Density-34 kg/m3	Expanded polystyrene, Density-34 kg/m3	Expanded polystyrene	34	0.035	134	
Foam glass, Density-1270 kg/m3	Foam glass, Density-1270 kg/m3	Foam glass	1270	0.056	0.75	
Foam glass, Density-160 kg/m3	Foam glass, Density-160 kg/m3	Foam glass	160	0.055	0.75	
Foam concrete, Density-320 kg/m3	Foam concrete, Density-320 kg/m3	Foam concrete	320	0.070	0.92	
Foam concrete, Density-400 kg/m3	Foam concrete, Density-400 kg/m3	Foam concrete	400	0.084	0.92	
Foam concrete, Density-704 kg/m3	Foam concrete, Density-704 kg/m3	Foam concrete	704	0.149	0.92	
Cork slab, Density-164 kg/m3	Cork slab, Density-164 kg/m3	Cork slab	164	0.043	0.96	
Cork slab, Density-192 kg/m3	Cork slab, Density-192 kg/m3	Cork slab	192	0.044	0.96	
Cork slab, Density-304 kg/m3	Cork slab, Density-304 kg/m3	Cork slab	304	0.055	0.96	
Rock wool (unbonded), Density-92 kg/m3	Rock wool (unbonded), Density-92 kg/m3	Rock wool (unbonded)	92	0.047	0.84	
Rock wool (unbonded), Density-150 kg/m3	Rock wool (unbonded), Density-150 kg/m3	Rock wool (unbonded)	150	0.043	0.84	
Mineral wool (unbonded), Density-73.5 kg/m3	Mineral wool (unbonded), Density-73.5 kg/m3	Mineral wool (unbonded)	73.5	0.030	0.92	
Glass wool (unbonded), Density-69 kg/m3	Glass wool (unbonded), Density-69 kg/m3	Glass wool (unbonded)	69	0.043	0.92	
Glass wool (unbonded), Density-189 kg/m3	Glass wool (unbonded), Density-189 kg/m3	Glass wool (unbonded)	189	0.040	0.92	
Resin bonded mineral wool, Density-48 kg/m3	Resin bonded mineral wool, Density-48 kg/m3	Resin bonded mineral wool	48	0.042	1	
Resin bonded mineral wool, Density-64 kg/m3	Resin bonded mineral wool, Density-64 kg/m3	Resin bonded mineral wool	64	0.038	1	
Resin bonded mineral wool, Density-99 kg/m3	Resin bonded mineral wool, Density-99 kg/m3	Resin bonded mineral wool	99	0.036	1	
Resin bonded mineral wool, Density-16 kg/m3	Resin bonded mineral wool, Density-16 kg/m3	Resin bonded mineral wool	16	0.040	1	
Resin bonded mineral wool, Density-24 kg/m3	Resin bonded mineral wool, Density-24 kg/m3	Resin bonded mineral wool	24	0.036	1	
Exfoliated vermiculite (loose), Density-264 kg/m3	Exfoliated vermiculite (loose), Density-264 kg/m3	Exfoliated vermiculite (loose)	264	0.069	0.88	
Asbestos mill board, Density-1397 kg/m3	Asbestos mill board, Density-1397 kg/m3	Asbestos mill board	1397	0.249	0.84	
Hard board, Density-979 kg/m3	Hard board, Density-979 kg/m3	Hard board	979	0.279	142	
Straw board, Density-310 kg/m3	Straw board, Density-310 kg/m3	Straw board	310	0.057	1.3	
Soft board, Density-320 kg/m3	Soft board, Density-320 kg/m3	Soft board	320	0.066	1.3	
Soft board, Density-249 kg/m3	Soft board, Density-249 kg/m3	Soft board	249	0.047	1.3	
Wall board, Density-262 kg/m3	Wall board, Density-262 kg/m3	Wall board	262	0.047	1.26	
Chip board, Density-432 kg/m3	Chip board, Density-432 kg/m3	Chip board	432	0.067	1.26	

