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INSTITUTE OF ENGINEERING  
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**Life Cycle Energy Analysis of An Academic Building (3-C-9 Type Design of  
CLPIU-Education):**

**A Case Study of Kathmandu Valley**

by

**Roshani Subedi**

**A THESIS**

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**DEPARTMENT OF APPLIED SCIENCES AND CHEMICAL ENGINEERING  
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## ABSTRACT

A life cycle energy analysis of a 648.12 m<sup>2</sup>, three-story structure with an expected 60-year life span is undertaken as part of a thorough case study. For the building structure, façade, interior layout, and finishes, an inventory of all installed materials and material substitutions was undertaken. The foundation, structural frames, masonry work, and finishing work account about 22 %, 32 %, 14 %, and 13 % of total embodied energy, respectively. The work of concreting accounts for 59 percent of the total embodied energy. The total embodied energy of the brick masonry is 16 percent. During construction, the material footprint is 1448.77 kg/m<sup>2</sup>. The principal energy usage for cooling and lighting is calculated using computer simulations. The main energy intensity of the building is expected to be  $2.9 \times 10^4$  GJ over its lifetime. The manufacturing of building materials, their transportation to the location, and the construction of the building account for 12.11 percent of life cycle fundamental energy consumption, with operating energy accounting for the remaining 87.89 percent. This clearly demonstrates that energy use is focused in the operational stage of a building throughout its existence. This study demonstrates that life cycle energy analysis of a building can successfully lead to a sustainable and energy efficient building. In a broader sense, building life cycle energy analysis will assist in understanding the energy consumption pattern of a building, which can be used to maintain energy efficiency in the design and construction of the building.

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## LIST OF ABBREVIATIONS

UN	United Nations
SDGs	Sustainable Development Goals
IEA	International Energy Agency
NDCs	Nationally Determined Contributions
HADCM3	Hadley Centre Coupled Model, version 3
CCWeatherGen	Climate Change Weather Gen
CLPIU	Central Level Project Implementation Unit
GDP	Gross Domestic Product
GBRS	Green Building Rating Systems
BREEAM	Building Research Establishment Environmental Assessment Method
LCA	Life Cycle Assessment
EOL	End of Life
ISO	International Organization for Standardization
LCIA	Life Cycle Impact Assessment
HVAC	Heating Ventilation and Air Conditioning
HSE	Health and Safety Executive
DBT	Dry Bulb Temperature
MRT	Mean Radiant Temperature
RH	Relative Humidity
DP	Dew Point
IHG	Internal Heat Gain
SERS	Special Report on Emission Scenario
IPCC	Intergovernmental Panel on Climate Change
TAR	Third Assessment Report
USGS	United States Geological Survey
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
SIDA	Structural Integrity Damage Assessment
NRA	National Reconstruction Authority
MOEST	Ministry of Education, Science and Technology
PCC	Plain Cement Concrete

SWERA	Solar and Wind Energy Resource Assessment
CFL	Compact Fluorescent Lamp
ICE	The Inventory of Carbon and Energy
RCC	Reinforced Cement Concrete

# **1 CHAPTER ONE: INTRODUCTION**

## **1.1 Background**

In order to meet the Paris Agreement and the Sustainable Development Goals (SDGs) of the United Nations, it is essential to decarbonize the buildings and construction sector, which accounts for almost 40% of energy and process-related emissions. But according to the Global Status Report on Buildings and Construction 2019, the sector isn't taking the necessary climate action. The year 2018 saw a 1% increase over 2017 and a 7-percent increase over 2010 in the final energy demand for buildings.

According to the 2019 Emissions Gap Report, we'll have to cut emissions by almost 8 percent a year starting in 2020. The IEA's World Energy Outlook 2019 also found that energy intensity improved at a slower pace (1.2%) in 2018 than it had in the past five years. Both reports stress the necessity for policymakers and investors to take immediate steps. IEA's sustainable development scenario calls for a 3 percent annual decarbonization and energy efficiency increase in buildings in order to meet the SDGs and the IEA's Sustainable Development Scenario.

An opportunity to increase ambition in buildings and construction cannot be missed as the Nationally Determined Contributions (NDCs) required under the Paris Agreement are due for revision. Total 136 nations have included buildings in their Nationally Determined Contributions (NDCs), but few have specified the actions they will take to reduce emissions. As a result, nations must make decarbonization of this essential sector a priority in their new NDCs. This requires a switch to sustainable energy sources, such as solar and tidal. It entails improving the design of the buildings in terms of heating, cooling, ventilation, appliances and equipment. The use of nature-based solutions and approaches as part of the city's eco-system is required to achieve this goal.

## **1.2 Need of the Research**

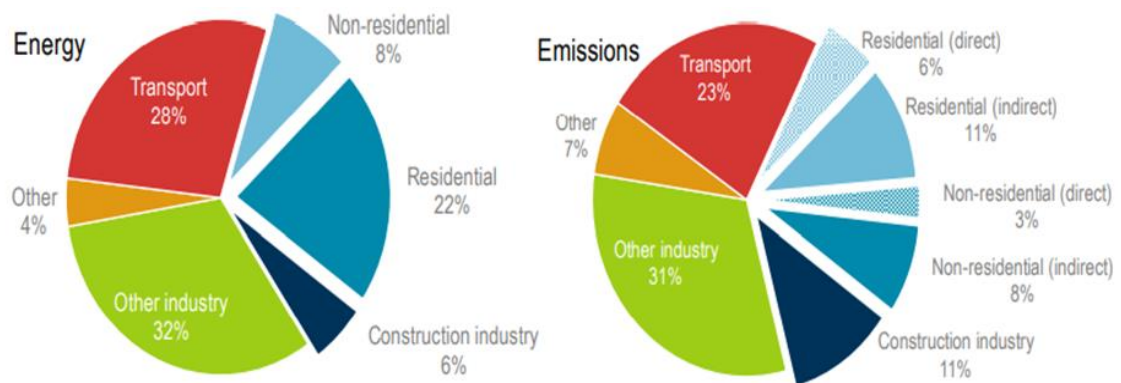
There are very less studies in Nepal on the subject of renewable energy and energy-efficient building construction. Moreover, almost all building construction in Nepal happens without considering energy efficiency, making buildings vulnerable in the case of energy crisis. We can determine the need for a building sustainability rating system in Nepal by analyzing the lifecycle energy of government buildings that have been constructed or are currently under construction in large numbers. In addition to

supporting policy formulation, implementation, and regulation, life cycle-based approaches can also be used to evaluate policies and to evaluate the effectiveness of policies.

### 1.3 Importance of the Research

Commercial space design today incorporates technical, organizational, and behavioral changes to the built environment as a whole. A building's operation and energy costs increase if it's not designed with energy efficiency in mind and the comfort of its occupants. Urban heat islands are outcome of high energy consumption in commercial buildings in industrialized countries (Ruparathna, Hewage, & Sadiq, 2016). So, to maximize efficiency of commercial structures, it is important to conduct an energy analysis and include appropriate guidelines in local ordinances.

### 1.4 Problem Statement



**Figure 1-1 Global share of final energy and emissions from buildings and construction, 2018 (IEA. (2019))**

Globally, the year 2018, has highest share of final energy consumption (36%) and CO<sub>2</sub> emissions (28%) (39 percent when construction industry emissions are included) in the building construction and operations. The building sector's emissions were 9.7 GtCO<sub>2</sub> in 2018, 2 percent increase from 2017 and 7 percent from 2010(IEA, 2019).

Global environmental and human health problems are driving designers, developers, and building users to adopt more environment friendly construction and design techniques. Buildings are difficult to evaluate because they are huge, have complicated materials and functions, and are constantly changing due to the limited-service life of building components and changing user requirements. Quantitative information on environmental impacts of construction materials manufacturing or construction and demolition processes is scarce. Building industry environmental and life cycle energy

assessments are complicated by these factors.

Building energy and water-saving techniques are well-known, as are hazards related to building materials. However, there is a dearth of information on the subject in the context of Nepal. Some of these issues are being addressed in the course of current research efforts.

### **1.5 Research Objectives**

- To conduct lifecycle energy analysis of a contemporary academic building to identify and evaluate the building's energy performance.
- To prepare a directory of all installed and replacement building materials, as well as their operational characteristics.
- To analyze the effects of climate change on the energy performance of building.

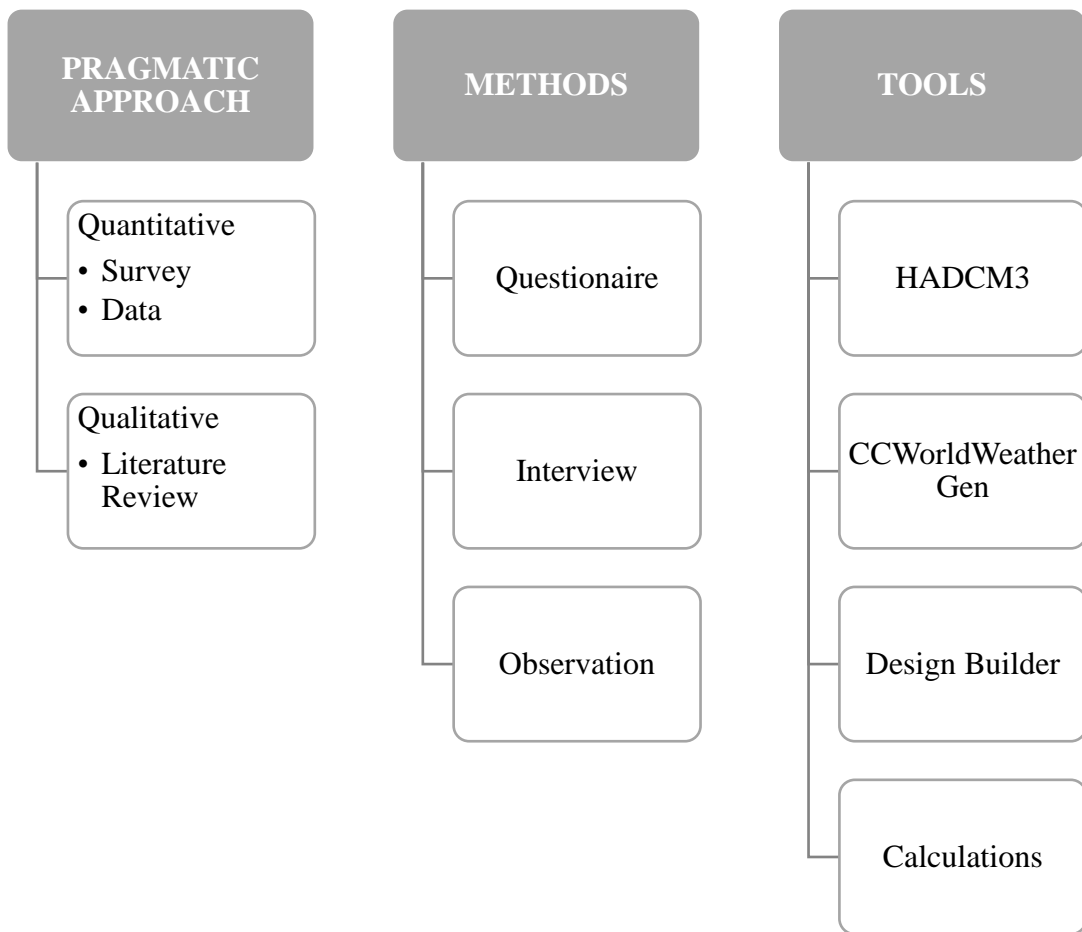
### **1.6 Methodology**

The research has used pragmatic paradigm to conduct the study of life cycle energy analysis of the building. According to Creswell (2003) (Lianga, Qiua, & Hu, 2019) the pragmatic paradigm implies the mixing of data collecting methods and data analysis methodologies.

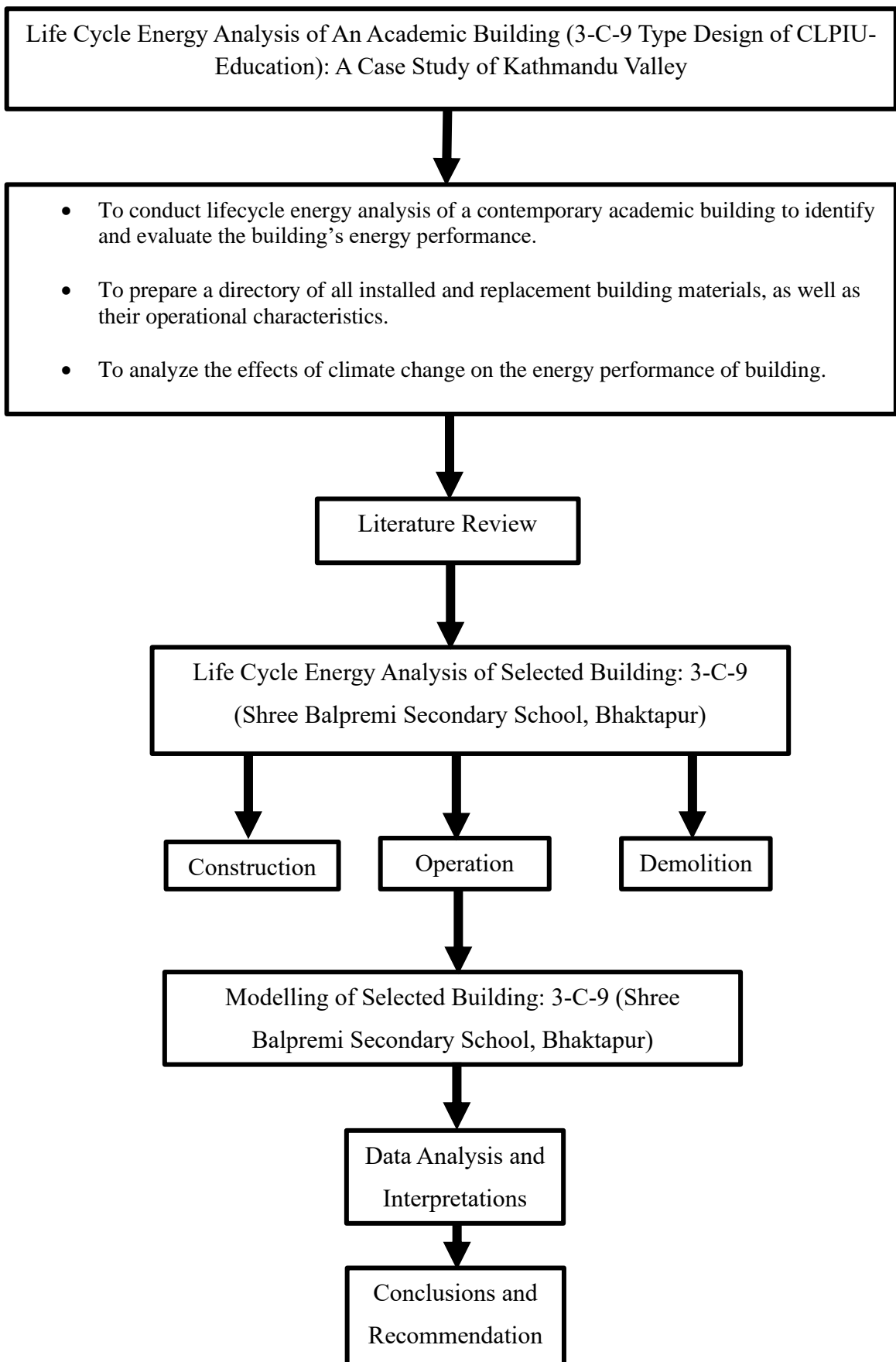
The research objectives were met by employing a combination of qualitative and quantitative methods. Data collection methods, as well as analysis and interpretation methods, have been used.

The study portion have been conducted based on explanatory method through literature review and case study. Explanatory research is often focused with understanding the relationship between things and how they have been in the past and how they will be in the future, therefore it uses a quantitative method. The study examined and assessed the temperature, solar radiation, humidity, and other variable tendencies of meteorological data files, as well as their impact on the building envelope. This qualitative approach also comprises of case studies of buildings and climate change. The next step focused on selection of a case study site and building for data regarding the building materials, size, occupancy, orientation, and other parameters to undergo energy modelling.

Using a positivist approach, this research examines the energy performance of a school's building. The building's energy consumption was modeled using a simulation tool. With Design Builder, simulation research was carried out by calibrating the software with recorded weather data, as well as by evaluating weather data at certain time intervals. In this way, energy performance of a building was observed in a virtual lab with strictly objectified quantitative data. Based on findings from modelling, interpretative approach to building research was taken to propose retrofitting measures. Findings from modeling, as well as findings from background and literature studies, will assist in interpreting necessary energy efficiency measures that can be applied.



**Figure 1-2: Research methodology**



**Figure 1-3: Research framework of the selected building**

## 2 CHAPTER TWO: LITERATURE REVIEW

### 2.1 Background

Rapid worldwide energy consumption has already sparked worries about supply challenges, energy resource depletion, and the environmental consequences of consuming vast amounts of energy. According to IEA, energy consumption trends are threatening. Between 1984 and 2004, energy consumption increased by 49%, while CO<sub>2</sub> emissions increased by 43%, with yearly increases of 2% and 1.8 percent, respectively.

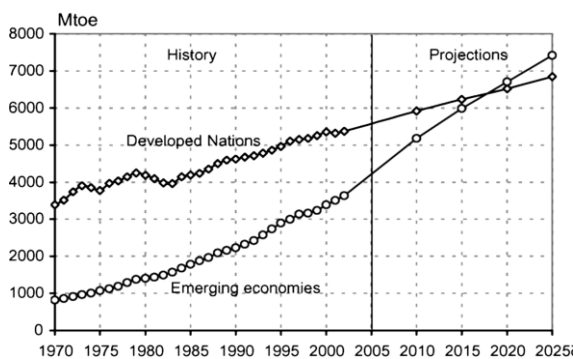


Figure 2-1 : World energy use by region.

