ENERGY EFFICIENCY IN RESIDENTIAL BUILDINGS

Thesis Submitted for the Award of Degree of Doctor of Philosophy in Civil Engineering Department

by

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Dedicated to

My beloved parents, whose guidance is invaluable

CERTIFICATE

This is to certify that the thesis entitled "**Energy Efficiency in Residential Buildings"** submitted by Ms. Shambalid Ahady, Roll no. 2k18/PhD/CE/29 to Delhi Technological University for the degree of Doctor of Philosophy award is a bonafide record of the research work carried out by her under our supervision and guidance. The thesis work, in our opinion, has reached the requisite standard, fulfilling the requirements for the degree of Doctor of Philosophy.

The contents of this thesis, in full or in parts, have not been submitted to any other University or Institute for the award of any degree or diploma.

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DECLARATION

I, hereby declare that this thesis entitled, "**Energy Efficiency in Residential Buildings**", is being submitted to Civil Engineering Department of Delhi Technological University in fulfilment of the requirement of the award of the degree of **Doctor of Philosophy in Civil Engineering** is the original research work of mine and has not formed previously the basis for the award of any degree, diploma or any other similar title or recognition.

Place: Delhi

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ABSTRACT

Despite having abundant natural resources, Afghanistan is not an energy-self-sufficient country; and relies on imported electrical energy from neighboring nations. Increasing population and urbanization further contribute to the rise in energy demand and energy deficiency. Metropolitan areas consume about 70% of Afghanistan's energy accounting for 50% of the country's CO_2 emissions. Moreover, extreme weather conditions trigger more usage of fossil fuels for generating electricity and biomass for indoor heating, which produce higher CO_2 of the total building energy consumption in Afghanistan, residential buildings are the major consumer, with a proportion of 71 %.

Due to extreme climatic conditions in the country, especially the arid climatic zone, a large proportion of energy is consumed for cooling and heating in residential buildings. Such energy consumption practice is further affected by the non-consideration of scientific principles and energy efficiency in building designs. This thesis argues that there is significant scope for improving the energy efficiency of buildings to reduce energy consumption and substantially influence national energy consumption levels. Hence, the research proposes technically feasible energy-saving solutions by improving the energy efficiency of buildings through the design and analysis of realistic and practical approaches. The research also considers the unique challenges regarding awareness, construction practices, and affordability for building energy efficiency in Afghanistan.

The research began by assessing Afghanistan's energy situation and analyzing the climate conditions of the selected regions to outline the external context for the research on energy-efficient building solutions. For this, data were collected from open source and climate portals and analyzed using Climate Consultant and ArcGIS-Earth tools.

Subsequently, five research objectives were identified, covering – (i) identification of characteristics of urban residential buildings and energy consumption patterns; (ii) Determining adaptive summer thermal comfort levels for residents, (iii) Passive solar radiation control strategy for reduction of heating and cooking requirements, (iv) Sustainable energy retrofit plan for apartments, and (v) Analysis of building envelop in the early design stage for improving energy efficiency.

Due to the muti-facet research problem, each objective required a different research method. For the first two objectives, questionnaire surveys combined with statistical analyses, SPSS, and CBE thermal comfort tools were used to understand the external environment, energy consumption patterns, dwelling characteristics, and determining parameters that support building energy efficiency analysis. The last three objectives focused on building energy simulations using the latest energy modeling tools to produce measures for enhancing the energy efficiency of buildings. Different modules of DesignBuilder with EnergyPlus simulation engine were used for simulations. In simulations, the values of the thermal properties of construction materials such as brick and indoor plaster from Afghanistan were obtained through Lab testing in India. All the location-specific data were collected from the city of Mazar-I-Sharif, including case studies of a seven-story residential building and the typical house.

The findings indicate that energy usage in households is affected by dwelling types, and the bulk of the energy is consumed for indoor heating and cooling. The result revealed the neutral temperature in summer was about 27.8°C and the comfort zone (responses in the range of -1 and +1) from 23.6 - 32.1°C. The south has been found to be the optimal orientation to face the building's glazed façade, saving up to 7.4% of cooling and 9.7% of heating energy. Movable shading devices installed on the building's openings in the

summer can reduce the building energy load by up to 19%, with a total energy cost saving of AFN 188448 (USD 2447) annually.

The thesis also proposes potential combinations of building retrofit measures. The research concludes that retrofitting existing apartments can provide substantial advantages and increase buildings' energy efficiency. Further, the study highlights the potential for increasing the energy efficiency of housing by up to 53% by adopting energy-efficient measures for building envelopes in the early design stage. The energy modeling and simulations demonstrated in this study will be a valuable resource for building designers in Afghanistan. The findings from this study will aid in the energy efficiency of Afghanistan’s residential sector and provide valuable references for future building thermal retrofit research and efficient design and innovation.

The thesis makes a novel contribution to the body of knowledge, especially for Afghanistan, by demonstrating energy modeling and simulations in the local context. Practitioners may readily use the thermal properties of local construction materials.

Keywords: Energy Efficiency, building envelope, Energy consumption, Energy simulation, Building and comfort, payback period, Energy, Climate.

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LIST OF ABBREVIATION

ANSI	American National Standards Institute
ANDS	Afghanistan National Development Strategy
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AMD	Afghanistan Metrological Department
BIM	Building Information Modeling
DABA	Da Afghanistan Breshna Sherkat
EEM	Energy Efficiency Measure
EPS	expanded polystyrene
EPW	EnergyPlus weather format
CBE	Center for the Built Environment
CFD	Computational Fluid Dynamics
CSO	Central Statistics Organization
CO_2	Carbon dioxide
CvRMSE	Coefficient of variation of the root mean square error
DABS	Da Afghanistan Breshna Sherkat
DHW	Domestic Hot Water
GHG	Greenhouse gases
GS	Gypsum Soil
HCI	Human Capital Index
HVAC	Heating Ventilation and Air Conditioning
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ISO	International Organization for Standardization
LCC	Life cycle cost
LPG	Liquefied petroleum gas
MEW	Ministry of Energy and water
NEPA	National Environmental Protection Agency
NMBE	Normalized mean bias error NPV Net present value
nRES	Non-renewable energy source
NSGA-II	Non-dominated sorting genetic algorithm

NSIA	National Statistics and Information Authority
nZEB	Nearly zero energy building
PCMs	Phase Change Material
PMV	Predicted mean vote
PPD	Predicted percentage of dissatisfied
PVC	Poly Vinyl Chloride
RES	Renewable energy source
RECR	Renewable energy contribution ratio
RCC	Reinforced Cement Concrete
SHGC	Solar Heat Gain Coefficient
SPSS	Statistical Package for the Social Sciences
STC	Solar thermal collectors
Tn	Thermal neutrality
TSV	Thermal sensation vote
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
USGBC	US Green Building Council
VOC	volatile organic compounds
XPS	extruded polystyrene
WDI	World Development Indicators
WMO	World Meteorological Organization
WHO	World Health Organization
WWR	Window Wall Ratio
ZEB	Zero energy building

CHAPTER 1
INTRODUCTION

1.1 Context

The rising energy demand is a global concern that is being intensified by the need to manage carbon emissions and climate change (Kim and Yu, 2018). The role of buildings in the environmental issue is increasing rapidly. The construction industry is considered one of the biggest consumers of energy, accounting for 36% of end-use energy and 39% of global CO_2 emissions rooted in energy and industrial processes (IEA, 2020; IPCC, 2014). In the construction industry, energy use in residential buildings takes up a large proportion of national energy consumption (Swan and Ugursal, 2009). The primary reasons for the large proportion of energy usage in residential buildings are the cooling and heating required to maintain thermal comfort for occupants (Albatayneh et al., 2017). This highlights that increasing buildings' energy efficiency has enormous scope in reducing overall energy and GHG and ensuring sustainable development.

Due to the apparent advantages of improving energy efficiency, researchers have produced an appreciable amount of literature on building design and modeling, building orientation, thermal properties of manufactured and natural materials, and efficient equipment for active cooling and heating. However, existing knowledge on energy efficiency needs to be adapted to local contexts. This need for local adaptation is rooted primarily in four aspects of buildings – (i) Majority of building materials constituting bricks, plaster, and concrete are local materials. So, there is a need to evaluate the thermal properties of such materials for better-informed designs. (ii) Orientation and design of buildings are subject to sunlight, climate, weather patterns, and altitude. Thus, energy models must be fed with local climatic data to produce sample designs. (iii) Thermal comfort is linked to cultural behavior, customs, clothing, and lifestyle. Hence, levels of thermal comfort must be determined concerning end-users. (iv) Economic status and affordability of the community for whom buildings are being designed must be considered to ensure more acceptable solutions. These factors must be integrated into the building design for better building energy efficiency and residents' thermal comfort.

The research presented in this thesis was motivated by an acute need to adapt the latest knowledge and technology for the construction of buildings in Afghanistan. Moreover, to fully appreciate the context of research and the challenges that were needed to be addressed, it is imperative to briefly analyze the major characteristics of Afghanistan in terms of climate, energy status, developmental trends, building characteristics, housing energy patterns, and comfort.

Afghanistan, a landlocked country with a population of 31.7 million (NSIA, 2019), is located in South Asia. It is one of 47 nations categorized as least-developed nations by the International Monetary Fund (IMF) (WEO, 2018). The UNDP categorizes Afghanistan as a developing nation (UNDP, 2019). Moreover, the country is classified as having a low-income level by the WDI (World Development Indicator), with an HCI of 0.39 (WB, 2019a). In addition, with an HDI score of 0.496 (Fantom, N.J.; Serajuddin, 2016; UNCTAD, 2017), and a global GDP per capita of $579, Afghanistan is placed 170th out of 189 countries (UNCTAD, 2019)(NEPA, 2017). Although the per capita of electricity usage in the country is 178 kWh, which is one of the lowest consumers globally (GIZ, 2017) Yet, the country's total net greenhouse gas (GHG) emissions (as of the year 2013) are estimated to be 60,237 Gg CO2 e. Environmental pollution has a severe negative impact on Afghanistan's urban areas. Furthermore, metropolitan regions use around 70% of the nation's energy while generating 50% of its CO_2 emissions. The primary sources of these gases in cities are electricity generation and biomass combustion for indoor heating (NEPA, 2017). Despite energy efficiency improvements, GHG reduction, and the production of renewable energy are all taken into account at varying tiers of Afghan government legislation and regulations, there is no established structure that all parties may adhere to and that has a defined strategic objective (MUDL, 2019).

While developed country energy consumption for thermal uses in buildings accounts for most of the global energy consumption, it tends to expand slowly over time, whereas developing countries have seen significant growth.

1.2 Problem motivation

Increasing energy efficiency is a crucial step in sustainable development and reducing the impact on climate. Developed and developing economies have devoted vast resources to find solutions for increasing the energy efficiency of buildings and have achieved it to a great extent. In contrasts, Afghanistan is lagging much behind. Such trends emerge from the lack of research in designing energy-efficient buildings to local conditions, practices, and materials, lack of institutional capacity, limited awareness, and political instability. Thus, there is a need to customize the existing knowledge and technology of energy efficiency of buildings for adaption to the specific attributes of Afghanistan in terms of geographical location, weather and climatic conditions, construction materials, construction, and cultural practices. In this direction, this thesis has attempted a multi-pronged research approach to analyze critical challenges for achieving energy efficiency in residential buildings in Afghanistan. The multi-pronged approach delves deep into five/six attributes of achieving energy efficiency coving – understanding of energy status of Afghanistan, understanding the climatic conditions, understanding the characteristics of buildings and energy consumption, determining the thermal properties of select local materials, and developing measures for energy efficiency through energy modeling.

Understanding the energy status of Afghanistan explores energy prices, affordability, demand-supply gaps, and access to building dwellers. Such information feeds to determine availability and the economic aspects of energy modeling. A preliminary study of Afghanistan's climatic and weather conditions was necessitated because such information is not readily available. Hence, this step was included to generate reliable and adequate data to run the energy models and arrive at suitable suggestions. To obtain localized information about building construction practices, preference of dwellers, and dwelling energy consumption patterns, a study was required whose findings could guide the selection of representative buildings and for parametric values of energy modeling.

An experimental study was required to determine the characteristics of primary local materials like bricks and plasters to ensure the outcome of energy modelings are relevant and sensitive to locally available materials. A major challenge in such a study was the unavailability of such material testing laboratories in Afghanistan. The later part of the research was to use suitable energy modeling and simulation technology and software to devise energy efficiency measures. The case study approach was assessed to ensure the energy modeling is suitable for local building design and practices. Overall, the research problem consists of answering sub-questions about different aspects of buildings that can help in energy efficiency in residential buildings—and then integrating them into the larger question of achieving energy efficiency. The problem also delves into determining a suitable technological solution and software for energy modeling and simulation of buildings. The research also attempts to quantify the influence and CO_2 emissions and cost savings. As stated in the next section, these problems and their parts were instrumental in determining Research Aim and Objectives. The research questions threading across these attributes are: What best practices can lead to sustained energy efficiency?

1.3 Aim of the Study

This thesis investigates the effect of various energy efficiency measures on residential buildings' energy loads in the arid climate while considering the region’s economic and technical feasibility. To achieve this aim, two sets of objectives were identified. The first set of objectives (1 and 2) focuses on understanding the external environment of the buildings and determining parameters that support the analysis of the energy efficiency of buildings. The second set of objectives (3 to 5) focuses on in-depth simulations using the latest energy modeling software to produce measures for energy efficiency.

1.4 Research Objectives

The present study has the following five objectives:

1. To analyze building characteristics, energy consumption patterns, and efficiency in residential buildings to understand the overall scope of improvement.
2. To identify the summer thermal comfort range for residential apartment dwellers.
3. To identify the most relevant factors to reduce heating and cooling energy consumption in residential buildings by applying energy efficient techniques and performing energy simulation focusing on Passive solar control strategies.
4. To formulate measures for increasing energy efficiency in a residential building focusing on energy retrofit.
5. To formulate measures for increasing energy efficiency in residential buildings focusing on new dwellings.

This thesis intends to address the following research questions:

1. Do passive solar control strategies positively affect residential buildings' heating and cooling loads in the climate of Mazar-I-Sharif?

2. How do various envelope retrofits in arid climates impact the energy requirements of existing buildings?
3. What is the potential of energy saving considering an energy-efficient envelope for Afghan dwellings?

1.5 Scope of the Study

This research aimed to examine the effects of energy efficiency measures on the energy performance of new and existing residential buildings in Afghanistan's arid climate, considering technological and economic feasibilities. As a prerequisite, the research also attempted to assess the region's energy pattern, housing characteristics, and summer thermal comfort levels for residents. The research required the collection of field data for which Mazar-I-Sharif was selected. Detailed sampling of buildings is explained in Chapter 5. Several energy efficiency measures affect the energy performance of buildings. This thesis focus on building envelope (e.g., wall, roof, floor, window, shading) and environmental factors (i.e., outdoor temperature and humidity). The scope of research covered analyzing field survey and experimental data regarding residential buildings' energy consumption, and efficiency.

1.6 Organization of the Thesis

This thesis is presented in seven chapters, which include: i) Introduction, ii) Theoretical Framework, iii) Literature Review, iv) Energy Status and Climatic Condition of Afghanistan v) Research Methodology, vi) Result and Discussion vii) Summary and Conclusions.

Chapter I introduces this study by presenting its background, establishing its necessity, and stating its purpose and objectives.

Chapter II demonstrates a deep understanding of the research topic. Moreover, it provides a conceptual framework for the study by identifying the key concepts, variables, and relationships that will be investigated.

Chapters III provide a systematic review of literature related to each objective of the thesis.

Chapter IV presents an outline of Afghanistan's energy status and climatic conditions. Raw data is collected and analyzed to provide a comprehensive understanding of the current energy situation and the country's climate. The findings of this analysis provide valuable insights for policymakers and researchers working on energy issues and designing energy efficient buildings in Afghanistan context.

Chapter V provides overall research methodologies adopted for research objectives. Chapter VI covers the result and discussion of the overall research. The first section of the result chapter presents the outcome of the thesis's first objective: the energy consumption patterns and housing characteristics in urban Afghanistan to highlight issues with building energy usage and the requirement for energy efficiency and climatic design of buildings. Subsequently, section two presents an assessment of the Afghanistan residents' summer thermal comfort levels, which help generate parameters for later objectives; section three reports the analysis of passive solar radiation control strategies for reducing heating and cooling demand with recommendations on passive design techniques. Moreover, sections four and five present energy efficiency analyses using energy modeling and simulation for existing and new buildings.

Finally, Chapter VII summarizes the research, key findings, and conclusions. The chapter also underlines contributions to the body of knowledge, limitations, suggestions for further research, and a list of publications emerging from this thesis. Appendix A to F provides additional information for supporting the thesis.

CHAPTER 2
THE THEORETICAL FRAMEWORK

This chapter contains the theoretical framework and explains the climate's importance on building design, building and energy, human and comfort, energy-efficient housing, energy modeling tools, and building rating systems worldwide.

2.1 Climate and Weather

The climate of any planet determines several essential aspects. The word “climate” derives from the Greek “Klima,” which signifies the earth's slope relative to the sun. Climate is defined as a "region with specified temperature, humidity, wind, sunlight, and other factors" (Kabre, 2018). The average weather in a particular place over a prolonged period is also referred to as climate (Climateurope, 2022). While climate is the combination of all the quantitative meteorological data that assist in defining a region or zone, the weather is the collection of atmospheric situations, including the temperature, humidity, wind, rainfall, sky state, prevailing at a specific location, and time (Kabre, 2018). There are several different climate climatic zones and classifications to consider. Air temperature and humidity are often used to classify climate zones.

The well-known Koppen climate classification was developed by Wladimir Koppen (Britannica, 2022) in 1900. Monthly mean temperature, mean precipitation, and mean yearly temperature form the basis of the Koppen system. This system has evolved and is still in use today. As per Koppen, there are five main types of climate classification:

(A) Tropical or mega thermal

(B) arid

(C) temperate or mesothermal

(D) continental or microthermal

(E) polar or alpine

Then, depending on the amount of precipitation and the temperature, each category can be further divided. Thirty-one different Koppen-Geiger-climate categorization is presented in Appendix A-1 (Kabre, 2018; Plantmap, 2022)**.** Furthermore, the World map of the Koppen-Geiger climate classification is presented in Appendix A-2 (Climateviewer, 2022).

2.2 Climate Parameters

Numerous factors affect a region's climate. The primary characteristics of the climate are measured and summarised by the meteorological department on a periodical basis. The comprehensive meteorological data from several decades is statistically analyzed to create the hourly weather data files, and the developed weather file is utilized for energy modeling. The US Department of Energy provides weather data in EnergyPlus Weather (EPW) format for various nations worldwide. Each station contains a STAT file with summary data and an EPW file with detailed information. The fundamental climatic characteristics that a building must meet are as follows:

2.2.1 Temperature

Clouds, dust, and water vapor in the atmosphere reflect 50% of the solar energy that reaches the earth back into space, while the earth and oceans absorb the other half and release it to the atmosphere as heat. The temperature is the caloric energy that accumulates in the air and can change during the days due to the earth's position concerning the sun (rotation and translation). The temperature measuring units used are degrees Celsius, Kelvin, and Fahrenheit. The thermometer and the thermograph are the instruments utilized to measure temperature. The isotherms are often used to plot temperature measurements on a climate map (Givoni, 1969).

2.2.2 Precipitation

Precipitation, often known as rain, results from a meteorological process in which liquid or gaseous water falls to the earth's surface. Bodies of water absorb most of the water that falls in this process, and the remainder evaporates. The volume of precipitation that falls in a particular area is determined by latitude and the presence of water masses. The areas around the terrestrial equator receive more rain each year than the rest of the world. The rainfall index is based on the amount of water that falls in a given territory over a year. An index like this is measured in millimeters per square meter.

A rain gauge is a device that measures a location's rainfall index, while a pluviometer is a device that graphs the index. Convective, cyclonic, and orographic precipitation are the three types of precipitation. This classification is based on how the mass of air that gave rise to the atmosphere was distributed.

2.2.3 Humidity

Humidity refers to the quantity of water vapor in the air, which is mainly influenced by temperature and precipitation. Even in the hottest regions, there is a certain amount of humidity. In fact, the hotter it gets, the more likely it is to rain. The hygrometer and the psychrometer are used to measure and record it. The percentages represent the outcomes of these measurements. The term "relative humidity" refers to the proportion of moisture with respect to the number of air molecules in the atmosphere. It fluctuates or changes throughout the day since it is inversely related to temperature.

2.2.4 Cloudiness

Clouds occur when relative humidity rises and water molecules attach to dust or ash particles, carried aloft by the small and slight dimensions of the water particles. Clouds, among other meteorological phenomena, indicate the presence of fronts (two air masses of differing temperatures), humidity, and precipitation possibilities. Clouds can drift in opposite directions to the wind and be a precursor to precipitation. The shape, size, and type of cloud forms are influenced by atmospheric pressure and humidity. Luke Howard offered just that typology or classification based on the shape and behavior of these gaseous masses: Low clouds include stratus, nimbostratus, stratocumulus, cumulus, cumulonimbus, and towering cumulus. Altostratus, altocumulus, and altocumulus lenticularis are typical clouds. Cirrus, cirrocumulus, and cirrostratus are high clouds.

2.2.5 Wind

Wind refers to air moving horizontally due to pressure changes in the atmosphere. The wind comes in various forms: trade winds, eastern polar, brave west, and southern winds are planetaries. Asian monsoons, sea breezes, and cyclonic winds dominate the continental climate. It is measured in kilometers per hour using an anemometer. The lowering of humidity, the creation of storms, and the evaporation of water are all aided by the wind.

2.2.6 Irradiation

Solar radiation refers to the electromagnetic radiation that the sun emits (Givoni, 1969). During the winter months, solar radiation can be utilized to heat up buildings. A pyranometer (solarimeter) is used to detect solar radiation on a free, horizontal surface. An electronic integrator stores the data as either the continuously fluctuating irradiance in W/m2 or irradiation over an hour or day in Wh/m2. The average irradiance (W/m2) for that hour will be quantitatively equal to the hourly irradiation amount in Wh/m2. Although it is simply a "tolerated" unit in the SI, the Wh (Watt-hour) is used as an energy unit for solar radiation.

2.3 Indoor Climate

Various observable physical, chemical, and biological elements contribute to the indoor environment. The World Health Organization (WHO) defines "indoor climate" as follows:

- Thermostatic conditions (heat, cold, draughts, and humidity)
- Atmospheric conditions (pollution, air quality, and volume of fresh air)
- Acoustic conditions (noise, perception of speech, and sound)
- Actinic conditions (lighting, radiation, and electrical/magnetic fields)
- A mechanical setting (ergonomics, anti-slip protection, vibrations, etc.)

It is essential to maintain the indoor climate as people in some climates spend more than 90% of their time indoors. Therefore, indoor air quality is critical to individuals' health, well-being, productivity, and quality of life. The inhabitants' short- and long-term health is determined by indoor air quality. It measures the air quality in the building's interior condition, focusing on the president's health and comfort.

2.3.1 Factors influencing indoor climate

Various physical, biological, and chemical factors influence the indoor environment. The physical factors, including severe changes in temperature and humidity, lack of airborne ions in the air, airflow, and increase of fine pollution particles, can cause respiratory tract damage, decreased lung function, and cardiovascular illness. A variety of biological factors in inhaling the air might expose one to mold, bacteria, parasites, viruses, and allergies. Allergens can be found in dust, mold spores, animal epithelia, construction materials, and plants. Inflammation of the nose and eyes, as well as a runny nose and asthma, are all possible side effects. Odors, formaldehyde, solvents, VOC, CO_2, and smoke are all chemical factors to be mindful of. Odors can originate from various places, including furniture and floor coverings, drainages, and the outside. It harms one's mental health and can even lead to stress.

2.4 Comfort and Energy Demand

Buildings' primary functions are to provide shelter and comfort for humans. The senses of sight, smell, hearing, and feeling determine whether or not the indoor environment is pleasant. Discomfort causes distraction and reduces productivity, leading to illness if left unattended for a long time. The three types of comfort which have a direct influence on the energy demand of a building are Thermal comfort standards (ISO 7730, ISO 10551, ANSI/ASHRAE 55), (BEEG Nigeria), visual comfort and lighting (ANSI/IESNA RP-1-04, EN 12464, ISO 8995-1), and quality of the air (ISO 16814). Finding the correct balance of needs for comfort and building energy efficiency in the early design is essential for the design team.

2.4.1 Thermal comfort

Thermal comfort is obtained within a building by utilizing energy, which is influenced by the climate. Thermal comfort refers to when a person's body heat and temperature are balanced (with no visible sweat), and they are at ease in their surroundings (ASHRAE, 2010). In other words, thermal comfort is the balance between the heat produced by the body and the heat loss in the surrounding environment. Physical activity, clothing type, gender, health, age, the amount of time spent indoors, room climate, and season influence a person's sensitivity to heat. In addition, thermal comfort is influenced by air temperature, humidity, velocity, distribution, and radiation conditions. In order to maintain a steady core body temperature, one must transfer excess heat created by their metabolism to the environment.

Thermal comfort is a more complicated outcome of air temperature, relative humidity, and radiant heat interaction. These elements, considered together, are referred to as 'operative temperature.' Operative temperature is a more thorough measurement that accounts for radiative and convective heat exchange between occupants and their surroundings. Compared to simply monitoring air temperature, it more accurately depicts comfort judgments. When the operative temperature is used as a measuring and design tool, it usually leads to solutions that improve occupant comfort while lowering energy use.

Several international standards use both operative temperature and adaptive comfort modeling to give more contextual parameters to quantify comfort. ASHRAE 55-2013 and the German DIN 15251 Standard are two examples. For instance, according to the DIN Standard, allowable interior operative temperatures vary depending on outdoor air temperature. Furthermore, for a tiny proportion of the time, those temperatures are allowed to surpass the tolerable comfort threshold. (TRP, 2017)

Psychrometric charts are used to demonstrate thermal comfort in response to external climate variables such as temperature and humidity. Based on the ASHRAE-55 comfort zones for winter and summer, psychrometric charts explain how to establish the desired room temperature.

2.4.2 Visual comfort

Room illumination is vital for safety, visual comfort, and the quality of the user's eyesight. Visual comfort can be accomplished using natural, artificial light, or both. Since the human eye has evolved to adapt to it, daylighting is the most energy-efficient technique for illuminating spaces. Therefore, daylighting should be utilized extensively throughout the day, with artificial lighting used exclusively at night or in areas where daylight is not accessible. In addition, artificial light must be used in regions where natural light is insufficient to meet the minimum lighting requirements. Moreover, automatic control would be ideal for reducing artificial lighting and its accompanying energy consumption to a minimum.

2.5 Energy and Building

Buildings have a critical role in combating climate change. Buildings utilize roughly one-third of world energy, which is mainly consumed for space cooling, heating, electrical devices, and systems (DOE, 2015). Global energy consumption in buildings is expected to grow as cities in emerging nations continue to develop and per capita income levels rise (DOE, 2015).

Energy has arisen as a decisive economic concern at the top of policymakers' agendas. Unsustainable energy supply and demand have far-reaching implications, from personal finances to international relations. Buildings are at the forefront of this issue due to their significant energy use. Energy-efficient buildings and appropriate land use have frequently been proven to have significant monetary savings while lowering greenhouse gas emissions. A building is significantly seen as a highly complex energy system when improving its energy performance. Building efficiency, generally known as "green" or "sustainable" building, refers to buildings with higher energy efficiency as a primary design consideration. The purpose is to minimize the effects of buildings on the environment while also improving the well-being of the occupants (Karlsson et al., 2015). Building energy consumption is influenced by several factors, including good architecture, energy-efficient materials, energy system design, and efficient post-occupancy operations and maintenance (DOE, 2015).

Energy efficiency means using less energy to accomplish the same amount of work. Moreover, Energy intensity refers to the ability to accomplish the maximum work per unit of energy. Buildings and neighborhoods are measured in terms of energy consumption per square foot and capita. An efficient building requires less energy to provide acceptable comfort levels, air quality, and occupancy criteria, including energy used to manufacture building components and construction. Climate, building typology, and location all influence the energy efficiency of buildings. In addition, the discrepancy between retrofitting old structures and designing new buildings and the disparity between developed and developing countries is crucial. Energy efficiency must permeate all levels of society and not be limited to high-end buildings; due to this intricacy, it is not feasible to develop a single solution for all cultures and the entire market. Energy efficiency will provide considerable potential for national energy saving to meet the energy crisis and promote global low carbon emissions (WB, 2015).

2.5.1 Building orientation

Several factors influence the overall challenge of building orientation. Local terrain, aesthetics, noise reduction, privacy concerns, and environmental elements like wind and solar radiation are all factors to consider (Olgyay, 1963). The orientation of the building significantly affects the interior conditions by regulating the factors such as -sun radiation and its impact on rooms facing in different directions; natural ventilation issues arise as a result of the prevailing wind direction and the building's orientation (Givoni, 1969).