Chip board (perforated), Density-352 kg/m3	Chip board (perforated), Density-352 kg/m3	Chip board (perforated)	352	0.066	1.26	
Particle board, Density-750 kg/m3	Particle board, Density-750 kg/m3	Particle board	750	0.098	1.3	
Coconut pith insulation board, Density-520 kg/m3	Coconut pith insulation board, Density-520 kg/m3	Coconut pith insulation board	520	0.060	1.09	
Jute fibre, Density-329 kg/m3	Jute fibre, Density-329 kg/m3	Jute fibre	329	0.067	1.09	
Wood wool board (bonded with cement), Density-398 kg/m3	Wood wool board (bonded with cement), Density-398 kg/m3	Wood wool board (bonded with cement)	398	0.081	1.13	
Wood wool board (bonded with cement), Density-674 kg/m3	Wood wool board (bonded with cement), Density-674 kg/m3	Wood wool board (bonded with cement)	674	0.108	1.13	
Coir board, Density-97 kg/m3	Coir board, Density-97 kg/m3	Coir board	97	0.038	1	
Saw dust, Density-188 kg/m3	Saw dust, Density-188 kg/m3	Saw dust	188	0.051	1	
Rice husk, Density-120 kg/m3	Rice husk, Density-120 kg/m3	Rice husk	120	0.051	1	
Jute felt, Density-291 kg/m3	Jute felt, Density-291 kg/m3	Jute felt	291	0.042	0.88	
Closed cell flexible elastomeric foam- NBR, Density-40-55 kg/m3	Closed cell flexible elastomeric foam- NBR, Density-40-55 kg/m	Closed cell flexible elastomeric foam- NI	40-55	0.043	1.2	
Air Layer- 5 mmWallWarm Temperate and Temperate	Air Layer- 5 mm	Wall	Warm Temp			0.12
Air Layer- 7 mmWallWarm Temperate and Temperate	Air Layer- 7 mm	Wall	Warm Temp			0.12
Air Layer- 10 mmWallWarm Temperate and Temperate	Air Layer- 10 mm	Wall	Warm Temp			0.14
Air Layer- 15 mmWallWarm Temperate and Temperate	Air Layer- 15 mm	Wall	Warm Temp			0.16
Air Layer- 25 mmWallWarm Temperate and Temperate	Air Layer- 25 mm	Wall	Warm Temp			0.18
Air Layer- 50 mmWallWarm Temperate and Temperate	Air Layer- 50 mm	Wall	Warm Temp			0.18
Air Layer- 100 mmWallWarm Temperate and Temperate	Air Layer- 100 mm	Wall	Warm Temp			0.18
Air Layer- 300 mmWallWarm Temperate and Temperate	Air Layer- 300 mm	Wall	Warm Temp			0.18
Air Layer- 5 mmWallCoolTemperate and Cold	Air Layer- 5 mm	Wall	CoolTemper			0.12
Air Layer- 7 mmWallCoolTemperate and Cold	Air Layer- 7 mm	Wall	CoolTemper			0.12
Air Layer- 10 mmWallCoolTemperate and Cold	Air Layer- 10 mm	Wall	CoolTemper			0.14
Air Layer- 15 mmWallCoolTemperate and Cold	Air Layer- 15 mm	Wall	CoolTemper			0.16
Air Layer- 25 mmWallCoolTemperate and Cold	Air Layer- 25 mm	Wall	CoolTemper			0.18
Air Layer- 50 mmWallCoolTemperate and Cold	Air Layer- 50 mm	Wall	CoolTemper			0.18
Air Layer- 100 mmWallCoolTemperate and Cold	Air Layer- 100 mm	Wall	CoolTemper			0.18
Air Layer- 300 mmWallCoolTemperate and Cold	Air Layer- 300 mm	Wall	CoolTemper			0.18
Air Layer- 5 mmRoofWarm Temperate and Temperate	Air Layer- 5 mm	Roof	Warm Temp			0.10
Air Layer- 7 mmRoofWarm Temperate and Temperate	Air Layer- 7 mm	Roof	Warm Temp			0.12
Air Layer- 10 mmRoofWarm Temperate and Temperate	Air Layer- 10 mm	Roof	Warm Temp			0.14
Air Layer- 15 mmRoofWarm Temperate and Temperate	Air Layer- 15 mm	Roof	Warm Temp			0.16
Air Layer- 25 mmRoofWarm Temperate and Temperate	Air Layer- 25 mm	Roof	Warm Temp			0.18
Air Layer- 50 mmRoofWarm Temperate and Temperate	Air Layer- 50 mm	Roof	Warm Temp			0.20
Air Layer- 100 mmRoofWarm Temperate and Temperate	Air Layer- 100 mm	Roof	Warm Temp			0.20
Air Layer- 300 mmRoofWarm Temperate and Temperate	Air Layer- 300 mm	Roof	Warm Temp			0.21
Air Layer- 5 mmRoofCoolTemperate and Cold	Air Layer- 5 mm	Roof	CoolTemper			0.10
Air Layer- 7 mmRoofCoolTemperate and Cold	Air Layer- 7 mm	Roof	CoolTemper			0.12
Air Layer- 10 mmRoofCoolTemperate and Cold	Air Layer- 10 mm	Roof	CoolTemper			0.14
Air Layer- 15 mmRoofCoolTemperate and Cold	Air Layer- 15 mm	Roof	CoolTemper			0.16
Air Layer- 25 mmRoofCoolTemperate and Cold	Air Layer- 25 mm	Roof	CoolTemper			0.17
Air Layer- 50 mmRoofCoolTemperate and Cold	Air Layer- 50 mm	Roof	CoolTemper			0.17
Air Layer- 100 mmRoofCoolTemperate and Cold	Air Layer- 100 mm	Roof	CoolTemper			0.17
Air Layer- 300 mmRoofCoolTemperate and Cold	Air Layer- 300 mm	Roof	CoolTemper			0.17