Source: IEA

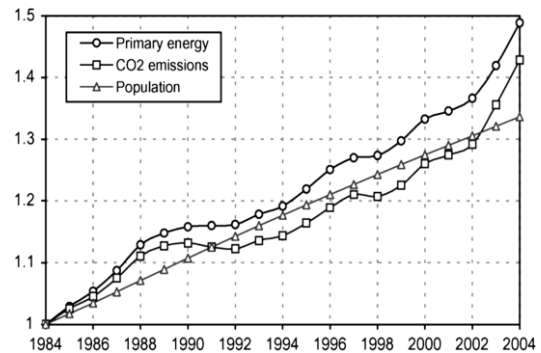
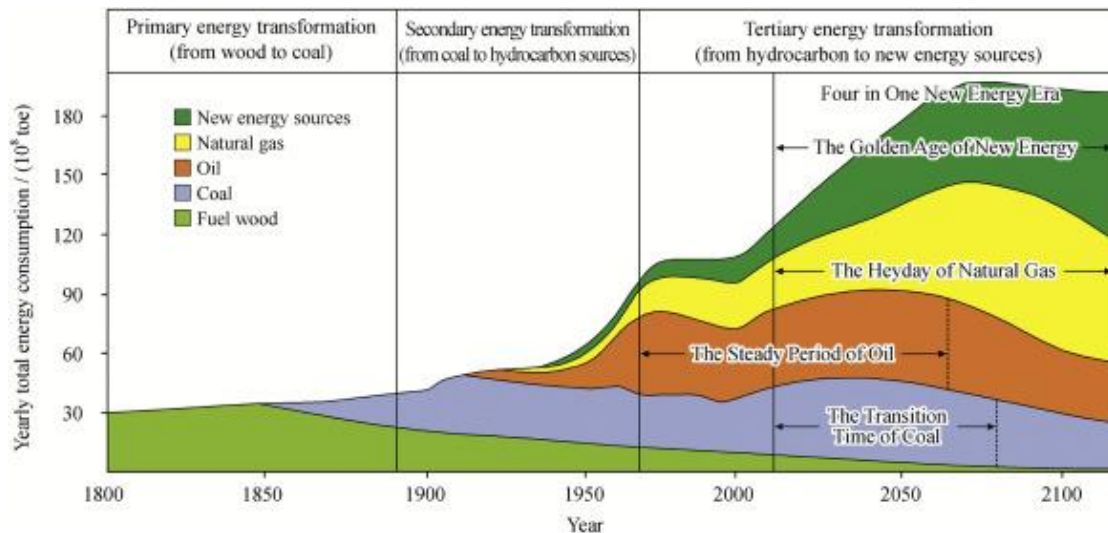


Figure 2-2: Energy consumption, CO<sub>2</sub> emissions and global population.

Source: IEA

It is projected that the increasing trend will continue. The combined energy consumption of Southeast Asia and the Middle East, South America, and Africa's is expected to surpass that of prosperous countries by 3.2 percent by 2020. (Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008)).

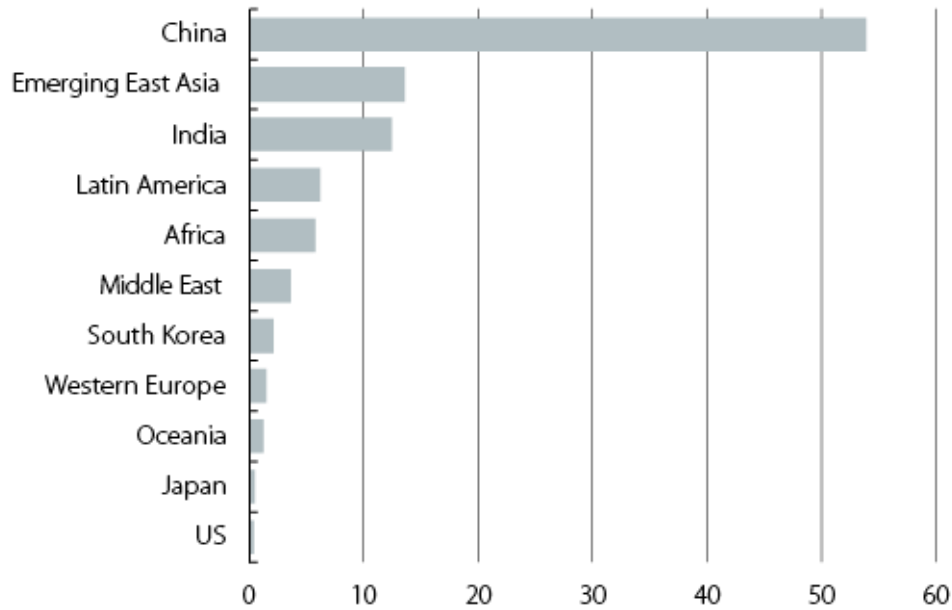
The global energy business is moving from oil and gas to renewable technology, and the world will enter a new age in which oil, gas, coal, and renewable technology will each account for a quarter of the world energy consumption. The following are some of the projections made at the time. To begin with, the oil sector has progressed to a stable level of development. The natural gas business will achieve its pinnacle as well. A transition will take place in the coal industry, too. As time goes on, the field of new energy will reach its zenith.



**Figure 2-3 : Trends and forecast of global energy consumption**

Between 1973 and 2004, the trend of the major global energy indicators revealed some intriguing findings: population growth is well below GDP growth, leading to significant increases in individual income and world's wealth per capita; primary energy consumption is increasing faster than population, resulting in a 15.7% increase in its per capita value over the last 30 years. While energy consumption has increased, CO<sub>2</sub> emissions have grown at a slower rate of 5 %, electrical energy use has increased dramatically (by more than 2 and 1/2 times) resulting in a percentage increase in total energy consumption (18% in 2004), and energy efficiency has decreased by 7%. Final and primary energy intensities have reduced as a result of faster GDP growth than energy consumption growth, resulting in a global improvement in energy efficiency. (Pe´rez-Lombard, Ortiz b, & Pout, 2008).

The figure confirms the relationship between energy consumption, population, and economic growth, and it calls into question global policy's efforts to reverse this trend by enhancing energy efficiency. It is known that globalization, better standard of living in developing regions, and the advancement of communication networks have influenced the lifestyles of developed nations and raised energy demands to levels that will exhaust non-renewable energies (fossil fuels) and have a serious effect on the environment. Energy and socio-economic systems are unsustainable in this sense.



**Figure 2-4 Chart showing global growth in energy consumption from 2018 to 2030**

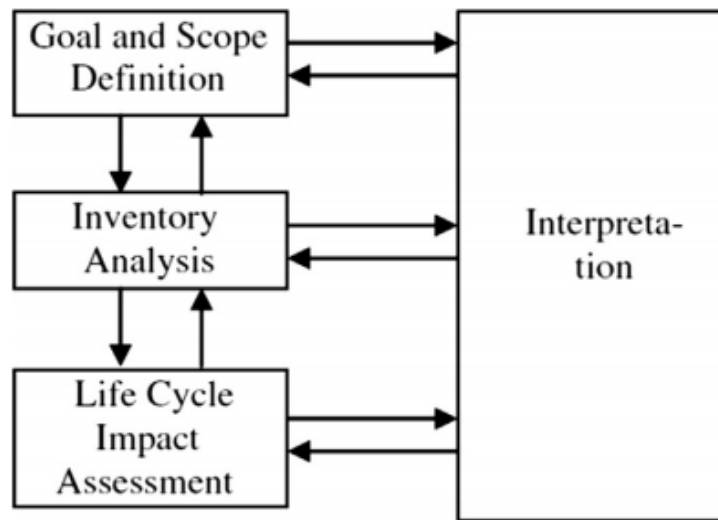
In today's urbanized world, the building and construction being one among the driving engines of worldwide economy, it has become the main concern of sustainability. Green building design applies processes and techniques that are environmentally sensible. There are a variety of green building rating systems (GBRSs) all over the world today. BREEAM came into effect in 1990 for the first time. In green buildings environment friendly and sustainable processes are used in the entire building lifecycle - from site selection to construction, operation, maintenance, renovation and demolition. In spite of this, buildings continue to be a major contributor to climate change (GRIHA manual, Vol I, 2013). Designing buildings should therefore follow a scientific and integrated approach. Energy efficiency in the construction industry is regarded as a critical method for mitigating the impacts of climate change through reduced usage fossil fuels. There is a gap in building assessment in Nepal, especially in terms of vulnerability and sustainability. In contrast to the previous study, which focused solely on climate responsive design and climate change, this research is based on the life-cycle energy calculation of buildings. This strengthens Nepal's need for a sustainability rating system. Built-structures are the primary energy consumers in present day's cities and are responsible for 30 to 40% of total energy and 70% of total electricity consumption (IEA-2016). As a result, the construction industry provides tremendous opportunities for reducing energy consumption through energy-efficient design. Extreme heat and cold, precipitation changes, rising sea levels, and increased storm frequency all pose

serious threats to the construction industry. Many factors influence building performance, including its structure, materials, acoustics and lighting, weathering, thermal comfort, energy (renewables), and resilience to high winds, snow, and rain. A complete energy analysis is required to determine the functionality of a structure in order for it to meet the functional (adaptation) criteria for climate change.

## **2.2 Lifecycle Assessment (LCA)**

Life-cycle assessment is used for analyzing environmental performance of products over their entire life cycle, including raw material extraction, manufacturing, use, and end-of-life (EOL) disposal and recycling. It is an approach that evaluates environmental impacts from the beginning of a product's lifecycle to the end of its lifecycle (Joshi, S. (1999)). The life cycle studies were first developed around 1970s and 1980s. The life cycle studies have focused on quantifying the amount of energy and materials used, as well as the number of wastes released into the environment, throughout the entire life cycle (Sharma, A., Saxena, A., Sethi, M., & Shree, V. (2011)). In the 1990s, the International Organization for Standardization (ISO) adopted an environmental management standard as part of its 14,000 standards series focusing on establishing methodologies for LCA (International Organization for Standardization. (2006)); similar approaches have been adopted by other international organizations (Pelletier, N., Allacker, K., Pant, R., & Manfredi, S. (2014)). For LCA analyses, the ISO standard provides an iterative framework with four steps. The four phases include: goal and scope definition; inventory analysis; life-cycle impact assessment (LCIA); and interpretation (Fig.2-5). It defines the efficient unit, system boundaries, and quality standards for inventory data in the goal and scope definitions. The lifecycle inventory analysis collects and synthesizes physical material and energy flows at various stages of a product's lifecycle. During a life cycle impact assessment, the characterization factor is used to calculate each constituent's contribution to various environmental impact categories (climate change, ozone depletion, acidification, eutrophication, resource depletion, land use and so on). Thus, life cycle interpretation is concerned with the interpretation of the results of both the life cycle inventory analysis and the life cycle impact assessment. Since 1990, life cycle assessment has been used in the construction industry, and it has been used for many years to evaluate product development processes from conception to disposal. LCA has grown in importance as a process for evaluating the environmental impact of construction practices as a result

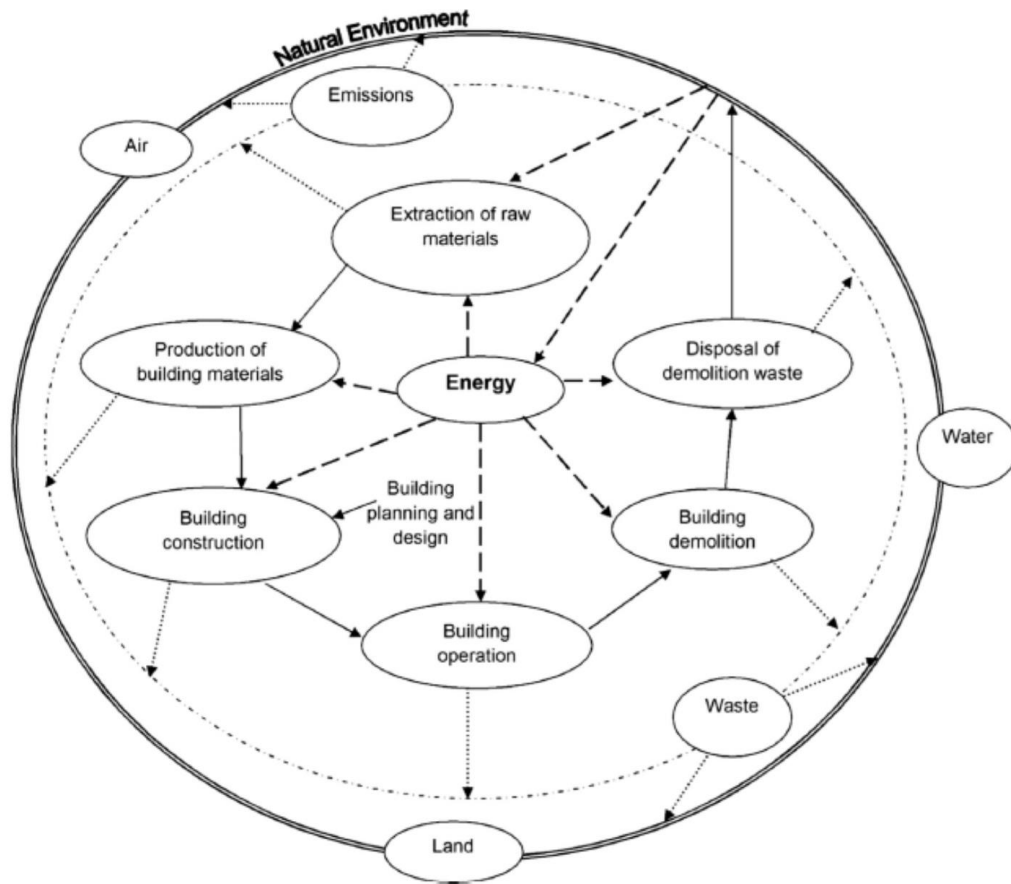
of the current push toward sustainable construction (Ortiz, O., Castells, F., & Sonnemann, G., 2009).



**Figure 2-5 : LCA framework based on ISO 14040:2006**

### **2.2.1 Life Cycle Assessment (LCA) of Buildings**

Since the 1970s oil crises, a key problem in building design and performance has been to reduce the need for operational energy. (Cabeza, L. F., Rincón, L., Vilariño, V., Pérez, G., & Castell, A. (2014)). Increasing regulatory requirements for building energy performance have driven building construction to ever more complicated levels, requiring the use of additional materials and technologies to decrease the energy consumption during operation phase. LCA is an obvious component of building evaluation due to the evolution of buildings toward highly complicated products, combined with the attribute of significantly longer product service lives. In the building applicability, LCAs are principally used to compare various form, layout, or material choices at a specific building stage. The possible effects of innovative design options are compared to the benchmark performance of the specific type of building and use.



**Figure 2-6 : Resources and energy involved in the lifecycle of building (Praseeda, K. I. (2018))**

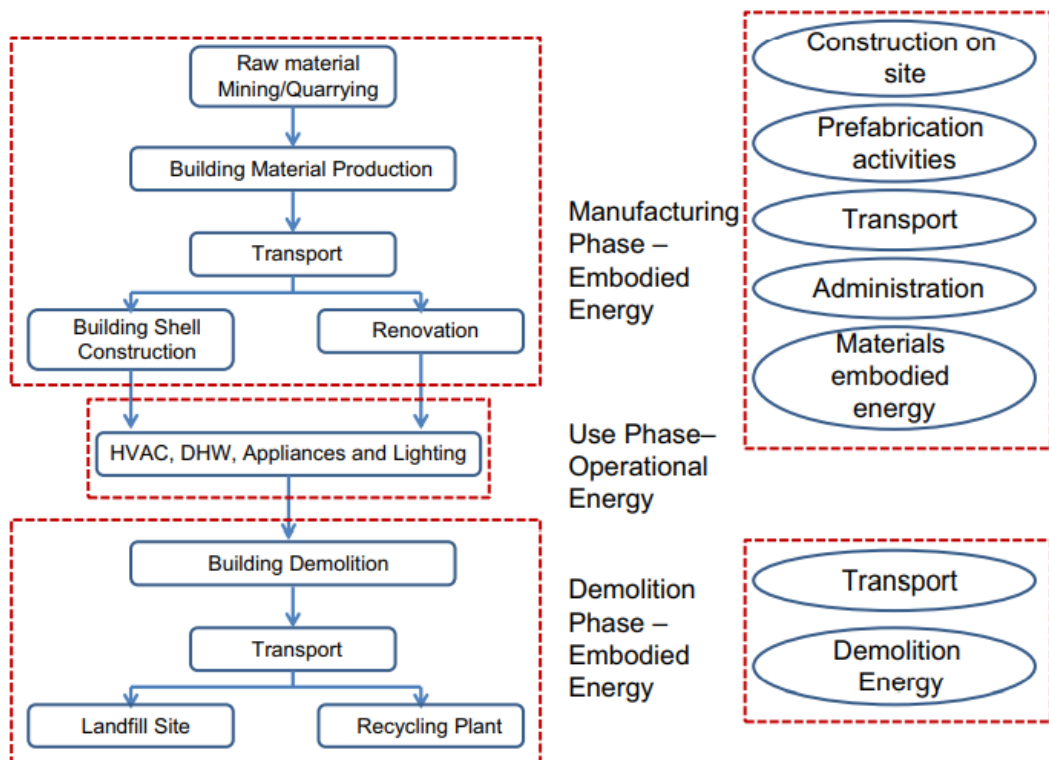
Over the last decade, there has been an increased focus on life cycle thinking, the improvement of building sustainability certification systems (e.g., BREEAM, DGNB), and the parallel development of standards and LCA methodology in general. For example, the ISO/TC 59 SC 17 and European CEN/TC 350 standards series on building and construction sustainability assessment provide harmonized methods for configuring and assessing environmental impacts of a building's life cycle. But it is difficult to compare the environmental impacts of one specific building to another as each building's service life is unique and has different range of specific requirements as:

- Type or purpose of building (e.g., office, hospital)
- Location specific requirements (e.g., related to built environment)
- Technical necessities (e.g., thermal transmittance of building envelope)
- User specific requirements

Though LCAs are done after the completion of design or after the construction, there is common accord in the industry that LCA based decisions should be integrated in the early design phases. In contrast to as-built impact accounting, intervention during the start of design stage will affect the actual form of the structure to increase its energy efficiency. Still, regardless of the time-based focal point for evaluating the environmental sustainability of buildings, a number of issues such as system boundaries and research setup remain unresolved in building LCA practice.