The impact of solar radiation on building orientation is positive (during winter) and negative (during summer). As a result, the amounts of solar radiation falling on different sides of a building at various times must be addressed for optimal climatic orientation. An optimal orientation maximizes radiation during the underheated phase (when it is desired) while minimizing insolation during the overheated phase (when it is undesirable), thereby balancing these two periods (Olgyay, 1963).

2.5.2 Building thermal envelopes

The building envelope is the barricade that separates the interior and exterior environment. Its efficiency evaluates how much environmental factors influence occupant comfort within a building by transferring heat and air through exterior walls. The thermophysical characteristics of the materials control the heat loss and gain via building components. There are primarily two types of materials used to make building envelopes: Opaque and transparent. However, translucent materials are occasionally utilized (Givoni, 1969). Specific envelope designs and materials can benefit from or overcome climate-related concerns. The majority of heat loads can be internal (humans & equipment) than external (Solar), affecting how quickly a building gains or loses heat.

Moreover, Poor building envelope performance can lead to inconsistent indoor environments. In the winter, for instance, thermal bridges on cantilevered concrete balconies generate cold indoor surfaces, creating breezes a discomfort. Therefore, considerable heat loads are required to compensate for the cold produced by these bridges. The dangers of cold bridging go beyond occupant discomfort; if indoor air temperatures are not raised to compensate for cold surfaces, condensation can form, leading to mold and other health issues. In the summer, cooled air from air conditioning dissipates quickly, reducing active cooling effectiveness and necessitating continuous cooling systems (TRP, 2017). The goal of the window, foundation, wall, roof, and ceiling design is to reduce uncontrolled air movement inside the building while minimizing conductive and radiative heat loss or gain, depending on the outside air temperature.

2.5.2.1 Windows

The transparent envelopes provide a boundary between thermal comfort and climate, significantly affecting buildings' operational energy usage (Alston et al., 2019). Moreover, heat gain/loss and thermal and visual discomfort are caused mainly by windows. To compensate undesirable heat loss/gain through windows, a large amount of energy has been used in buildings. Heat losses occur due to air infiltration around the window frame and radiation from the windows' outside glazing surface. During the heating and cooling seasons, windows' glass surfaces enable solar radiation to enter the building. Moreover, Glazing transmits much thermal gradient per unit of area than an insulated surface since it has lower resistance and higher thermal conductivity. (Mark DeKAY and G.Z.BROWN, 2014). Therefore, windows' heat loss is higher than the opaque portions of the thermal envelope. The glass's thermal resistance and windows' frame must be enhanced to reduce heat loss through conduction. Energy-efficient windows can considerably lower a building's energy use. Multiple glazing, unique transparent coatings, insulating gas between glass panes, and strengthened frames are all included in such high-performance windows. These characteristics reduce heat transmission, lowering the energy load imposed by window openings. Table 2.1 shows the various glazing varieties and their key characteristics.

Table 2.1 Characteristics of various glazing (Wolf, 1992; Szokolay, 2008)

Type of Glazing	Thickness mm	U-Value W/m-K	SHGC	Age years	The annual maintenance cost %
Single-glass clear 6 mm	6	6.121	0.81	50	3
Single-glass, low e 6 mm	6	4.233	0.71	30	3
Single-glass grey 6 mm	6	6.121	0.567	50	3
Single-glass, reflective tinted 6 mm	6	5.243	0.245	30	3
Single-glass, reflective clear 6 mm	6	5.36	0.277	30	3
Double-glass transparent, 13 mm air/6 mm	25	2.708	0.697	30	5
Double-glass Low e, 6 mm/13 mm air	25	1.949	0.629	30	5
Double-glass, reflective clear 6mm/13mm air	25	2.449	0.216	30	5
Double-glass, reflective tinted 13mm air/6mm	25	2.404	0.182	30	5
Triple-glass, transparent 13mm air/6mm	44	1.91	0.592	25	6
Triple-glass, low e 13mm air/6mm	44	1.223	0.355	25	6

Low-E glass: Low-E or low-emissivity glass is manufactured with a special metal coating that allows it to reflect a considerable portion of the infrared spectrum while transmitting the bulk of visible light. Low-E glass controls the radiant rays and minimizes the solar heat entering the building by filtering the sun's short-wave radiation.

Double/triple glazing: Glasses with two layers of glazing are manufactured with two or three glass panels. A spacer and an even layer of vacuum or gas separate these panes, limiting heat transmission and serving as a building envelope component. Due to the apparent thermal resistance, the quantity of artificial heating required is reduced, minimizing the total cost and environmental impact. These glasses are also known as insulating glasses, and depending on the purpose, they come in thicknesses ranging from 3mm to 12mm or more. Figure 2.1 illustrates a schematic view of glazing with a different layer.

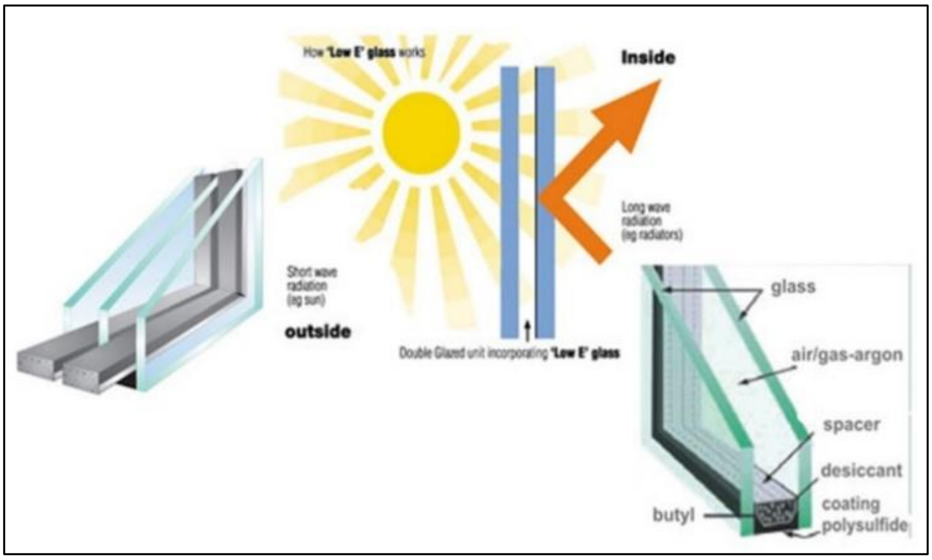


Figure 2.1 Schematic view of glazing with different layers (Loweburoiho, 2022)

2.5.2.2 Shadings

Preventing the summer light from reaching the windows is one of the efficient techniques to minimize a building's overheating. To lower the interior heat load, it is critical to shade windows. This can be done in various methods, contributing to the overall design (Bokalders and Block, 2010).

Internal, external, and mid-pane shading devices can be designed as movable or fixed, horizontal or vertical, automatic or manually operable. The shading strategy chosen among numerous shading systems is influenced by the building site location, building orientation, typology and function, sky conditions, and many other lighting effects such as invasive street lights. On the other hand, interior shading devices are adjustable components used on the interior surface of an occupied space. Roller or Venetian blinds, curtains, and draperies are all typical types. Figure 2.2 represents internal and external shading devices commonly utilized in residential buildings.

a) Retractable awning

b) Fixed louver

c) Roll shutter

d) Venetian blinds

Figure 2.2 Internal and external shading devices (BBP, 2022)

Internal shade systems do not prevent direct sunlight from entering the room once it has passed through the glass. Consequently, the shading devices capture solar energy, convert it to heat, and release it into the atmosphere. However, external shading operates by preventing direct sunlight from a space. Furthermore, external shadings minimize the amount of heat transferred directly through the walls. External shade devices are the most effective method for controlling solar heat gain.

2.5.2.3 Walls

Walls separate the indoor and outdoor environment and change the impact of weather on the indoor environment. Walls absorb and transfer heat, thereby affecting the indoor climate. Heat loss and gain are affected by the orientation of the walls. In other words, the radiant temperature is affected by the interior surface temperature of a wall, which significantly impacts indoor thermal comfort. Thus, walls need to be designed to prevent indoor and outdoor heat transfer through conduction. Insulating the walls is one way to accomplish this.

2.5.2.4 Roofs

The type of roof installed on a building considerably influences its energy consumption and efficiency. Essentially, a roof must be capable of preventing rather than absorbing heat to be energy efficient. When a roof absorbs heat, it is radiantly transmitted to the air inside the building, making the entire interior dramatically warm. A roof is the topmost structural component of a building that serves as a protective covering from the outdoor environment (i.e., rain, sun, wind, etc.). The type of roof chosen is influenced by the design and shape of a building, the climate of a region, and available construction materials. The three primary types of roofs are slope or pitch roofs, flat (terraced) roofs, and curved roofs.

The roof is the element of the building which is most exposed to the weather. Moreover, solar radiation during the summer, heat loss by longwave radiation during the night, and winter, snow, and rain significantly affect buildings' roofs (Givoni, 1969). In addition, In the summer, when it is not required, a building may obtain more heat from the roof, and in the winter, when it is essential, it can receive less heat. Therefore, by enhancing the thermal resistance of the roof, heat movement through the roof can be controlled.

2.6 Effects of Thermophysical Properties on Energy Performance

A high-performance building envelope is a prerequisite and basis for an energy-efficient building. Thermophysical factors such as thermal transmittance, thermal conductivity, and volumetric heat capacity can substantially influence the energy performance of an envelope. In other words, energy-efficient materials are distinguished by their thermal conductivity, thermal transmittance, and volumetric heat capacity.

The thermal conductivity of a material, often known as its k-value, is a measurement of how well it transmits heat. It depicts how much heat (W) is transferred through a 1m2 wall with a thickness of 1m when the difference in temperature between the wall's opposite sides is 1K (or 1◦C). The lower the k-value, the greater the insulating characteristics of the material. A building element's thermal transmittance (U-value) describes how it conducts heat from indoor to outdoor in steady-state conditions. It calculates the quantity of heat that will flow throughout a unit area in a given time duration for each unit change in temperature between the various conditions in which the component is used. The reciprocal sum of the resistances of each structure component, including the cavity, air space, and inner and outer surfaces, is estimated and measured in W/m^2K. Heat flow is influenced by the temperature difference across a building, thermal conductivity of material, and thickness. In other words, A thicker material with a lower conductivity provides for significantly less heat flow. Moreover, the combination of these factors determines the building's thermal resistance. The total resistance of a composite element is the sum of each component's resistances (Pacheco-Torgal, 2015).

2.7 Energy Efficient Residential Buildings

Energy-efficient dwellings provide several appealing features for homeowners and residents, save natural resources, reduce harmful carbon dioxide emissions, and lower utility expenses. There are various energy-efficient buildings, such as energy plus houses, Net zero energy, passive house etc.

2.7.1 Energy plus houses

Dwellings that generate more energy than they consume are referred to as "energy plus. "Solar photovoltaic systems convert the solar energy into power, allowing homeowners to be less reliant on price fluctuations from traditional electricity sources. On the other hand, electrical systems in Energy Plus houses transmit surplus power back into the national grid, offering the homeowner a financial gain. Depending on their design, solar thermal systems can be utilized to produce heat energy in Energy Plus houses. Figure 2.3 depicts an Energy-Plus house located in Germany.

Figure 2.3 Plus energy house Wriedt, Unterallgäu, Germany (Baufritz, 2022)

2.7.2 Net zero energy

As a result of increased efficiency, a Net-zero or Zero Energy Building (ZEB) has substantially less energy requirement. Moreover, renewable energy technologies could meet all their energy demands (Torcellini et al., 2006). A ZEB lacks a clear and distinct definition; depending on the measure, boundary, and project aims, it can be described in various ways. In a net zero energy building concept, energy efficiency should come first, followed by on-site renewable energy sources.

2.7.3 Passive houses

A passive house is energy efficient, comfortable for the occupants, cost-effective, and ecologically benign. In passive energy-efficient dwellings, heat exchangers and insulated triple-glazed windows make use of solar energy to minimize heating energy requirements. Such dwellings are pollution-free, constructed with only environmentally friendly material, and integrated with self-contained sensors that regulate airflow and eliminate stale air. Figure 2.4 illustrates the passive house concept.

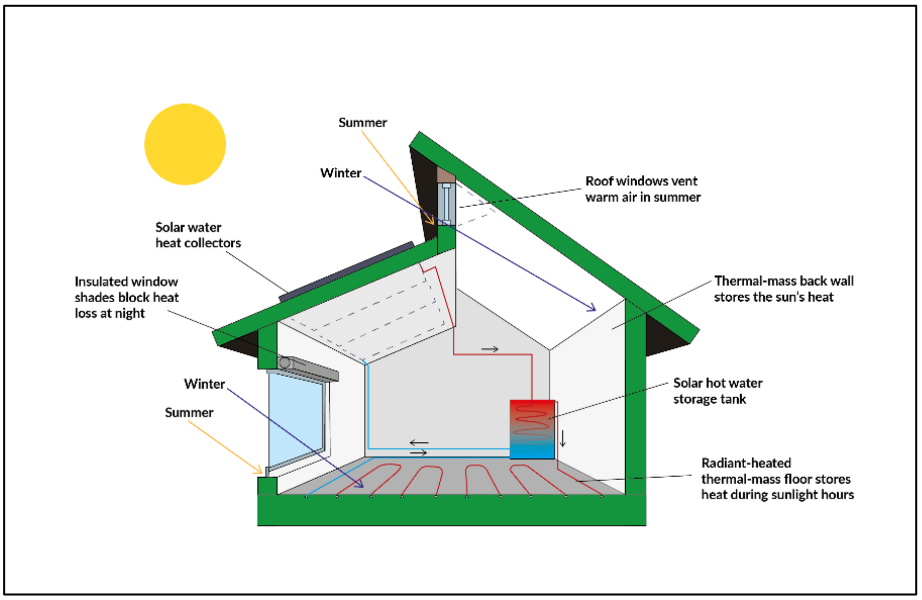


Figure 2.4 The passive house concepts (Passipedia, 2022)

2.8 Element of Energy-Efficient Buildings

An energy-efficient building offers several benefits, including decreased energy costs, increased occupant comfort, a better living environment, and less environmental impact. Designing and constructing an energy-efficient building involves vision, planning, and follow-up with many stakeholders, resulting in years of comfort and energy savings.

The best technique for understanding how a building consumes energy is to look at how various linked energy systems interact and respond to changing climatic conditions and occupant comfort requirements. The architectural design elements that directly influence a building's energy efficiency are landscaping, site, building orientation and layout, the envelope (wall, window, foundation, roof, and ceilings), HVAC system, infiltration and ventilation, lighting, and appliances.

2.9 Improving Energy Efficiency in buildings

An energy-efficient building provides the requisite indoor comfort and other essential services with minimum energy usage in a cost-effective and ecologically conscientious manner (CIBSE, 2004).

Building energy consumption and efficiency are classified by end-use categories such as space heating, cooling, and lighting. In many end-use categories, energy efficiency is defined by the design and construction of a building (including the materials and components used) and the technical efficiency and operational management of the facility's energy-consuming equipment. Energy usage is influenced by temperature, building function, energy cost, billing systems, and occupant behavior. There are three main techniques to improve building energy efficiency:

1. *By employing better design and construction approaches:* Enhanced design and construction techniques are employed while creating and constructing new structures. Well-designed and constructed new buildings offer the best possibility of reducing cooling, heating, lighting, and ventilation loads. The most efficient technique for ensuring energy efficiency is included in the design and construction process is introducing and enforcing Building Energy Efficiency Codes. The energy efficiency code specifies a building's minimum energy efficiency requirements, such as the thermal performance of the building envelope, interior devices, and equipment energy efficiency standards.

2. *Through renovations or retrofitting of existing buildings:*

Renovating existing buildings and replacing power-hungry equipment and system are essential for increasing energy efficiency in cities with low building stock turnover. Towns must seize this opportunity by incentivizing and mandating energy efficiency improvements as part of all crucial upgrades and equipment replacement projects. This necessitates the establishment of an appropriate environment, as well as efficient project finance and delivery channels.

3. *Through energy management systems:* EMS (Energy management systems), which monitor and control energy consumption in significant public and commercial buildings, are a low-cost solution to improve energy efficiency and demand reduction.

2.9.1 Energy efficiency in new buildings

Buildings must be energy efficient to combat climate change (Natural Resources Canada 2021). Newly built properties have the most incredible opportunity and maximum capacity to cut heating, cooling, and lighting needs while incorporating promising energy-efficient technology with a shorter payback period. The most efficient method to get these benefits is to develop and implement building energy efficiency regulations.

2.9.2 Energy efficiency in existing buildings

Most buildings are gradually upgraded when their components age and require maintenance. Using a whole-building approach and taking advantage of the opportunity to conduct significant retrofits is often an ideal way to increase energy efficiency. Although the initial investment may be higher, the potential long-term savings will be more significant during the building's lifetime.

The appliances inside an existing building may generally be replaced during a 10-to-20-year period, although the building's shell, or envelope, can sometimes remain untouched for decades apart from essential required maintenance. It is frequently necessary to renovate a building's envelope in order to lower heating and cooling demands. Specific climatic conditions and good economic considerations must govern technical approaches to building improvements. Encouragement of building retrofits in the residential sector is often more challenging than in other sectors due to the highly disaggregated nature of house ownership and the modest scale of individual investments and returns. However, both minor and major energy-efficiency improvements are achievable. The majority of efforts in this area have focused on equipment replacement (WB, 2015).

Minor retrofit: Minor renovation may provide an opportunity to apply technical energy-saving measures. This generally comprises internal upgrades and minor space layout and landscaping alterations. Among the energy-saving possibilities are:

- Altering space to maximize daylight, ventilation, and zone controls to save energy
- Enhancing lighting and switching provisions, together with automatic controls
- Enhancing window performance by installing shades and other window treatments
- Improving lighting efficiency, using lighter-colored interior surfaces and furnishings.

Major retrofit: This usually entails the replacement of major components as well as some material alterations, such as window replacement. It frequently enables major modifications to build service methods. Energy saving opportunities include:

- Enhancing passive measures utilization or mixed mode methods in building with air-conditioning systems to maximize free cooling
- Incorporating atria and sunspaces to allow for daylight and natural ventilation

- Enhancing perimeter services and window controls to prevent desks and other obstructions
- Establishing zones for equipment and other items with high heat gains or specific environmental requirements.
- Eliminating (partially or entirely) air conditioning by making minimal changes to building fabric and lighting.
- Choosing a plant that is energy efficient and has a variety of control options, such as zone controls
- Electing a high-efficiency, well-insulated hot water system with localized water heating reduces standing losses (CIBSE, 2004).

Figure 2.5 Enhancing thermal efficiency of building through energy retrofit (Safeguardeurope, 2022)

2.10 Energy Efficient Building Design Strategies

Buildings are considered energy efficient if they are constructed or upgraded to make the most of the energy provided to them by minimizing energy losses, such as heat loss through the building envelope (US Green Building Council, 2022). Considering innovative energy efficiency solutions only on the basis of cost has limits. Several techniques can be applied to enhance the energy efficiency of buildings (DOE, 2015).

2.10.1 Addressing the envelope

Building walls, roofs, and foundations also control the flow of heat, air, and moisture. Moreover, their color and optical characteristics significantly affect heat absorption and heat release to the surrounding environment. In addition, building shells also impact how buildings absorb and release heat. In theory, the refractive indices of building materials should be adaptive to changes in weather and other external elements, including lighting (DOE, 2015).

2.10.2 Installing high-performance appliances and mechanical systems

When selecting high-performance appliances and mechanical systems, it is wise to perform the life cycle method to analyze the trade-off between capital, operating expenditure, and investment technologies (DOE, 2015). even though well-designed building envelopes may significantly decrease cooling and heating loads, mechanical systems will always require in many climates. The two distinct operations involved in space conditioning (i.e., adding or removing sensible heat) are increasing or reducing air temperature and humidifying or dehumidifying the air.

2.10.3 Energy simulation

Energy efficiency opportunities can be identified and prioritized using computer modeling. Sufficiency measures refer to decreases in net energy demand or the actual building demands as calculated by the energy balance equation. As a result, sufficiency refers to how transmission, radiation, ventilation, and internal loads interact to minimize the net energy requirement for space cooling, heating, and lighting.

2.10.4 Monitoring and verifying performance

Using control systems, building automation systems, commissioning, and retro-commissioning, the performance of the building system can be verified (USGBC, 2022). Table 2.2 provides the technological methods for increasing energy efficiency in each focus area.

Table 2.2 Strategies for Increasing Building Energy Efficiency (WB, 2015)

Focal Area	Technical Approach
Heating, cooling, lighting, and ventilation load reduction for newly constructed and existing buildings	Building orientation, sun shading, surface color, envelope insulation, ventilation, air tightness, and other passive design strategies should all be employed.
The enhancement of energy-consuming machinery and equipment efficiency	Through commissioning and retro-commissioning, system operation and design are enhanced to meet actual heating, cooling, and lighting demands. Replace or upgrade HVAC systems, lighting systems, water heating, appliances, and other electrical and mechanical equipment.
Optimize the use of energy in commercial and public buildings.	Utilizing energy performance benchmarking enables you to monitor, assess, and manage your energy use. Establish new maintenance standards, give buildings a name for their energy efficiency, and educate building owners and residents about energy performance metrics—plan initiatives to raise awareness and educate the audience.

Moreover, the three approaches for enhancing energy efficiency in buildings are improving building design and construction, increasing equipment efficiency through upgrades and replacement, and actively controlling energy consumption in buildings.

2.11 Construction Materials and their Impact on Energy and Environment

The primary source of carbon dioxide emissions is global energy usage. Since the building envelope accounts for most energy loss, using energy-efficient building materials with fewer carbon emissions becomes a priority. Energy-efficient materials and suitable building insulation reduce energy consumption and improve thermal comfort. Thermal tile, foam concrete, smart opaque glass, polycarbonate sheets, aluminum panels, and other new building materials significantly affect the energy consumption of buildings. In addition, PCMs (Phase Change materials) have a solid potential to reduce energy demand without raising costs.

The high energy consumption of the building is mainly attributable to energy loss and gain via the building envelope. The walls, roof, and fenestration make up the building envelope. The building envelope affects inside temperatures, thermal comfort, sufficient cooling/heating demand, heat gain/loss, daylighting, and natural ventilation. Energy-efficient construction materials can assist sustain buildings both ecologically and economically due to their environmentally friendly characteristics. Furthermore, materials that require less energy emit fewer harmful pollutants and help to reduce pollution from building materials. As a result, energy-efficient building materials are essential to reducing energy use and achieving significant economic, social, and environmental benefits.

2.11.1 Heavy building materials

Heavy materials such as concrete with high heat capacity, cement blocks, and bricks are employed to improve the building's thermal stability. Energy-efficient building materials are crucial in lowering the building's energy consumption. Thermal parameters such as thermal diffusivity, specific heat capacity, thermal resistance (R-value), thermal transmittance (U-value), and thermal emittance are used to identify energy-efficient building materials. As mentioned, the thermal performance of the building envelope is measured in U-Value; in a cold region, lowering the U-Value reduces heat loss through the building envelope, enhancing thermal comfort and lowering the energy required for heating.

2.11.2 Phase change materials (PCMs)

Phase Change Materials (PCMs) utilize chemical bonds to charge and discharge heat, lowering the energy needed by buildings. Depending on the surrounding air's temperature, PCMs can convert between solid and liquid or liquid to solid states, accumulating or emitting heat. They may release heat to increase the minimum room temperature or absorb heat within buildings to prevent overheating. Additionally, they encourage the concept of comfort in an interior environment due to various thermal properties (such as heat storage and heat retention). Microcapsules, planar, and cylindrical PCM components can all be used in construction in several ways. The microcapsules are then incorporated into mortars utilized in PCM delivery and are covered with a polymer. According to research on PCM on the hollow brick, PCM encapsulation in the treated wall reduces the room temperature and inner surface of the wall by around 4.7 °C, increases the time lag by two hours, and reduces temperature fluctuation by 23.84% (Abbas et al., 2021). Gypsum is another essential building material that comes into contact with indoor air and can be used as a PCM matrix material to minimize room cooling load. PCM-impregnated gypsum boards might cut cooling loads by 7- 20% in buildings (Shukla et al., 2012).

2.11.3 Insulating material

The properties of a building outside wall components greatly influence how much energy it uses and are essential for increasing energy efficiency. Insulation reduces heat transmission (both gain and loss) via the numerous surfaces of a building, including the roofs, walls, ducts, and other components. A well-insulated building requires lower energy to cool and heat. The heat transmission during the winter is limited if the exterior wall is insulated, and there would be equal temperature between the indoor air and indoor surfaces. Therefore, a well-insulated wall avoids indoor air humidity harm while creating an enjoyable indoor environment. The thermal properties of common insulating material are presented in Table 2.3.

Table 2.3 Thermal properties of common insulation (BIS, 1987)

S No.	Type of material	Density (kg/m^3)	Thermal conductivity (w/m.K)	Specific heat capacity (kJ/kg.K)
1	Expanded polystyrene	16	0.038	1.34
2	Expanded polystyrene	24	0.035	1.34
3	Foam-glass	127	0.056	0.75
4	Foam-concrete	320	0.07	0.92
5	Foam-concrete	400	0.084	0.92
6	Foam concrete	704	0.149	0.92
7	Cork-slab	164	0.043	0.96
8	Rock-wool (unbonded)	92	0.047	0.84
9	Rock-wool (unbonded)	150	0.043	0.84
10	Mineral wool (unbonded)	73.5	0.03	0.92
11	Glass-wool (unbonded)	189	0.04	0.92
12	Resin bonded mineral wool	64	0.038	1
13	Exfoliated vermiculite (loose)	264	0.069	0.88
14	Asbestos mill board	1397	0.249	0.84
15	Straw board	310	0.057	1.3
16	Hard board	979	0.279	1.42
17	Soft board	249	0.047	1.3
18	Chip board	432	0.067	1.26

S No.	Type of material	Density (kg/m^3)	Thermal conductivity (w/m.K)	Specific heat capacity (kJ/kg.K)
19	Wall board	262	0.047	1.26
20	Chip board (perforated)	352	0.066	1.26
21	Coir board	97	0.038	1
22	Saw dust	188	0.051	1
23	Rice husk	120	0.051	1

2.12 Energy Modelling Tools

Over the past few decades, various building energy simulation programs have been developed, updated and are currently used by the building energy industry to improve a project's performance. Many are basic simulation programs, while others are more advanced simulation tools that quickly become the most effective tool for designing a sustainable building. Energy simulation systems for the entire building are crucial tools in the building energy sector as they offer users access to crucial building performance metrics, including energy demand and usage, temperature, humidity, and pricing. Table 2.4 presents various analytical programs and their use during the design phases

Table 2.4 Various analytical programs and their use during the design phases

Tools	Project planning	Design concept	Detailed design
eQUEST		/	/
EnergyPlus		/	
DesignBuilder			/
ArchSim/Diva		/	/
Ecotect		/	/
Sefaira		/	/
ReLux		/	
DIALux		/	
Athena	/		
Sun-Earth Tools	/		
IDA ICE			/
Open studio	/	/	/

Tools	Project planning	Design concept	Detailed design
Therm Version1.0		/	/
TADSIM	/	/	/
TRNSYS	/	/	/
DOE-2.1E	/	/	/

2.13 Conclusion

This chapter briefly discusses various theoretical terms and information related to energy efficiency, building elements, and green and efficient building rating system. The information helps in understanding the overall energy efficiency studies and strategies. The next chapter starts with the overall research-related literature and ends with the research gap.

CHAPTER 3
REVIEW OF LITERATURE

The literature on building energy efficiency is vast, with diverse threads of theories and models. For this thesis, the review presents a critical overview of existing knowledge relevant for supporting the science presented, particularly on improving the energy efficiency of residential buildings considering building envelop. Improving energy efficiency is a significant necessity to reduce energy use and manage related adverse environmental effects (Jami et al., 2021). Various sections of this chapter directly relate to the thesis's research objectives and substantiate the identification of research gaps and potential solution approaches.

3.1 Energy Usage Patterns and Residential Buildings Characteristics

The world is witnessing an alarming growth in energy consumption. The increased population and living standards are the primary reasons for the higher energy consumption. Energy consumed in the building sector will likely grow by 65% between 2018 to 2050 — from 91 quadrillions to 139 quadrillion Btu (British thermal unit) — as rising incomes, urbanization, and increased access to electricity leads to escalating demand for energy (EIA, 2021). This share of energy is generally derived from fossil fuels and biomass. Thus, as demand increases, a growing burden is levied on limited fossil fuels. In addition, the extensive use of non-energy-efficient equipment also places an extra burden on supplies. The widespread application of fossil fuels is a significant cause of environmental degradation. Therefore, there is a need to reduce dependence on fossil fuels for energy consumption.