7.7 ANNEX 7: Construction time Emission Calculation

Study Reference	Year	Baseline Emission Factor (tCO2/m3)
Study- Brick Alternatives	2025	0.1126

Burnt clay brick technology	Specific Coal Consumption (tons/100000		Specific Coal Consumption (kg of coal /kg of fired	
	Range	Average	Weight of Bricks	Kg coal /kg of fired brick
BTK - Fixed Chimney	17 to 24	20.5	300000	0.068
BTK - Moving Chimney	19 to 28	23.5	300000	0.078
High Draft/zig-zag firing	12 to 20	16.0	300000	0.053
Clamp	32 to 71	51.5	300000	0.172
Vertical shaft brick kiln	4 to 16	10	300000	0.033

No. of brick	12400000
In Lakh	124

Burnt clay brick technology	Specific Coal Consumption (tons/100000 bricks)*		Specific Coal Consumption (kg of coal /kg of fired bricks)		Number of Plants (Nx)**	Production capacities (Qx)(100000 bricks/year)**		Weight (kg/brick)	Total bricks (100000 kg)	Total Coal Consumption (100000 kg)
	Range	Average	Weight of Bricks	Kg coal /kg of fired brick		Range	Average			
BTK - Fixed Chimney	17 to 24	20.5	300000	0.068	20000	30-100	65	3	12400000	847333
BTK - Moving Chimney	19 to 28	23.5	300000	0.078	13000	20-80	50	3	12400000	971333
High Draft/zig-zag firing	12 to 20	16.0	300000	0.053	200	30-50	40	3	12400000	661333
Clamp	32 to 71	51.5	300000	0.172	60000	0.5-10	5	3	12400000	2128667
Vertical shaft brick kiln	4 to 16	10	300000	0.033	27	5 - 40	22	3	12400000	413333