### 2.2.2 Lifecycle Energy Analysis

A life cycle energy analysis is a process of keeping records of all energy inputs over its life (Ramesh, T., Prakash, R., & Shukla, K. K., 2010). This analysis process includes the energy during manufacturing, operation and demolition phases. Materials used during construction and renovations are produced and transported during the manufacturing phase. While the operation phase comprises, all activities associated with the building's usage during its age.



**Figure 2-7: Life cycle energy of a building. Adapted from Ramesh et al.**

These activities include thermal comfort, water usage, and powering appliances. Dismantling and transport of the materials to landfills or salvaging plants are final steps in the demolition process. Life cycle energy includes (Ramesh, T., Prakash, R., & Shukla, K. K. (2010)):

- Embodied energy
- Operating energy
- Demolition energy

### **2.2.3 Embodied Energy (EE)**

Embodied energy is the total energy used for the primary processes that take place in the material's production (direct energy input) and the energy spent on the acquisition of materials and supplies needed for the primary production processes (indirect energy inputs). It is the sum of energy required for the extraction, transportation, production, assembly, disassembly, and disposal of the product (Monahan and Powell, 2011). Depending on the scope of the system, different interpretations of EE in buildings are available (as shown in Table 1).

Different open access institutional, individual and commercial database are the common sources of embodied energy values of different material (Menzies et al., 2007). Table 2 presents the details of the mentioned databases with respect to data features. The EE values in various databases show an extensive range for any particular construction material's embodied energy. The varied EE values of a specific material in different databases are due to differences in manufacturing process, methods of EE analysis, data features and so on. Different researches show that the EE of materials varies significantly over time-period and regions, emphasizing the need of regular update of EE values (Debnath et al., 1995; Cole and Rousseau, 1992).

**Table 1 : Definitions of Embodied Energy from Different Literatures (Dixit et al., (2010)**

Yohanis, Y. G., & Norton, B. (2002).	Energy used to extract, process, manufacture, and transport building materials and components.
Fay, R., Treloar, G., & Iyer-Raniga, U. (2000).	Energy required to provide a product (both directly and indirectly) through all processes upstream (i.e., traceable backwards from the finished product to consideration of raw materials).
Crowther, P. (1999).	Total energy required in the creation of a building, including the direct energy used in the construction and assembly process, and the indirect energy, that is required to manufacture the materials and components of the buildings
Cole, R. J., & Rousseau, D. (1992).	Direct and indirect energy used to manufacture, transport, and install building products, where direct energy is the energy actually consumed in the construction of buildings and indirect energy is the energy consumed in the production of building materials and their associated transportation.

**Table 2 : Institutional Data of Embodied Energy**

<b>Institutional Databases</b>	<b>Data Source and Characteristics</b>
ATHENA Sustainable Materials Institute building material inventory, Canada	Life cycle data estimated using process analysis method
United States Life Cycle Inventory database by National Renewable Energy Laboratory (NREL) (USLCI, 2012)	Database compiled from various sources
Database from Centre for Building Performance Research, New Zealand (NZ) (Alcorn, 2003)	Estimated embodied energy data using process-based hybrid analysis method
Inventory for Carbon and Energy (ICE) developed by University of Bath, UK (Hammond and Jones, 2008)	Embodied energy data collected from journal articles, conference articles, books, life cycle studies, etc.

#### **2.2.4 Operational Energy (OE)**

The operational energy of a building is largely defined by its activity, the climate of the area, the building layout, building material properties, and usage characteristics. In any conventional building, OE accounts for 80–90% of LCE usage. In the literature, there is no strong agreement on which energy elements should be included in OE analysis. It would be absurd to compare OE in buildings based on climate responsive research that only include heating, cooling, ventilation, and lighting, as opposed to other studies that include energy for hot water generation, household electricity, equipment operation, water supply, waste water treatment and so on.

### **2.3 Energy Assessment Methods in Building**

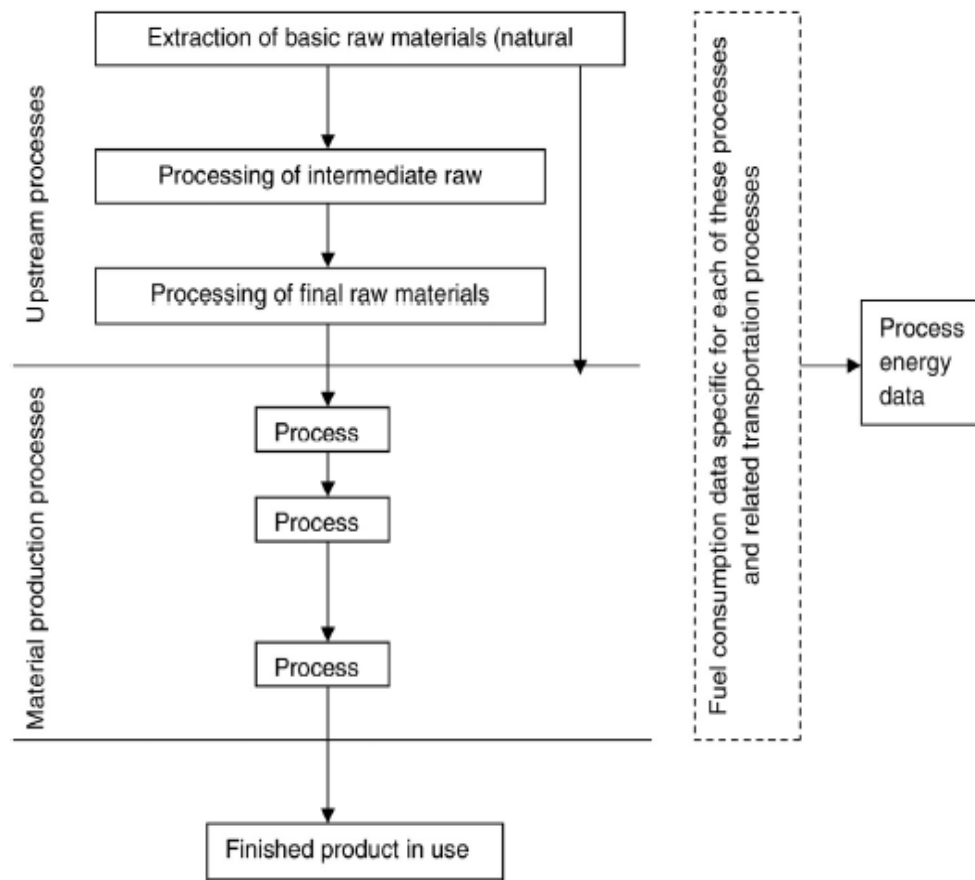
#### **2.3.1 Embodied Energy (EE) Assessment**

EE assessment is critical for quantifying the material and energy consumed during manufacturing, as well as its effects on environment. Materials can be evaluated using a variety of methods, including (Praseeda, K. I., Reddy, B. V., & Mani, M. (2017)):

1. Process analysis
2. Input–output analysis
3. Hybrid methods such as (Menzies et al., 2008; Treloar et al., 2000)
  - Process-based hybrid analysis
  - Input–output-based hybrid analysis
  - Tierred hybrid method
  - Integrated hybrid analysis

Process analysis starts with an evaluation of the direct energy input to the end product and moves upwards by including indirect energy inputs from the upstream process of raw material extraction. Based on the availability of data and knowledge of the complete process, the method entails defining the system boundary. Due to system boundaries, ignoring upstream remote inputs frequently leads to inefficient process analysis. Using input-output tables, the input-output approach was first devised to record financial interactions between different sectors or industries within a country. To quantify energy flows between sectors of the country, this method has been extended by transforming monetary transactions into energy flows based on proportionality

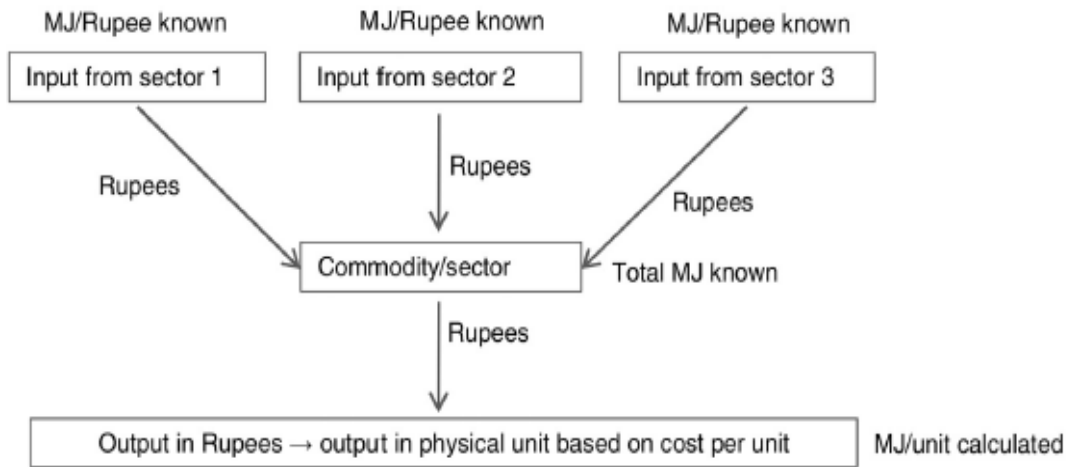
assumptions. The key benefit of this approach is the completeness of the system boundary data, as it includes all of a country's economic operations.



**Figure 2-8 : Process analysis for EE assessment (Praseeda, K. I. (2018))**

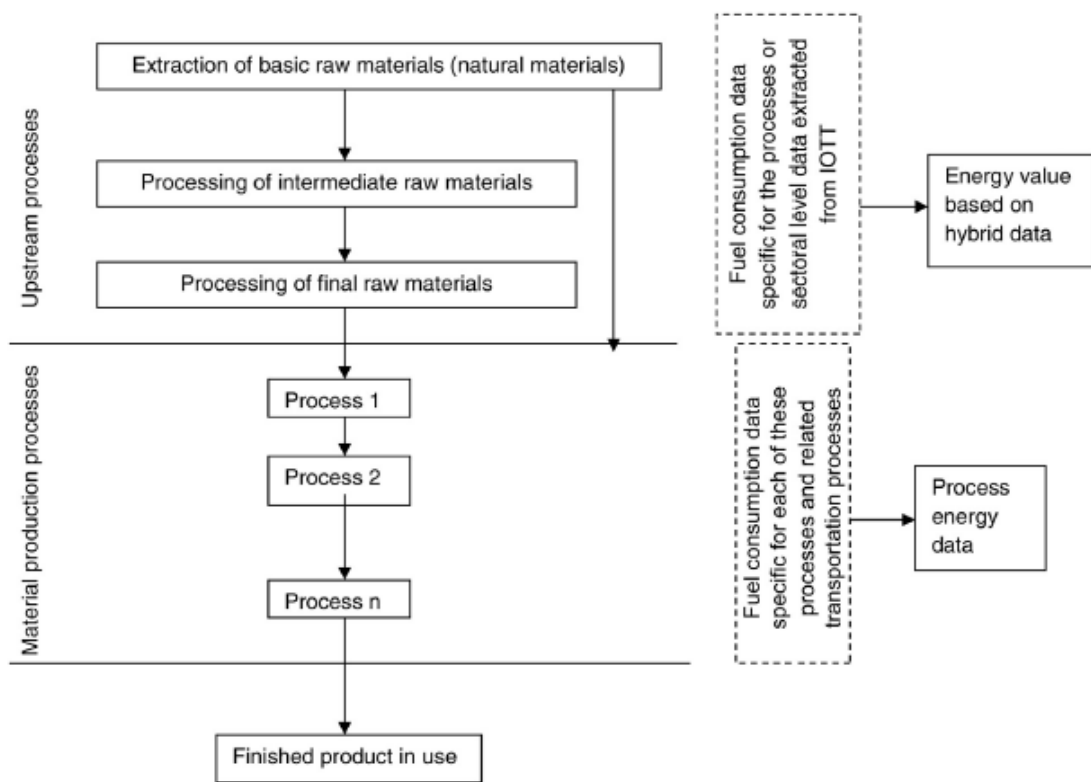
The hybrid energy analysis method overcomes the constraints of the classic method and combines the advantages of the two methods. However, process analysis is considered more suitable for product specific calculations as it can accurately capture direct energy input and upstream level energy input.

Changes and variances in energy and commodity rates have a substantial impact on the input-output approach used for EE evaluation, resulting in changes in energy values over time and between locations. EE calculations for specific items, such as construction materials, are also incorrect due to numerous assumptions made in the I/O approach. The advantage of the input-output technique is that its framework has become increasingly broad, encompassing the entire economy of the region, allowing it to be applied to macroeconomic or sectoral energy flow research.

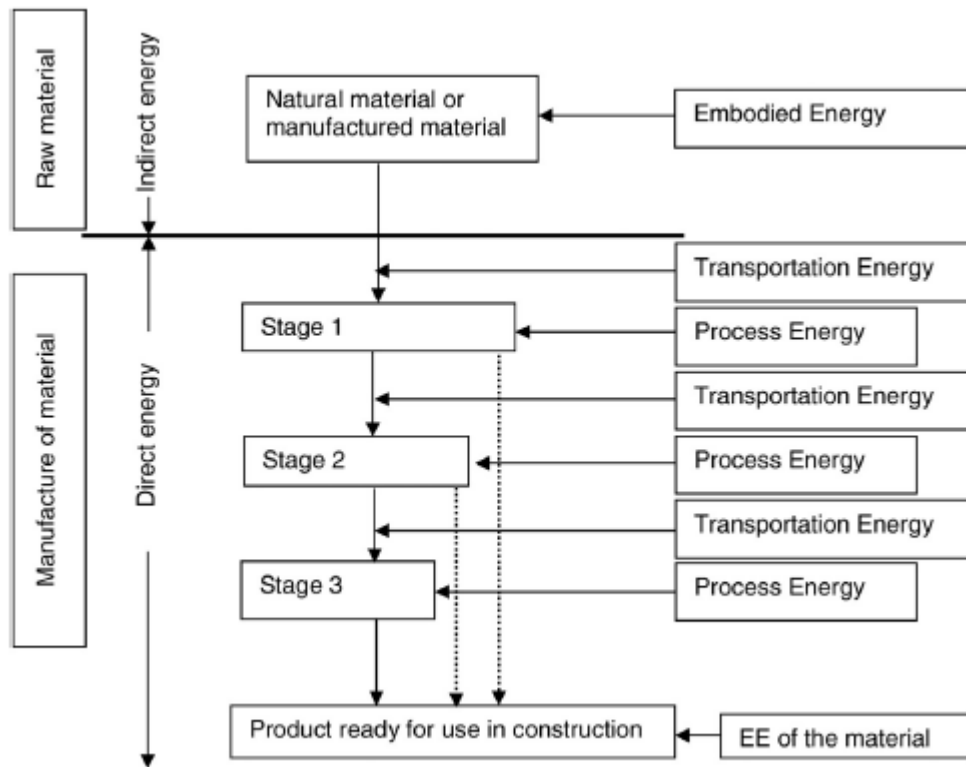


**Figure 2-9 : Input-output methods for EE assessment (Praseeda, K. I. (2018))**

The energy efficiency of building materials calculated using the input-output method is higher than that of building materials based on process analysis (Nassen et al., 2007). However, the increase in EE value predicted using the I / O approach may be inappropriate due to the aforementioned reasons. Figure 2-10 depicts a practical framework based on process analysis.



**Figure 2-10 : Hybrid method of analysis for EE assessment (Praseeda, K. I. (2018))**



**Figure 2-11 : Practical framework for EE assessment (Praseeda, K. I. (2018))**

### **2.3.2 Embodied Energy (EE) Assessment in Buildings**

EE is the total quantity of energy utilized to construct a building, including building materials, transportation energy, and building energy. The largest contribution to EE in structures comes from the EE of construction materials. Building energy efficiency can be controlled by selecting the right building materials based on their individual energy content. Traditional buildings use natural materials that are less energy intensive and have a low EE. Existing conventional buildings have high EE due to the use of energy-intensive manufactured products such as bricks and cement, steel and glass.

The following information about the building is required for an EE assessment:

- Physical measurements of buildings based on real measurements or published floor plans for determining building component volumes.
- Additional working drawings, bills of quantities, work specifications, and other pertinent data

- Information about the various building materials, technology, and procedures used, as well as their origins.
- EE values for a variety of materials.

Manually-processed natural materials have no environmental impact (EE). In rural traditional houses, transportation energy for locally available resources is considered zero because animals are utilized to transport supplies across small distances. Natural seasoned wood and the minimally processed timber-based building are both believed to have an EE of zero. Quantities for distinct work items and specific factors for EE are taken into account while calculating energy efficiency. Construction energy efficiency (EE) is calculated as the sum of all scope of work and their respective EE factors. EE values for residential buildings have been reported to range from 1 to 10 GJ/m<sup>2</sup>. There are two primary categories of residential buildings identified by EE studies: indigenous (found primarily in remote regions) and contemporary (found in semiurban and city areas) based on design concepts and materials used. To establish comfortable living environments, the use of organic, locally sourced materials and the implementation of traditional building design demands the use of lesser resources and energy than traditional building construction and maintenance. Human determination and expertise are important here. They rely heavily on natural energy as opposed to mechanically produced energy. Modern structures have high material and energy usage for building construction and operation due to the widespread use of manufactured construction materials, advanced construction methods, and automated techniques for building operations and users comfort provision.