Like other countries in the world, Afghanistan is also facing the challenge of an energy crisis. It has a total land area of 647,230 km^2 and a population of 39 million. The population growth rate is growing at an average rate of 2% per year, projected to double over the next 25 years (WBG, 2020). Afghanistan's GDP per capita is significantly lower than that of other low-and middle-income countries, though the economy has grown almost tenfold since the year 2000 (USAID, 2018), and the GDP per capita increased from $120 to $580 (WBG, 2020). Afghanistan has yet to recover from over four decades of conflict and remains among the world's poorest nations (Pitfalls and promise, 2020). The living conditions of the Afghan population are primarily determined by housing conditions, including drinking water and sanitation facilities. Most people (83%), particularly in rural areas, live in dwellings constructed with non-durable and non-efficient materials, and 44% live in overcrowding conditions, meaning that there are more than three persons per room (CSO, 2016). However, living standards in the cities differ from those of rural areas. Over the previous 15 years, many urban and semi-urban centers have been developed. Though poverty is concentrated in rural areas, the difference is becoming less pronounced over time due to an upward trend in rural-urban migration (WBG, 2020).

Rapid urbanization, population growth, and rising demand for higher living conditions will likely accelerate the demand for building energy. The Afghan construction industry has experienced unprecedented growth over the previous decades, and the construction sector has received the most private-sector investment compared to other industries. Due to the rise in population rate and income level, there is substantial demand for dwellings, particularly in major cities (Li and Yao, 2009). As an aspect of urbanization, people relocate to towns and cities, seeking improved living conditions and higher incomes.

Therefore, the energy demand in buildings has also grown steadily. Figure 3.1 indicates the urban population growth in the country.

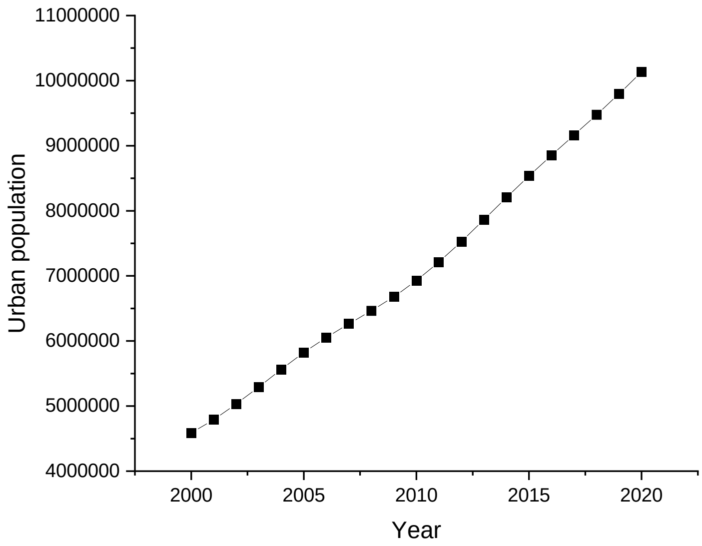


Figure 3.1 Afghanistan urban population growth 2000-2020 (Macrotrends, 2021)

Buildings are the major consumer of energy and producer of greenhouse gases worldwide. Moreover, buildings produce more than twice as much indirect carbon emissions as direct carbon emissions because the type of fuels used to generate electricity for buildings also contributes to carbon emissions. According to the World Energy Outlook, compared to the present course of action under the Stated Policies Scenario, cost-effective, proven energy efficiency and decarbonization solutions in buildings may provide over 6.5 Gt of CO_2 reductions in annual emissions by 2040 (IEA, 2020).

Afghanistan's growing urban population poses a significant housing affordability challenge. In the best-case scenario, if the urban population density remains constant, there is a need to enhance the proportion of the urban area to about 6,959 km^2 (or approximately 350%) between 2010 and 2050 (WB, 2021; CRISL, 2018).

Numerous studies have been conducted on the energy patterns of residential buildings in developing countries, and such studies have indicated several factors influencing household fuel consumption. In developed countries, energy regulations for buildings have been extensively applied to facilitate the efficient use of energy (Pramen P. Shrestha, 2010). However, the developing world is still finding means to obtain reliable data on energy usage and documentation on energy control to formulate related rules and regulations (Iwaro and Mwasha, 2010). For instance, Shahi et al. (Shahi et al., 2020) studied household energy-consumption patterns in Nepal through a field survey and determined the current state of domestic energy use in Nepal. The study revealed that the rate of electricity use is correlated with income levels.

Similarly, a comparative study was performed by researchers (Permana et al., 2008) to identify the urban development form of household energy-consumption patterns in Indonesia. The authors explained that the energy consumption per unit of income exceeds that of the authorized houses (those houses that were not constructed following government norms) energy consumption per unit of income exceeds that of the authorized houses in the same area. Moreover, the study indicated that people with lower incomes spend a higher percentage of their income on energy bills than those with higher incomes.

While economic growth necessitates a considerable shift away from traditional bioenergy and toward modern fuels such as natural gas and electricity (Ai et al., 2021), many variables influence household fuel selection, including socioeconomic concerns, household size, culture, and affordability (Chen et al., 2017). (Ravindra et al., 2019) A case study in India studied the socio-cultural, economic, and behavioral aspects that might impact household fuel choice. The study revealed that, rather than relying on a particular source of household energy, rural households depend on numerous approaches.

This finding contradicts the energy ladder concept, in which an increase in income results in an improvement in energy sources.

Residential energy-pattern research is seldom available, particularly concerning urban Afghanistan. A report published by the government of Afghanistan on overall energy usage in rural and urban Afghanistan has, however, provided some statistics related to types of energy use and indicated the sources of fuel used for heating, cooking, and lighting in the country (CSO, 2016). (Mohammad et al., 2013) studied the energy pattern of one of Afghanistan's cities, Kandahar, and identified household fuel types. The authors demonstrated that firewood is the primary energy source used for cooking. The transition from traditional to modern fuels is an ongoing process in the Afghan household sector. As urbanization has expanded over the previous decades, fuelwood use has become less prevalent. However, household fuelwood-use patterns differ significantly between cities and are based on various factors such as the cost and accessibility of resources, industrialisation, and people's income levels. For example, per kWh electricity is 6.25 AFN in Mazar-I-Sharif, whereas it is 2.5 AFN in the capital, Kabul (DABS, 2021).

A multinomial logit model on demographic health surveys studied household-cooking fuel-use patterns in Afghanistan (Paudel et al., 2018). The study revealed that the probability of switching from dung fuel to higher-ladder alternative fuel sources (such as gas, wood, and shrubs) grows considerably as poverty levels decrease and education levels rise. However, it is different in each area of the country, as the region's geography and the distances between towns complicate the provision of even basic amenities (such as gas, water, and electricity) to the inhabitants. The studies demonstrate that the fuel-type transition in Afghanistan has primarily focused on cooking energy. However, the overall energy consumption in residential buildings has remained inadequately researched in the region, and there is a lack of detailed information regarding heating and cooling energy, type of urban housing, and efficiency conditions.

3.2 Thermal Comfort

The primary goal of building design is to create comfortable thermal conditions for humans. Thermal comfort is "a state of mind that indicates satisfaction with the thermal environment." (ASHRAE, 2017). Thermal comfort is a complex function of the physiological factors: metabolic rate (level of activity), clothing, and environmental factors, viz., air temperature, humidity, movement, and radiation. The other contributing factors determining how thermally comfortable a human feel in a given situation are: living habits, acclimatization, body shape, subcutaneous fat, gender, age, food, and drink.

It was widely held for a very long time that the limits of human comfort could be defined as an equation of heat exchanges between the individual and the environment and that comfort could be defined independently of the climate or acclimatization (Fanger, 1970). The adaptive model contradicts this belief. It is an empirical model developed based on in-situ measurement. The model links certain quantifiable environmental elements to how individuals vote.

First, Humphreys (Humphreys, M.A., 1976; M. A. Humphreys, 1975) brought the results of some 44 field studies of average monthly indoor temperatures and correlated these against outdoor temperature. He showed a close correlation between thermal neutrality and monthly mean outdoor temperature. These correlations were better than those for group sensation votes under laboratory conditions and explained over 90% of the variation of group comfort.

Auliciems (Auliciems, 1982) reanalyzed Humphreys' data, rejected some of it as being inappropriate, and added substantially more data from Australia (Auliciems, A, 1977; Woolard, D. S., 1981). He examined the results of 52 studies combining free-running and actively controlled buildings. The temperature at which a wide sample of individuals experiences neither warmth nor cool is known as thermal neutrality. Auliciems reported that thermal neutrality and mean monthly outdoor DBT exhibit a substantial link. The following equation represents the relationship between neutrality (tn) and the mean monthly outdoor temperature (tm):

$$tn = 17.6 + 0.31 . tm \quad \text{………………….} \ (3\text{-}1)$$

He claims that neutralities may be calculated for every globe region within the range of 17-31°C. In related research conducted in Pakistan by (Nicol J. F. and Roaf, S., 1996), the regression equation was determined to be:

$$tn = 17.0 + 0.38 . tm \quad \text{…………………..…} \ (3\text{-}2)$$

Griffith (Griffith, 1990), through the study of European passive buildings, found the regression equation similar to Humphreys. Moreover, a study for ASHRAE (de Dear, R. J., Brager, G. & Cooper, 1997), which analyzed all the research reports for free running and conditioned buildings, found that the relationship

$$tn = 20.9 + 0.16 . ET^* \text{…………………..…} (3\text{-}3)$$

best represented the line of best fit through all the data from all buildings. ET* is the mean monthly new effective temperature, which allows for humidity variations rather than the mean monthly DBT. For free-running buildings the study proposes the relationship

$$tn = 18.9 + 0.255 . ET^* \quad \text{……………..…} (3\text{-}4)$$

In the case of free running, building the outdoor environment highly influences comfort, as evident from the higher coefficient value. Figure 3.2 collates the expressions of thermal neutrality for free-running buildings given by the studies mentioned above. There is quite a variation, particularly between the earlier study by Humphreys and the most recent work of Auliciems, Nicol, and Roaf, de Dear, et al. The expression (line 3 in Figure 3-3) by de Dear is in terms of ET*, while all other expressions use DBT. These temperature measurements are identical only when the relative humidity is 50%, so there will be a discrepancy at other relative humidity values. Perhaps a more significant reason for the variation lies in the type of buildings the respondents to the various studies were occupying at the time and their thermal expectations. Auliciems (Auliciems, 1982) formulated an adaptive (psycho-physiological) model of thermal perception.

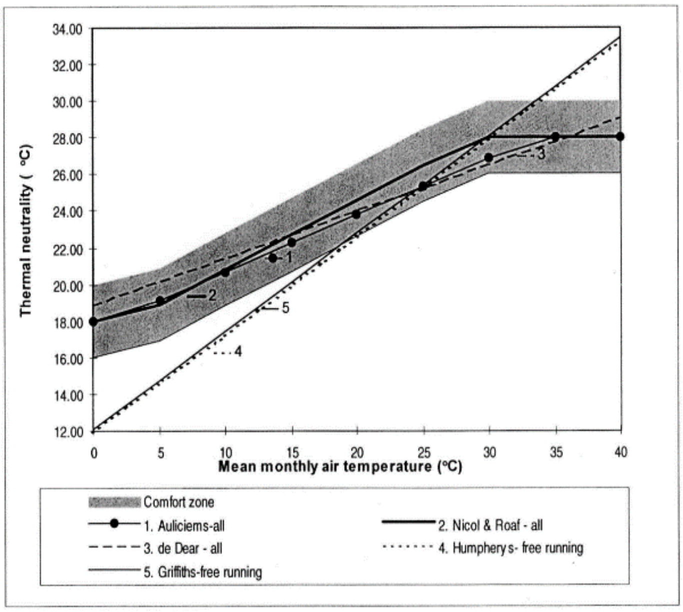


Figure 3.2 Collation of thermal neutrality expressions by five authors (de Dear, R. J., Brager, G. & Cooper, 1997)

The model has the thermal expectations that determine thermal preferences influenced by past thermal environments, reflecting cultural practices. This could account for the marked difference between respondents' preferences in free-running buildings. People in free-running buildings are more prepared to make tradeoffs such as better air quality and airflow against higher temperatures in winter. Building design, envelope material, and outdoor climate substantially influence thermal comfort (Kabre, 2021). A study was carried out by (Fatima and Elaiab, 2014) on the thermal comfort in the Mediterranean climate of Darnah, Libya considering multi-story residential buildings. Using an adaptive model to measure human thermal comfort, it was demonstrated that the indoor environment and perception of comfort are significantly influenced by the climate and the building's envelope. Indraganti (Indraganti, 2010) investigated the adaptive use of natural ventilation to improve thermal comfort in apartments in Hyderabad through a field survey. It is stated that during the summer season, 60% of the occupant were not comfortable due to poor adaptive opportunity. As per the study, the neutral temperature is obtained at 29.23 (T◦) with a comfort range of 26.0–32.5°C for the region. Udaykumar (Udaykumar et al., 2015) investigated thermal comfort features in naturally ventilated apartments in Ahmadabad, India's hot and dry climate. Their findings showed the ambient comfort range of 25◦C and 31◦C for summer and 21.5◦C-27◦C for the region. In addition, Kumar {et al., 2018) evaluated students' comfort preferences and behavioral adaptation in naturally ventilated classrooms in a tropical climate zone of India. The result revealed that for several studied buildings, the neutral temperature, as predicted by linear regression, differed by more than 3◦C. Additionally, more than 90% of the current databank's comfortable votes (±1 votes) fall within the climate's adaptive comfort limits.

3.3 Passive Solar Radiation Control Strategies

Solar radiation's intensity affects subjective and physiological reactions (Xiao et al., 2020). Moreover, it can cause building overheating which has been one of the growing issues related to climate change and increased cooling demand (Habitzreuter et al., 2020).

Global attention is currently focused on developing techniques to enhance the thermal performance of buildings to provide indoor comfort with minimum reliance on energy load for different localities and climates (Alwetaishi and Taki, 2020). There are many options to shade the building's glazed façade to take account of the sun paths at different times of the year. Researchers worldwide have worked on solar control solutions to mitigate direct sunlight into buildings (Albayyaa et al., 2019; Alwetaishi and Taki, 2020). Recent studies in hot climates show that external shading can help minimize the incidence of building overheating by 74% (Habitzreuter et al., 2020) and decrease the internal temperature of the building by 4-5°C. This helps in saving energy by 18-20% as compared to buildings without a shading system. (Ahmed et al., 2016) However, controlling solar heat gain with shading devices is critical for improving summer thermal efficiency (Sarri et al., 2021)(Rana et al., 2021). Since shading would prevent passive heating and block solar radiation when required; therefore shading devices are not suggested in the cold season (Sarri et al., 2021). Ge et al.(Ge et al., 2018) (2018) studied the thermal performance of buildings in the hot summer and cold winter climate of China and reported that in such climatic conditions, the installation of sun shading components contributes significantly to reducing the cooling energy consumption in summer but has little impact in winters.

Nikoofard (Nikoofard et al., 2011) stated that the dwelling heating and cooling energy requirement could be influenced by neighboring obstructions, such as trees and buildings. Meanwhile, the distance and size of such objects affect the magnitude of the shading on energy requirements. Moreover, proper orientation in unfavorable climates can elevate the building's energy efficiency and significantly impact the building's heating and cooling (Nematchoua et al., 2015). The appropriate orientation would create the potential for energy savings by using passive solar techniques. Meanwhile, it is a low-cost alternative, reducing energy use and changing building energy behavior by maximizing passive solar benefits (Morrissey et al., 2011). On the other hand, precise orientation and on-site location may reduce 20% of the energy in a typical building and offer building professionals economic tools to decrease energy consumption (Mirkovic and Alawadi, 2017). Albatayneh (Albatayneh et al., 2018a) examined orientation and its effect on the building thermal performance in Jordon and stated that the energy requirement for heating would reduce by approximately 35% per annum when the openings in the southern walls faced the northern hemisphere to allow the solar energy to enter into the building in the winter.

Similarly, research conducted by (Mulyani et al., 2017) in Padang City, Indonesia, examined the energy consumption for different orientations. Results showed that orientation mainly contributes to reducing active building cooling and reported that cooling, heating, and ventilation (HVAC) account for 64%, whereas the lighting and various equipment comprise 18% of energy usage in buildings. Additionally, appropriate orientation has a vast energy-saving potential in the entire life cycle of the building (Abanda and Byers, 2016).

The literature on building energy efficiency, particularly for Afghanistan, is very scarce. GERES (GERES, 2010) is one of those few reports published on the energy efficiency of public buildings in Afghanistan. However, it (GERES, 2010) is a technical guidebook that only highlights some good practices which had been performed during the reconstruction of Afghanistan in 2006. However, this technical guidebook gives some measures to be taken up while constructing buildings; applying the given measures cannot be mainly replicated because the guidebook is considered single-story public buildings. Afghanistan has witnessed many new residential multi-story buildings for rehabilitation of Afghan residents in recent years, along with public buildings. Therefore, it becomes necessary to identify some energy efficiency measures for residential buildings in Afghanistan. One of the studies has focused on building energy analyses - Yarramsetty (Yarramsetty et al., 2020). Nevertheless, this study used BIM to analyze the energy consumption of the building by considering only a single house instead of a residential tower.

The studies on this research area have been conducted by considering either cold or hot geographical regions but were limited to developing countries with harsh climates having hot summer and cold winter conditions. This work presents an integrated approach for solar radiation control of the mid-rise residential buildings for heating and cooling energy reduction and provides a baseline for energy-efficient residential building design in the context of Afghanistan, considering the climate, material, technology, and architectural specification.

3.4 Energy Efficiency Improvement of Existing and New Buildings

3.4.1 Energy retrofit

Many researchers have examined the energy-saving and CO_2-reduction potential of existing housing. A study on Danish buildings has revealed a potential for a 50% saving in primary energy consumption in apartment buildings (Rose et al., 2019); however, there are still several obstacles to the renovation process of residential buildings, such as selecting measures for various climatic and economic levels. AlFaris et al. (AlFaris et al., 2016) have confirmed the efficacy of energy retrofit measures in dry regions and reported savings ranging from 14.4% to 47.6%, based on the combination of conservation practices used. However, the authors do not provide quantitative data on specific indicators or their utilized costing methodology. Their findings revealed that increasing thermal insulation may not always be the best option. Increasing the wall and roof thermal resistance may be detrimental to buildings with high internal heat gains, including office buildings. This anti-insulation impact could retain excess heat within the structure, necessitating more powerful equipment to eliminate the additional thermal load. However, this phenomenon occurs only in high-internal-gain structures and under particular structural and environmental conditions (Gomes et al., 2021).

Similarly, a study investigated retrofit measures by simulating two residential homes that reflect a high proportion of households in Portugal. The findings revealed that the measures associated with implementing active systems yield rapid results. Moreover, Evangelisti et al. (Evangelisti et al. 2015a) studied an early 1950s Italian residential structure through the dynamic simulation software TRNSYS (Transient System Simulation Tool) to propose strategies for the building envelope. The study found that while increased thermal insulation provides the most significant reduction in heating demand, the window solar gain factor is crucial during summer. Indeed, solar control glazing may reduce cooling energy use by half while also being effective in the winter.

Regarding the effect of an expanded polystyrene exterior insulating layer, the researchers indicated that higher thermal insulation reduces wintry heat dissipation but increases cooling energy demand by up to 45%. Most of Afghanistan’s new housing stock comprises multi-apartment buildings that are commonly energy inefficient. With the climate in Mazar-I-sharif, mechanical cooling in the summer is essential for comfort; the hot and dry environment, combined with poorly constructed homes, results in significant cooling demands. According to the literature, 75.76 % of building envelope energy retrofit research utilized simulation, 16.27 % used mathematics, and just 7.97 % used experimentation. Furthermore, parametric analysis was used in 66 % of the research, whereas non-parametric simulation was used in just 35%.

Literature on existing buildings (energy retrofit), listed in Appendix B-1, is analyzed and presented in Figure 3.3.

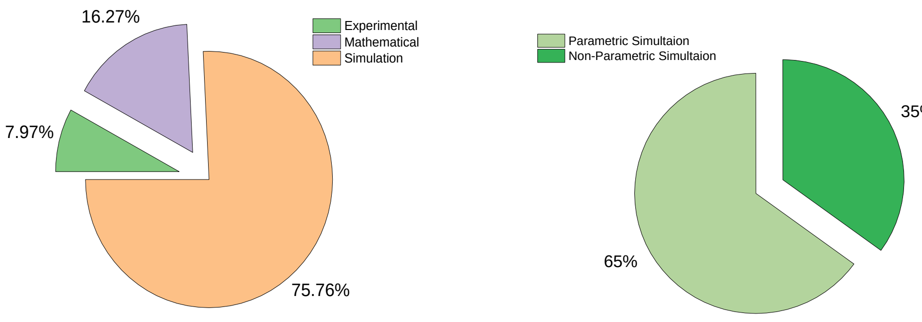


Figure 3.3 The proportion of different approach types employed in the literature review (Existing buildings)

3.4.2 Building early design stage

Several studies have investigated the thermal performance of building fabric. Appendix B-2 presents the author, year, goals, location, climate, utilized simulation tools and techniques, and critical findings of the selected studies.

The visualizations in Figure 3.4 were created utilizing Appendix B-2 literature review findings. It should be mentioned that only research involving residential buildings was considered. Several studies considered various building envelope parameters for different climatic conditions. As a result, each study yields a different outcome.

As illustrated in Figure 3.4, most studies (80%) employed parametric simulation, and a considerable number focused on just one factor at a time. Moreover, past studies relied mainly on simulation approaches. In addition, a new study has used multivariate simulation to examine how one design variable affects another. Mathematical modeling and simulation are used in 15% of the research. Since it involves more time and money, the experimental technique is only used in a limited fraction of cases (2.5%).

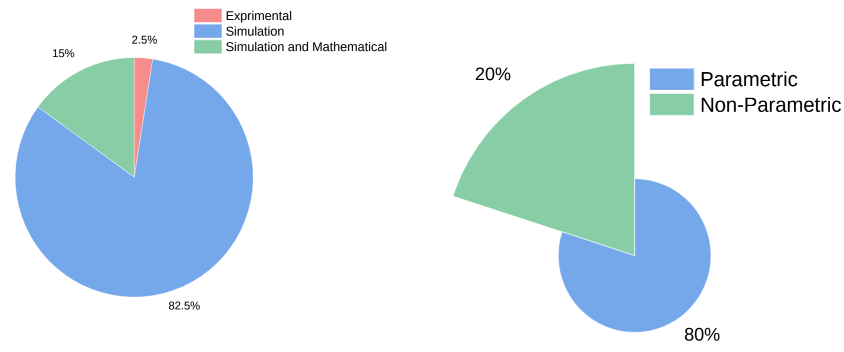


Figure 3.4 The proportion of different approach types employed in literature (early design stage)

According to the literature, 28 % of research is verified against actual measurement, while 47 % is not. Over 18% of investigation effort validation is based on previous studies, 3% on experimental work, and 3% on sensitivity analysis. Figure 3.5 depicts the calibrating method used in earlier studies.

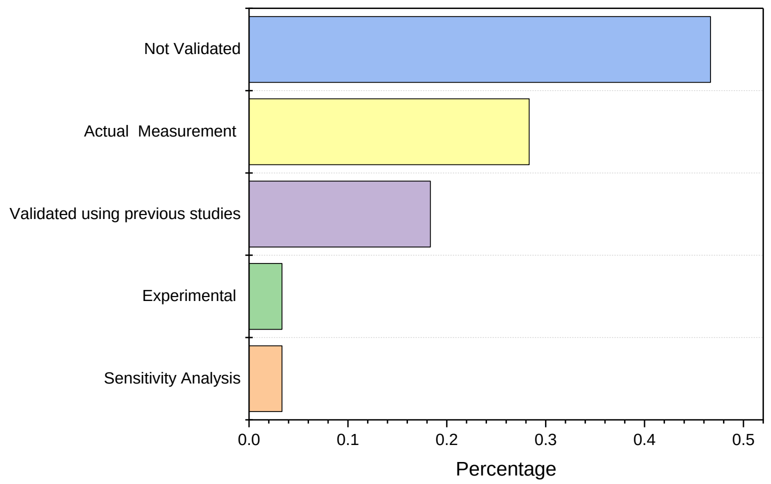


Figure 3.5 Calibration methods in previous studies

Figure 3.6 illustrates the timeline of studies published in refereed journals and conference proceedings. The number of selected studies increased rapidly from 2011 to 2021.

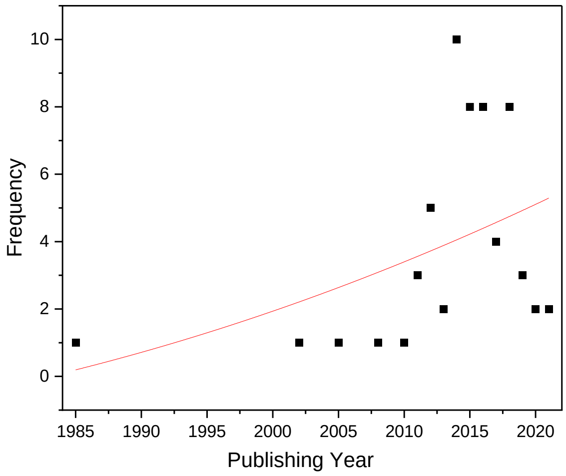


Figure 3.6 The published articles timeline

Thermal simulation and modeling have sparked much research interest due to this trend. For specific purposes, researchers have started identifying the advantages of simulation modeling to improve building efficiency.

3.2.3 Building envelope design factors

The parameters used to enhance the efficiency of envelopes research are energy- or cost-related. The scholars employed different methods to determine which approach influenced achieving a goal (Appendix B-1, B-2). The influencing variables are as follows:

- Orientation of buildings: (Al-ajmi and Hanby, 2008; Albatayneh et al., 2018b; Andersson et al., 1985; Ashmawy and Azmy, 2018; Gulati, 2012; Lee et al., 2018; Yarramsetty et al., 2020)
- Devices for solar shading: (Ascione et al., 2016; Giovanardi et al., 2015; He et al., 2021; Lai and Wang, 2011; Yao, 2014)
- Material for building envelope: (Aldawi et al., 2012; AlFaris et al., 2016; Asadi et al., 2012; Castiglia Feitosa and Wilkinson, 2018; Chen et al., 2015; Evangelisti

et al., 2015a; Gugul et al., 2018; Kotti et al., 2017; Lee et al., 2018; Ortiz et al., 2016; Sage-Lauck and Sailor, 2014; Terés-Zubiaga et al., 2015) (Ahmad et al., 2014; Al-ajmi and Hanby, 2008; An-Naggar et al., 2017; Asadi et al., 2016; Ascione et al., 2016; Cheung et al., 2005; Dehwah and Krarti, 2021; Dhaka et al., 2012; Dhaka Shivraj et al., 2011; Dodoo et al., 2019; Eisabegloo et al., 2016; Fang et al., 2014; Ferrara et al., 2014; Fuad Abaza, 2002; Gulati, 2012; Hwang, 2014; Iwaro and Mwasha, 2013; M. Alwetaishi, 2018; Mata et al., 2013; Morrissey et al., 2011; Neroutsou, 2016; Penna et al., 2015; Pisello et al., 2012; Samuelson et al., 2016; Shabunko et al., 2018; Simon et al., 2018; Stazi et al., 2014; Tuhus-Dubrow and Krarti, 2010)(Zou et al., 2021)

- Building geometry: (Fallahtafti and Mahdavinejad, 2015; McKeen and Fung, 2014; Tuhus-Dubrow and Krarti, 2010)
- Fenestration density and geometric location: (Al-ajmi and Hanby, 2008; Asadi et al., 2012; Cascio et al., 2017; Chen et al., 2015; Cheung et al., 2005; Evangelisti et al., 2015a; Fuad Abaza, 2002; Gulati, 2012; He et al., 2021; Neroutsou, 2016; Pisello et al., 2012)
- The HVAC system’s type, size and schedule: (Abdallah et al., 2015; Ahmad et al., 2014; AlFaris et al., 2016; Dhaka et al., 2012; Dhaka Shivraj et al., 2011; Evangelisti et al., 2015a; He et al., 2021; Mata et al., 2013; Ortiz et al., 2016; Terés-Zubiaga et al., 2016)
- Lighting type and schedules: (Ahmad et al., 2014; Cascio et al., 2017; He et al., 2021; Neroutsou, 2016; Ortiz et al., 2016)
- Energy management: (Abdallah et al., 2015; AlFaris et al., 2016; Cascio et al., 2017; Gugul et al., 2018; He et al., 2021; Ortiz et al., 2016; Terés-Zubiaga et al., 2016)

Various experts have examined the impact of each of the aforementioned design elements on energy and cost savings in residential structures. Building envelope materials, structure orientation, solar shading devices, high-performance glazing, efficient HVAC and lighting systems, HVAC thermostat set points, and other particular aspects uncovered by the researchers all impact the residential building's overall energy consumption. 47 % of the studies reported that the appropriate use of envelope construction materials minimizes building energy consumption, while 15% reported that high-performance glass decreases energy demand. Using energy-efficient lighting and HVAC with appropriate set points may decrease a residential building's energy consumption by 24%. The literature indicates that the performance of the building envelope and the installation of high-performance glazing systems are perhaps the essential retrofit options for residential buildings. Figure 3.7 presents design factors for overall building envelope studies

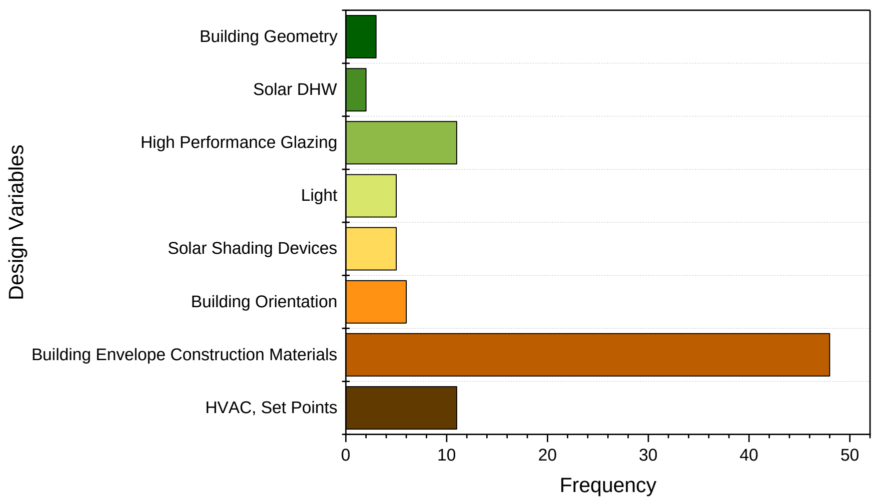


Figure 3.7 Design factors for overall building envelope studies

Building orientation was simulated by 7% of the researchers, whereas shading devices were studied by 5% of the researchers. Moreover, building envelope materials were simulated by 53% of the studies, while 12% and 3% of studies optimized window configuration and building geometry, respectively. Few researchers tried to optimize the HVAC and solar DWH systems to increase residential buildings' energy efficiency. 12% of these studies focused on HVAC, while only 2% selected solar DHW. The studies reveal that the performance of the envelope material of a building and the HVAC system was deemed the most critical factors in this respect.