Parameter		**Value**	**Unit**
Total Coal Coal Consumption	$FC_{BL\ i\ j}$	212,866,667	ton
Net Calorific Value of Coal*		4,500	kCal/kg
Net Calorific Value of Coal	$NCV_{,j}$	0.018841	TJ/Ton
Emission Factor	$EF_{,CO2,j}$	96.1	tCO2/TJ
Average historical baseline brick requirement rate in units of weight or volume	P_{Hy}	6,200,000,000	Ton
Density of the Brick	d	1.8	ton/m3
Average historical baseline brickrequirement rate in units of weight or volume	P_{Hy}	3,424,178,794	m3
The specific emission factor for the pr	EF_{BL}	0.1126	tCO2/m3

Emission Reduction Calculations CER

Specificic Emission Factor			
$EF_{BL} = \Sigma (FC_{BL\ i\ j} \times NCV_{,j} \times EF_{,CO2,j}) / P_{Hy}$			
Parameter		**Value**	**Unit**
Total Coal Consumption	$FC_{BL\ i\ j}$	212,866,667	ton
Net Calorific Value of Coal*	$NCV_{,j}$	4,500	kcal/kg
Net Calorific Value of Coal	$NCV_{,j}$	0.018841	TJ/Ton
Emission Factor	$EF_{,CO2,j}$	96.1	tCO2/TJ
Average historical baseline brick requirement rate in units of weight or volume	P_{Hy}	6,200,000,000	Ton
Density of the Brick	d	1.8	ton/m3
Average baseline brick requirement rate in units of weight or volume	P_{Hy}	3,424,178,794	m3
The annual production specific emission factor for year y	EF_{BL}	0.1126	tCO2/m3

Project Baseline Emission			
$BEy = EF_{BL} \times P_{PJY}$			
Theproduction specific emission factor for year y	EF_{BL}	0.1126	tCO2/m3
The net production of the facility in year y	$PP_{J,y}$	24,800	m3
The baseline emissions from fossil fuels displaced by the project activity in year y (of the crediting period)	BE_Y	2,791	tCO2
Emission due to Consumption of Biomass		**2%**	
Total Baseline Emission	$\mathbf{BE_Y}$	**2,736**	**tCO2**

Project Emission - Stonewall			
$PEy = (\Sigma EC_{PE,y} \times EF_{CO2\ ELEC,y})$			
Specific Energy Consumption		0.00000	MWhe/m3
Total Volume of the Stone in project		24,800	m3
Total electricity consumption	$EC_{PE,y}$	0.00	MWh
Grid Emission Factor	$EF_{CO2\ ELEC,y}$	0.9	tCO2/MWh
Project Emission due to other factor	PE_y	0.0	tCO2
Total Project Emission	$\mathbf{PE_y}$	**0**	**tCO2**

Project Emission - CSEB Block			
$PEy = (\Sigma EC_{PE,y} \times EF_{CO2\ ELEC,y})$			
Specific Energy Consumption		0.00467	MWhe/m3
Total Volume of blocksrequired		24800	m3
Total electricity consumption by unit in Project	$EC_{PE,y}$	116	MWh
Emission Factor	$EF_{CO2\ ELEC,y}$	0.85	tCO2/MWh
Project Emission due to projects	PE_y	98.4	tCO2
Total Project Emission	$\mathbf{PE_y}$	**98**	**tCO2**

Leakage in CSEB

Total volume of blocks used	24,800	m3
Total Weight of blocks used	49,600,000	kg
% of cement used	4%	of volume
Total amount of Cement used	992	m3
Total amount of Cement used	1428	Tons
Cement Emission Factor	0.825	tCO2/tonne of Cement
Total Leakage Emission	1178.5	tCO2

Emission reductions	$\mathbf{ER_Y}$	**1459**	**tCO2**

7.8 ANNEX 8: Plagiarism Test Result

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