### **2.3.3 Operational Energy (OE) Assessment in Buildings**

OE in buildings is mainly governed by space heating, cooling and lighting requirements, as well as the weather conditions of the region and the comfort of the building's occupants. Buildings in regions with severe climatic conditions would need more OE to achieve the HVAC energy demands. Traditional houses use passive space conditioning methods to avoid the notions of severe climatic variations and thus need less OE. The use of mechanical systems for space conditioning and artificial lighting result in higher OE in conventional buildings. The particular building architecture, construction materials used, and local environmental conditions all have a major impact on OE in buildings and should all be thoroughly modeled for simulation studies. The

building envelope governs thermal comfort conditions based on the material configuration of its elements and the widespread exposure conditions. A perfect building envelope would passively govern thermal comfort conditions throughout the year, requiring no OE. To accomplish this, the building envelope must be developed properly in terms of orientation, window area, exposed surface area, and building envelope material.

The following methods could be used to assess OE in buildings:

1. As a product of various equipment's power levels, operational time, and a power factor.
2. Proper measurement with energy meters set up in key positions throughout the building.
3. Thermal performance and energy consumption of buildings may be assessed and predicted at the design phase by employing building models (OE simulation tools) and input data on microclimate, building configuration, building products, and occupant attributes.

The establishment of multiple simulation tools for the whole energy performance simulation along with analyzing the performance of service components such as air conditioning (AC), lights, and so on has been achieved by extensive building research over the previous few decades. Building simulation studies help estimate OE for multiple design approaches and comfort requirement possibilities so that solutions for minimum OE can be tested. The geometry and form of a conceptualized or existing building, and the material composition, building services, and occupancy requirements, are all reflected in building models. Simulation tools employ thermal comfort models to compute the number of discomfort hours related to internal heat gain/loss, as well as the energy necessary to maintain the occupants' desired comfort levels. Thermal comfort is typically characterized as an interconnected set of characteristics, such as temperature, humidity, mean room temperature, and wind speed, that are used to determine a comfortable area for the occupant's clothing and activity level. This zone changes by geography and is governed by the occupant's physiological resistance and level of acclimatization. The duration of discomfort and the energy needed to sustain the methods utilized to obtain comfort are used to calculate OE. Existing studies from around the world have yielded OE values ranging from 4 to 59 GJ/m<sup>2</sup> for residential

structures with a life expectancy of 50 years. Buildings are classified as passive houses, net zero energy buildings, self-sufficient houses, and so on based on their self-sufficiency in terms of energy consumption and generation, and EE in these kinds of buildings can range from 40%–60% of LCE.

## **2.4 Thermal Comfort**

Thermal comfort is "the state of mind that conveys satisfaction with the thermal environment," i.e., "the state of being neither too hot nor too cold."

The human thermal environment is complex and thus cannot be quantified in terms of degrees. It cannot be clearly described by allowable temperature gradients, either. It is a subjective experience that differs from person to person, even within the same location, due to a variety of reasons. According to the Health and Safety Executive (HSE-UK), an environment is considered 'reasonable' when at least 80% of its occupants are thermally comfortable. This means that thermal comfort can be tested by interviewing residents if they are satisfied with their existing heating and cooling conditions.

### **2.4.1 Factors Influencing Thermal Comfort**

Thermal comfort is calculated on the basis of environmental and individual factors:

Personal Factors:

- Clothing
- Activity level
- Well-being and sicknesses

Environmental Factors:

- Air temperature
- Air velocity
- Radiant temperature
- Relative humidity (RH)

## 2.5 Operative Temperature

The operative temperature, which is a simple measure of human thermal comfort, is calculated using temperature of the air, mean radiant temperature, and air velocity. It can be useful in assessing the occupants' potential thermal comfort in a building.

Operative temperature is defined as:

$$\text{Operative temperature} = (tr + (ta \times \sqrt{10v})) / (1 + \sqrt{10v})$$

Where

ta = air temperature

tr = mean radiant temperature

v = air speed (m/s)

## 2.6 Dry Bulb Temperature and Wet Bulb Temperature

The dry-bulb temperature (DBT) is a temperature measurement. Because the thermometer bulb is dry, the temperature measured does not fluctuate with the moisture present in the air and is referred to as dry-bulb temperature. Wet-bulb temperature is the temperature recorded by a thermometer with its bulb wrapped in fabric and soaked in distilled water. Wet-bulb temperatures are equal to dry-bulb temperatures at 100 percent relative humidity, but otherwise wet-bulb temperatures will be lower than dry-bulb temperatures due to the cooling effect of evaporation (also known as wet-bulb depression) (Dry-Bulb Temperature, 2020).

## 2.7 Dew Point Temperature

The dew point temperature (DP), is the temperature where a parcel of moist air must be decreased to achieve saturation with constant atmospheric pressure and water vapour content. It can alternatively be described as the temperature at which the absolute pressure of the vapour present in an air parcel equals the saturation pressure under constant atmospheric pressure and mixing ratio. Although it is commonly referred to as the DP of the 'air,' it is a property of the vapour that can be expanded to the 'air parcel,' or the small mass of dry air and vapour taken into account.

From the definition, it is a conservative characteristic of the air parcel in terms of isobaric heating or cooling but without addition or subtraction of vapour (Camuffo, D. (1998)).

## 2.8 Internal Heat Gain (IHG)

IHG can make up a large amount of a building's overall cooling requirement. This is true in the context of non-residential structures (commercial, institutional, and industrial). IHG for lights may be calculated if the kind and quantity of light fittings are available. Electrical components are no exception. Because the degree of activities changes, IHG for people and system loads are estimates.

Internal heat gains (IHG) are a result of a variety of factors:

- Individuals (sensible and latent heat gain)
- Lighting (sensible heat gain only)
- Equipment
  - a) Loads from receptacles or electrical plugs (sensible heat gain only)
  - b) Activities such as cooking (sensible and latent heat gain)

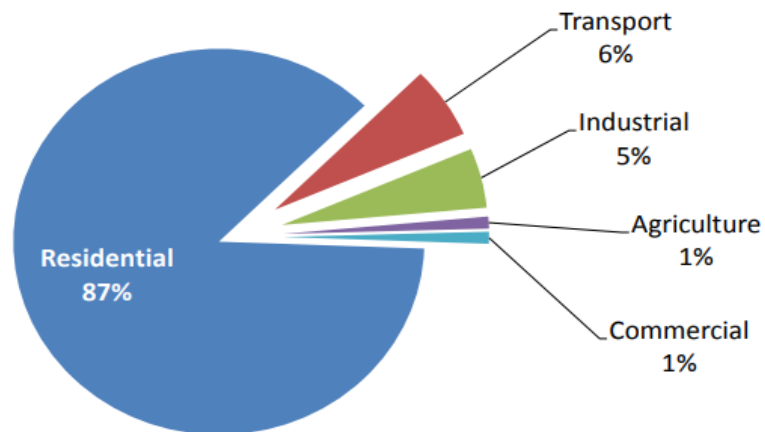
IHG loads are calculated as a percentage of maximum design load for each hour of the year. Internal loads can fluctuate from hour to hour and year to year, just like the hourly weather data that impacts energy loads due to the building exterior, infiltration, and ventilation (Varkie, C. T. (n.d.)).

## 2.9 Weather files generation from HadCM3 future climate data

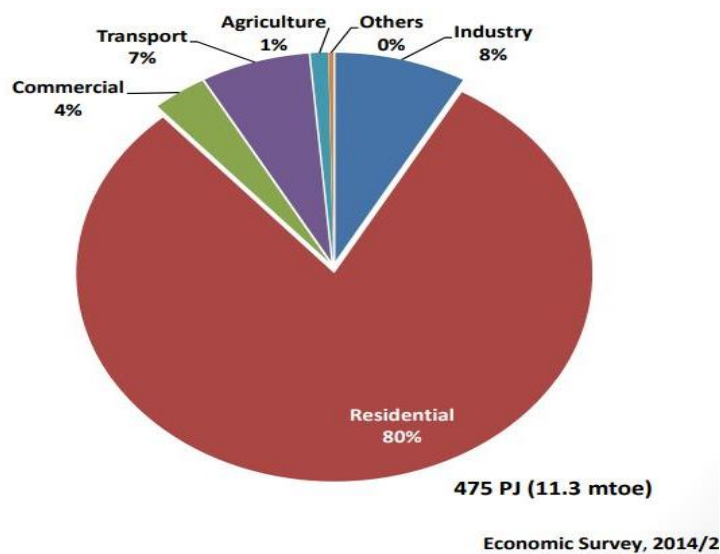
The Hadley Centre Coupled Model, version 3 (HadCM3) was created at the UK's Hadley Centre. HadCM3 contains the HadAM3 atmospheric model and HadOM3 ocean model. It features a 2.5° x 3.75° spatial resolution (latitude by longitude). In this model, the IPCC's Special Report on Emission Scenario (SERS) A2 is utilized, which indicates increased emissions and resulting in high degrees of climate change. Dry bulb temperature, maximum and lowest dry bulb temperatures, horizontal solar radiation, overall sky cover, total precipitation rate, relative humidity, mean sea level pressure, and wind speed are the important factors in HadCM3 for building future weather files. The University of Southampton's CCWorldWeatherGen (SERG 2013) future weather data technology is also applied. The climate change world weather file generator (CCWorldWeatherGen) makes use of IPCC TAR model summary data from the HadCM3 A2 experiment set, which is accessible from the IPCC DDC, to create climate change weather files that can be used in building performance simulation programs. It is based on Microsoft Excel and converts 'current' EPW weather information into climate change EPW or TMY2 weather files that are compatible with

most building performance simulation applications. The fundamental weather file creation procedures of this program are based on Belcher, Hacker, and Powell's morphing technique for climate change modification of meteorological data (Belcher, S. E., Hacker, J. N., & Powell, D. S. (2005)). Additional calculation techniques for generating simulation-ready EPW and TMY2 files are included in the CCWorldWeatherGen program.

### 2.10 Energy Consumption Pattern of Commercial Buildings in Nepal



**Figure 2-12 Sectoral consumption of energy 2010**



**Figure 2-13 Sectoral consumption of energy 2014/15**

The commercial sector of Nepal consumed only about 4% of the entire consumed energy. The residential sector consumed the highest percentage of energy 80% followed by industrial sector 8% and transportation sector 7%. In comparison to the sectoral energy consumption of 2010, the consumption of commercial sector increased from 1% to 4%.

### **3 CHAPTER THREE: RESEARCH CONTEXT**

On April 25, 2015, a powerful earthquake devastated Central Nepal (local time 11:56 a.m.). The earthquake's moment magnitude was Mw7.8, and its epicenter was in Gorkha (approximately 80 kilometers north–west of Kathmandu). The earthquake took place along the Himalayan arc's tectonic junction between the Indian and Eurasian plates (Avouac, 2003; Ader et al., 2012). The earthquake erupted from west to east and also from deep to shallow areas of the weakly descending failure plane, causing significant tremor in Kathmandu and the adjacent towns (United States Geological Survey (USGS), 2015). This was the most powerful earthquake since the 1934 Mw8.1 Bihar–Nepal earthquake (Ambraseys and Douglas, 2004; Bilham, 2004). The mainshock of 2015 devastated a huge number of structures and infrastructure in both urban and rural areas, as well as generating multiple landslides and rock/boulder slides in mountainous locations, blocking highways and hindering rescue and recovery efforts. Furthermore, aftershocks have continued occurring since the major earthquake, with numerous significant aftershocks (e.g., Mw6.7 and Mw7.3 earthquakes in the Kodari region, north–east of Kathmandu) causing additional damage to rural towns and villages in Central Nepal. People and communities in Nepal will suffer severe long-term socioeconomic consequences as a result of the 2015 earthquakes (United Nations Office for the Coordination of Humanitarian Affairs (UN-OCHA), (2015)).

#### **3.1 Reconstruction after Earthquake of 2015**

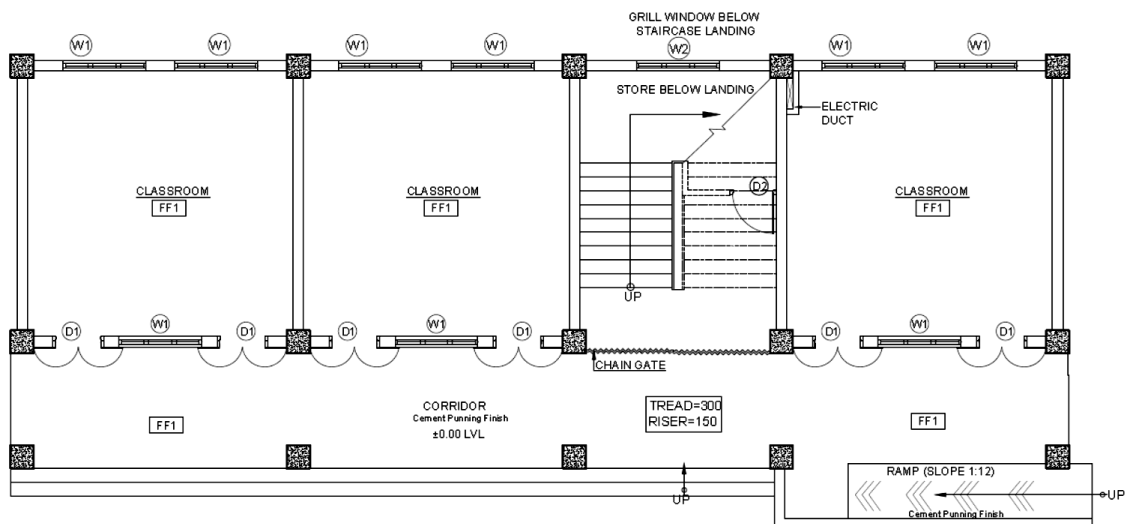
Damages and losses from the disastrous Gorkha earthquake in 2015 were estimated to be worth \$7 billion, with 8,790 deaths, 22,300 injuries, 7,800 schools damaged, and an estimated 8 million people impacted, or over 29 percent of the population (Government of Nepal, National Planning Commission. 2015. Nepal Earthquake 2015).

More than 72 percent of the country's 35,000 educational facilities were deemed dangerous and needed seismic retrofitting. According to the 2016 Structural Integrity Damage Assessment (SIDA), 2,234 schools in 14 districts were seriously affected and are no longer in service as a result of the 2015 earthquake (Government of Nepal, Department of Education and the World Bank. 2016). These institutions were operating out of improvised shelters and lacked basic educational facilities like laboratories, libraries, and information and communication technologies (ICT). They also had very restricted access to basic services like as water, sewage, and power. So, under the

auspices of the Asian Development Bank (ADB), the National Reconstruction Authority (NRA) and the Ministry of Education, Science, and Technology (MOEST) initiated a school reconstruction project involving the reconstruction of more than 150 schools through the central level project implementation unit [CLPIU (Education)]. Several type designs were developed for the reconstruction of those schools in 14 most affected districts.

### 3.2 Selection Criteria for Case

For the reconstruction of school, 7 type designs were developed for school building for classroom purposes whereas 5 separate type designs were developed for toilet block. Among the seven type designs for school building, the type design 3-C-9 is selected for

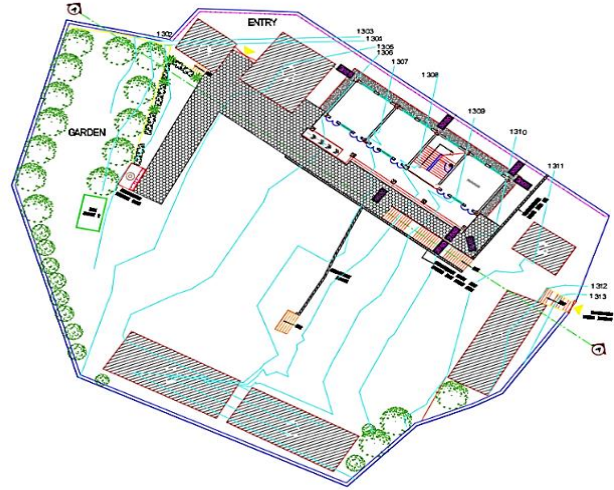


**Figure 3-1 : Ground floor plan of 3-C-9**

90 schools out of which seven 3-C-9 blocks are being built in Kathmandu Valley. The selection of the type design for each school was done based on land available, no of students and no of classrooms needed. The design and structure of the block is identical in every school so the lifecycle energy analysis of single block of one school will help to give an idea about overall energy consumption in other schools also. This will help in analyzing the need of energy efficient design in such national projects. Also, the study can be the solution for the impacts of climate change presents as a profound effect on building energy usages depending on the climatic condition and building characteristics.

### 3.3 Site Introduction

For the research purpose Shree Balpremi Secondary School is selected. It is in Madhyapur Thimi Municipality-4. This school has one 3-C-9 block (fig 4-1) proposed for about 215 students as the some of the existing structures were intact after the earthquake and can be used for educational purpose. The building is extended towards East-West long axis with main entry towards South.