3.4.3 Climate and geographical conditions

Understanding the combined impact of several factors on energy demand and the thermal performance of buildings in various climate zones is critical. The influence of climate type and geographical location on building thermal behavior has been studied in several research (Appendix B-1, B-2). Figure 3.8 depicts the climatic type chosen in prior studies considering the Koppen classification.

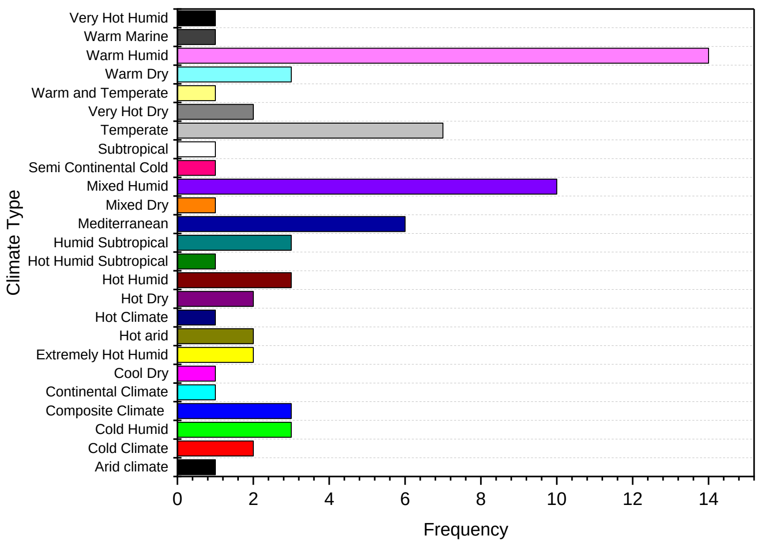


Figure 3.8 Selected climate type (As per Koppen classification)

Based on the previous studies illustrated in Figure 3-9, The majority of the reviewed studies, 18.9 %, were selected in warm, humid climates, followed by mixed humid climates 13.5%, while 9 % in temperate and 8.1% in meditation climates. Approximately

8% of the research is focused on warm-marine climates, while the remaining 21% is focused on warm-humid, hot-humid, hot-humid, hot-dry, and very hot-humid climates.

It should be noted that the climatic zone in previous studies was selected per each country's and Koppen's classification; however, some studies used the ASHRAE classification, while many researchers did not mention climate type in their research. Therefore, the author included ASHRAE (ANSI/ASHRAE Standard 169-2020, 2021) to present the climatic zone of each region as per the studied city and country, which is visualized in Figure 3.9.

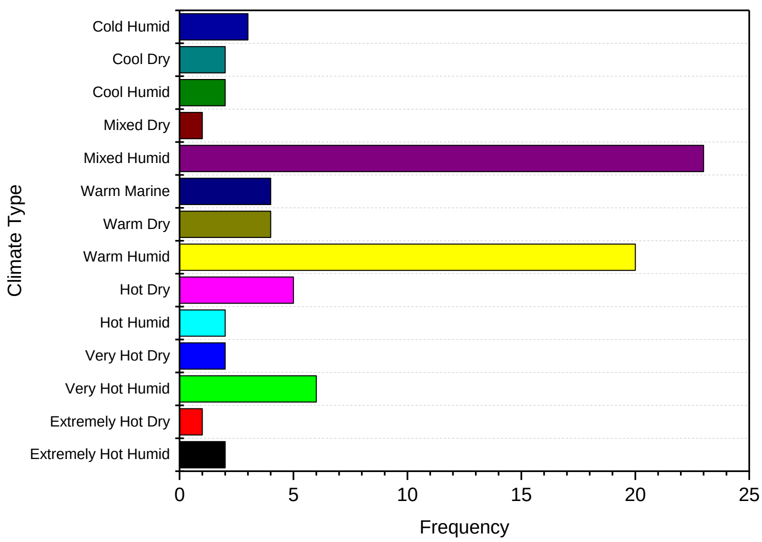


Figure 3.9 Climate type studied (As per ASHRAE)

The mixed humid climate was chosen by 29.9% of studies, the Warm Humid climate by 26.0%, and very Hot Humid by 7.8%. It was observed that the remaining types of climates employed by the selected researchers were limited and under 7%.

3.4.4 Methodology for creating base case models

The base case is a general preference building utilized in parametric simulation to estimate the thermal impacts of various parameters. Generally, there are three base cases:

physical, virtual, and physical and virtual (Figure 3.11). As per literature analysis, the virtual and actual base case buildings have been considered in 26.81% and 71.5% of reviewed research, respectively. The virtual base case is generally developed from codes or standards or based on practicality, whereas actual basis case buildings are formed from authentic case studies of a particular building type. Furthermore, some research (1.69%) employed a combination of actual and virtual base case buildings. Figure 3.10 presents the base-case generation methodology employed for model simulation in the previous research.

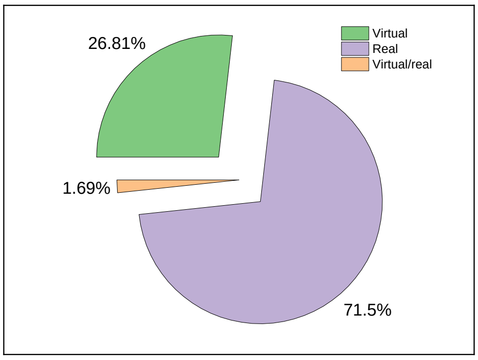


Figure 3.10 Base-case development method for simulations

(Tuhus-Dubrow and Krarti, 2010) generated the base case from Building America Research Benchmark Model. (Samuelson et al., 2016) employed a virtual base case, considering three Squares, a Rectangle, and a T-shape of 1200m^2. Similarly, (Fallahtafti and Mahdavinejad, 2015) employed 8x8 =64 m3 volume as the virtual base case. (Albayyaa et al., 2019) used two two-story detached residential houses to create the base case. (Ferrara et al., 2014; Sang et al., 2014) did not give any specific reasons for their base-case model.

As per the literature, the base-case model can be created using average data from the investigated building, standards, and local ordinances. As a result, the base-case model should represent the existing and future residential constructions in a particular area.

3.4.5 Creating the base-case building models

A base-case model is representative of a prototype of existing and future residential buildings in a particular region. The average of collected data from chosen residential dwellings in the specified region is required to generate the base-case model. Furthermore, the case study selection criteria should be determined, which can be achieved using the sampling approach. To begin, at least one building from the city’s strategic area should be chosen. Then a descriptive database should be created to include all the data that has been collected during the survey either by the researcher personally or by the appointed person (Sawsan Mohamad Saridar, 2004). Eventually, in order to develop the base-case model, the data must be analyzed and evaluated.

3.4.6 Base-case building model calibration and modification

The simulation model should be calibrated to ensure the accuracy and usability of the simulation output. The calibration process comprises comparing simulation results to observed data and fine-tuning the simulation until the results are almost identical to the measured data.

The reviewed study utilized one of three methods to calibrate the building base-case model:

- Comparing the model's predicted air temperature against actual indoor air data.
- Employing monthly energy bills to compare them against the simulated base-case model's monthly predicted energy.

To quantify the difference between predicted and actual values, researchers have employed statistical indices such Coefficient of the Variation of Root mean squared error (CV(RMSE), and normalized mean bias error (NMBE).(Asadi et al., 2016; Balaji et al., 2015; Dhaka et al., 2012; Evangelisti et al., 2015b). The parameters given above can be determined using the formulae below ((ANSI/ASHRAE, 2002), (Royapoor and Roskilly, 2015)):

$$CV\ (RMSE) = \frac{1}{\bar{m}} . \sqrt{\frac{\sum_{i=1}^{n}(\mathrm{mi-si})^2}{n-p}} X100\ (\%) \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3\text{-}5)$$

$$NMBE = \frac{1}{\bar{m}} . \frac{\sum_{i=1}^{n}(\mathrm{mi-si})}{n-p} X100\ (\%) \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3\text{-}6)$$

Where;

m_i =measured value, s_i = simulated/predicted value, n = the number of measured data points, $\bar{m}$ = mean of measured values, and p = the number of variables.

As per ASHRAE Guideline 14 (ANSI/ASHRAE, 2002) the acceptable range of CVRMSE and NMBE between actual and simulated models using hourly weather data is ±30% and ±10 %, respectively. When less than 12 months of data is utilized, the base-case model must have a CV(RMSE) of a maximum of 20% for energy usage and demand quantities of 30%. While to calculate savings for 12 to 60 months, these needs are 25% and 35 %, respectively.

If the statistics imply that the model is not calibrated appropriately, the generated model input must be modified, and re-simulated, and once again, the predicted output should be compared with the actual recorded data. It's crucial to figure out which input parameters may be adjusted to calibrate the model.

3.4.7 Simulation tools and methods

Building envelops simulation and design are linked to the building energy modeling tools and simulation engine. Numerous energy modeling and simulation tools have been developed to model building daylight and thermal performance. To choose an appropriate tool, it is required to use selection criteria. The previous studies have chosen different tools based on their simulation requirement, listed in Appendix B-1 and B-2. Figure 3.11 demonstrates that energy plus is the most often utilized simulation tool (18.3%), followed by TRNSYS (12.7%) and DesignBuilder (9.9%) by researchers.

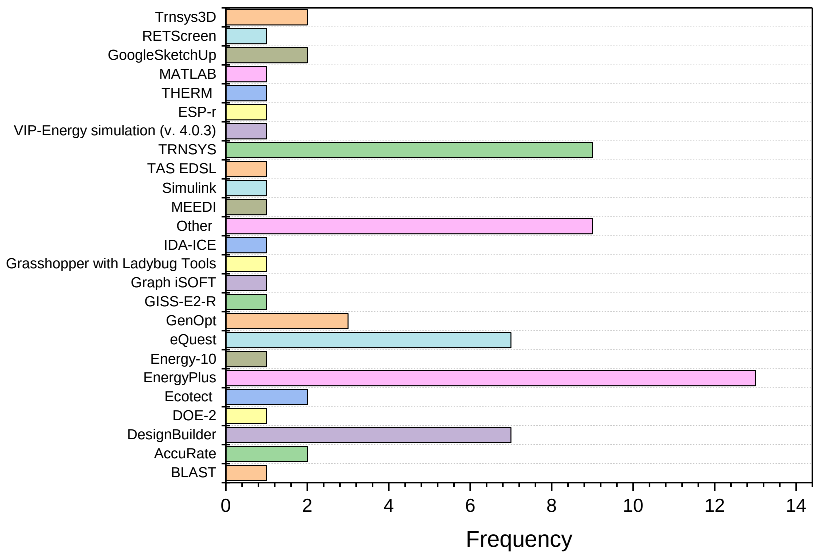


Figure 3.11 Employed simulation tools in previous studies

EnergyPlus is one of the oldest software. Moreover, EnergyPlus as a simulation engine and radiance for daylighting are both used by DesignBuilder. In addition, 9.9% of the reviewed research used eQuest for conducting the simulation and optimization. A limited number of studies chose Ecotec, blast, and Ladybug.

3.5 Conclusion and Knowledge Gaps

This chapter reviews the literature related to each objective of the thesis. The literature related to building energy efficiency in new and existing buildings highlights five trends.

First, varied research enhances residential buildings' energy efficiency by enhancing building envelope thermal performance. Related standards and codes have also been established in developed and developing countries. However, there is negligible work in Afghanistan.

Second, trends suggest using several methodologies and tools for simulating and designing building envelopes to reduce energy consumption without compromising thermal comfort. For energy-efficient design, extensive data regarding the energy and climate of the region is required. Third, most research employed case studies to construct a base-case model to represent ongoing and future buildings in the region. In addition, prevalent variables for building envelope simulation research were the wall, roof, window glazing, and construction materials. Fourth, the EnergyPlus simulation engine is the most popular simulation program. Fifth, statistical indices such as MSE and CVRMSE are commonly used for calibrating the models.

Given that analyzing a building energy model necessitates familiarity with the energy consumption pattern, building characteristics and the selection of a representative building of the region, as well as an understanding of the comfort level of residents since it varies depending on the geographical location and climatic conditions, it is apparent that the literature reveals insufficient research on building characteristics and housing type in urban Afghanistan. Additionally, there appears to be a scarcity of investigation into thermal comfort. Overall, building energy efficiency simulation results are specific to climatic conditions, construction material, construction practices, and technical know-how. Hence, the vast amount of research done in several countries needs to be customized for adoption in Afghanistan. Thus, research is needed to enhance the energy efficiency of residential buildings in Afghanistan, as demonstrated in the next chapter.

CHAPTER 4

ENERGY STATUS AND CLIMATIC CONDITION OF AFGHANISTAN

This chapter deals with the energy status and climatic condition of Afghanistan. There is a scarcity of updated literature regarding energy and its sectorial use, climate zones, and weather conditions in Afghanistan. Moreover, the Afghanistan energy efficiency code addressed the absence of climatic zone classification (ANSA, 2015). This work derived data from a variety of sources. For energy study, the primary sources were raw data and statistics from the ministerial databases, either online or printed reports. Furthermore, the available literature was the reports submitted to the Afghan government by the World Bank and the Asian Development Bank. Figure 4.1 shows the steps for analyzing the energy status of Afghanistan, the challenges, and possible solutions.

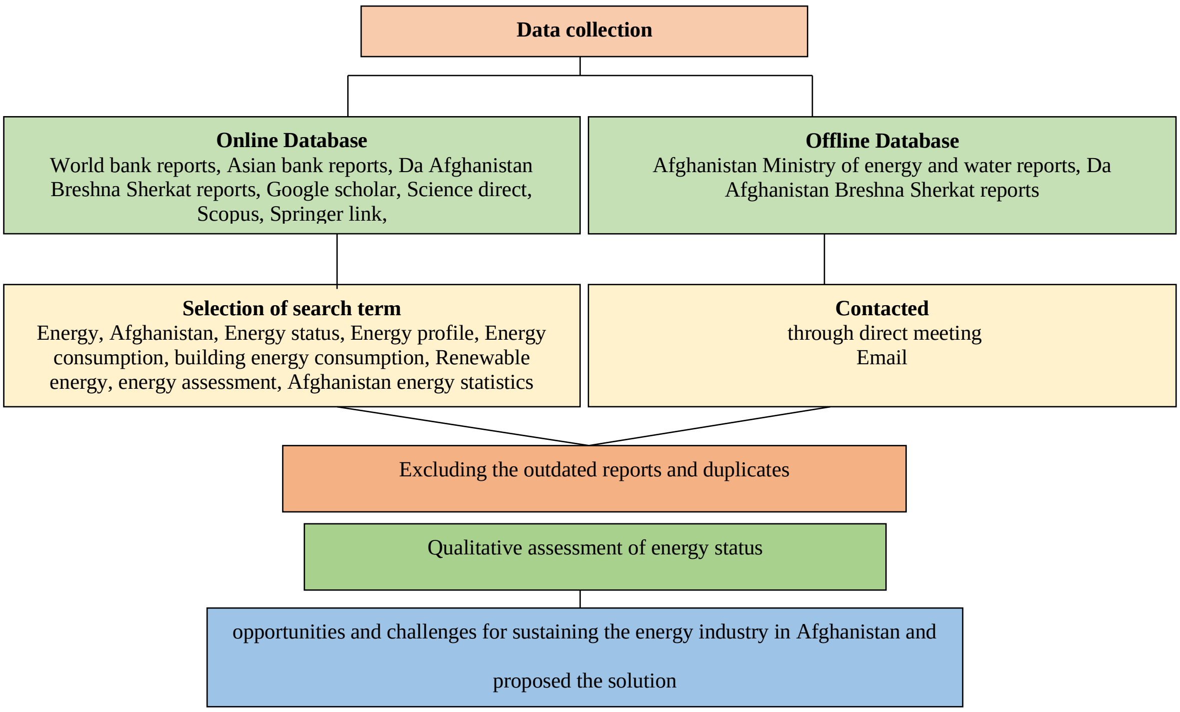


Figure 4.1 Steps of the study

The Koppen climate classification map provides worldwide climatic data considering the vegetation in the region. The Koppen map has been adopted to specify the climatic zone for the selected region. The high-resolution global climate data in kmz format, predicted for 1986-2010, then analyzed and visualized with ArcGIS Earth tool.

The ASHRAE (American Society of Heating Refrigerating and Air-Conditioning Engineers) has provided climatic data for countries around the world for building design standards. The updated version was released on July 2021 and obtained from ASHRAE online source.

To identify the climatic parameters of the selected region, the metrological data was obtained from the Afghanistan metrological department. Due to incomplete available data in their database, the historical weather data in EPW (EnergyPlus Weather Format) has been collected from a data source (Climate.onebuilding, 2019), which provides worldwide weather data for building energy simulation software by the US department of energy. Figure 4.2 illustrates the schematic weather data analysis process.

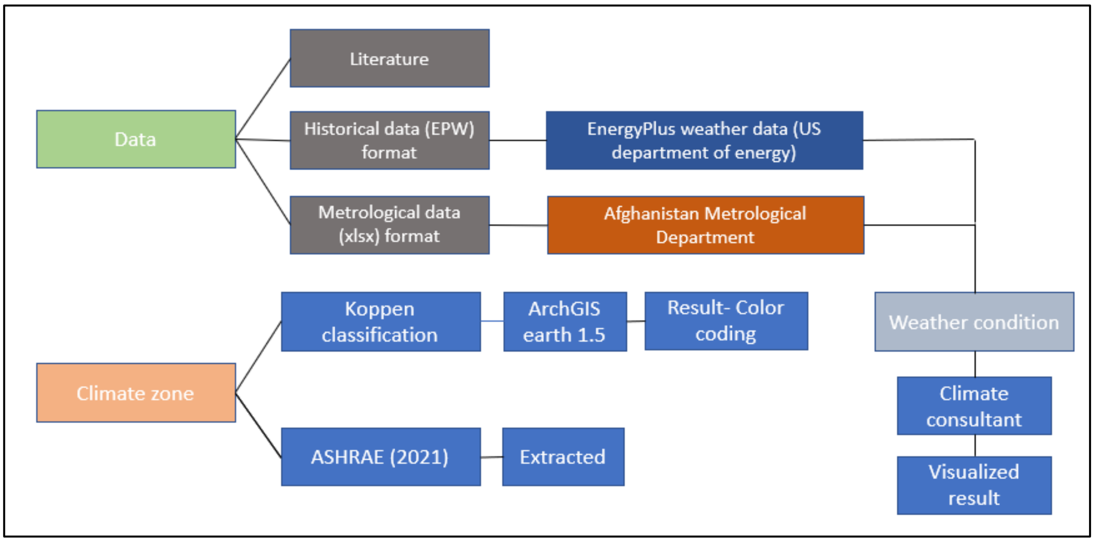


Figure 4.2 The analysis steps

Each meteorological parameter in a TMY dataset has 8,760 values in EPW files, corresponding to the number of hours in a year. Climate consultant tools have been used to analyze historical weather data. Climate Consultant is a user-friendly and graphic-based software tool that assists in comprehending the local climate.

4.1 Energy

Asia has a significant influence on the global environment and energy trends. The energy choices made in the region have many social and health effects on nearly half of the world's population. Governmental decisions in Asia regarding energy production and consumption, energy conservation, and greenhouse gas affect energy resource depletion trends, global greenhouse gas emission levels, and environmental conditions (Miranda A. Schreurs and Julia Balanowski, 2017).

Afghanistan being a landlocked country, lies at a strategically important location. Afghanistan is the 41st largest nation in the world, with a population of roughly 29.7 million (as of the 2017 update) and a total area of 652,864 km2 (CSO, 2017). Four decades of conflict, civil war, foreign intervention, and political instability have constrained the country's development and have severely affected its economic growth. However, the last decade has been characterized by remarkable progress after the security transition in 2014, but poverty increased to 54.5% (WB, 2019b). Access to stable and affordable energy supplies leads to even economic growth. Energy access is crucial for any strategy to advance a nation's social welfare and health.

Afghanistan's energy infrastructure, generation, transmission, and distribution during various conflicts have been destroyed. The international development organizations have made developing and rebuilding the country's physical capital their primary objective since 2001. The progress is hindered due to the high level of damage and massive investment requirements (NEPA, 2017). Afghanistan is among the world's lowest per capita consumers of energy, with fuelwood accounting for more than 85% of total energy consumption (ADB, 2015a). Afghanistan's per-capita annual power consumption is 150 kWh, which is negligible to the global average of 2728 kWh. Due to the ever-growing gap between demand and supply, 85 % of the local population in Afghanistan still does not have continuous access to electricity (Bochkarev D, 2014). Energy access is one of the priorities for the Afghan government, and efforts have been taken for the modernization and expansion of the national electricity grid with the possibility of power trade with central and south Asia. However, due to its limited infrastructure, the national grid will not be able to serve the country's entire population in the near future (MEW, 2017).

Energy access is not only crucial for economic growth but also important for any strategy to improve the health and social welfare of a nation. Afghanistan’s energy industry is in poor condition due to many years of war and negligence. Despite international agencies' support and energy policies adopted in the last few years, Afghanistan has no universal access to power. Besides, the residences suffer from an irregular distribution of power supply. There is a growing gap between demand and supply, and the current predictions of demand do not show reality due to hindered economic growth. Afghanistan's domestic power transmission is limited, which must be extended for the country to enjoy a stable and sustainable energy supply. The sustainability and security of Afghanistan’s power sector would rely on its ability to become self-reliant in power generation. Overall, this chapter's objective is to summarize Afghanistan's current energy status and identify energy opportunities for self-sufficiency and challenges in various aspects of energy sources.

4.1.1 Energy demand

The electricity demand is proliferating in Afghanistan due to increasing population, GDP growth, historical shifts in intensity, per capita expenditure, energy availability, and domestic energy circumstances. However, there is limited information on the energy consumption of Afghanistan's rural residents since they are highly impoverished by the standards of most other nations, and more than 20.4% of them do not consume enough food to maintain a healthy lifestyle (ANDS, 2008).

According to Afghanistan's power sector master plan, net demand is predicted to increase from 2800 GWh in 2012 to 15909 GWh in 2032, with an average 9.8% yearly growth rate (WBG, 2018). The predictions indicated that Afghanistan would require new energy supplies to meet the energy demand even before its domestic energy supplies develop full accessibility (Bochkarev D, 2014). It is asserted that if the energy supplies are efficiently and effectively managed, then the local resources might satisfy Afghanistan’s mid-term primary energy requirements (2014-15 to 2024-25). Figure 4.3 shows Afghanistan projected Electricity Demand from 2012 to 2032.

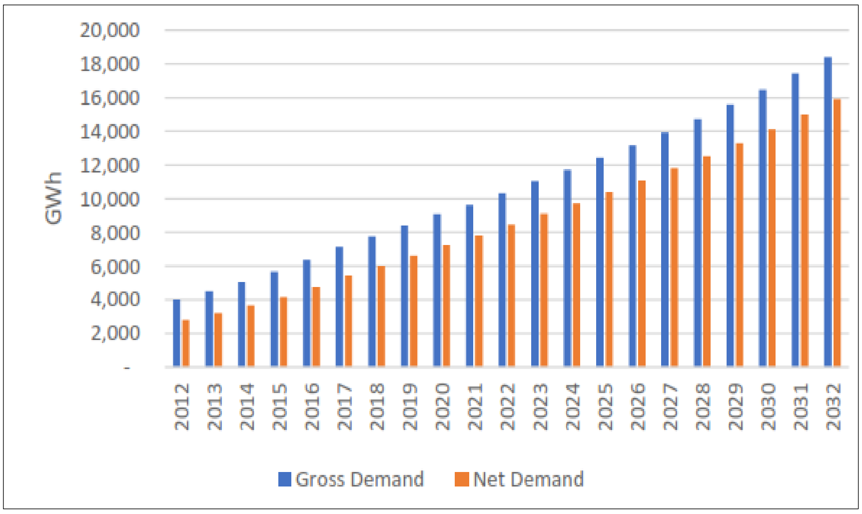


Figure 4.3 Afghanistan projected Electricity Demand from 2012 to 2032 (WB, 2018)

Theoretically, domestic energy resources might soon let Afghanistan become energy self-sufficient (Bochkarev D, 2014). According to the report, hydrocarbon deposits in Afghanistan can meet up to 80 percent of its requirement for petroleum products (WB, 2013a).

4.1.2 Energy supply and potential

In Afghanistan, the current power supply system is deficient in various aspects, such as regional geographic coverage, capability, flexibility, and the cost of domestic supply (WB, 2018). Although the energy supply has almost tripled between 2006 and 2011, yet energy access in Afghanistan is low. As per the Ministry of Energy and Water (MEW), only 30% of Afghanistan's population has access to energy. In Kabul, electrification is reaching 70-75 %, but approximately 85% of the rural population does not have access to the electricity required for daily needs (Bochkarev D, 2014). Commercial electrical energy is supplied by kerosene hydropower and diesel. Hydropower and solar energy have the highest potential as renewable energy sources, but the high initial cost is a significant hindrance (ANDS, 2008).

Approximately 9% of the population has access to irregular domestic public power, and the nation primarily depends on electricity imported from its neighbors (ADB, 2015a). Da Afghanistan Breshna Sherkat (DABS) estimates that just (22.6%) of the country's power is produced domestically; the remaining (77.4%) is imported (Table 4.1). Supplies come from Uzbekistan (35.3%), Tajikistan (30.7%), Iran (21.7%), and Turkmenistan (12.3%). Despite being the primary outside source, Uzbekistan's transmission capacity is constrained (DABS, 2016). With the support of the International Development Organization, Afghan authorities have significantly improved access to electricity for the residents. However, people are still suffering from a deficiency of adequate and consistent supply of electricity, domestic power, and fossil fuel production.