**Figure 3-2 : Master plan of Shree Balpremi Secondary School**

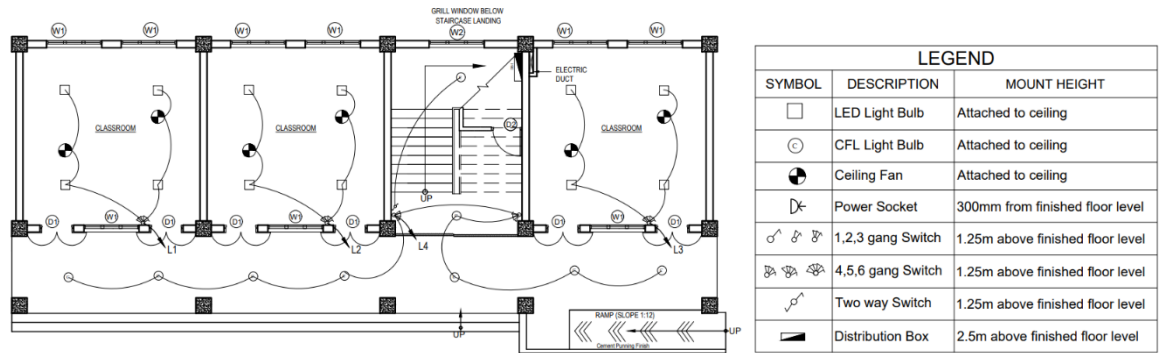
#### 3.3.1 3-C-9

The 3-C-9 is three storied building blocks with three rooms in each floor and has total floor area of 648.12 sq.m. It has rectangular floor plans with similar floor plans at every level. The classroom layout is designed for 20 students (i.e., 1 sq.m. per student) (GON, DOE. (2016)). It is a frame structured building. It has wall made up of brick masonry with thickness of 230mm. Both outside wall and partition wall are of a same thickness. Similarly, the doors and windows are of powder coated metal. The front and back side of the building has total 9 windows and 6 doors in each floor while two side faces are kept bare. Based on the school design guidelines published by government every classroom is provided two doors of 1.1m width opening towards the corridor for earthquake safety purpose. The corridor is 2m wide with stainless pipe for railings.



**Figure 3-3 : 3D views of 3-C-9**

The framed structure is of M20 (1:1.5:3) concrete mix. The floor finish is of 38 mm PCC with cement punning. Likewise, the painting works are of two coats of distemper paints and two coats of weather coat paints. All the rooms of this block are used for classroom purposes and are naturally ventilated. For lighting purpose each classroom has 4 led light bulbs of 24W and two ceiling fans attached to ceiling. The corridors and



**Figure 3-4: Electrical layout of 3-C-9**

staircase is provided with total 8 CFL bulbs each of 12W in each floor as shown in figure 3-4. Power consumption for lighting and each equipment's electrical power requirement are calculated based on based on government school running hours and government holidays.

## 4 CHAPTER FOUR: RESULTS

### 4.1 The Construction Phase

Inventory analysis has been performed by documenting the building structure. The key components are expressed as volumes of constitutive materials; as a result, the 19 most important materials have been examined and shown in table 3 with their respective quantities. The total embodied energy thus calculated for construction phase is 3541.35 GJ.

**Table 3 : Bill of Materials**

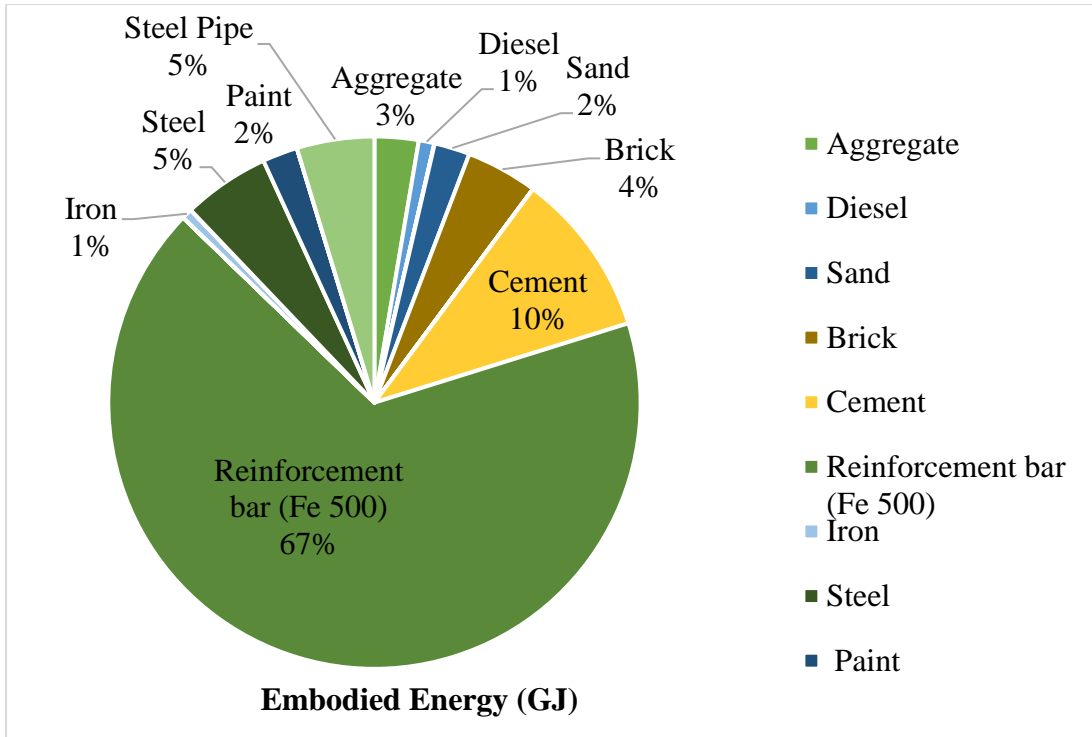
S. No	Material	Unit	Quantity
1	Aggregate	m <sup>3</sup>	432.80
2	Diesel	ltr	1579.37
3	Petrol	ltr	44.01
4	Water	ltr	108253.30
5	Sand	m <sup>3</sup>	444.78
6	Brick	No	72265.05
7	Stone	m <sup>3</sup>	38.17
8	Polyethene Sheet	m <sup>2</sup>	238.41
9	Cement	MT	229.01
10	Reinforcement bar (Fe 500)	kg	75868.61
11	19mm board	m <sup>2</sup>	326.86
12	Local wood	m <sup>3</sup>	4.60
13	Iron pipes (NMB50-M)	No.	87.16
14	Iron	kg	686.49
15	Kota stone	m <sup>2</sup>	338.70
16	Steel	m <sup>2</sup>	391.10
17	Paint	ltr	607.30
18	Glass	m <sup>2</sup>	23.60
19	Steel Pipe	rm	837.82

The building drawings are used to accomplish the quantity calculations for elements such as the foundation, grade beam, column, lintel, staircase, roof slab, masonry work, plastering, painting, flooring, and woodwork. The bill of materials for the 3-C-9 block is shown in Table 3. The quantity and energy coefficients of construction materials are used to calculate the embodied energy of those materials (Thormark, C. (2002)). The embodied energy coefficient of the construction materials used in the computations is shown in Table 4. The embodied energy of materials is determined using the bill of materials (Table 3) and the energy intensity of materials (Table 4). The embodied energy of construction materials for 3-C-9 building is shown in Table 5. The relative contribution of each material is shown in Figure 4-1. Cement, brick, and steel rebar

represent 81% of the total embodied energy of materials. This is comparable with the findings of an earlier study by Pinky Devi, L., & Palaniappan, S. (2019). Sand and gravel account for 5% of total embodied energy, although accounting for a significant fraction of the overall weight of all materials used. The energy use of stone, timber and glass is found to be less than or equal to 1%. The energy intensity of polythene sheet is significantly high compared to cement, rebar and brick. However, the relative contribution of polythene sheet on total embodied energy is less since it is used in less quantity. The material footprint is 1448.77 kg/m<sup>2</sup>. The embodied energy of materials is 2.36 GJ/m<sup>2</sup>. The energy footprint per square meter is in the range of 2360.46 MJ.

**Table 4 : Total Embodied Energy of Building Materials**

S. No	Material	Embodied Energy (GJ)
1	Aggregate	52328.09
2	Diesel	18431.86
3	Petrol	256.40
4	Water	233.96
5	Sand	42263.74
6	Brick	85289.44
7	Stone	18.32
8	Polyethene Sheet	9.11
9	Cement	195730.65
10	Reinforcement bar (Fe 500)	1311244.24
11	Plywood	19.6116
12	Local wood	36.8
13	Iron pipes	72.56
14	Iron	12385.78
15	Kota stone	32.79
16	Steel	103237.67
17	Paint	41775.81
18	Glass	4.41
19	Steel Pipe	92080.22

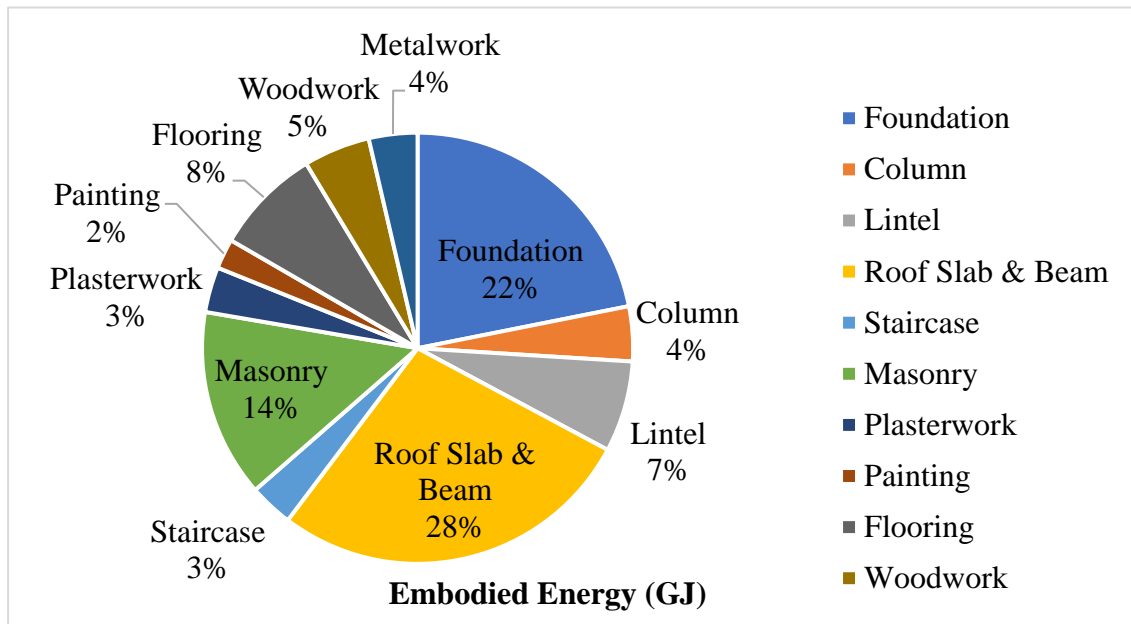


**Figure 4-1 : Relative contribution of building materials**

**Table 5 : Bill of Quantities**

S. No	Building Components	Building Materials	Unit	Quantity
1	Foundation	PCC (1:3:6)	m <sup>3</sup>	16.26
		Concrete	m <sup>3</sup>	106.22
		Sand	m <sup>3</sup>	9.02
		Brickwork	m <sup>3</sup>	11.75
		Reinforcement	kg	17,510.36
2	Column	Concrete	m <sup>3</sup>	39.13
		Reinforcement	kg	6,450.58
3	Lintel	Concrete	m <sup>3</sup>	12.39
		Reinforcement	kg	2,042.49
4	Roof Slab & Beam	Concrete	m <sup>3</sup>	157.40
		Reinforcement	kg	25,947.39
5	Staircase	Concrete	m <sup>3</sup>	18.83
		Reinforcement	kg	3,104.13
6	Masonry	Brickwork	m <sup>3</sup>	103.70
7	Plasterwork	Mortar	m <sup>2</sup>	1,755.35
8	Painting	Paint	m <sup>2</sup>	2,416.39
9	Flooring	PCC	m <sup>2</sup>	136.81
10	Woodwork	Wood	m <sup>2</sup>	133.01
11	Metalwork	Metal	m <sup>2</sup>	105.92

Table 6 presents the bill of quantities of 3-C-9 block. The quantity and energy intensity of building materials are used to calculate the embodied energy of building components.



**Figure 4-2 : Relative contribution of building components**

The total embodied energy of building components as foundation, structural frames (plinth beam, column, lintel, roof slab, and staircase), masonry work, and finishing work (plastering, painting, flooring) is shown in Table 7. The foundation, structural frames, masonry work, and finishing work account about 22 %, 32 %, 14 %, and 13 % of total embodied energy, respectively. The work of concreting accounts for 59 % of the total embodied energy. The total embodied energy of the masonry work is 16 %. The contribution of masonry work is comparatively less as the percentage of opening is more in academic building.

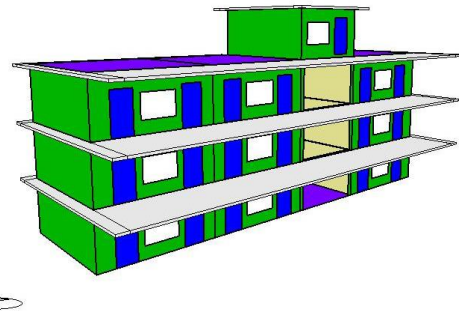
**Table 6 : Total Embodied Energy of Building Component**

Building Elements	Embodied Energy (GJ)
Foundation	619.05
Column	116.46
Lintel	193.34
Roof Slab & Beam	777.72
Staircase	93.04
Masonry	399.67
Plasterwork	96.23
Painting	63.73
Flooring	226.73
Woodwork	141.35
Metalwork	103.23

## 4.2 The Operation Phase

This analysis just looks at the construction, envelope, interior, and electrical appliances of the building. For HVAC analysis only the cooling provided by electrical fan is considered as schools in Nepal lack mechanical heating and cooling systems. The energy mix for cooling and electrical services, and the constitution of material replacements during renovations, are expected to remain constant over the life of the building. The energy analysis for operation phase is done in separate phases. At first the energy analysis for the year 2020 AD is done by energy

126mm reinforced concrete slab with screed  
 Copy of 230mm single leaf brick (plastered both sides)  
 Copy of Solid brick wall, 225 mm, uninsulated Pre 1919  
 Project external door  
 Sgl Clr 6mm



**Figure 4-3 : 3D view of building during simulation**

modelling in design builder software. The effect of the climatic condition was analyzed based on thermal comfort, internal gain and relative humidity.

Since the life span of building is taken 60 years the weather data of 2020 AD is forecasted for the year 2050 AD and 2080 AD using CCWorldGen tool separately. The weather data thus extracted in epw format are simulated respectively in design builder and the climatic effect was analyzed on the building for respective year. The general simulation details obtained from the modelling is presented in the table below.

**Table 7 : General Simulation Details**

	Value
Program Version and Build	Energy Plus, Version 8.9.0-40101eaafd, YMD=2021.07.18 09:25
Run Period	3C9 (O1-O1:31-12)
Weather File	KATHMANDU_INTL_ARPT - NPL SWERA WMO#=444540
Latitude [deg]	27.7
Longitude [deg]	85.37
Elevation [m]	1337
Time Zone	5.75
North Axis Angle [deg]	0
Hours Simulated [hrs.]	8760

### 4.2.1 Case Scenario for 2020

The building is modelled with the weather data for 2020 in design builder. All specifications are as per actual site data collection and conditions. This scenario is modeled with the best possible way to represent the actual findings in the site. From the energy simulation following results were obtained.

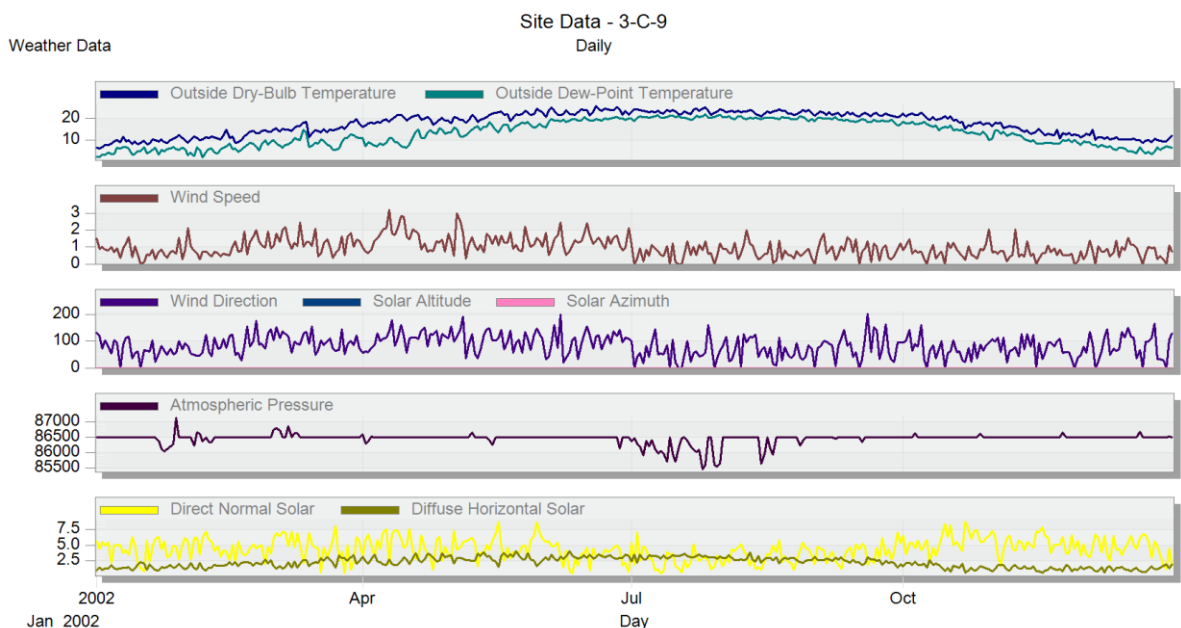
#### 4.2.1.1 Annual energy consumption for 2020

**Table 8: Annual Energy Consumption For 2020**

	<b>Total Energy [GJ]</b>	<b>Energy Per Total Building Area [MJ/m<sup>2</sup>]</b>
<b>Total Site Energy</b>	257.42	746.62
<b>Total Source Energy</b>	323.43	938.08

Table 9 shows the annual energy consumption of 3-C-9 building for the year 2020. The total source energy is 323.43 GJ while energy consumption per square meter is 0.938 GJ. This is similar with the study conducted in US for a University building which was 1.5 GJ/m<sup>2</sup>/year (Scheuer, C., Keoleian, G. A., & Reppe, P. (2003)). Also, the Department of Energy's (DOE) Commercial Buildings Energy Consumption Survey ("Summary Comparison Table") shows 1.0 GJ/m<sup>2</sup> per year for educational buildings (DOE, U. (1998)).

#### 4.2.1.2 Daily site weather data for 2020



**Figure 4-4 : Daily weather data for 2020**

The figure 4-4 shows the daily site data of outside dry bulb temperature, dew-point temperature, wind speed, wind direction, atmospheric pressure and direct normal solar and diffused solar. The outside dry-bulb and dew point temperature is maximum for the month of July which is 23.28 °C and 20.58 °C respectively whereas January has the minimum outside dry bulb and dew-point temperature which is 9.21 °C and 4.25 °C respectively.

The graph of wind speed shows the highest value of 1.54 m/s for the month of April and lowest value of 0.62 m/s for the month of November. The wind direction, solar altitude and solar azimuth angle are represented in degrees. The atmospheric pressure is almost same throughout the year with slight declination in July which is 86098.96 Pa and high in March with 86544.22 Pa. Also, the direct normal solar and diffused horizontal solar are shown in KWh. The maximum and minimum direct normal solar is 175.33 KWh in October and 84.64 KWH in July respectively. Also, the maximum and minimum diffuse horizontal solar is 97.48 KWh in July and 39.43 KWH in November respectively.

#### 4.2.2 Case Scenario for 2050

The building is modelled with the weather data for 2050 in design builder. The weather file is forecasted and changed in epw format using CCworld weather generation tool. The data is then used in design builder for energy simulation. Since the objective of the study is to calculate the life-cycle energy of the 3-C-9 building, no changes in the building is done and the base data of electrical appliances, number of students and building functionality is taken constant. This scenario is modeled with the best possible way to represent the actual findings in the site. From the energy simulation, following results are obtained.

##### 4.2.2.1 Annual energy consumption for 2050

**Table 9: Annual Energy Consumption For 2050**

	<b>Total Energy [GJ]</b>	<b>Energy Per Total Building Area [MJ/m<sup>2</sup>]</b>
<b>Total Site Energy</b>	352.93	1023.63
<b>Total Source Energy</b>	424.25	1230.50

Table 10 shows the annual energy consumption of 3-C-9 building for the year 2050. The total source energy is 424.25 GJ while energy consumption per square meter is 1.23 GJ. The annual energy consumption increased by 31.19% with comparison to the

energy consumption of 2020. All the data used for simulation are BAU. The weather data is updated according to the climatic condition of the year 2050 as per the report published by IPCC. Thus, increase in energy consumption clearly shows that there is increase in cooling load of the building to maintain the thermal comfort inside the room as there is prediction of increase in temperature due to climate change in the future.

#### 4.2.2.2 Daily site weather data for 2050

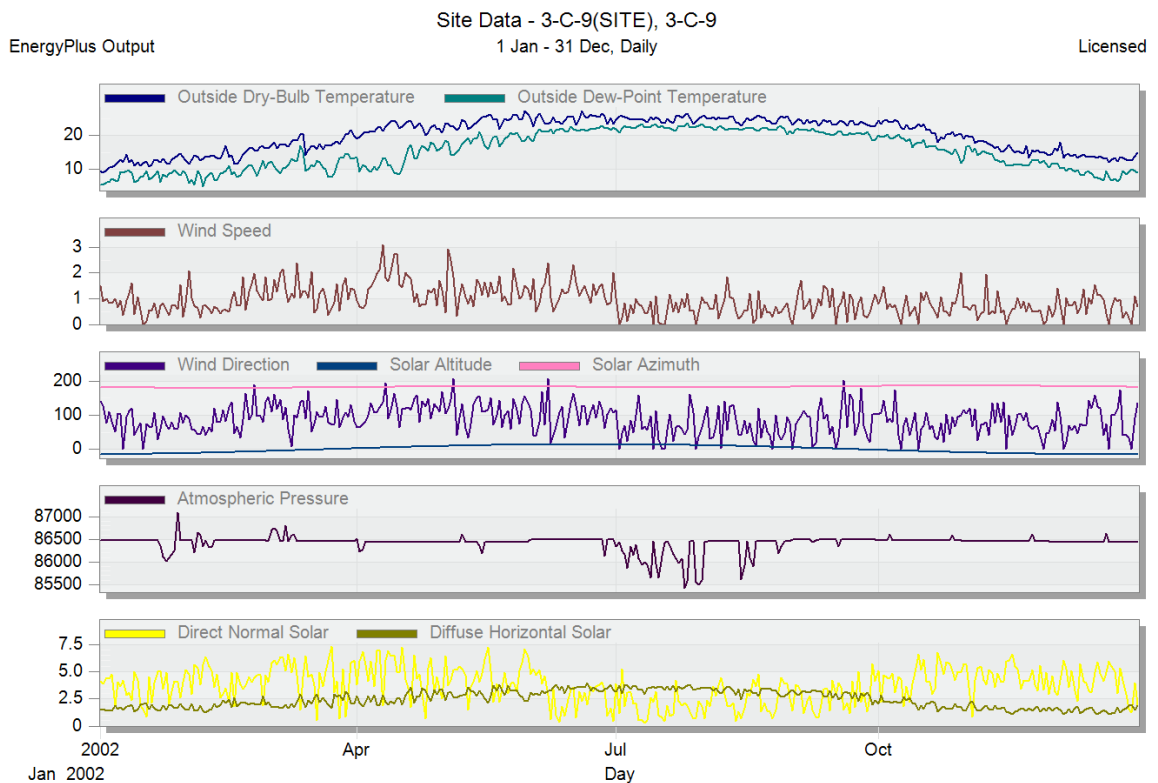


Figure 4-5 : Daily site weather data for 2050

The figure 4-5 shows the daily site data of outside dry bulb temperature, dew-point temperature, wind speed, wind direction, atmospheric pressure and direct normal solar and diffused solar. The outside dry-bulb and dew point temperature is maximum for the month of July which is 24.99 °C and 22.54 °C respectively whereas January has the minimum outside dry bulb and dew-point temperature which is 11.99 °C and 7.78 °C respectively. These data clearly show there is increase in both maximum and minimum dry bulb temperature and dew point temperature in comparison to the data of 2020. This further explains the reason for increase in annual energy consumption for the year 2050. The graph of wind speed shows the highest value of 1.51 m/s for the month of April and lowest value of 0.59 m/s for the month of November. This shows slight decrease in wind speed in 2050 as compared to 2020. The wind direction, solar altitude and solar

azimuth angle are represented in degrees. The atmospheric pressure is almost same throughout the year with slight declination in July which is 86056.28 Pa and high in March with 86505.08 Pa. The maximum and minimum direct normal solar is 146.13 KWh in April and 57.37 KWH in July respectively. Also, the maximum and minimum diffuse horizontal solar is 107.98 KWh in July and 45.33 KWH in December respectively.

### 4.2.3 Case Scenario for 2080

As for year 2050, the building is modelled with the weather data for 2080 in design builder. The weather file is forecasted and converted in epw format for simulation. This scenario is modeled with the best possible way to represent the actual findings in the site. From the energy simulation, following results are obtained. All the base data are according to the year 2020. Only the weather file is changed which is generated using the forecasted climatic data for 2080 using CC weather generation tool.

#### 4.2.3.1 Annual energy consumption for 2080

**Table 10: Annual Energy Consumption For 2080**

	<b>Total Energy [GJ]</b>	<b>Energy Per Total Building Area [MJ/m<sup>2</sup>]</b>
<b>Total Site Energy</b>	440.25	1276.88
<b>Total Source Energy</b>	516.43	1497.86

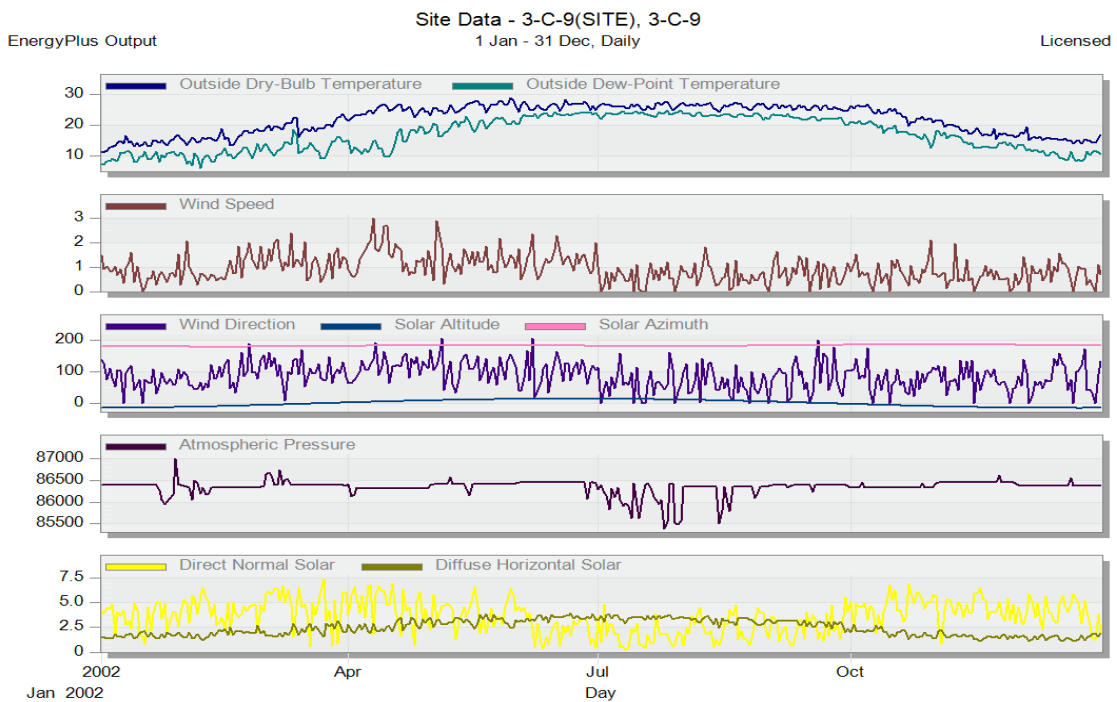
Table 11 shows the annual energy consumption of 3-C-9 building for the year 2080. The total source energy is 516.43 GJ while energy consumption per square meter is 1.49 GJ. The annual energy consumption increased by 59.67% and 21.73% with comparison to the energy consumption of 2020 and 2050 respectively. The increase in energy consumption is due to increase in cooling load to maintain the thermal comfort inside the building as for the year 2050.

#### 4.2.3.2 Daily site weather data for 2080

The figure 4-6 shows the daily site data of outside dry bulb temperature, dew-point temperature, wind speed, wind direction, atmospheric pressure and direct normal solar and diffused solar. The outside dry-bulb and dew point temperature has maximum value of 26.52 °C in August and 23.89 °C in July respectively whereas January has the minimum outside dry bulb and dew-point temperature which is 14.12 °C and 9.62 °C respectively. These data clearly show there is increase in both maximum and minimum

dry bulb temperature and dew point temperature in comparison to the data of 2020 and 2050. This further explains the reason for increase in annual energy consumption for the year 2050.

The graph of wind speed shows the highest value of 1.47 m/s for the month of April and lowest value of 0.58 m/s for the month of July. This shows slight decrease in wind speed in 2080 as compared to 2020 and 2050. The wind direction, solar altitude and solar azimuth angle are represented in degrees. The atmospheric pressure is almost same throughout the year with slight declination in July which is 86030.50 Pa and high in November with 86468.57 Pa. The maximum and minimum direct normal solar is 146.55 KWh in March and 52.51 KWH in July respectively. Also, the maximum and minimum diffuse horizontal solar is 108.41 KWh in July and 45.77 KWH in December respectively.



**Figure 4-6 : Daily site weather data for 2080**

#### **4.2.4 Total Lifecycle Energy for Operation Phase**

The energy consumption for three different years i.e., 2020, 2050 and 2080 are calculated using the software. Since the energy consumption pattern was increasing in the linear way the energy consumption from 2020 to 2080 are calculated by using the trendline equation:

$$y = 3.2167x - 6172.8$$

After the detail calculation using the above equation the total energy consumption from 2020 to 2080 of operating phase is 25692.1 GJ.

### 4.3 The Demolition Phase

Buildings are demolished using energy, and “waste” material is transported and disposed of with energy. The current demolition method needs a lot of energy and transportation to the dump. The most difficult aspect of measuring demolition energy is projecting demolition procedures for the next 60 years or more. We may expect that material scavenging will become more important at that time, and that more attention, effort, and time will be spent removing, classifying, and cleaning items for future reuse or transfer to the materials sectors for recycling. Differentiating between the energy used to move various building elements from the demolition site to their ultimate destination is neither relevant nor suitable. These materials are commonly piled and transported to a shared disposal site, unless only one or two include hazardous pollutants. There are few published estimates on the actual amount of energy used in demolition and the subsequent transportation of recyclable materials and trash. For the demolition of concrete buildings, the US Advisory Council on Historic Preservation recommends 136.2 MJ/m<sup>2</sup> (Maddex, D. (1981). The study does not specify what is included in the demolition process, such as whether it just refers to dismantling or involves transportation. In terms of percentages, these amounts constitute about 1-3 percent of the total embodied energy. As a result, the demolition energy is 106.24 GJ, based on 3% of the initial embodied energy.

### 4.4 Total Energy Consumption

The total life cycle energy (embodied energy, operational energy for 60 years and demolition energy) of the 3-C-9 building is 29339.45 GJ ( $2.9 \times 10^4$  GJ) which is the sum of total embodied energy during construction and total energy consumption during operational years of 60 years. This data is comparable to study done in Northern India on the educational building by Sharma, A., Shree, V., & Nautiyal, H. (2012). The result for that study was estimated to be 26398.33 GJ ( $2.6 \times 10^4$  GJ) for building lifespan of 50 years.

## 5 CHAPTER FIVE: DISCUSSION

From the energy analysis of the building, we can say that the embodied energy during construction stage is 12.11% of the total lifecycle energy while the remaining 87.89% of the total energy is due to operation energy of the building during its lifespan. This clearly demonstrates that energy use is centered in the operating phase of a building throughout its existence. It is also known from the data from different studies which are presented in table 12. The figures in table indicates that commercial structures have more energy usages than residential houses. This is because commercial buildings have more energy consumption through different types of electrical appliances than residential buildings. However, electricity consumption varies, with some commercial buildings consuming less energy than residential buildings. Some commercial buildings operate 24 hours a day, while others may operate for 8–10 hours a day, reducing their energy requirements by up to 50% when compared to buildings that operate 24 hours a day. Furthermore, we know from the literature that the particular design of the building, construction materials employed, and local climatic conditions all have a substantial effect on operational energy, which accounts for around 50-80% of overall life cycle energy. As a result, the primary focus of design should continue to be on enhance the efficiency of the operations phase. For example, design enhancements to the building envelope can dramatically lower accumulated loads despite rising material production and construction costs. These tradeoffs can be quantified using life cycle modeling. Many pressures are alleviated by the preliminary concept, which also determines effective improvement chances. While designers have little control over the outcome after a structure is finished (for example, how it is restored or operated), the early design of a building will set the tone for the rest of its life. (Scheuer, C., Keoleian, G. A., & Reppe, P. (2003)).

**Table 11 : Comparison with Previous Studies**

Reference	Study Type	Country	Area	Service Life (years)	Embodied energy	Operation Energy	Lifecycle Energy
Scheuer, C., Keoleian, G. A., & Reppe, P. (2003)	University Building	USA	7300 m <sup>2</sup>	75	51 x 10 <sup>6</sup> MJ	2260 x 10 <sup>6</sup> MJ	2.3×10 <sup>6</sup> GJ or 316 GJ/m <sup>2</sup>
Sharma, A., Shree, V., & Nautiyal, H. (2012)	School Building	North India	3960 m <sup>2</sup>	50	10 X 10 <sup>6</sup> MJ	15 X 10 <sup>6</sup> MJ	2.6 X 10 <sup>4</sup> GJ
Fay, R., Treloar, G., & Iyer-Raniga, U. (2000).	Residential Building	Australia	128m <sup>2</sup>	50	1803 GJ	38.2 GJ/year	76 GJ/m <sup>2</sup>
Ding, G. K. (2007).	Secondary Schools	Australia	1300-16 000 m <sup>2</sup>	60	72 025 GJ or 7.83 GJ/m <sup>2</sup>	237110 GJ or 0.55 GJ/m <sup>2</sup> /year	3.84 X 10 <sup>5</sup> GJ or 48.95 GJ/m <sup>2</sup>
Muñoz, P., Morales, P., Letelier, V., Muñoz, L., & Mora, D. (2017).	School Building	Spain	222.51 m <sup>2</sup>	75	16.56 GJ/m <sup>2</sup> or 0.22GJ/m <sup>2</sup> /year	0.33GJ /m <sup>2</sup> /year	0.58GJ/m <sup>2</sup> /year
Pinky Devi, L., & Palaniappan, S. (2019).	Residential Building	South India	32.5 m <sup>2</sup>	50	217,897 MJ	541,987 MJ or 0.3335 GJ/m <sup>2</sup> /year.	0.467 GJ/m <sup>2</sup> /year

## 6 CHAPTER SIX: CONCLUSION

The main objective of the study has been accomplished through calculations for embodied energy and simulation results of various scenario cases based on current and future weather files. The qualities of construction materials are responsible for the entire energy consumption of the building during both the construction and operating stages, according to the life cycle energy analysis. Material conduction, solar reflectivity, solar energy transmitted through the window, shading characteristics, and other factors can all help to reduce electrical consumption during the operation phase. The secondary goals are to analyze the effects of climate change on building energy performance, which has been clearly demonstrated by developing charts comparing required energy loads in 2020, 2050, and 2080. According to the comparison chart, the load has increased in later years with the existing building envelope. So, to withstand the effects of future climate the building with more energy efficient designs should be given priority. High-performance facades and technology, building certification, and planning with future upgrades in mind (through flexibility, component-based interiors, and so on) can all contribute to a building's long-term efficiency. Therefore 3-C-9 being a type designs being built in more than hundred school through government project could have been an exemplary example for all. After earthquake, the focus is only shifted to structural stability by government through norms, codes, policies, type designs and building construction and everyone followed it. There is a gap in sustainability and energy conservation. Likewise, now is the time for building guidelines, rating system for sustainable building construction, energy efficient designs as we all can now feel the effects of climate change.