Table 4.1 Electricity imports from neighboring countries (ICE, 2016a)

Countries	Apr 2013- Mar 2014	Apr 2014- Mar 2015	Apr 2015-Mar 2016
Tajikistan	947179	1137602	1179581.05
Uzbekistan	1392581	1242839	1356475.46
Turkmenistan	398586	427702	472958.96
Iran	839570	869143	831724.79
Total Imports	3577916	3677285	3840740

Afghanistan's grid-connected installed capacity is almost eventually divided between hydropower and thermal. Off-grid renewables (large hydropower, solar, wind, and biomass) offer balanced energy. Out of 623 MW installed domestic capacity, 312.5 MW is from thermal, 255.5 MW is from hydropower, and 55.0MW is from renewable energy, as shown in Figure 4.4 (ICE, 2016a).

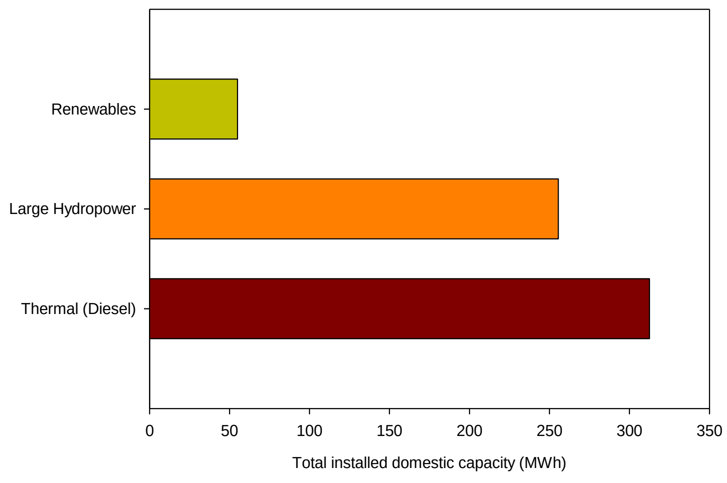


Figure 4.4 Sources of electricity in Afghanistan- Total installed domestic capacity (MW)

The energy sector in Afghanistan is dominated by expensive fuel oil and diesel generation, which is expensive. It can cost up to 35-40 U.S. cents per kWh and is about 6 to 7 times higher than the price of the electricity being imported from Central Asian countries (Bochkarev D, 2014). Due to the lack of grid integration, the existing thermal generation capacity is costly to operate and increases dependence on different import sources, though, in recent years, the government has invested in renewable energy sources. The import bill of energy has increased 14 times from $16 million to $224 million from 2007 to 2015. The electric supply, i.e., domestic vs. import, has been shown in Figure 4.5.

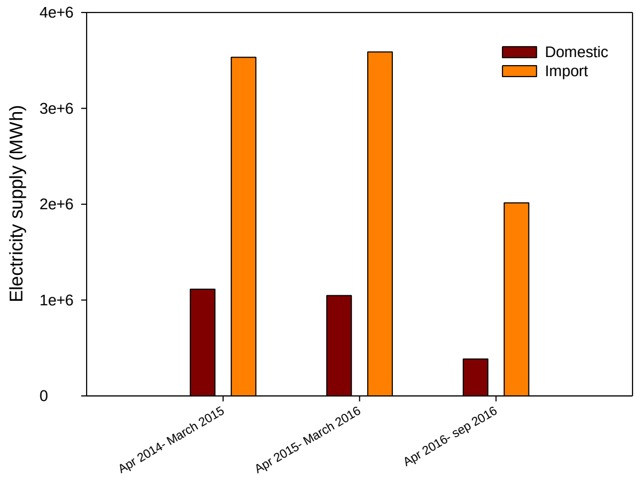


Figure 4.5 Electricity supply MWh (Domestic vs. Imports)

Table 4.2 and Figure 4.6 illustrates the cost of supply, i.e., the average estimated unit price in Usc /kWh (ANDS, 2008).

Table 4.2 Cost of Supply (ANDS, 2008)

S/N	Type	Average Unit Price (Usc /kWh)
1	Diesel (all provinces)	29.53
2	Thermal (NW Kabul)	27.115
3	Hydro, thermal, and Diesel	6.473
4	Hydro and Diesel	5.19
5	Natural gas	2.8- 3.5
6	Imported	2.62
7	Hydro	2.29
8	Coal (1MW=4.5ton)	1ton=Afs 2.200

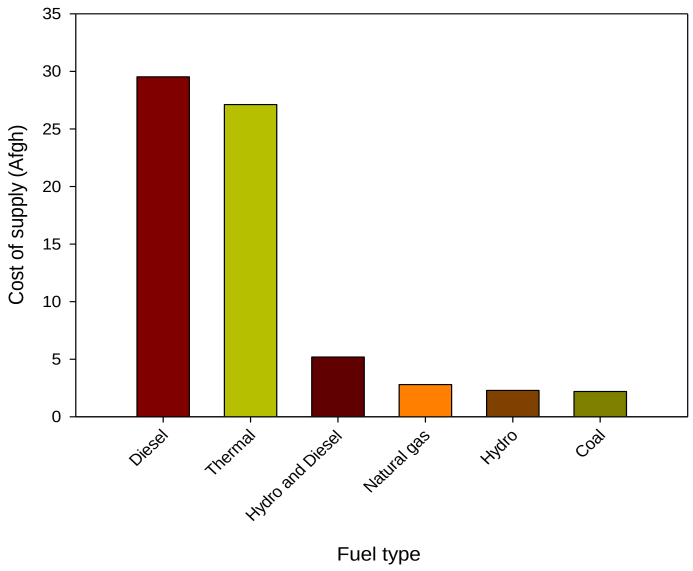


Figure 4.6 Cost of supply (ICE, 2015)

4.1.3 Transmission and distribution

The least developed part of the Afghan power system is power transmission and distribution. The transmission system is independent grids or islands supported by various power systems and import sources. It has been noted that between 2010 and 2015, there was a 60% rise in the number of residential connections to the grid and a 57% increase in all connections. Of the total connections, 93% are households, and the remaining 7% are commercial customers and government agencies. The sole autonomous state-owned utility in Afghanistan with ownership of all the generating, transmission, and distribution is Da Afghanistan Breshna Sherkat (DABS).

Four major working groups connect different supply sources to the grid for operational needs. The North East Power System (NEPS) links 17 load centers, including Mazar-e-Sherif, Kabul, and Jalalabad with Uzbekistan and Tajikistan (at 110 kV, 220 kV, and 35 kV); the Southeast Power System (SEPS) includes Khandar and linking with Kajaki (110 kV); and the Herat System links Iran with Turkmenistan (132 kV and 110 kV);

Turkmenistan System that links Herat, Andkhoy, , Faryab, Sar-e-Pul , JawzJan provinces (110 kV) (WBG, 2018).

Distribution networks in areas apart from NEPS also need to be rehabilitated as those were destroyed during conflict or have exhausted their economic life causing technical losses (ADB, 2015a). Hence, for the major urban centers, the main focus has been the rehabilitation and expansion of the distribution system. It is seen that each new connection is expensive and costs about $1,000 in distribution alone. Also, due to the weak distribution systems, there is a power wastage of up to 75% (MEW, 2007).

A focus of energy sector efforts development has been to upgrade Afghanistan's electricity grid from isolated islands into a national transmission grid. A unified grid will make the transmission of power generated from one part to another country. It will also ensure that imported power can be transmitted to the remote area of the country. Table 4.3 presents the existing and planned transmission line lengths per the source.

Table 4.3 Current and anticipated transmission line lengths (ICE, 2015)

Line Voltage KV	Existing/ Km	Planned / km	Total/km
13.2	2	-	2
20	80	-	80
35	78	-	78
110	1,287	2,841	4,128
132	148	-	148
220	669	2,667	3,336
500	-	1,393	1,393
Total	2,261	6,907	9,168

4.1.4 Energy resources and consumers

Hydropower is one of the widely used renewable energy. Due to water resource availability and environmental benefits, hydropower plants have attracted particular attention. As discussed earlier, access to energy is limited in Afghanistan though it has considerably improved in the past few years. There is a very high per capita consumption of fuelwood and charcoal due to high altitude and severe winter conditions, which has increased to more than 10 tons/year for households in some cases. The average households in the rural areas of Afghanistan frequently lack adequate cooking fuel. In rural areas, solid biomass is the primary fuel; on the other hand, wealthier families frequently use fossil fuels as a part of their energy portfolio. Solid fuel utilization is related to major health issues and results in natural resource depletion. As per DABS, there was an 8% increase in the number of connections by 2015, and there has been an approximately 4% year-on-year increase (ICE, 2016b; WB, 2013b). Table 4.4 presents the number of DABS Electricity connections.

Table 4.4 Number of DABS Electricity connections (ICE, 2016b)

Type of usage / Year	2013	2014	2015
Household	1,009,445	1,112,833	1,197,388
Commercial	77,980	82,467	87,694
Government	13,999	15,643	17,011
Total	1,101,424	1,210,943	1,302,093

Various factors determine choices for the energy system, including technology, cost, accessibility, politics, demographics, convenience, and safety. Figure 4.7 presents electricity consumption in different sectors in Afghanistan (Temori, 2017).

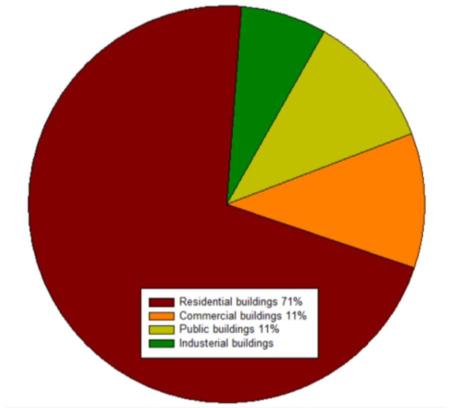


Figure 4.7 Electrical energy consumption by different sectors in Afghanistan

4.1.5 Renewable energy technologies

In Asia, renewable energy technologies viz. hydropower, solar, thermal, wind, and traditional biomass have been well-establish**.** According to the International Renewable Energy Agency (IRENA), Asia's renewable-energy power generation capacity increased from 387 550 MW in 2010 to 918 655 MW in 2017 (IRENA, 2018). Figure 4.8 depicts the total renewable energy capacity in Asia.

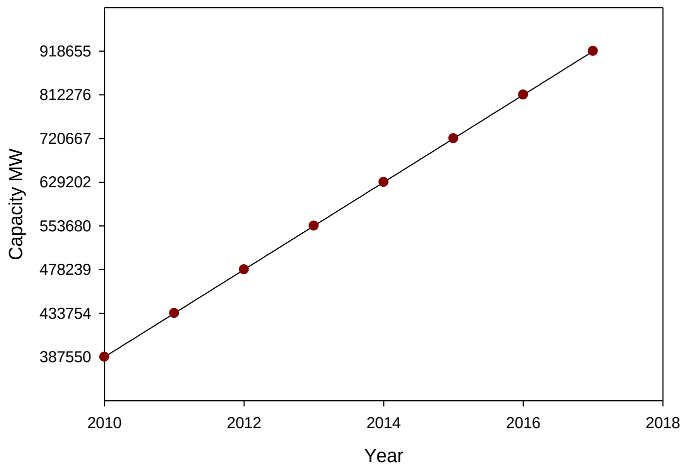


Figure 4.8 Total renewable energy capacity in Asia (IRENA, 2018)

Renewable energy will be vital to Afghanistan's economic, social, and sustainable growth. Renewable resources such as hydro, biomass, and solar are available in plenty, and their exploitation would help enhance future supply gaps in terms of economic and financial conditions. Table 4.5 shows the Hydro project's capacity in Afghanistan (MEW, 2015).

Table 4.5 Hydro Projects (ICE, 2016b)

Type of Hydro project	Capacity (MW)
Small	<25000 kW
Micro	<2500 kW
Micro	<250 kW
Pico	<2.5 kW

According to World Bank, Afghanistan's hydroelectric capacity is 23,000 MW, out of which about 87 % (20,000 MW) is located in the northeast on the Amu Darya, Kokcha rivers, and Panj (WBG, 2018)—installed Hydro projects of the capacity of up to 3 Megawatts. Figure 4.9 displays the overall Levelized cost of solar PV generation for the geographical units supporting grid-level solar installations (WBG, 2018).

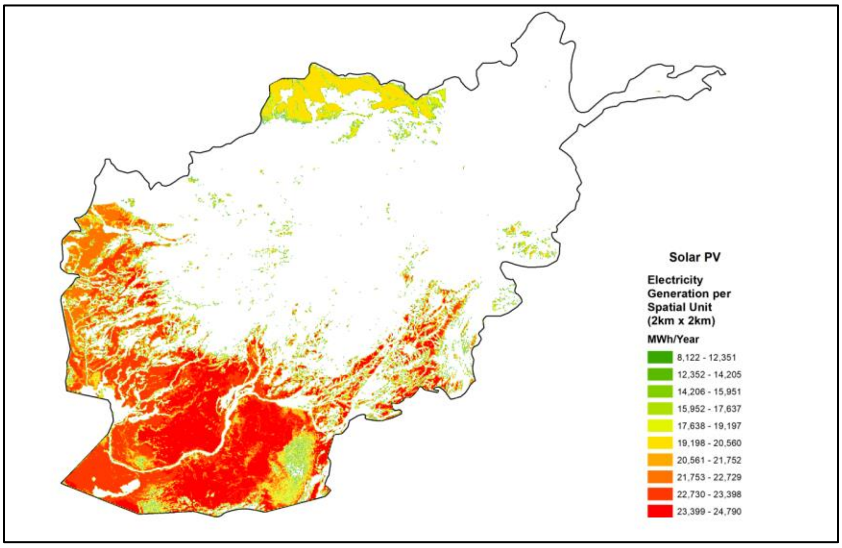


Figure 4.9 Average annual solar PV generation (MWh/year)

Afghanistan's average solar-energy potential is about 6.5 kWh per m^2 per day, with approximately 300 days of sunshine per year. Higher values of solar potential are available in the southern areas of Kandahar, Farah, Herat, and Helmand provinces.

Electricity generation is technologically feasible even though the average irradiation in the northern provinces is just 4.5 kWh per m2 per day (WBG, 2018). Afghanistan's total renewable energy capacity and growth from 2010 to 2017 are shown in Figure 4.10.

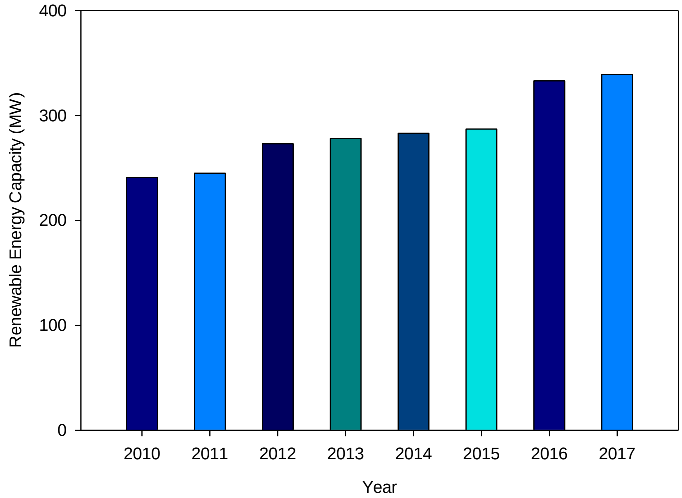


Figure 4.10 Total renewable energy capacity in Afghanistan (IRENA, 2018)

Table 4.6 Potential for renewable energy in Afghanistan (MEW, 2015)

Type of energy	Potential
Solar	222000 Megawatts Average solar insolation of 6.5 kWh/m per day 300 days of sunlight
Hydropower	23000 Megawatts Potentials of Large Dams, Mini and Micro potential each 600 Megawatts
Wind	67000 Megawatts 36000 Km 5 MW per Km, windy land
Biomass	4000 Megawatts Animal waste 840 Megatts 3090 Megawatts of agriculture waste
Geo-Thermal	3000 – 3500 Megawatts Three big possible regions 4-100Gwatts

Table 4.6 shows the potential for renewable energy resources in Afghanistan. The wind resources also have considerable potential in Afghanistan, but it is concentrated in the southwest near the Iran border. The nation's total wind energy capacity is 150,000 MW, whereas the exploitable capacity is estimated at 66,700 MW. Also, there are signs of the significant potential of geothermal and biomass, but further study of such energy sources are required (WBG, 2018). To meet citizens' energy needs, biomass plays an essential role since fuel demand is in the form of fuelwood, charcoal, animal manure, and crop residues, mainly used by households. Geothermal energy for power generation can be harvested at a low cost.

4.2 Energy Policy

Since 2004, the Afghanistan government and the international community have been developing the National Development Strategy, and the energy sector has been the top priority. In order to overcome the challenge of coordinating between many local organizations and their foreign partners to reform the power sector, the Afghanistan National Development Strategy (ANDS) was approved in 2008 (ADB, 2010).

The Ministry of Energy and Water (MEW) was appointed the apex agency for establishing and executing energy policy by the National Integrated Energy Policy, established in 2016, and offered broad parameters on the scope for the country's energy industry (MEW, 2016a).

The Renewable Energy Policy, which was designed by the Ministry of Energy and Water (MEW), also aims to integrate renewable energy projects into the energy industry's growth. After considering transmission losses and wheeling fees, the policy allows investors to produce power using renewable energy resources at one or more locations and get an equivalent quantity for personal use elsewhere on the grid. The policy also deregulates small-scale power production projects through renewable resources up to 100 kW (MEW, 2015). Although the government has adopted energy policies and strategies for power generation, there has been limited focus on energy efficiency in different sectors and energy conservation. Additionally, households' cooking and heating devices are based on either renewable energy sources or traditional biomass, which can support the country's demand.

4.2.1 Challenges in reaching self-sufficiency

Every nation has a different path to achieving energy requirements and following the transition to a sustainable energy sector. It involves a unique mixture of source opportunities and challenges related to access and efficiency. Afghanistan's energy challenges are somewhat different from other developing countries for reasons noted earlier. Afghanistan is an energy deficient nation, which can be seen from its domestic power generation capacity provided only 22 percent of the country's total consumption till 2015. Afghanistan faces many challenges, viz., economic and political problems due to insurgency, decreasing economic growth, and unending poverty. Also, Afghanistan's public electricity sector is facing problems related to workforce and technical capability (USAID, 2010).

- Afghanistan lacks policy frameworks that specify the provision of energy for sustainable development. There has been difficulty in implementing the existing policies and enforcing the laws because of poor infrastructure, which poses many challenges in promoting energy efficiency.
- There is an irregular distribution in the country, and of which Afghan consumers are suffering. Presently, about 70 percent of consumers in the city of Kabul

receive a continuous supply of electricity, while about two third (67–75 percent) of the country's population do not get regular power (MEW, 2016b).

- The country has a limited capacity of transmission and distribution networks that needs to be extended to have much energy security. The number of households connected to the electricity grid was 1,176,030 in March 2015 and has increased by 11 percent in the past few years. Further, the government's power extension policy has increased the transmission line length from 2,261 km to 6,907 km (ICE, 2016b).
- Accessibility to the water resources under climatic uncertainties - for future hydropower generation is a major apprehension in the country's long-term energy planning (WB, 2018).
- The absence of funding for gas production and transmission infrastructure limits the expansion of the gas reserves from 75 billion cubic meters to only 150 square kilometers. Substantial renewable energy and fossil fuel resources are essential for development through private and public investment (ADB, 2015b).
- Since several organizations are involved in the administration process, authorizing procedures and maintenance activities lead to coordination problems among the various authorities.
- There is limited public awareness and responsiveness of renewable energy technologies, social advantages, environmental benefits, and the accessibility to inexpensive fuel energy resources.

4.2.2 Self-sufficiency opportunities

The self-sufficiency goal in the energy industry in any region can be achieved through the government's well-laid - vision and objectives to produce enough energy locally.

Demand stability can be achieved by supplying even, secure, and high-quality energy services to Afghan citizens and promoting renewable energy and energy conservation measures in different sectors.

4.2.2.1 Best use of autochthonous hydrocarbon and renewable energy resources

Afghanistan has plentiful fossil fuel and renewable resources that must be exploited to meet the energy requirements. Adopting national and regional policies can support autochthonous hydrocarbon and renewable energy development and implementation. It will help the nation identify the priorities and ways to construct a sustainable and cost-effective energy market.

Renewable energy, including hydro, solar, wind, geothermal, biomass, and wood, offers the greatest hope for Afghanistan. However, despite its potential, hydropower is still untapped in many parts of Afghanistan. The country's annual renewable surface water resources are estimated at 57 billion $m^{3,}$ which is distributed across five river basins. Nonetheless, the water resources are unevenly distributed across the country or not equally accessible - throughout the year (MEW, 2017; NEPA, 2017) There has been evidence that geothermal and biomass have considerable potential (WB, 2018). Providentially, the government, with the support of the international community, is setting specific targets for the renewable energy sector by supporting national and international companies to meet the country's energy demand and reach self-sufficiency in near future.

4.2.2.2 Energy efficiency and conservation

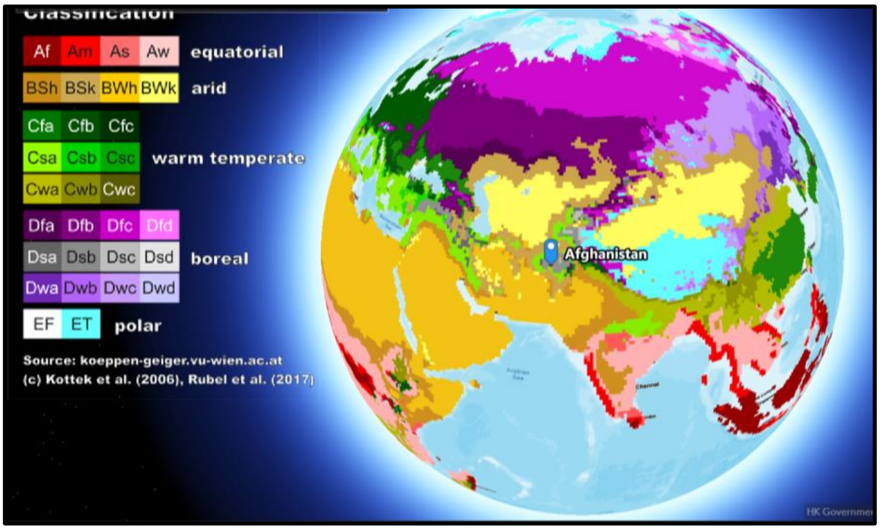
Developed countries have proven that energy can be well-preserved by reducing waste and losses, enhancing efficiency through technological advancements, and improving operation and maintenance (A.Al-Mofleh., S.Taib, M.A. Mujeebu.,W.Salah, 2009). An effective way to fill the energy demand gap in Afghanistan would prompt energy efficiency through rehabilitation, implementation of valuable technologies, and construction of energy-efficient cities. This will decrease energy consumption and lead to cost-saving after an offset from the initial investment cost. Besides the financial benefits, energy-saving may contribute to environmental protection through the reduction of the emission of greenhouse gases. Energy conservation decreases energy demands, which in turn helps increase the quality of the environment, national security, personal financial security, and cost savings. Therefore, the government needs to improve energy efficiency by focusing on application mechanisms in different sectors and should follow energy efficiency policies more conscientiously. Energy efficiency in the building sector will play a significant role in energy conservation since buildings consume a high energy level. Along with other initiatives, enhancing energy efficiency is the quickest, cheapest, and greenest approach to fulfilling a sizable portion of Afghanistan's energy needs and will reduce the need for investing in the energy supply.

4.3 Climate and Weather Condition

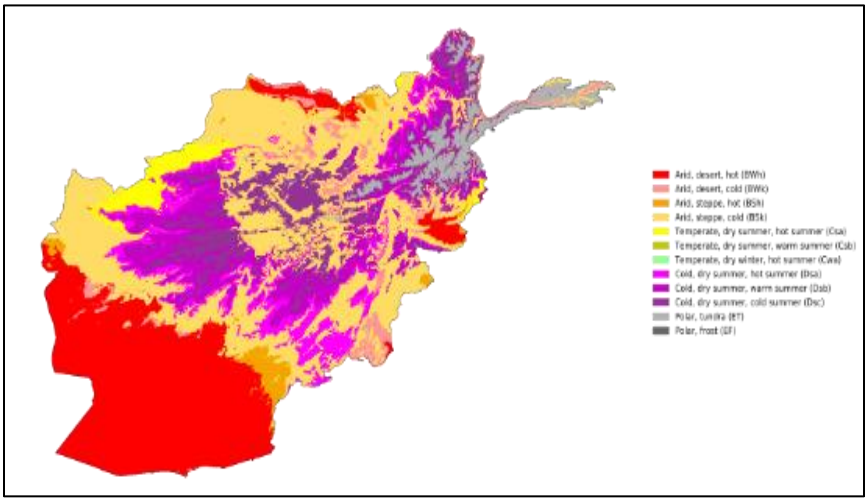
The most critical step for an energy-efficiency and sustainability in buildings is to comprehend and study the climate and its peculiarities to use them best while minimizing energy waste for indoor comfort. Throughout human history, people have consistently developed a responsive and flexible interaction with their immediate surroundings, realizing the relevance of weather conditions in constructing structures despite the lack of measurement techniques. Climate has a remarkable impact on building design and its energy requirement. With this in mind, meteorological parameters are considered one of the leading factors in any building design.

4.3.1 General climatic region's

Afghanistan is a hilly, dry nation with a continental climate that is characterized by harsh winters and hot summers (NEPA, 2017). According to the Koppen Climate Map, the nation comprises various distinct climatic areas, and one must be chosen as the research subject. Figure 4.11 presents the Koppen map of classification for Afghanistan.



(a)



(b)

Figure 4.11 a) Afghanistan in Köppen map, b) Afghanistan Koppen climate (ArcGIS Earth, 2021)

The elevation, longitude, latitude, annual cooling, and heating degree days of Mazar-I-Sharif and Kabul, two major cities in Afghanistan, are illustrated in Table 4.7 (AMD, 2020). Köppen's classification defines the climate of Mazar-I-Sharif as arid (Table 48) and Kabul as cold (dry summer, warm summer)(Köppen-Geiger, 2022). Moreover, the ANSI/ASHRAE (American Society for Heating, Refrigeration and Air-Conditioning Engineers) Standard 169-2020 defines Mazar-I-Sharif as a hot-dry (2B) and Kabul as a mixed-dry climate (4B) (ANSI/ASHRAE Standard 169-2020, 2021). Figure 4.12 highlights the difference in the average temperature of Mazar-I-Sharif and Kabul city during 2019 (AMD, 2020).

Table 4.7 General geographical information of Mazar-I-Sharif and Kabul

City	Latitude	Longitude	Elevation	StdP
Kabul	34.566 N	69.212 E	1791 M	81.58
Mazar-I-Sharif	36.706 N	67.219 E	391 M	96.71

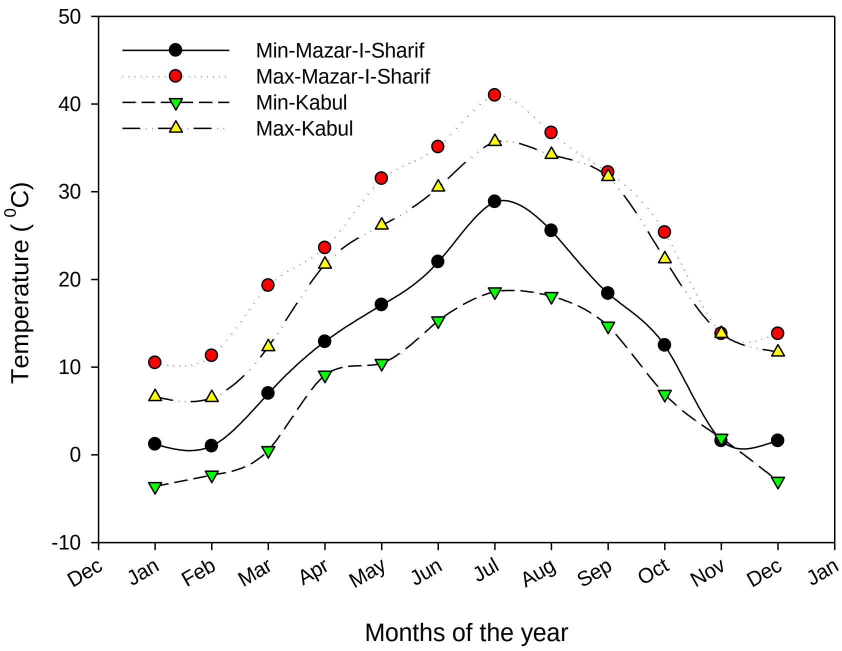


Figure 4.12 Comparison of average minimum and maximum temperature in Mazar-I-Sharif and Kabul city during the year 2019

Table 4.8 Mazar-I-Sharif and Kabul Climatic zone

City	ANSI/ASHRAE		Köppen-Geiger	
Kabul	4B	Mixed-dry	Dsb	Cold, dry summer, warm summer
Mazar-I-Sharif	2B	Hot-dry	BSk	Arid, steppe, cold

4.3.2 Air temperature and humidity of Mazar-I-Sharif

Mazar-I-Sharif's annual average temperature ranged from 15-25 °C (Figure 4.13). It experiences high air temperature and intense solar radiation in summer. With an average high temperature of 40.2 °C, July is recorded as the hottest month of the year. Reversely, the winter season is characterized by the lowest mean monthly temperature of 5.2 °C, which emerges in January with an average low air temperature of 1.3 °C (Climate.onebuilding, 2019).

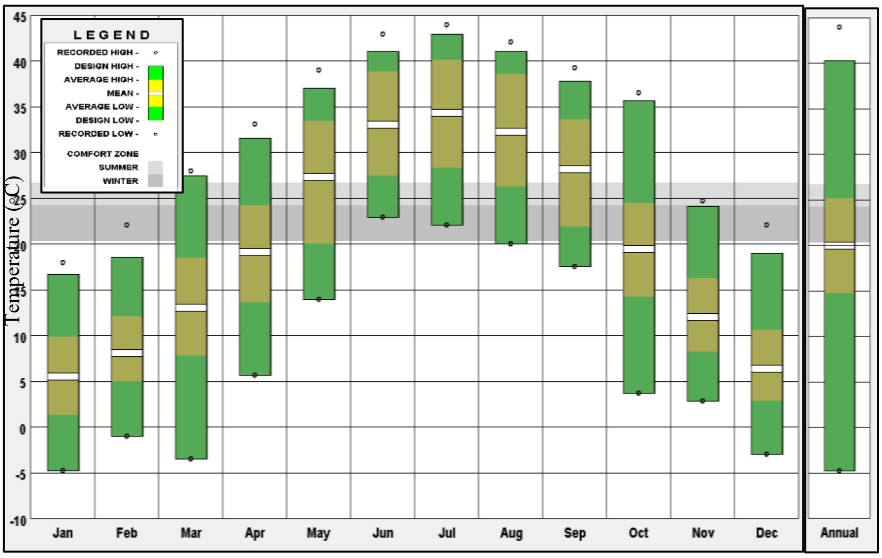


Figure 4.13 Air temperatures range in Mazar-I-Sharif City over a year

Source: (Climateconsultant, 2020)

Figure 4.14 demonstrates the average minimum and maximum temperature of Mazar-I-Sharif city during the year.

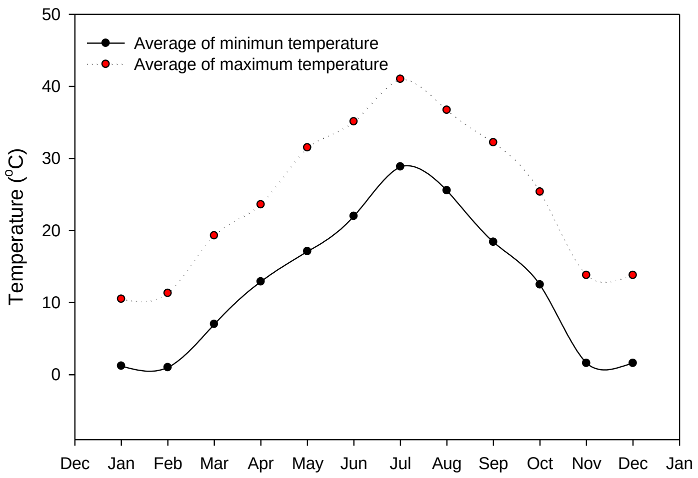


Figure 4.14 Average minimum and maximum temperature in Mazar-I-Sharif city during the year 2019

Source: (AMD, 2020)

The average monthly dry bulb temperature is recorded 5◦C and 34◦C in Jan and July, respectively. Figure 4-15 shows the 3D charts of the dry bulb temperature of Mazar-I-Sharif city.

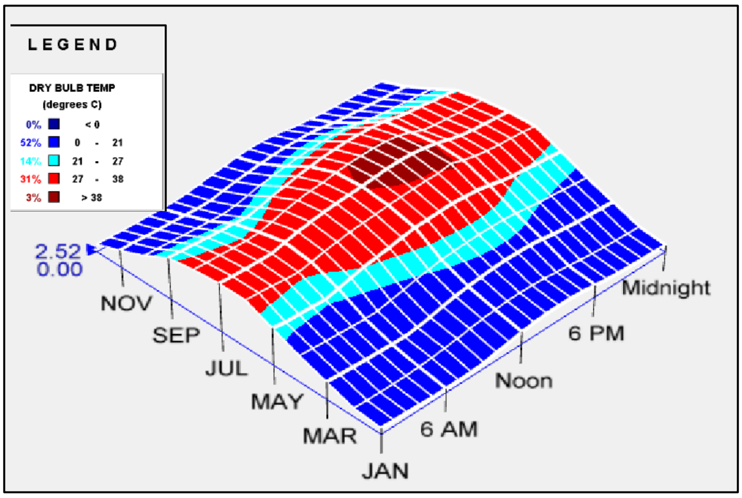


Figure 4.15 3D charts of dry bulb temperature of Mazar-I-Sharif city.

Source: (Climateconsultant, 2020)

Figure 4.16 presents the relative humidity and dry bulb temperatures of Mazar-I-Sharif for various months throughout the year. The average monthly relative humidity ranges from 13% in July to 78% in February, while the average annual relative humidity accounts for 43.33%. Meanwhile, the average dry bulb temperature is 19.66 °C (Figure 4.17).

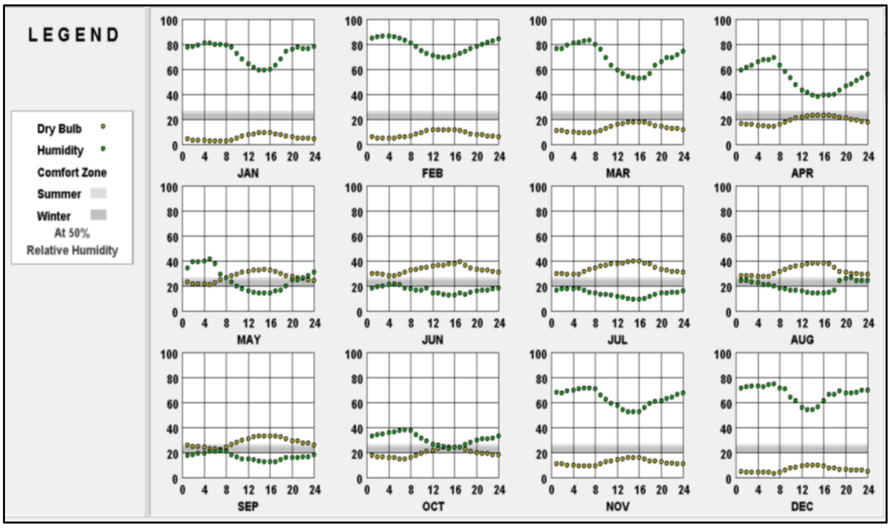


Figure 4.16 The relative humidity and dry bulb temperature of Mazar-I-sharif city in different months

Source: (Climateconsultant, 2020)

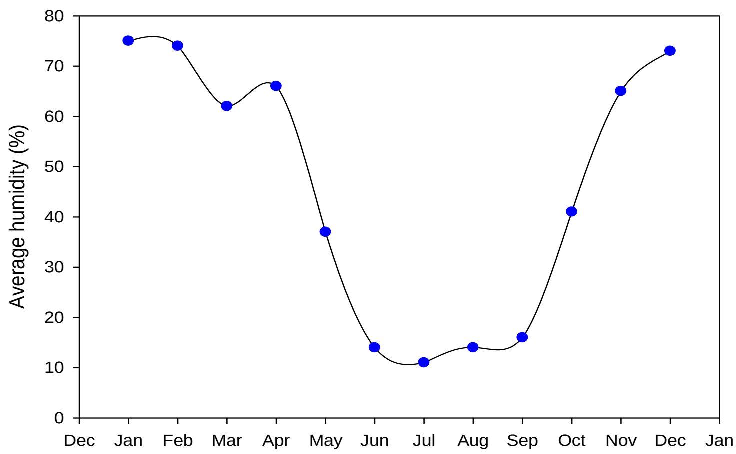


Figure 4.17 Average humidity in Mazar-I-Sharif city during the year 2019

Source: (AMD, 2020)

Afghanistan enjoys plenty of sunshine, with an annual average of about 3000 hours (300 days). However, the quantity of solar radiation received in Afghanistan varies based on variables such as; climate, latitude, and elevation. Figure 4.18 presents the annual direct average solar radiation in each province of Afghanistan (DABS, 2016).

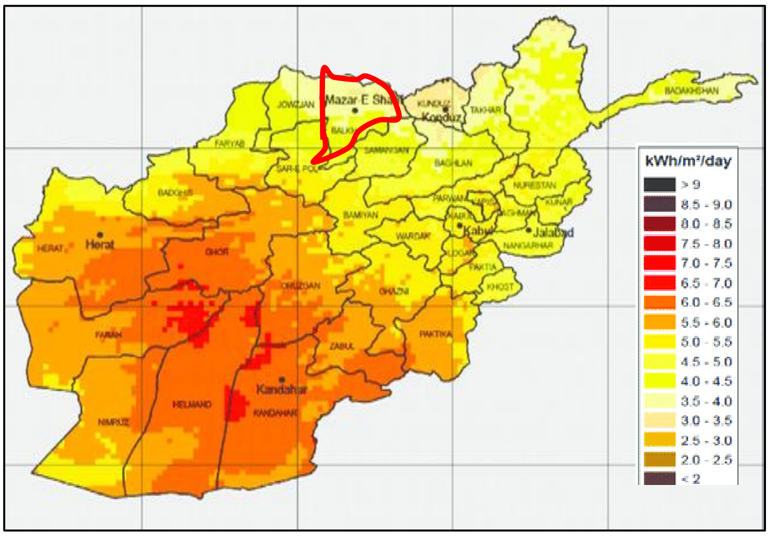


Figure 4.18 Afghanistan's annual direct average solar radiation (DABS, 2016)

Figure 4.19 illustrates all-sky solar radiation for Mazar-I-Sharif city during the year.

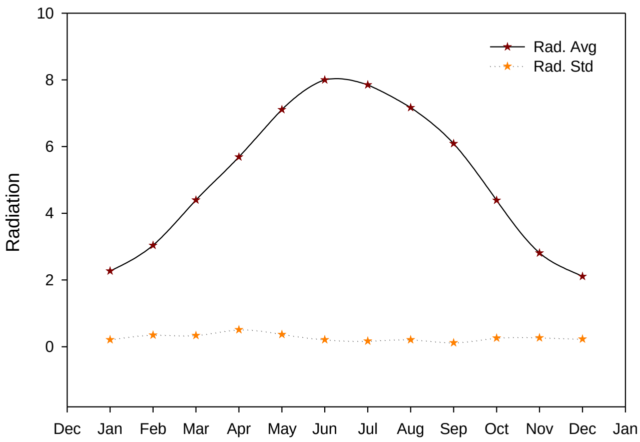


Figure 4.19 All sky solar radiation for Mazar-I-Sharif city

Source: (ANSI/ASHRAE Standard 169-2020, 2021)

Figure 4.12 demonstrate the daily and hourly solar radiation range for Mazar-I-Sharif city for different months.

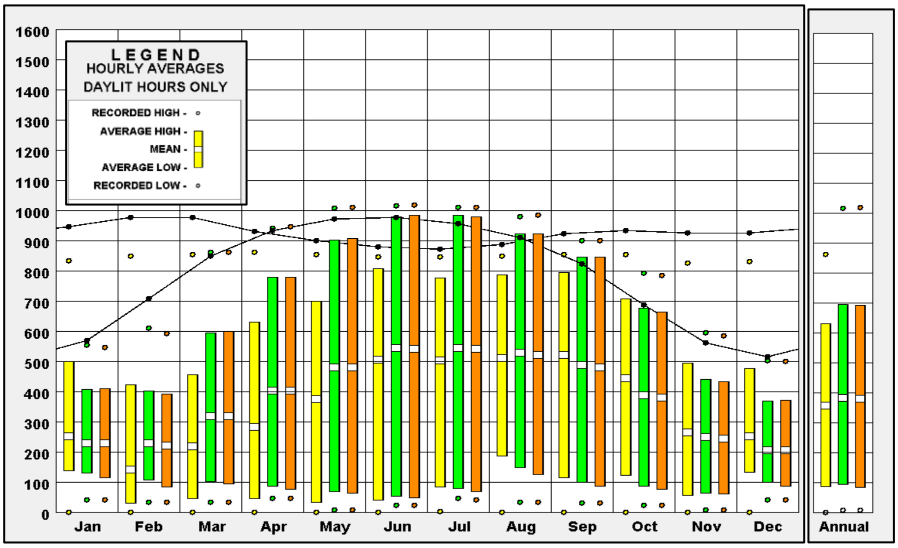


Figure 4.20 Daily and hourly solar radiation range for Mazar-I-Sharif city for different months.

Source: (Climateconsultant, 2020)

The overall solar radiation in Mazar-I-Sharif city is recorded as high with average hourly global horiz radiation of 207 Wh/sq.m in December and 547 Wh/sq.m in July. In addition, the highest average daily total direct normal radiation is recorded at 7318 Wh/sq.m in June, while the lowest is recorded at 2430 Wh/sq.m in December.

Solar radiation may heat any section of a building that is exposed to the sun, and it can arrive at the building's surface in three ways: direct, diffuse, and reflected radiation. The sun shading chart of Mazar-I-Sharif city shows that during the winter Oct-April the north direction is mainly in the shade but has few hours of sunlight during the summer months. Besides, the East and West directions have low angle direct sunlight in morning and evening, respectively. From mid-May to mid-September, the temperature is mostly above 27°C, and there is direct solar in the south direction, especially in the months of June-

August when the sun exposure hours are from 5 AM to 7:00 PM. Figure 4.21 and 4.22 shows the sun exposure hours in each direction during the year.

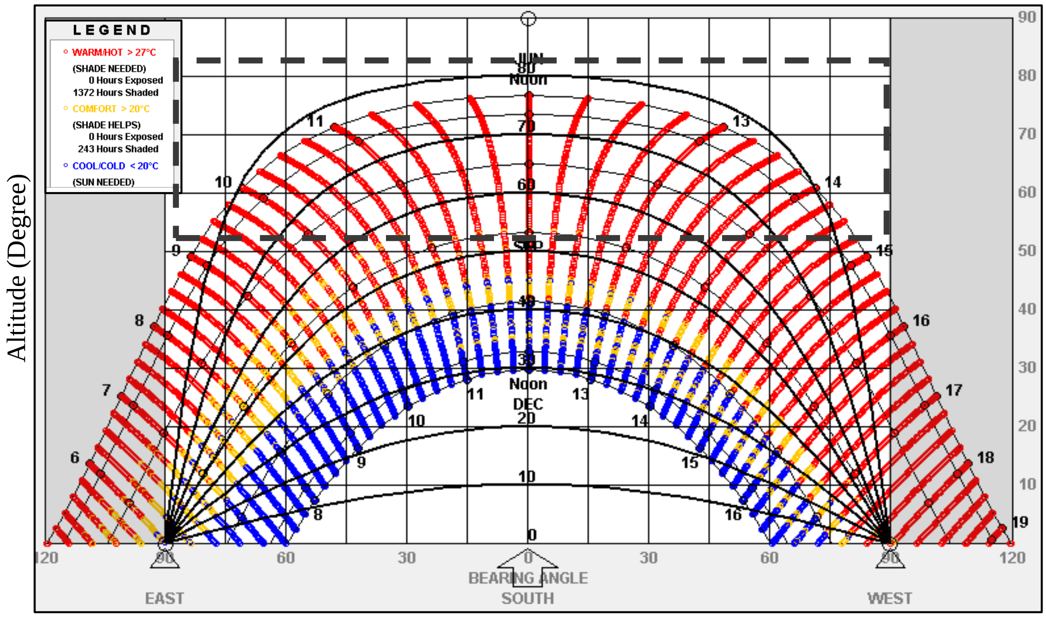


Figure 4.21 Sun exposure in south direction, June-September in Mazar-I-Sharif City

Source: (Climateconsultant, 2020)

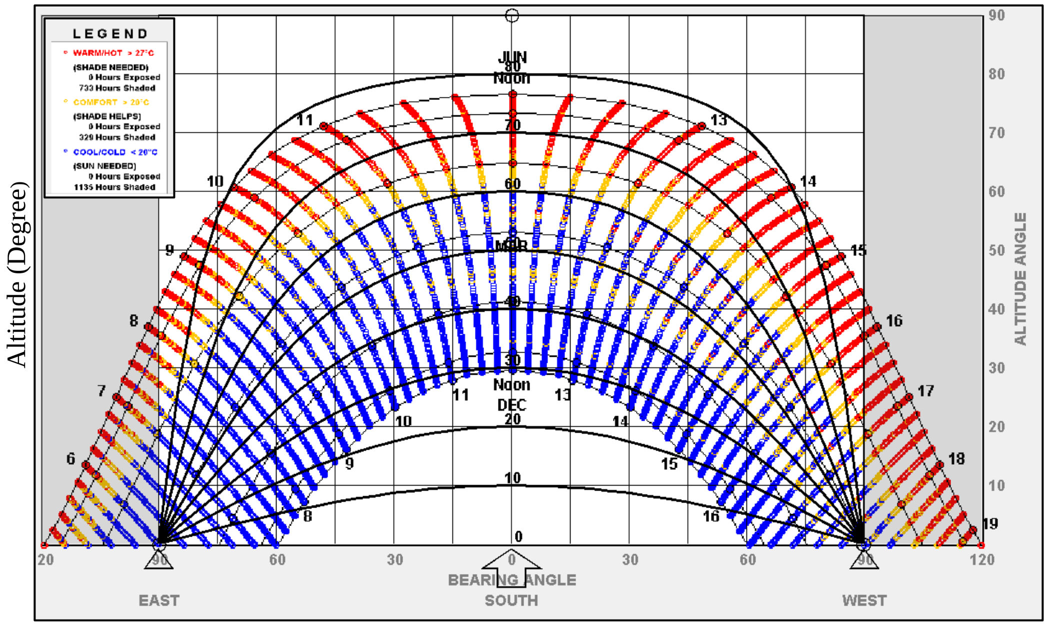


Figure 4.22 Sun exposure in south direction, December-June in Mazar-I-Sharif City

Source: (Climateconsultant, 2020)

Daytime temperatures in the hot-dry zone can be very high, but the diurnal range is considerable. Moreover, fenestration determines the admission of solar radiation; the building's thermal accumulative wall (thermal mass) influences its retention and release (Szokolay, 2008). The variation of climatic conditions produces a non-steady-state (time lag). Diurnal fluctuations produce the 24-hour cycle of increasing and decreasing temperatures. This effect of building heat moves from the outdoor into the indoor during the hot day, and the heat flow is reversed from the building to the environment at night when it is cold. Since the cycle is repeatable, it can be described as periodic heat flow (Koenigsberger et al., 1975). In a climate with an extensive diurnal temperature range, high thermal mass helps control temperature swings. Buildings having high thermal mass have a longer time lag, and with low thermal mass, minor time lag. In Mazar-I-Sharif city, the time lag in high mass is 12 hr, and in low mass is 3 hr due to periodic heat transfer. The passive solar direct gain in Mazar-I-Sharif city's high and low thermal mass zone is shown in Table 4.9.

Table 4.9 The passive solar direct gain in high and low thermal mass zone

High Mass Zone	157.7 Wh/m^2	Minimum south window radiation for 5.56°C temperature rise
	12.0 hr	Thermal time gal for high mass building
Low Mass Zone	157.7 Wh/m^2	Minimum south window radiation for 5.56°C temperature rise
	3.0 hr	Thermal time gal for low mass building

4.3.3 Wind environment features in Mazar-I-Sharif

The average monthly wind speed ranges from 2-5m/s (Figure 4.23). The mean annual wind velocity is 3.25 m/s, of which during summer, July has the maximum mean wind velocity of 5 m/s, while the minimum value of 2 m/s occurs in February mentioned in Figure 4.24.

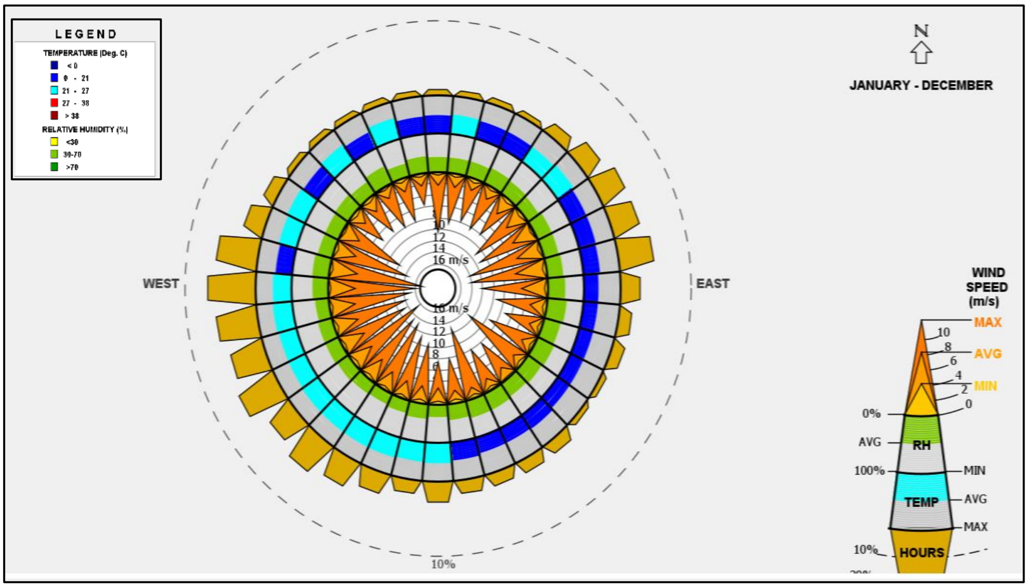


Figure 4.23 Wind wheel of Mazar-I-Sharif city in each direction

Source: (Climateconsultant, 2020)

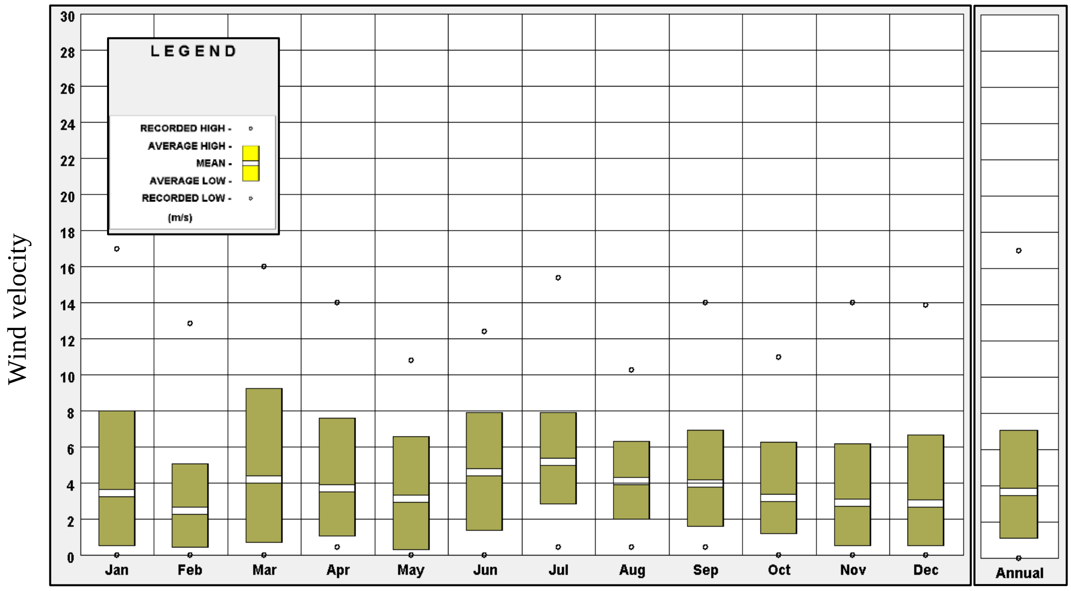


Figure 4.24 Monthly & annual air velocities in Mazar-I-Sharif

Source: (Climateconsultant, 2020)

4.3.4 Precipitation

The complex topography of Afghanistan has produced a variety of habitat types, with temperature and precipitation fluctuating significantly with elevation.

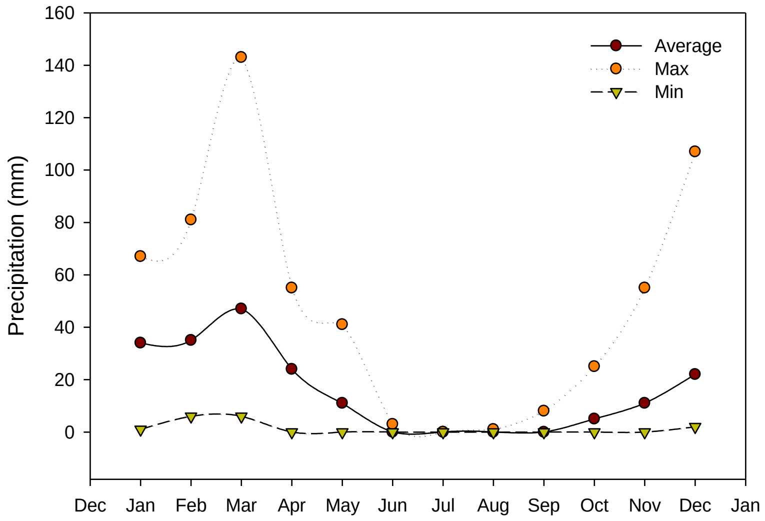


Figure 4.25 Precipitation graph of Mazar-I-Sharif city

Source: (AMD, 2021)

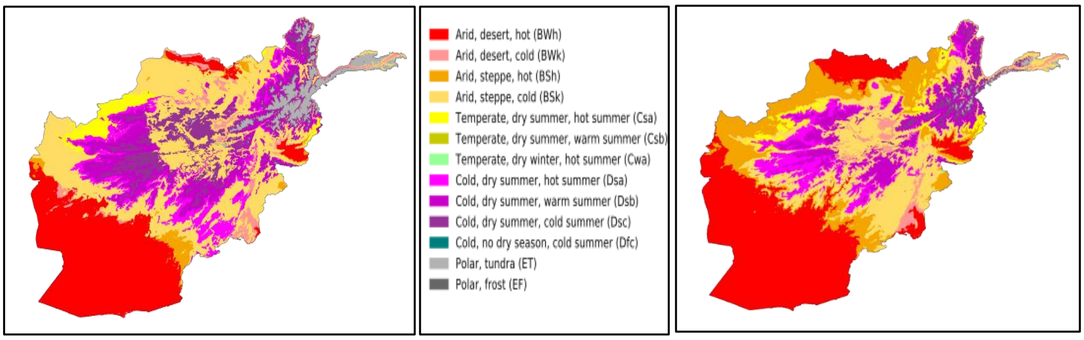
Figure 4.25 shows the precipitation graph of Mazar-I-Sharif city during the year. Afghanistan's available metrological information shows a decrease in average total precipitation by up to a third, offset by slight increases in winter (USAID, 2016; NEPA, 2017).

4.3.5 Impact of climate change

Afghanistan has had a substantial 1.8°C increase in mean yearly temperature since 1950. Future forecasts indicate that Afghanistan will warm by around 1.5°C until 2050 under the optimistic (RCP 4.5) scenario (NEPA, 2017).

Afghanistan is presently experiencing the worst drought that has ever existed. The nation is noted by vast regions with little or no precipitation. According to thorough historical examinations of spring and winter precipitation levels, precipitation is simply off, as spring precipitation declined (by up to a third) and winter precipitation marginally rose (Matthew Savage et al., 2009). Moreover, Beck (Beck et al., 2018) provided updated worldwide maps of the Köppen-Geiger climate classification at an exceptional 1 km resolution for the present (1980–2016) as well as for predicted future scenarios (2071–2100) due to climate change. Per their research, there is a significant change in the Afghanistan climatic region in the Koppen-Geiger map for future projection. The climate projection of the Koppen-Geiger map of Afghanistan shows a significant variation of climate type in the region, particularly Mazar-I-Sharif city.

Figure 4.26 compares the current and future projections of the Koppen-Geiger map for Afghanistan.



(a) (b)

Figure 4.26 Current and future climate projection of Koppen-Geiger map for Afghanistan.

a. Koppen-Geiger map (1980–2016) , b. koppen-Geiger map (2071–2100) (Beck et al., 2018)

4.4 Conclusion

From the above discussion, it has been found that Afghanistan is not an energy-self-sufficient country. The nation's energy status could be summarized as long-term "energy poverty" or a lack of access to modernized energy services. The country can achieve its long-term goal of self-sufficiency by promoting energy efficiency through proper management of utility distribution systems, use of indigenous hydrocarbon and renewable energy sources, local manufacturing of renewable energy products, and implementation of energy-efficiency strategies in the residential sector.