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## ANNEX

### Annex I

#### Building Data Collection Form 1

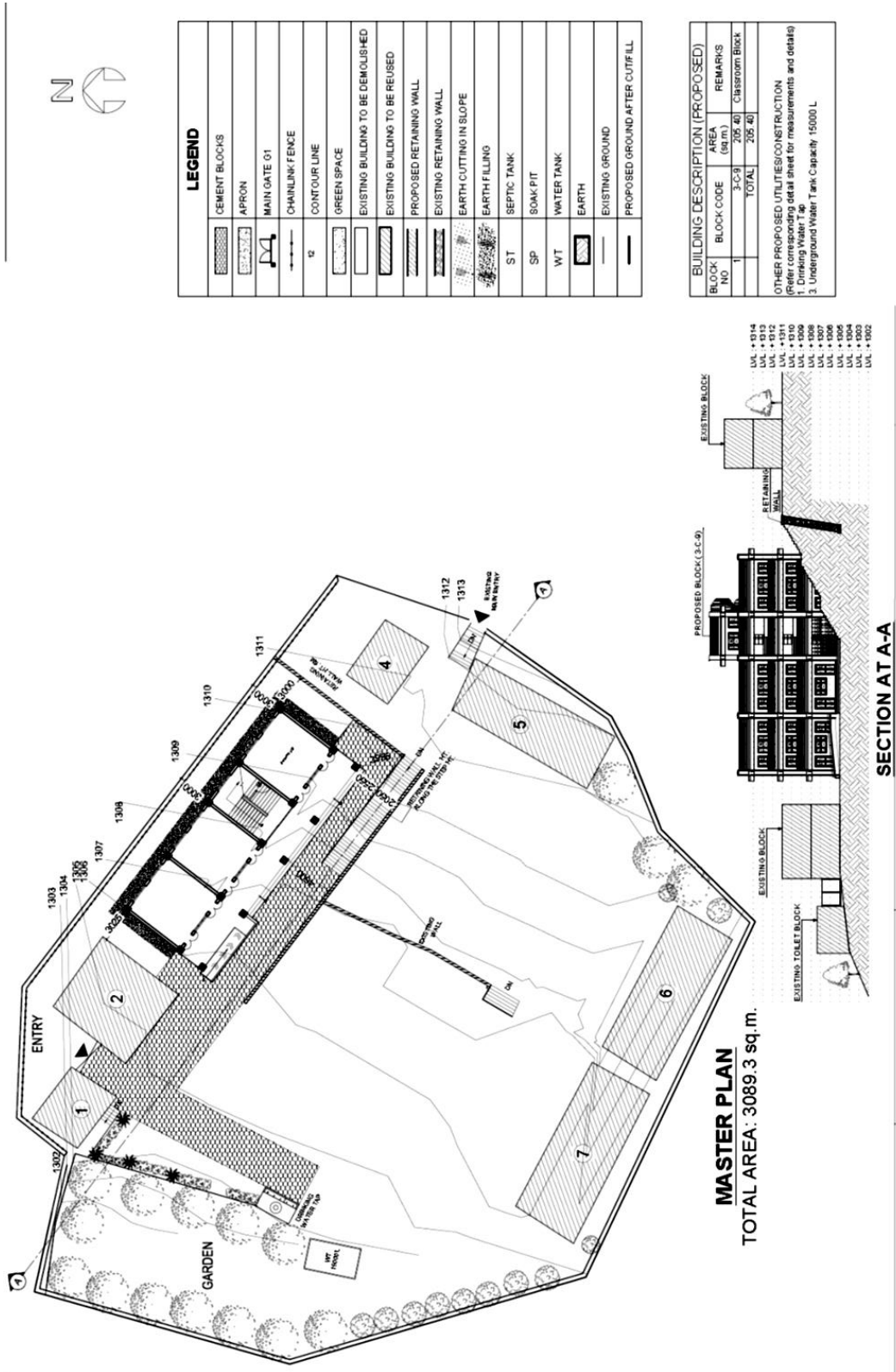
PROJECT INFORMATION		
Contact Person Details	Name	
	Designation	
Type of building		
Working hours		
Working days/week		
Building occupancy		
Area of the building (exclude parking, lawn, roads, etc.)	Built Up Area (sqm)	
	Conditioned Area (sq.m.)	
	Conditioned Area (as % of built-up area)	
BUILDING DOCUMENTS		
Architectural drawings of the building	<input type="checkbox"/> Yes	<input type="checkbox"/> No
Electrical drawings of the building	<input type="checkbox"/> Yes	<input type="checkbox"/> No
HVAC drawings of the building	<input type="checkbox"/> Yes	<input type="checkbox"/> No
Design basis report (HVAC & Electrical Systems)	<input type="checkbox"/> Yes	<input type="checkbox"/> No
Energy simulation report	<input type="checkbox"/> Yes	<input type="checkbox"/> No
Electricity bills for last 1 year	<input type="checkbox"/> Yes	<input type="checkbox"/> No

## Building Data Collection Form 2

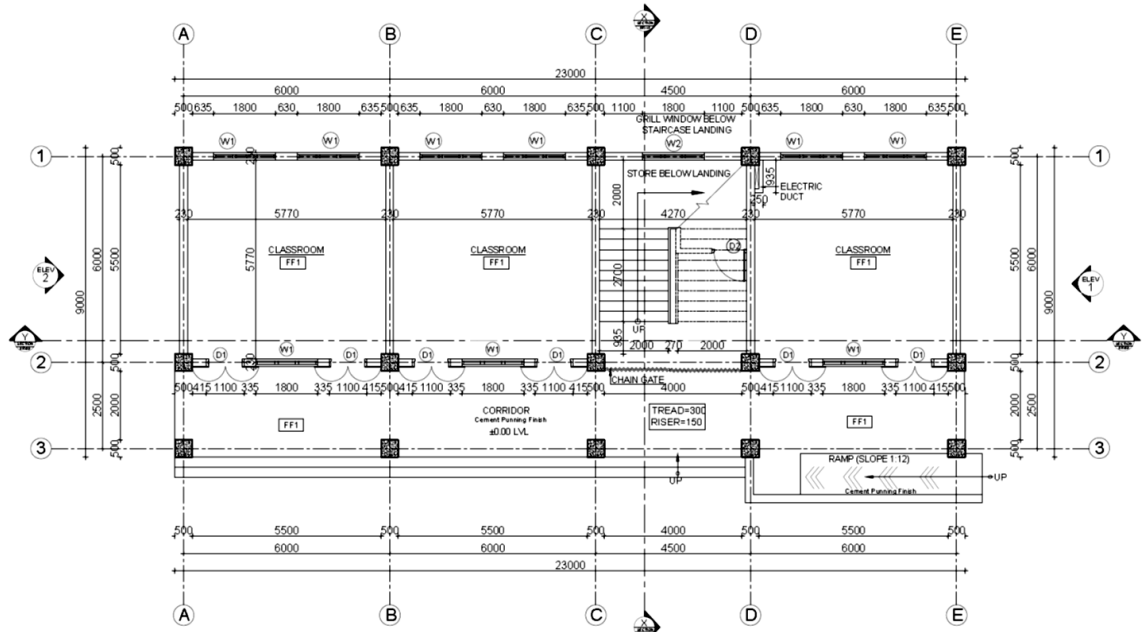
No. of storied	
Construction year	
No of students	
Maximum and minimum no. of students per class	
School holidays schedule	
Functionality of building	
Type of structure	
Exterior finish	
Interior finish	
Flooring	
Fenestration (Glass)?	
Door and windows materials	
Is natural ventilation provided?	
Horizontal shading If provided, projection factor	
Vertical Fins If provided, projection factor	
Roof Insulation details (Type, thickness, finish)	
Wall insulation details (Type, thickness, finish)	
Electrical appliances (type, number, placement)	
Running hour of electrical appliances	

Annex II

Drawings: Masterplan of school



# Drawings: Floor plans of 3-C-9

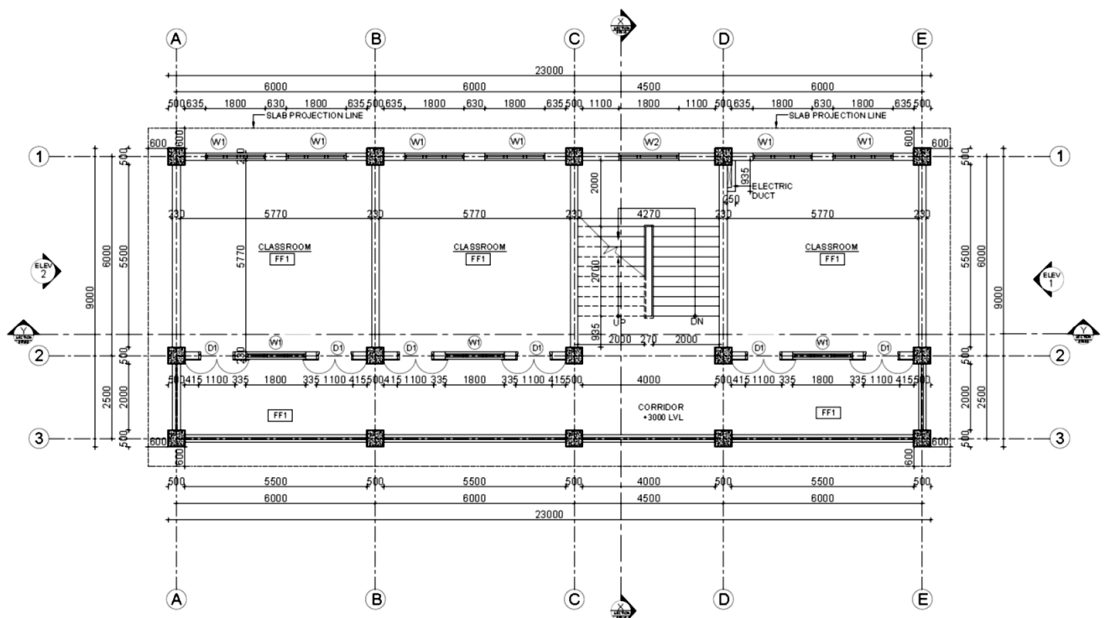


**GROUND FLOOR PLAN**  
PLINTH AREA: 205.40 SQ. M.

- NOTES:**
1. Any discrepancy in the drawing is to be immediately reported to the consultant or Site Engineer.
  2. Drawings are to be read, not measured.
  3. Read the drawing along with other engineering drawings.
  4. All dimensions are in millimeters (mm).
  5. The location of ramps and steps are to be adjusted as per site condition.

**FINISHING DETAILS**

FF1	38 mm PCC (M15) with 1:1 cement punning with floor hardener (Dretop FH, mapetop, Sika Chapdur or equivalent)
FF2	50 mm PCC (M15) with 1:1 cement punning in a 600x600 grid tread cut with floor hardener (Dretop FH, mapetop, Sika Chapdur or equivalent) and water proofing (safe-crete or equivalent)



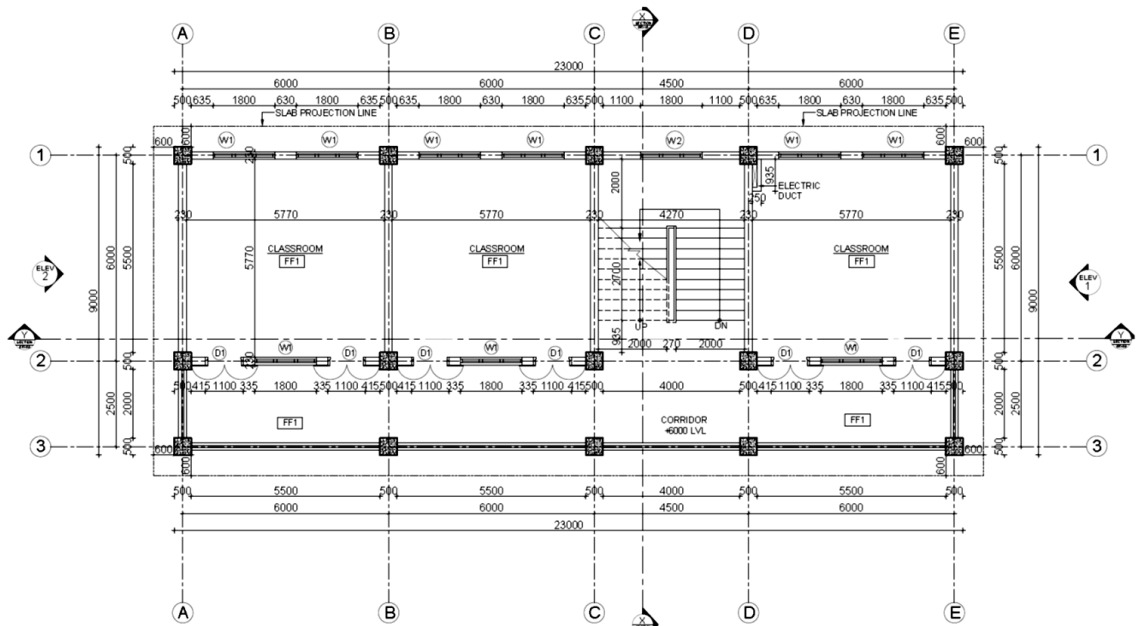
**FIRST FLOOR PLAN**  
AREA: 205.40 SQ. M.

- NOTES:**
1. Any discrepancy in the drawing is to be immediately reported to the consultant or Site Engineer.
  2. Drawings are to be read, not measured.
  3. Read the drawing along with other engineering drawings.
  4. All dimensions are in millimeters (mm).
  5. The location of ramps and steps are to be adjusted as per site condition.

**FINISHING DETAILS**

FF1	38 mm PCC (M15) with 1:1 cement punning with floor hardener (Dretop FH, mapetop, Sika Chapdur or equivalent)
FF2	50 mm PCC (M15) with 1:1 cement punning in a 600x600 grid tread cut with floor hardener (Dretop FH, mapetop, Sika Chapdur or equivalent) and water proofing (safe-crete or equivalent)

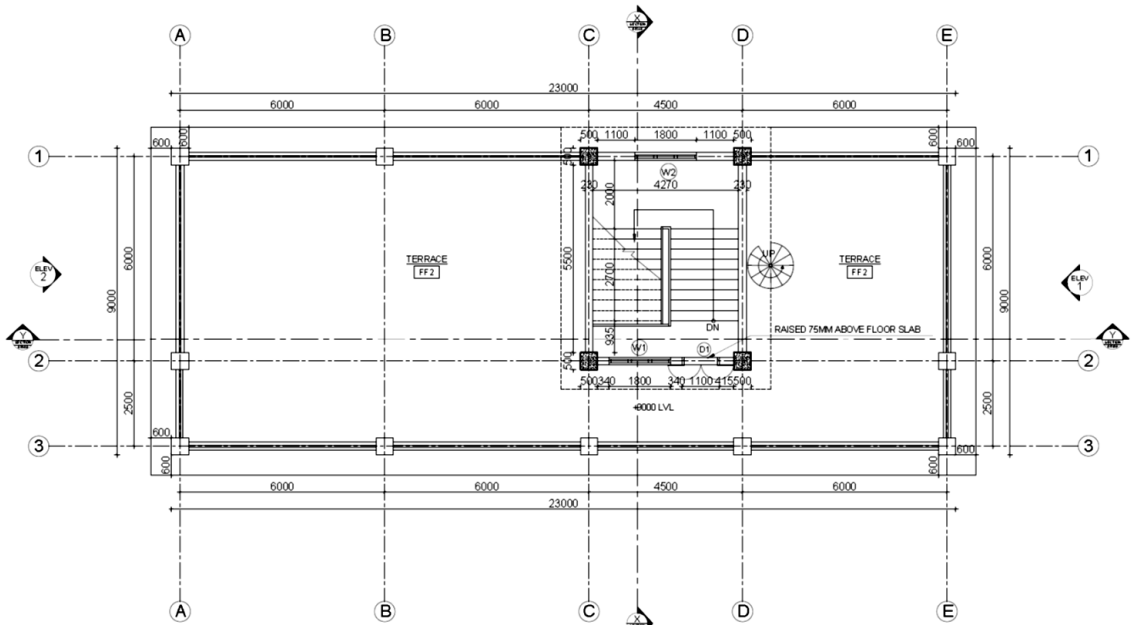
## Drawings: Floor plans of 3-C-9



**SECOND FLOOR PLAN**  
AREA: 205.40 SQ. M.

- NOTES:**
1. Any discrepancy in the drawing is to be immediately reported to the consultant or Site Engineer.
  2. Drawings are to be read, not measured.
  3. Read the drawing along with other engineering drawings.
  4. All dimensions are in millimeters(mm).
  5. The location of ramps and steps are to be adjusted as per site condition.

FINISHING DETAILS:	
FF1	38 mm PCC (M15) with 1:1 cement punning with floor hardener (Drehtop FH, mapetop, Sika Chapdur or equivalent)
FF2	50 mm PCC (M15) with 1:1 cement punning in a 600*600 grid thread cut with floor hardener (Drehtop FH, mapetop, Sika Chapdur or equivalent) and water proofing (safe-crete or equivalent)



**TOP FLOOR PLAN**  
AREA: 31.92 SQ. M.

- NOTES:**
1. Any discrepancy in the drawing is to be immediately reported to the consultant or Site Engineer.
  2. Drawings are to be read, not measured.
  3. Read the drawing along with other engineering drawings.
  4. All dimensions are in millimeters(mm).
  5. The location of ramps and steps are to be adjusted as per site condition.