Using Koppen Climate Map, the study reveals that the nation comprises various distinct climatic areas. Mazar-I-Sharif can be classified as an arid zone characterized by having scorching summer and cold winter, and Kabul as cold (dry summer, warm summer). Moreover, as per the ASHRAE climate for building design, Mazar-I-Sharif can be defined as hot-dry (2B) and Kabul as a mixed-dry climate (4B).

CHAPTER 5
RESEARCH METHODOLOGY

This chapter outlines the research methodology used to accomplish the objectives based on the necessity of the research and its applicability. The overall research methodology is explained in the subsequent section and subsections.

5.1 Objective 1: Urban Residential Buildings Characteristics and Energy Pattern

The first objective of this study was to determine the urban residential building characteristics and energy patterns. This was achieved by conducting a survey and pilot study with experts. The details are further elaborated in the following sections.

Many factors can affect the building's energy consumption. Weather conditions, architectural design, envelope performance, and energy devices can influence the amount and kind of energy consumed in residential buildings (Pérez-Lombard et al., 2008). Moreover, urban residents' satisfaction with indoor comfort and their knowledge of and reaction to prior energy-saving measures are also essential benchmarks for legislators and engineers who want to encourage energy-saving initiatives. Therefore, a survey questionnaire was developed to gain a holistic understanding of residential energy consumption and efficiency in urban residential buildings in Afghanistan. Figure 5.1 presents the content of this survey.

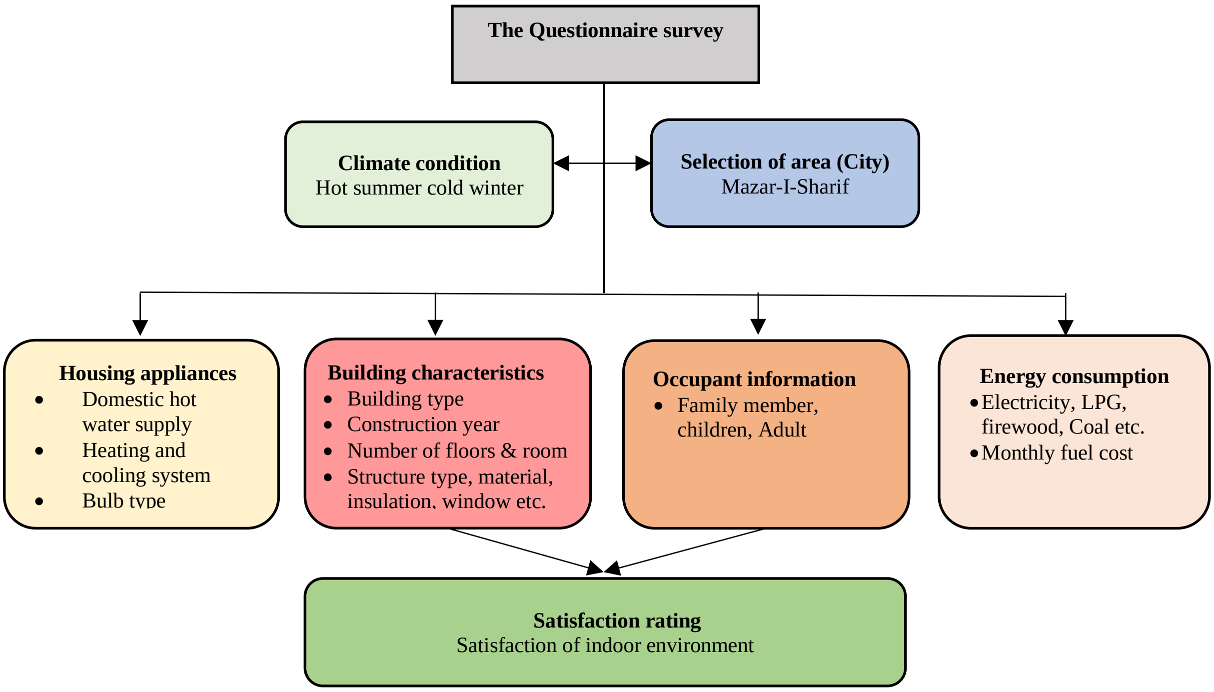


Figure 5.1 Content of the survey

5.1.1 Development of a questionnaire

To collect the residential energy-consumption data of Mazar-I-Sharif, a questionnaire survey approach was adopted because of the inferential nature of the study and the requirement for many residents to respond to the same set of questions. The following design parameters were used to design the questionnaire:

i. *The questionnaire type:* This research work used a self-administered questionnaire due to three different qualities: minimal distribution costs, rapid response time, and survey reach.

ii. *Questionnaire outline*: The questionnaire is divided into two sections: Section 1 contains information about the respondents' demographic profile, such as their name, the number of adults and children in their family, and the district in which they reside.

Part 2 provided information and specifications on energy and construction (Appendix C).

iii. *Pilot study*: The questionnaire was pilot tested by three professionals to ensure its appropriateness before being sent to respondents. The respondents were asked to assess the questionnaire's design and language. The authors made substantial changes to the questionnaire's design and phrasing based on the findings of the pilot survey to ensure respondents understood the questions. The majority of the corrections were made in the language of the questions, which the authors had translated from English to Persian. The readability of the questions increased once the modifications were implemented, and the questions became more intelligible.

iv. *Process of questionnaire distribution*: The questionnaire was distributed in two main ways. A face-to-face method was the first technique, and the internet was utilized for the second. The online questionnaire was constructed using the Google survey web domain, which allowed the authors to contact individuals who had previously been reached by phone. Data gathering using both techniques resulted in a high level of engagement from city residents.

v. *Size of the sample*: The minimum sample size was calculated by using Equations 1 and 2. The significance value was kept at 5%, and the test's statistical power was 95%.

$$Sample\ size\ (n) = 2 \times (\frac{\sigma}{\delta})^2 \times (t_{\alpha,v} + t_{2(1-P),v})^2 \quad (5\text{-}1)$$

$$v = (n - 1) \quad (5\text{-}2)$$

where the σ = population standard deviation, δ = desired detectable difference, α = significance level, v = degree of freedom, P = the desired statistical power and t α, v

= the t value corresponding to α and v.

By putting the value of $\sigma = 1$ and $\delta = 0.5$, the minimum sample size was determined to be 108. There were 300 responses received in all, of which 274 were identified as valid. Of the 274 responses,186 responses were received via face-to-face questionnaire and 88 via the internet. Column 4 of Table 5.1 illustrates the number of samples collected from each district. There are several reasons for not responding, which include refusal (categorical) to answer, disappointment in the state, statistics or the value of surveys, lack of trust, suspicion regarding the confidentiality of data, and not responding due to unusual conditions in the home.

Table 5.1 Respondent details

Age of respondent	18-25	26-35	36-45	>45
	103	**95**	**49**	**26**
District of residence				
1st District	8	10	1	2
2nd District	12	8	5	3
3rd District	9	11	4	2
4th District	18	10	2	4
5th District	5	9	4	1
6th District	10	6	7	3
7th District	6	9	7	3
8th District	17	13	8	6
9th District	4	6	8	1
10th District	5	6	3	0
11th District	4	3	0	1
12th District	5	4	0	0
Male	71	71	35	18
Female	32	24	14	8
Education qualification				
Secondary-high school level	3	9	15	12
undergraduate	90	5	26	10
Graduate	10	81	5	3
Postgraduate	0	0	3	1

The background and characteristics of surveyed household are presented in Table 5.2.

Table 5.2 Background characteristics of households

Type of house	**No**	**Percentage**
Single-family house	242	88
Multi-family apartment	31	11
Year of construction		
The 1990s	18	6.5
2000	82	29.8
2005	42	15.3
2010	97	35.3
2019	35	12.7
Type of structure		
RCC	118	42.9
Masonry (Burned brick)	106	38.5
Mud houses	50	18.2
Insulation		
Insulated	45	16.8
Not insulated	229	83.2

5.1.2 Study location and housing features

This research is based on surveys undertaken between 2020 and 2021 at Mazar-I-Sharif, one of the major cities of Afghanistan. The total population of Mazar-I-Sharif is 410,480 (MO, 2020). Mazar-I-Sharif, the center of Balkh province, is a focal point of major commercial activities and a hub of Afghanistan and Central Asia. From a political viewpoint, it is the center of northern Afghanistan. Balkh is Afghanistan's third largest province by population, with 4.8 % of the total population. Mazar-I-Sharif has pronounced dry weather, with a hot summer and a cold winter. While almost everyone in the city (98% of the population) has access to electricity (Pitfalls and promise, 2020), electricity fluctuations present a considerable challenge for urban residents, particularly in the winter. Moreover, the use of appliances is higher in these residential buildings. Figure 5.2 displays the map of Mazar-I-Sharif.

Figure 5.2 Mazar-I-Sharif map

Source: (ArcGIS Earth, 2021)

The planning and development of a location are intertwined, and they have an impact on a wide variety of factors, including the environment, sustainability, consumption, transportation, population, and living conditions (Shrivastava and Sharma, 2012). The housing shortage in urban Afghanistan has led to the expansion of informal settlements that lack access to the most basic city services. Decades ago, Mazar-I-Sharif contained only traditional houses built with the available local material. These houses were primarily mud or burnt-brick structures with wooden, mud, or domed roofs. This housing was constructed using methods appropriately responsive to the local climate. Afghan dwellings' architecture has entirely altered due to changes to lifestyle and amenities, such as the increased use of mechanical heating and cooling systems. In the present scenario, hardly any conventional climatic principles and architectural heating and cooling strategies are utilized in new buildings. Moreover, the construction industry followed the neighboring countries' prototypes without considering the local climate and region, and no official rules required the use of building components with specified thermal resistance. In 2015, the Afghanistan energy-efficiency code for the building was adopted

(ANSA, 2015); however, it is not applied due to technical inexperience and the lack of scientific research on buildings.

5.1.3 Research process

Three methods were used to analyze the collected data. In the first part of the study, an experimental research method was used to identify the city's building types, household sizes and structures, housing efficiency levels, awareness concerning the use of efficient devices, and building materials. The second part of the study explores the relationship between the variables, such as energy expenditure and types of buildings, windows, and indoor environments in summer and winter. Regression and correlation analysis was carried out to assess the relationship between the abovementioned variables. The third part of the research focused on the types and amounts of energy consumed by households in urban Afghanistan. Using SPSS 21 software, statistical analysis was used to find the type of energy consumed during daily activity in the city.

5.1.4 Data collection

The sample for this study was collected by considering equal representation from each district. Thus, a stratified sampling technique was adopted. This ensures that the collected data represents different aspects of the population of Mazar-i-Sharif, which includes different living conditions, family profiles, education, and social backgrounds. These aspects of peoples' lives appeared to represent all the people of Mazar-I-Sharif.

Within each district, a random sampling method was adopted to select the respondents for this study. A sample of 274 households from all twelve districts of Mazar-i-Sharif was collected. The data was gathered through an interviewer-administered questionnaire in Persian, the country's official language. To conduct the questionnaire, the authors randomly visited and contacted 638 houses, of which only 274 agreed to respond. Each of the respondents took approximately 30 minutes to complete the questionnaire. The number of dwellings surveyed in each city district depended on the residents' desire to cooperate with and participate in the survey. The head of the family from each house participated in the survey. The survey requested information primarily concerning the type of house, insulation, electricity bill, type of window and number of layers, type of cooling and heating system, and type of cooking fuel. Table 5.3 illustrates the average population of each district, the number of households in the city, and the number of households surveyed in each district for the study.

Table 5.3 Population and number of households in the districts of Mazar-I-Sharif (MO, 2020)

District	Number of houses	The average population in each district	Number of households surveyed
District 1	5582	27910	21
District 2	2478	12390	28
District 3	1850	9250	26
District 4	5567	27835	34
District 5	12025	60125	19
District 6	4367	21835	26
District 7	8951	44755	26
District 8	9467	47335	44
District 9	9791	48955	19
District 10	11458	57290	14
District 11	5310	26550	8
District 12	5250	26250	9
Total	82096	410480	274

The city residence income level was designated regardless of the respondents’ replies to the questionnaire, and the following algorithm was used in identifying low-, mid-, or high-income families from the survey. The algorithm was designed with the help of a survey and experts with abundant experience in Afghan urban development.

Low-income families identified if the household:

- Had ownership or rented a mud/burnt-brick house
- Consumed firewood/gas for cooking
- Consumed firewood/charcoal for heating
- Had a fan/desert cooler for indoor cooling
- Had one or two rooms
- Had a monthly electricity bill lower than 2,000 AFN

Middle-income families identified if the household:

- Had ownership of masonry/ Reinforced cement concrete (RCC) one-floor house /or rented apartment
- Consumed gas/electricity for cooking
- Consumed firewood/coal/electricity for heating
- Had more than two rooms
- Had a monthly electricity bill higher than 3,500 AFN

High-income families identified if the household:

- Had ownership of RCC structured personal house or apartment
- Consumed gas/electricity for cooking
- Consumed electricity/coal/firewood for heating
- Had four or more than four rooms
- Had a monthly electricity bill of at least 8,000 AFN or higher

5.2 Objective 2: Adaptive Summer Thermal Comfort Level of Apartment Resident

This study tries to identify an adaptive summer thermal comfort model in residential apartments in the arid climate of Mazar-I-Sharif. A specific questionnaire was administered to investigate six mid-rise residential buildings. In other words, the results from the adaptive thermal comfort model were confirmed by occupant logs and interviews. The subjects used regional attire and resorted to several adaptive measures to restore thermal comfort, like moderate indoor air movements, slowing down activities, or resting. Some of the socio-cultural reasons inhibited clothing adaptation. The details steps of the study are presented in the following sections.

5.2.1 Buildings selection and description

The reinforced cement concrete (RCC) construction is predominantly used for housing in Afghanistan. Residential apartments have been growing for the last two decades, so a residential complex with RCC apartments is chosen for this study (Table 5.4). All six buildings represent good conventional designed residential buildings currently practiced in the region. As the buildings in the residential complex were constructed at the beginning of 2017, its structural system is based on reinforced cement concrete, and the wall is constructed from traditional burnt brick. The operable windows are double glazed with Poly Vinyl Chloride (PVC) frames. The building is situated in the geographic location of Mazar-I Sharif, Afghanistan. All buildings have seven floors, three oriented to the north toward the interior courtyard of the buildings and three oriented to the south. Figure 5.3 represents the dimensional characteristics of the building.

Table 5.4 Surveyed residential buildings details

Buildings	Number of stories	The floor area of the flat (m^2)	Number of Flats/Apartment per floor
A	B+7	157	2
B	B+7	157	2
C	B+7	157	2
D	B+7	157	2
E	B+7	157	2
F	B+7	157	2

(B- indicates basement, A-F residential buildings labels)

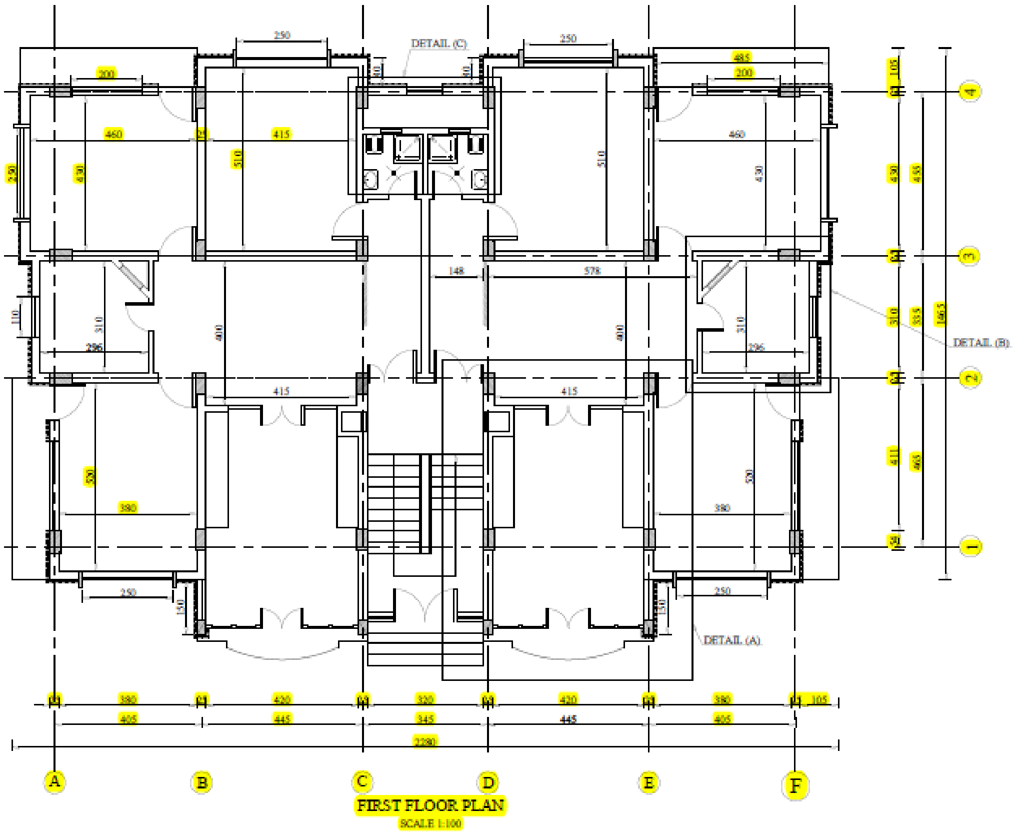


Figure 5.3 Floor plan of an apartment building

5.2.2 Monitoring and thermal comfort survey

The field study offers "first-hand" data, which assists in comprehending the occupant's thermal comfort in their daily environment. In most cases, objective and subjective measurement data are necessary for this investigation. Indoor air temperature and relative humidity were measured objectively. The indoor climate monitoring was carried out on peak summer days. The monitoring took place from 30/06/2019 to 30/07/2019, and to record the interior air temperature and humidity, a datalogger was placed in a naturally ventilated apartment room. The external air temperature and humidity were recorded by positioning a datalogger in the shade. In addition, the continuous daily outdoor temperature data is taken from a nearby weather station (AMD 2020). The spot measurements of temperature, humidity, and air movement were taken up during the questionnaire responses.

The instrumentation used for this experiment evaluation was LCD Apresys Data Logger, DIEHL thermotron hygro, and Omega Multi-functional Environmental meter (Figure 5.4 and Table 5.5).

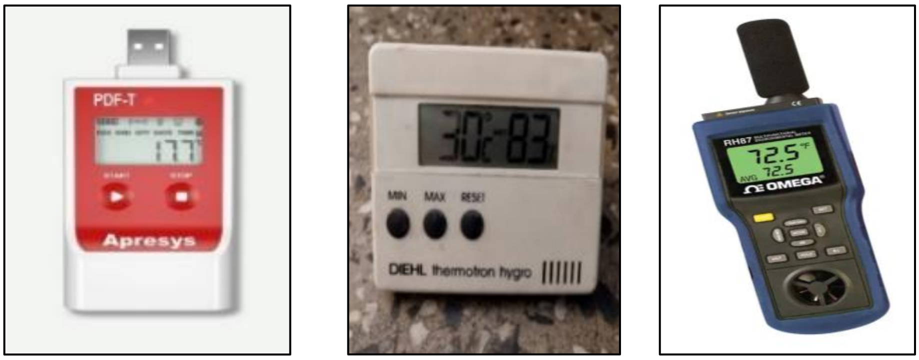


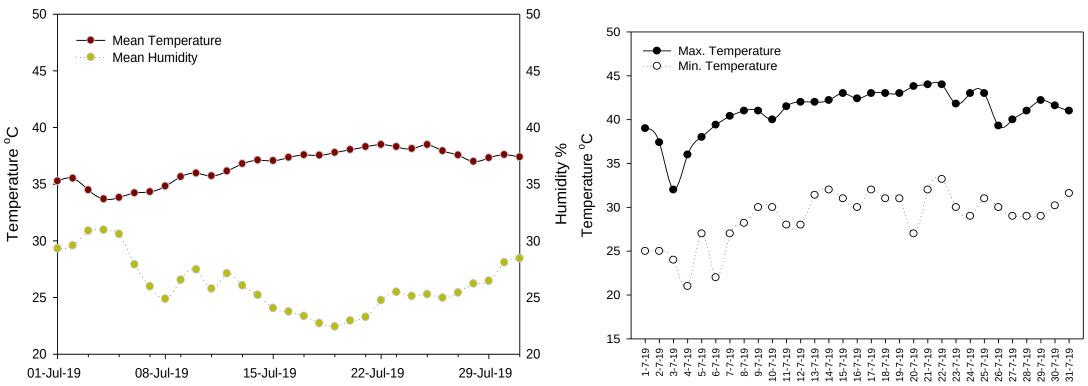
Figure 5.4 The instrument used for recording indoor and outdoor weather

Table 5.5 Instruments details

Instrument	Physical quality	Range	Accuracy
Omega Multi-functional environmental meter	Air, Temp., Humidity	-10- 60 ◦C	+/-3% RH, +/-1.5 ◦C
Apresys Datalogger	Global temperature	10 min interval	+/-0.5 ◦C
Apresys Datalogger	Relative humidity	10 min interval	+/- 3% RH
DIEHL Thermotron hygro	Temp. & humidity	-	+/-2% RH,0.5 ◦C

For subjective measurement, a questionnaire with 21 questions (Appendix D-1) was framed and administered to 70 subjects in the apartments. Since people in residential buildings employ a range of techniques, such as altering their activity levels, their clothing, and opening windows, to adapt to the current thermal environment (Mukhopadhyay, 2019), all methods were investigated. The windows were mostly closed during summer, and the fans mostly remained on during the occupancy hours. The author conducted all the data recordings and surveys after the subjects/instruments had stabilized in the survey environment.

Overall, apartments remained warmer, and the indoor humidity remained lower on most days. Understandably, lower floor apartments recorded approximately 1–2 K lower temperatures than the roof-exposed apartments during the month. Indoor environments were dry in June/July as relative humidity varied within the 28-36% range during the survey phase. During the survey, the mean daily temperature was 30- 32°C in June/July. Figure 5.5 demonstrates that the temperature of the indoor air follows the trend of the external air temperature



(a) (b)

Figure 5.5 Indoor and outdoor temperature and humidity

a) Indoor temperature and humidity, b) Outdoor Min. and Max. temperature

The mean indoor temperature was 31(C), and the mean relative humidity was 31% while taking the responses. Monitoring indoor and outdoor temperatures and relative humidity through dataloggers shows July's hot, dry season characteristics. As the temperature outside rises, the temperature inside rises as well. The indoor temperature varied with roof exposure of the apartment and personal environmental controls.

5.2.3 Sample size and characteristics

The study was conducted, fulfilling all the ethical requirements, like prior permission from the apartment owners to collect subjective and objective data. All the subjects were sensitized regarding the survey prior to recording subjective responses. There were 70 subjects, one selected from each apartment, consisting of males and females. Local subjects adaptively use covered clothing called "Perahan-tonban" inside the house; however, some males and females prefer wearing pants and a top/shirt (Figure 5.6).

Figure 5.6 Subjects and surveyed environment

Table 5.6 Thermal comfort scales employed for this study

Scale	Description			
	(TS) The sensation, according to ASHRAE	**(TP) Nicol's preferred temperature**	**(TA) Thermal acceptance**	**The moisture of the skin**
3	Hot			Profuse
2	Warm	Much cooler	(Acceptable)	Moderate
1	Slightly warm	A bit cooler	(Unacceptable)	Slightly
0	Neutral	No change		None
-1	Slightly cool	A bit warmer		
-2	Cool	Much warmer		
-3	Cold			

Olsen's 1985 summation method was used to determine the insulation of the clothing ensembles: "*Icl* = ∑*Iclu,I,*" in which Icl represents the overall insulation and Iclu, i represents the effective insulation of the garment (ASHRAE, 2005). All the subjects were interviewed between 11 am and 2 pm. The thermal comfort scales that were employed in this study are listed in Table 5.6. The survey questionnaire contained 21 questions (Table 5.7) adopted from (McCartney and Fergus Nicol, 2002) and (Indraganti, 2010).

Table 5.7 Summary of the questionnaire

Transverse survey details
Personal Details; Age, Sex, weight, Block, Date, Time
Thermal sensation; Temperature, humidity, noise, lighting, air quality
Thermal preference; Temperature, humidity, noise, lighting, air quality
Current activity, Productivity level, comfort
Types of clothing, material, heat feeling
The environmental control measures in the house
Indoor environment acceptability

Table 5.8 Occupants' characteristics of total six building

Sample size	70
Gender	
Male	19
Female	51
Age (Years)	
Maximum	60
Minimum	18
Mean Female (mean) Male (mean)	33 33 32.9
Standard Deviation Female (SD) Male (SD)	11.34 10.7 13.09

The subjects filled out the questionnaires except for some elderly subjects; the author filled out the responses. General demographic information of the respondents is presented in Table 5.8. The gender distribution of the overall sample was 72.9% female and 27.1%, male.

The average age among the respondent was 33 years, with a range of 18-60 years. The insulation of the clothing ensembles was determined using ASHRAE 55 standards. The activities of the subjects ranged from 1.2 to 2 Met (Metabolic rate). Microsoft Office Excel 2019 was used to tabulate and analyze all data, and SPSS version 26 was used to perform the statistical tests.

5.3 Objective 3: Solar Radiation Control Passive Strategies for Reduction of Heating and Cooling

As illustrated in Figure 5.7, the proposed research method was conducted through five major steps. The first step is focused on climate characteristics and analysis of weather data of the studied region; the second step considers a case study building for deriving the details of the local material to create a database; the third step includes uploading data from the database to the simulation interface and preparing building geometry and baseline simulation. The fourth step involves the validation, and the fifth step comprises the simulation of the substitute building’s orientations and the application of shading devices to determine how the building’s modifications affect building energy use with economic feasibility.

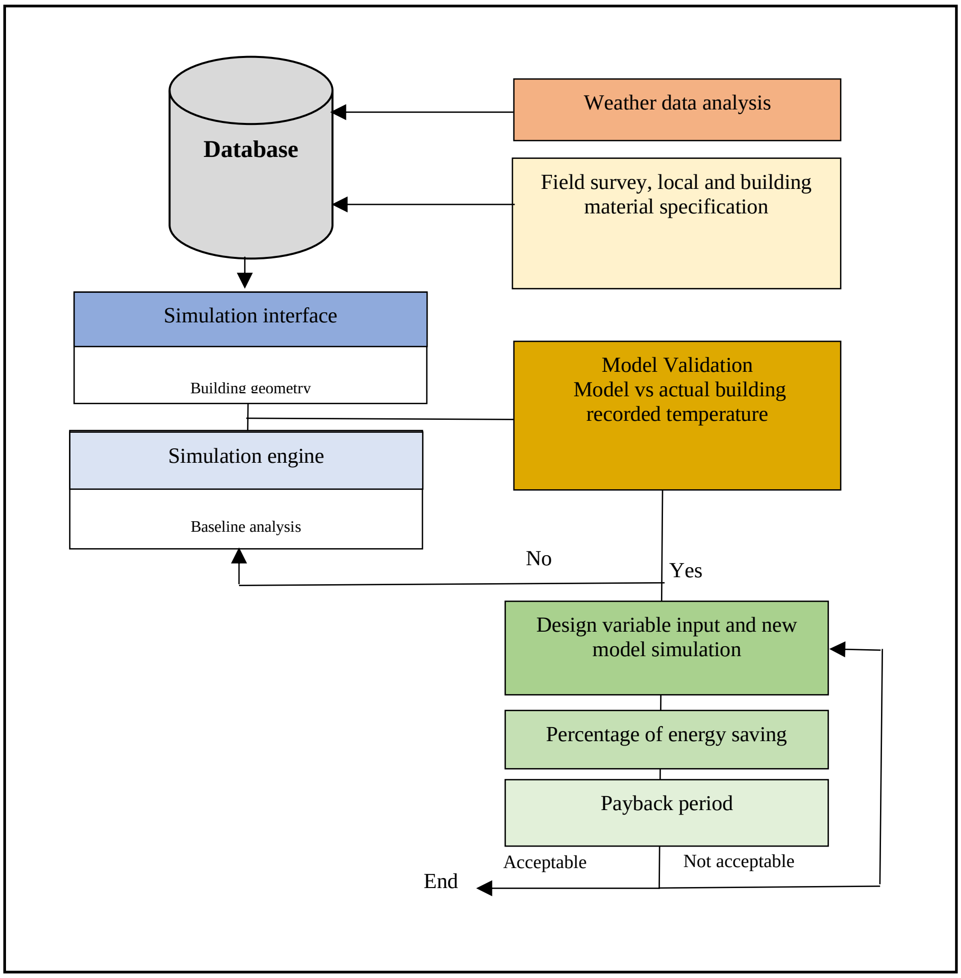


Figure 5.7 Research flowchart

5.3.1 Case study building

A seven-storey residential building from a Residential complex in Mazar-I-Sharif, Afghanistan, was considered a case study. The structure was built with reinforced concrete (two double facade apartments per typical floor) with a total area of the ground floor of 360.15 m^2 assembled from reinforced columns, beams, and traditional bricks. The floor plan and building views are presented in Figures 5.8 and 5.9. The energy source used for space cooling and heating is electricity and natural gas, respectively. The electricity from the DABA (Da Afghanistan Breshna Sherkat) power grid is the building's operating electricity. More specifications of the case building are tabulated in Table 5.9.