FINISHING DETAILS:	
FF1	38 mm PCC (M15) with 1:1 cement punning with floor hardener (Drehtop FH, mapetop, Sika Chapdur or equivalent)
FF2	50 mm PCC (M15) with 1:1 cement punning in a 600*600 grid thread cut with floor hardener (Drehtop FH, mapetop, Sika Chapdur or equivalent) and water proofing (safe-crete or equivalent)

**Drawings: Elevations of 3-C-9**

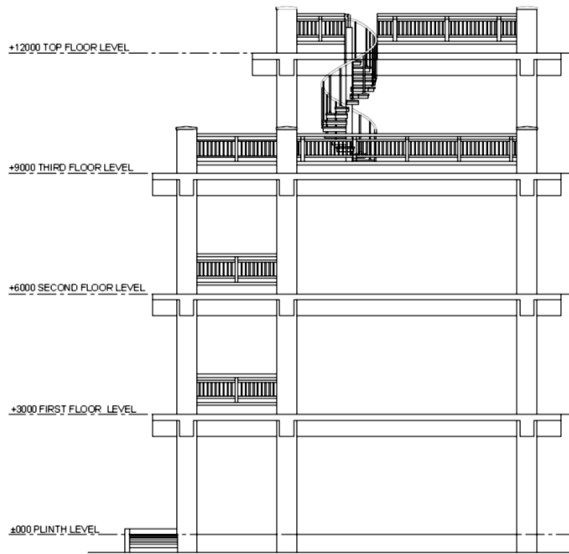


FRONT ELEVATION

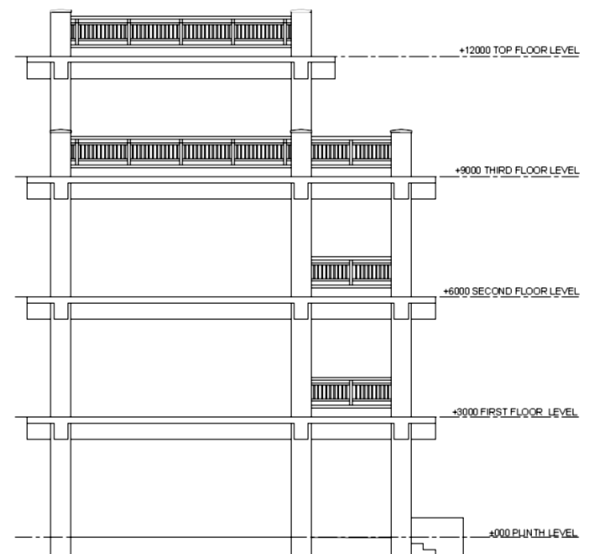


BACK ELEVATION

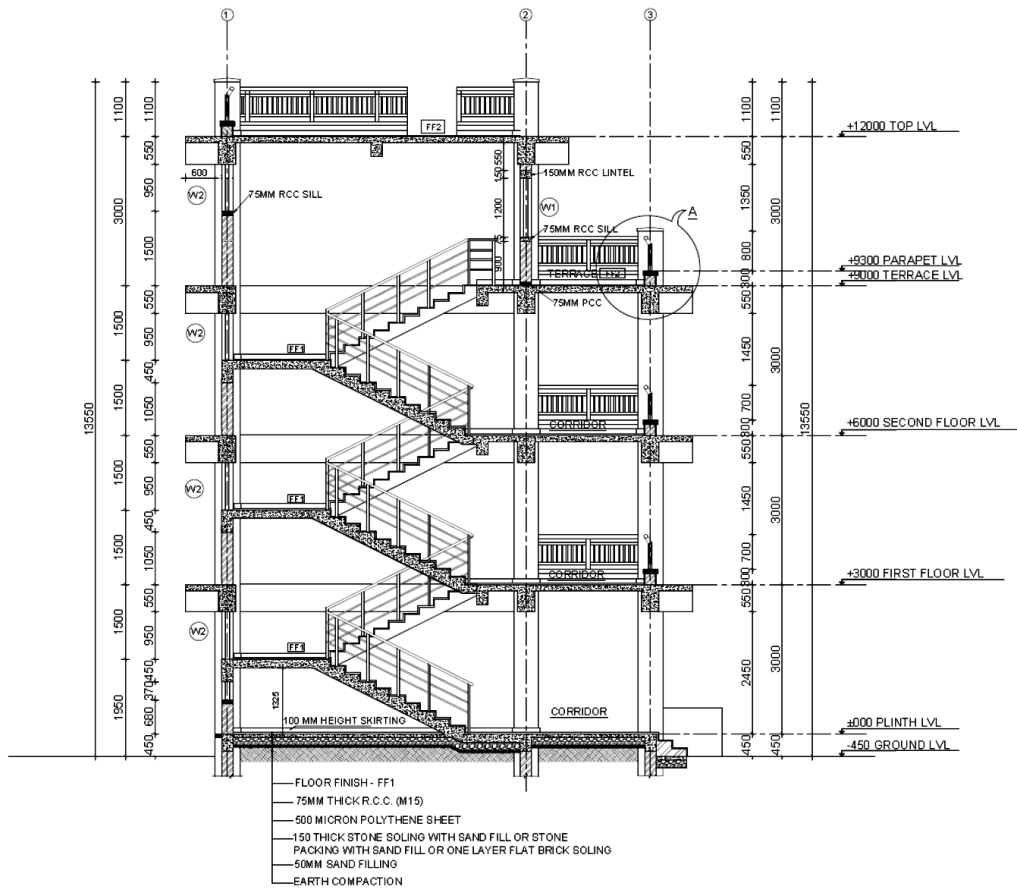
## Drawings: Elevations and section of 3-C-9



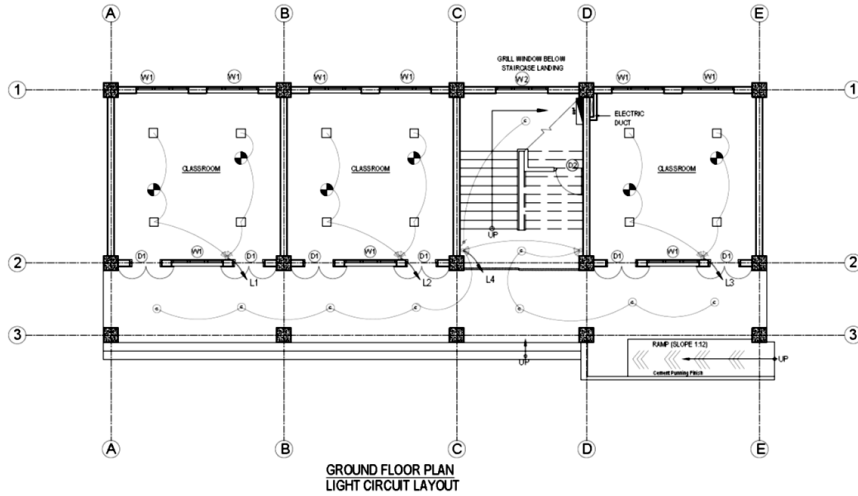
SIDE ELEVATION-1



SIDE ELEVATION-2



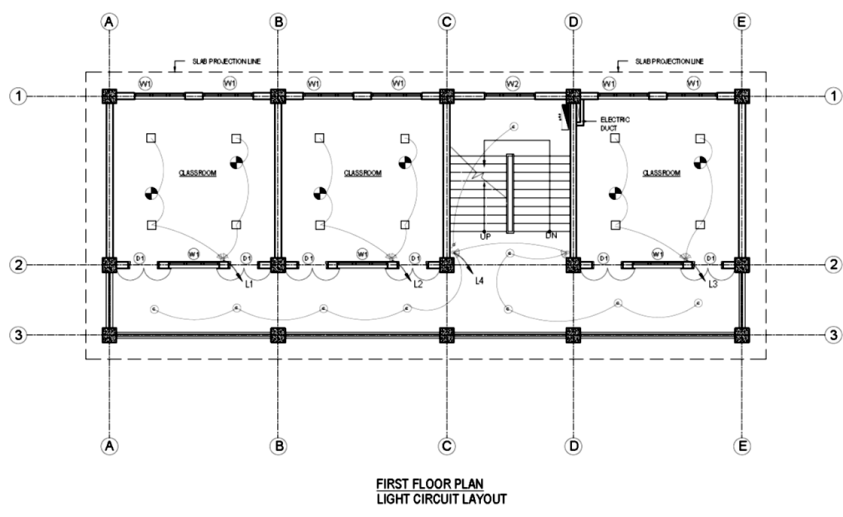
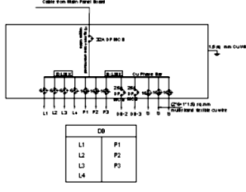
# Drawings: Electrical plans of 3-C-9



- NOTES:**
1. Any discrepancy in the drawing is to be immediately reported to the consultant or Site Engineer.
  2. Drawings are not to be directly measured.
  3. Read the drawing along with other related drawings and coordinate with Architectural and Structural drawings.
  4. The position of ceiling fans are to be adjusted according to secondary beams maintaining clear distance from secondary beams.
  5. No cable ducting shall pass through beam within two times depth of beam from the face of nearest column. It is to be passed through electric duct as shown in drawing.

LEGEND		
SYMBOL	DESCRIPTION	MOUNT HEIGHT
□	LED Light Bulb	Attached to ceiling
○	CFL Light Bulb	Attached to ceiling
⊕	Ceiling Fan	Attached to ceiling
D	Power Socket	300mm from finished floor level
S	1,2,3 gang Switch	1.25m above finished floor level
S	4,5,6 gang Switch	1.25m above finished floor level
S	Two way Switch	1.25m above finished floor level
DB	Distribution Box	2.5m above finished floor level

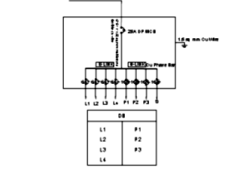
**GROUND FLOOR DB DETAILS**



- NOTES:**
1. Any discrepancy in the drawing is to be immediately reported to the consultant or Site Engineer.
  2. Drawings are not to be directly measured.
  3. Read the drawing along with other related drawings and coordinate with Architectural and Structural drawings.
  4. The position of ceiling fans are to be adjusted according to secondary beams maintaining clear distance from secondary beams.
  5. No cable ducting shall pass through beam within two times depth of beam from the face of nearest column. It is to be passed through electric duct as shown in drawing.

LEGEND		
SYMBOL	DESCRIPTION	MOUNT HEIGHT
□	LED Light Bulb	Attached to ceiling
○	CFL Light Bulb	Attached to ceiling
⊕	Ceiling Fan	Attached to ceiling
D	Power Socket	300mm from finished floor level
S	1,2,3 gang Switch	1.25m above finished floor level
S	4,5,6 gang Switch	1.25m above finished floor level
S	Two way Switch	1.25m above finished floor level
DB	Distribution Box	2.5m above finished floor level

**FIRST FLOOR DB DETAILS**



Annex III

Calculations: Embodied Energy

Table 12 : Embodied Energy Calculations of Sub-structure

S.N	Structural Position	Material	Unit	Quantity	Unit Weight (kg per unit)	Total Weight (kg)	Embodied Energy Coefficients (MJ/Kg)	Embodied Energy (MJ)
1	Sub-Structure	Aggregate	m <sup>3</sup>	91.3492	1600	146158.72	0.08	11692.70
		Diesel	ltr	577.46	0.83	479.29	38.39	18399.94
		Petrol	ltr	10.62	0.75	7.97	32.07	255.60
		Water	ltr	23312.40	1.00	23312.40	0.01	233.12
		Sand	m3	194.30	1840.00	357512.00	0.08	28600.96
		Brick	No	14156.80	2.00	28313.60	3.00	84940.80
		Stone	m3	38.17	1600.00	61072.00	0.30	18321.60
		Polyethene Sheet	m2	238.41	0.46	109.67	83.10	9113.58
		Cement	MT	43.31	1000.00	43310.00	4.50	194895.00
		Reinforcement bar (Fe 500)	kg	17510.36	1.00	17510.36	17.44	305380.68
								<b>671833.98</b>

**Table 13 : Embodied Energy Calculations of Super-structure**

S.N	Structural Position	Material	Unit	Quantity	Unit Weight (kg per unit)	Total Weight (kg)	Embodied Energy Coefficient s (MJ/Kg)	Embodied Energy (MJ)
2	Super Structure							
		Cement	MT	185.70	1000.00	185700.00	4.50	835650.00
		Sand	m <sup>3</sup>	92.66	1840.00	170494.40	0.08	13639.55
		Brick	Nos	876.25	2.00	1752.50	3.00	5257.50
		water	ltr	84940.90	1.00	84940.90	0.01	849.41
		River Sand	m <sup>3</sup>	157.82	1840.00	290388.80	0.08	23231.10
		Crushed agg.40mm down	m <sup>3</sup>	20.21	1600.00	32336.00	0.08	2586.88
		Crushed agg.20mm down	m <sup>3</sup>	198.34	1600.00	317344.00	0.08	25387.52
		Crushed agg.10mm down	m <sup>3</sup>	98.89	1600.00	158224.00	0.08	12657.92
		Diesel	ltr	1001.91	0.83	831.59	38.39	31924.74
		Petrol	ltr	33.39	0.75	25.04	32.07	803.03
		19mm board	m <sup>2</sup>	326.86	4.00	1307.44	15.00	19611.60
		Local wood	m <sup>3</sup>	4.60	800.00	3680.00	10.00	36800.00
		Iron pipes (NMB50-M)	No.	87.16	33.30	2902.43	25.00	72560.75
		Iron nails	Kg	495.24	1.00	495.24	25.00	12381.00
		Reinforcement bar (Fe 500)	Kg	57807.70	1.00	57807.70	17.40	1005853.98
		12mm Aggregate	m <sup>3</sup>	24.01	1600.00	38416.00	0.08	3073.28

		Binding wire	Kg	550.55	1.00	550.55	17.40	9579.57
		Kota stone	m <sup>2</sup>	338.70	64.55	21863.09	1.50	32794.64
		Wire Mesh	m <sup>2</sup>	285.18	0.50	142.59	20.10	2866.06
		Steel	m <sup>2</sup>	105.92	48.49	5136.06	20.10	103234.81
		Primer	LT	202.51	1.30	263.26	70.00	18428.20
		Enamel Paint	LT	18.17	1.30	23.62	70.00	1653.40
		Glass	m <sup>2</sup>	23.60	12.47	294.29	15.00	4414.35
		Alumunium	m <sup>2</sup>	37.73	13.00	490.49	155.00	76025.95
		Washable distemper	LT	197.21	1.57	309.62	70.00	21673.40
		Apex paint	LT	189.41	1.57	297.37	70.00	20815.90
		50mm Pipe	Rm	181.90	6.19	1125.96	25.00	28149.00
		75mm Pipe	Rm	248.16	10.30	2556.05	25.00	63901.25
		25mm Pipe	Rm	407.76	2.94	1198.81	25.00	29970.25
		Steel Plate	kg	221.94	1.00	221.94	25.10	5570.69
		Anchor Bolt	kg	191.25	1.00	191.25	25.00	4781.25
								<b>2526126.98</b>

**Table 14 : Embodied Energy Calculations of Materials**

<b>S.No</b>	<b>Material</b>	<b>Quantity</b>	<b>Unit</b>	<b>Unit Mass</b>	<b>Weight (Kg)</b>	<b>Embodied Energy Coefficient (MJ/Kg)</b>	<b>Embodied Energy (MJ)</b>	<b>Embodied Energy (GJ)</b>
1	Cement	229010	cu.m	1000	229010000.00	4.5	1030545000.00	1030545.00
2	Fine Aggregate/Sand	818395.2	cu.m	1840	1505847168.00	0.08	120467773.44	120467.77
3	Coarse Aggregate/Gravel	607392	cu.m	1600	971827200.00	0.08	77746176.00	77746.18
4	Reinforcement Bar	58358.25	kg	1	58358.25	17.4	1015433.55	1015.43
5	Bricks	30066.1	cu.m	2	60132.20	3	180396.60	180.40
6	Paint	630.61	lt	1.3	819.79	70	57385.30	57.39
7	Steel	105.92	sq.m	48.49	5136.06	20.1	103234.81	103.23
8	Wood	4.60	cu.m	800	3680.00	10	36800.00	36.80

**Table 15 : Interpolation of Energy Consumption Data**

<b>Year</b>	<b>Energy Consumption (GJ)</b>
2020	323.43
2021	328.09
2022	330.87
2023	334.09
2024	337.32
2025	340.54
2026	343.77
2027	347.00
2028	350.22
2029	353.45
2030	356.67
2031	359.90
2032	363.12
2033	366.35
2034	369.58
2035	372.80
2036	376.03
2037	379.25
2038	382.48
2039	385.71
2040	388.93

2041	392.16
2042	395.38
2043	398.61
2044	401.84
2045	405.06
2046	408.29
2047	411.51
2048	414.74
2049	417.96
2050	421.19
2051	424.42
2052	427.64
2053	430.87
2054	434.09
2055	437.32
2056	440.55
2057	443.77
2058	447.00
2059	450.22
2060	453.45
2061	456.68
2062	459.90
2063	463.13
2064	466.35
2065	469.58

2066	472.80
2067	476.03
2068	479.26
2069	482.48
2070	485.71
2071	488.93
2072	492.16
2073	495.39
2074	498.61
2075	501.84
2076	505.06
2077	508.29
2078	511.52
2079	514.74
2080	517.97
<b>Total Energy Consumption</b>	<b>25692.10</b>