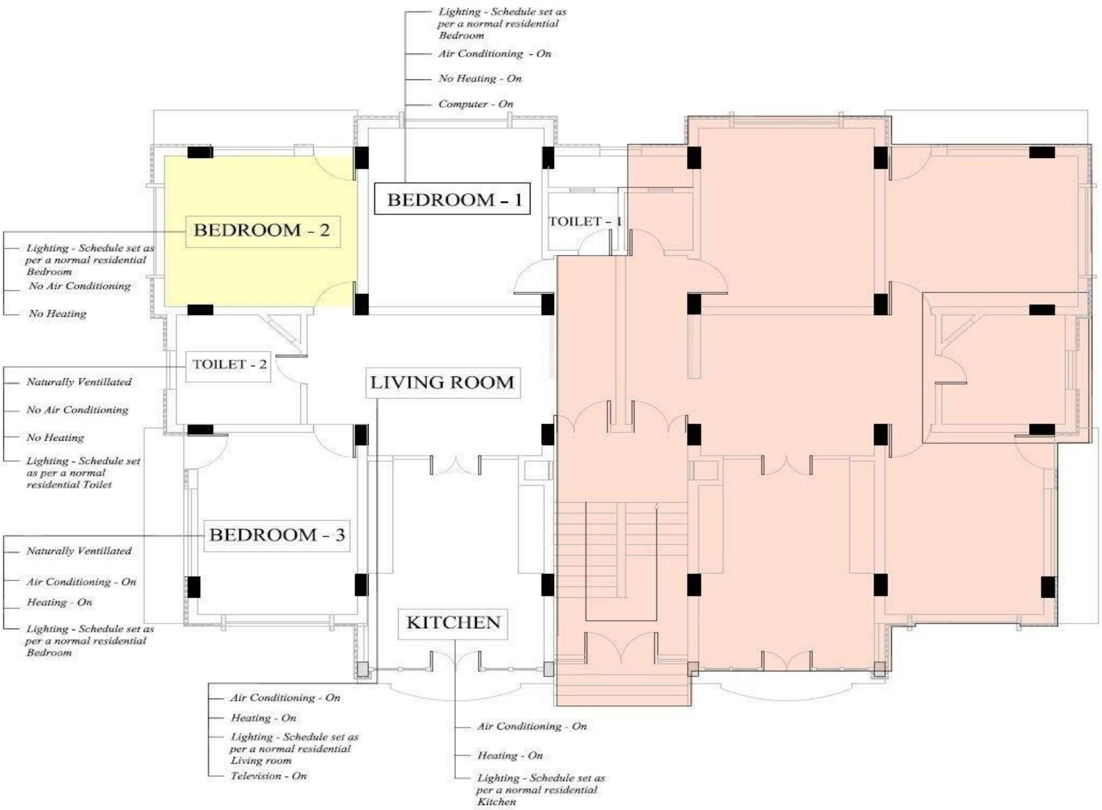


Figure 5.8 Residential building floor plan

(a) (b)

Figure 5.9 a) Building side view b) Building front view

Table 5.9 Specification of the studied residential building

S. No.	Parameter	Specification
1	Type of Building	Residential building
2	Location	Mazar-I-Sharif
3	Latitude	36° 42' 32.54" N
4	Longitude	67° 06' 39.13" E
5	Type of structure	Reinforcement concrete
6	No. of floors	Seven
7	Occupancy	0.018 person/m^2
8	Floor height	3 m
9	No. of residential Unit	14

Since most of the country's newly constructed urban housing is a residential apartment, this case study building can represent many more such newly constructed buildings in Mazar-I- sharif city and other major cities of the country. Also, the available local material which is commonly used for the building envelope (wall) material in Afghanistan, is used in the selected case building. Moreover, the selection of the case building was based on the criteria that the conventional building must be constructed on the standard code of practice by using standard materials. This is because more realistic results can be obtained by simulating a more standardized building in software. In addition, the case building is situated in the arid part of the country, which is located in the hot summer and cold winter zone, which comprises most of the other populated cities of Afghanistan, like Kunduz city.

The parameters input per the material used in the study building and the material's thermal properties were found through the experiment and ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) standards. The indoor thermal environment was monitored by temperature and humidity recorder Apresys (TH 18000436) (Appendix E-1). The DesignBuilder interface with the EnergyPlus simulation engine was used to produce the baseline model. The building's 3D layout was also developed based on the building's architectural design. For simulation purposes, the building was divided into several zones and checked the architectural features and the building visuals were generated. The windows were not allowed to open in the summer season, and there was a complete dependence on the air supply under the air conditioning system. This assumption is essential in Mazar-I-Sharif, as the climate is dry and scorching in summer and cold in winter, which necessitates air conditioners to achieve thermal comfort for residents. Neighboring building shading is involved in this research based on an actual building, the optimized orientation has been given, and internal and external shading devices are applied. The shading devices analyzed in the current research are external horizontal fixed louvers and internal blinds used on the south, east and west glazing. The exterior façade mainly was of brick walls with cement plaster. The building is faced to the north with a higher WWR (window-to-wall ratio). Table 5.10 represents WWR in each façade. A systematic base case survey and energy analysis of the building were done to extract base-case dimensions.

Table 5.10 Window-to-wall ratio of various oriented walls

S. No.	Orientations	WWR
1	North	0.34
2	South	0.21
3	East	0.17
4	West	0.17

The technical specification of the case-building material was obtained from the contractor company. Moreover, to obtain the actual thermal properties of some local materials, such as traditional brick and GS (Gypsum soil) Plaster, the authors performed a separate experiment (Appendix E-2, E-3, and E-4), and for the rest of the material, the ASHRAE 90.1 were used. Based on values obtained from the experimental result and the standard material which has been used for each element of the building, the building envelope's components' total heat transfer coefficients (U-value) were computed, which are presented in Table 5.11. The windows contain polyvinyl chloride as the frame material and double glazing with two layers of 0.006 m flat glass and 0.013 m air gap between them. In total, the window glazing's heat transfer coefficient (U_{window}) is 2.68 W/m2K, with a solar heat gain coefficient (SHGC) of 0.703.

Table 5.11 Thermal transmittance coefficient of case study building element

Elements	Layers	Thickness (m)	U-value (W/(m^{2}K)
Wall (External)	Cement plaster (outer side)	0.35	1.52
	Traditional brick		
	GS plaster (inner side)		
Partition wall	Cement plaster (outer side)	0.25	1.93
	Traditional brick		
	GS plaster (inner side)		
Floor	PVC flooring	0.168	2.135
	Cement plaster		
	Concrete slab		
	Cement plaster		
Roof	Cement mortar	0.17	3.710
	Waterproofing (bitumen)		
	Concrete slab		
	Cement plaster		
Glazing	Clear-Double glazed with PVC frame- 0.013-Air	0.006	2.68 SHGC-0.703

To better understand the building's indoor environment, indoor temperature and humidity were recorded. A continuous 24-hour cycle of data was collected for the peak summer months (July and August) of 2019. The data readings were scanned in the 10-minute interval and recorded by Apresys portable Data-logger (TH 18000436), which was placed on the 6th-floor apartment, an unoccupied room, without using an air conditioning system. The outdoor weather EnergyPlus weather data was taken from the metrological station of Mazar-I-Sharif, which was set for energy simulation (Climate.onebuilding, 2019).

5.3.2 Occupancy schedule in case building

Building occupancy is one of the main factors affecting building energy performance (D'Oca and Hong, 2015). As central heating and cooling facilities are rarely available in most city dwellings, most local residents adopted split air-conditioning and electric furnaces to improve thermal comfort, which is relatively energy inefficient. In the case building, decentralized heating and cooling systems such as gas-fire heaters and split air-conditioners were used for each residential unit. Also, the electric water heater was used separately in each bathroom and kitchen to supply hot water. The thermostatic control of 25 and 21°C was chosen for the building's cooling and heating, which was considered to hold operative temperatures within the ISO 7730 temperature range while preserving thermal comfort. Based on actual utilization, the main operating hours were set between 08:00 and 18:00 hrs on weekdays and 24 hrs on weekends. Artificial lighting was regulated with continuous lighting controls. The comfort model was also measured according to ASHRAE Standard 55 (ASHRAE, 2017). Table 5.12 presents the input parameters.

Table 5.12 Input parameters

S. No.	Particulars	
1	Occupancy density	0.0188 people/m^2
2	Occupied floor area	1678.6 m^2
3	Metabolic rate	1 met
4	CO_2 generation rate	0.0000000382 m^3/s-W
5	Indoors winter Clothing	1.0 Clo
6	Indoors summer Clothing	1.5 Clo

5.3.3 Simulation tools

To decide the impact of individual energy-efficient strategies without simulation tools is inconceivable. Simulation software delivers remarkable contributions to managing climate adaptations toward responsible and energy-efficient planning. Such tools give an understanding of the overall building performance and enable designers to estimate the thermal performance of the building envelope, optimize energy for residence thermal comfort, and are broadly used by energy professionals and engineers to allow investigation and evaluation of different design alternatives (Albatayneh et al., 2017, 2016). A popular and robust, versatile tool, DesignBuilder version 6.1.6.005 (DesignBuilder, 2020), was used to acquire the optimum solar control strategy (Figure 5.10) since it was found to be a mature product with a flexible geometry input (Crawley et al., 2001). Moreover, the EnergyPlus engine (Crawley et al., 2001) is integrated within the DesignBuilder interface, allowing energy professionals to perform perfect simulations within an integrated interface (Appendix E-5).

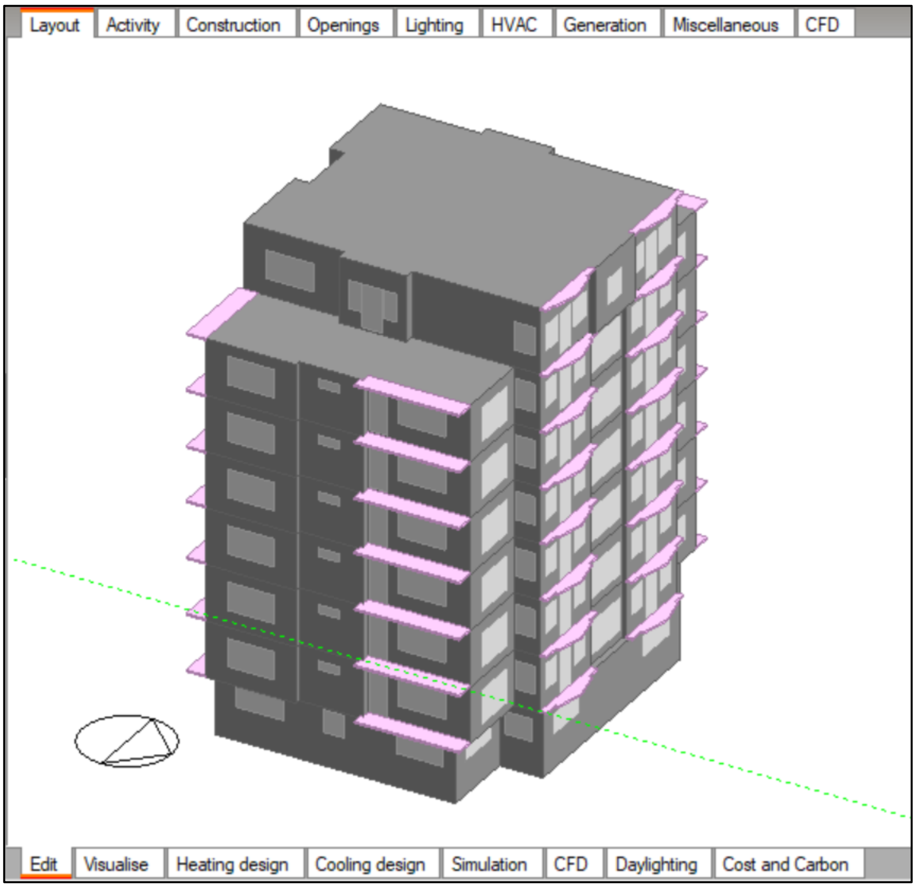


Figure 5.10 The 3D view of case-study building model using Designbuilder

5.3.4 Energy saving

Equation 5-3 was used to calculate the amount of saved energy by applying shading devices in the base case building.

$$\text{Energy-saving (\%)} = \frac{\text{Reduced energy by shading device}}{\text{Building Energy consumption without shading devices}} \times 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5\text{-}3)$$

5.3.5 Simple payback period

The payback period is the amount of time it takes for a product's entire initial investment to be repaid by compounded savings. In other words, the payback period indicates how long it will take to recoup the increased expenditure (increment cost) on efficiency improvement through lower operating costs (Mahlia et al., 2011). Equation 5-4 was used to calculate the payback time (Wong et al., 2007):

$$Payback\ period\ = \frac{Initial\ investment + maintainance\ cost}{Total\ cost\ of\ the\ energy\ saved\ (annually)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(5-4)$$

The established electricity charges for a one-kilowatt hour of electricity are required to calculate the payback period of shading elements. The electricity charge in Mazar-I-Sharif city was AFN 6.5 for one kilowatt per hour (kWh).

5.4 Objective 4: Sustainable Energy Retrofit Plan for Apartments

This research used modeling and simulation to examine how to reduce energy consumption through energy retrofit techniques and to analyze the technology choices in built environments. Figure 5.11 depicts the approach that was employed. At the outset, the energy modeling of the mid-rise residential building was performed with DesignBuilder, an EnergyPlus-based simulation program (DesigBuilder, 2022), using the original drawing and in-situ measurements. Prior to the energy retrofit, a comprehensive energy simulation of the whole building was performed, using the thermal transmittance of building materials acquired from experimental work and temperature and relative humidity measurements. Using the in-situ measurement data and the calibrated simulated energy consumption, the energy technologies suited for the purpose were then selected. The energy simulation program assessed and evaluated the various energy technology packages. Finally, the most cost-effective package option was identified, and the energy savings were determined.

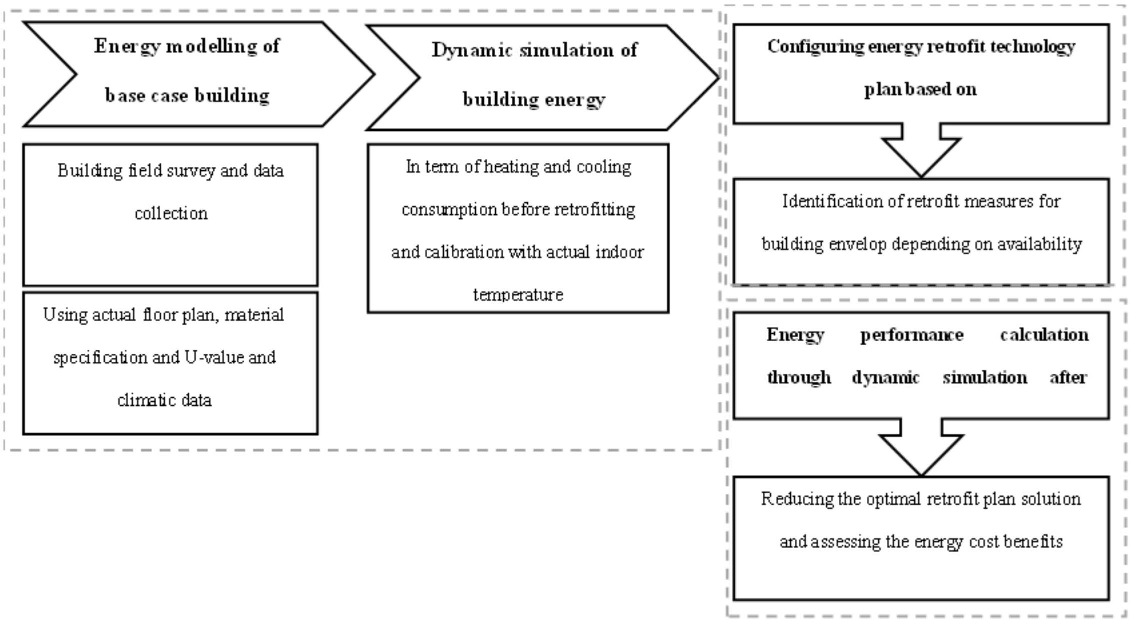


Figure 5.11 Applied methodology

5.4.1 Analysis approach

Building energy consumption is primarily determined by the characteristics and operating schedule of the building and the weather conditions. Therefore, prototypes that mimic actual residential buildings were created in the initial stage. For this purpose, a survey (Chapter 6) was carried out, and then a case study building was employed to represent the typical characteristics of buildings in urban Afghanistan (Table 5.13).

A prototype dwelling was defined to evaluate the most efficient thermal retrofit measures in a harsh climate with scorching summers and freezing winters. The residential building considered in this study is a multi-apartment residential building situated in Mazar-I-Sharif, Afghanistan. According to the survey, most recently constructed multi-apartment residential buildings contain similar materials. In other words, the case study building can serve as an example for many more newly designed structures in Mazar-I-Sharif and other major cities across the country. Moreover, available local material, which is typically utilized for constructing envelop (wall) material in Afghanistan, was used in the selected building.

Furthermore, the building was chosen because it was constructed with the standard code of conventional building practices. Therefore, more accurate results are possible by imitating standardized construction in software. Additionally, the building is located in an arid region of the country, characterized by hot summers and harsh winters, similar to most neighboring cities in the country. Consequently, improving the energy efficiency of these residential units may significantly lower overall energy consumption in the building sector in the region. The construction involved RCC and a single layer of burnt clay bricks in the vertical walls. Both sides of the walls are covered with plaster, the interior with GS (Gypsum Soil) plaster made from locally available material, and the exterior with cement plaster. The windows contain Polyvinyl Chloride (PVC) frames with 3 mm glazing. The apartments have been planned to employ a split air conditioning system for cooling and a gas heating system for heating. Each apartment has a floor space of approximately 334 m^2, with two residential units on each storey. The building comprises a central stairwell with apartments on either side.

The properties of the energy model were determined with a material experiment and a field survey. The data for the study were derived from three sources, namely, (i) a review of the construction company's building blueprints, (ii) site visits to the building, and (iii) interviews with the clients and contractors. Climate zone, glazing area, and building materials were all considered. The cooling and heating setpoint temperatures, building façade composition; occupancy density; type and schedule of lighting; and heating, ventilation, and air-conditioning (HVAC) systems were all entered into the simulation program. Figure 5.12 represents the photographs of the interior of a residential unit.

Table 5.13 Building location and specification

location	Afghanistan, Mazar-i-Sharif, longitude: 67° 06' 39.13" E, latitude: 36° 42' 32.54" N
Usage	Multi-apartment residential building
Construction	Reinforcement concrete (RCC) structure with brick wall
Building size	Number of floors: 1 basement level + 7 ground level
Window-to-wall ratio	0.35
Building ground floor area	360.15 m^2
Floor height	3m
Residential plan form	Square
Number of apartments per floor	2

Figure 5.12 Photographs of the interior of a residential unit

A field investigation was conducted to calibrate the input parameters. The simulation was calibrated with measured and simulated data. The measured and simulated free-running indoor air temperature for the peak summer months of 1st July to 12th August 2019 were compared. Apresys (TH 18000436) portable data logger measured the interior air temperature.

Two dimensionless error indices, cumulative variation of root mean square error (CVRMSE) and mean bias error (MBE), were employed to measure the difference between the simulated and measured values, respectively, using equations (5-5) and (5-6)

$$CV(RMSE) = \frac{\sqrt{\sum_{i=1}^{N_i}\left[\frac{[(M_i - S_i)]^2}{N_i}\right]}}{\frac{1}{N_i}\sum_{i=1}^{N_i} M_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5-5)}$$

$$MBE = \frac{\sum_{i=1}^{N_i}(M_i - S_i)}{\sum_{i=1}^{N_i} M_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5-6)}$$

M_i and S_i are the measured and simulated data at instance i, respectively, and M_i Is the total number of values used in the computation. In conclusion, these explain the discrepancies between EnergyPlus space temperature projections and actual measurements. The MBE and (CVRMSE) values achieved were 4.48% and 9.81%, respectively, within the ASHRAE-14 Guide acceptability level for energy model calibration (Royapoor and Roskilly, 2015).

The exterior façade has a u-value of 1.52568 w/m2 k and comprises brick walls and RCC structures with a 30% window-to-wall ratio. Each residential unit is cooled and heated with electricity and Liquefied Petroleum Gas (LPG). Floor plans for the study buildings were prepared in AutoCAD at the initial stage of the modeling process. The DesignBuilder model was then generated with scaled AutoCAD floor plans, and imported via the user interface. As a result, the software can precisely read and comprehend geometric elements of floor designs. The floor blueprints for each room were then traced to create a 2D representation. Thereafter, the model was enhanced with doors, windows, and other interior and external openings. Table 5.14 lists the parameters used in the building model.

Table 5.14 Applied parameters for the building modeling

Parameters	Value
The occupancy density (person/m^2)	0.018 person/m2
HVAC system	HVAC 2.7 seasonal cop
Metabolic rate	1 met
Infiltration rate	1.71 ac/hr @ 50pa (measured) / 6.02 m3 /hr/ m2

Moreover, the climate data, building orientation, and shading were added. Afterward, multiple zone classifications were introduced to the algorithm and assigned to every building zone, considering occupancy, internal heat generation, and ventilation. Finally, the building's construction data were included in the model for accurate energy use prediction, and the external and partition walls and the floor and roof materials were all entered. The same wall construction features were used to ensure that the models were consistent. Table 5.15 represents the characteristics of the building base model.

Table 5.15 Characteristics of the building base-model

Parameter	Specification
External walls (U-value: 1.52 W/m^2*k)	0.025m Cement plaster (outer side), 0.3m burnt mud brick, 0.025m Gypsum-Soil plaster (inner side)
Roof (U-value: 3.710 W/m^2*k)	0.02m Cement mortar, 0.005m waterproofing (bitumen), 0.12m Concrete slab, 0.025m Cement plaster
Internal walls (U-value: 1.93 W/m^2*k)	0.025m Cement plaster (outer side), 0.2m burnt mud brick, 0.025m Gypsum-Soil plaster (inner side)
Floor (U-value: 2.135 W/m^2*k)	0.003m PVC flooring, 0.02m Cement plaster, 0.12m Concrete slab, 0.025m Cement plaster
Glazing SHGC-0.703 (2.68 W/m^2*k)	0.06 ear-Double glazed with PVC frame, 0.013-Air

A rendering of the base-case building simulated model plan is presented in Figure 5.13

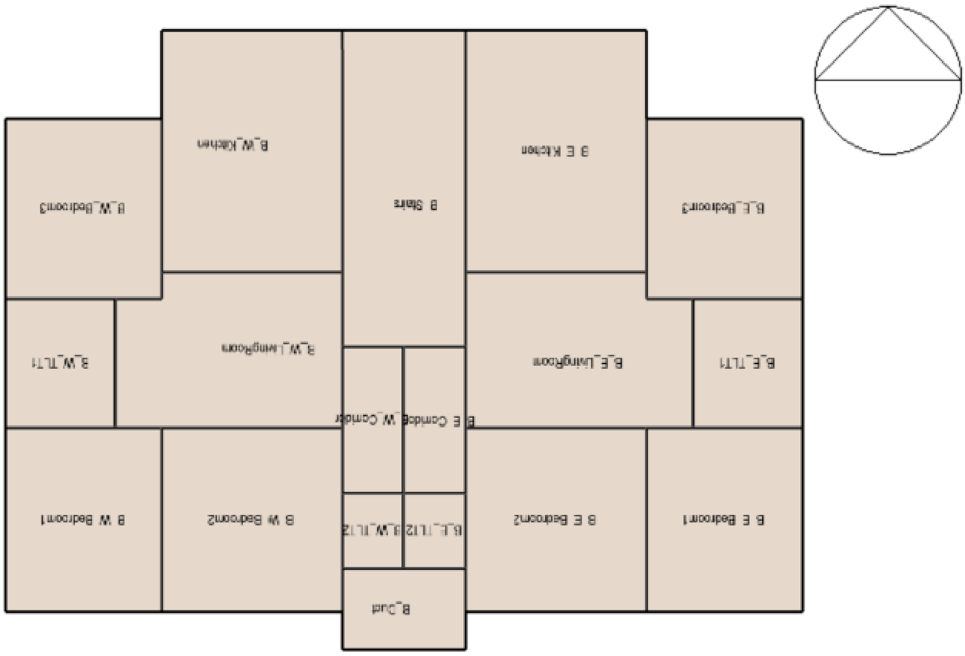


Figure 5.13 Floor and zoning plan

5.4.2 Employed retrofit measures

The application of energy measures aimed at restoring the original functioning of a particular building feature or improving the energy performance of a specific component or the entire building is incorporated in the energy retrofit linked with the renovation (Menna et al., 2021). Several metrics that depend on the designer's expertise and the most typical local practices could be investigated. Significant building energy modeling that considers the structure's dynamics and occupants' behavior is necessary to implement energy-saving measures. The renovated building's energy performance can be compared with a reference building to assess the efficacy of the energy-related solutions. This comparison aims to assess whether primary energy consumption has decreased through the appropriate measurements. The simple payback (SPB) must be assessed to estimate the viability of retrofitting measures in Afghanistan. Every investment was evaluated from a financial standpoint, considering the price of supplies and installation. The difference among the energy requirement of the current building ($EC_{Existing}$) and the energy requirement after the retrofit solution ($EC_{Retrofitting}$) is known as energy savings (ES). The energy savings were computed using equation 9-1 below (Mahlia et al., 2011).

$$ES = EC_{Existing} - EC_{Retrofitting} \quad \text{(5-7)}$$

The intervention, a standard energy retrofit strategy, may influence the building's primary components, namely the envelope and the systems. The degree of commitment in predefined performance objectives and an initial budget, particularly in emerging countries such as Afghanistan, will determine to what extent energy retrofit technologies will affect these two levels. Since the walls, windows, and roof account for 90% of the energy loss, the subject of this study involves the energy-saving retrofit of these specifically. The conditioned thermal zones in the buildings contain separate HVAC terminals. The primary heating system in the reference residential unit building is LPG. Electric split air-conditioners are conventional cooling systems and are installed in all the thermal zones in the building. Windows (double-glazed) with PVC frames constitute the transparent envelope. Existing RCC structures have low energy performance in building walls and roofs. For instance, the U-value of opaque envelope elements varies from 1.52 to 1.93 W/m2 K, and thermal inertia is high due to the materials utilized (such as burnt bricks). Similarly, double-glazed, air-filled windows with PVC frames with a U-value of 2.68 W/m2 K result in significant energy requirements (per square meter) for cooling and heating.

The study was conducted in two steps. First, the energy effect of each of the individual measures was calculated using the energy simulation of the building model, then the cost of each retrofit measure was calculated with a simple payback period. These findings result in a possible retrofit combination option. A blend of opaque and transparent components characterizes all building envelopes. Polyurethane, expanded polystyrene

(EPS), extruded polystyrene (XPS), rock wool, eco-friendly insulation, and other materials can be used to insulate building roofs and walls. However, insufflating insulation materials such as EPS can insulate a structure's walls. In addition, the availability, primary market pricing, and dependability of the technology applied for insulation should all be considered in the choice of material. External or internal insulation can be done, and the latter option could be a good fit for Afghan RCC structure buildings, known for having thicker exterior walls than interior partition walls. Typically, exterior insulation and finishing systems are ideal, particularly for residential properties, as, first, it produces higher internal surface temperatures, which improves thermal comfort, and second, it generates higher thermal inertia of the envelope and eliminates heat transfer. Based on the defined energy performance goal and the availability of construction materials and technology in the region, the interventions at the basis of building systems can be summarised as follows.

- In this instance, U-values of approximately 0.5 W/m2 K could be obtained with wall insulation, which significantly impacts heating demand.
- Roof insulation obtains U-values of less than 0.5 W/ m^2 K, especially for the climate zone. Since during the summer season, solar radiation is concentrated on roofs, and solar heat gain may be reduced by insulating these flat roofs.
- Window glass replacement with coated reflective glass can be selected. Double-glazed windows filled with argon or air can be employed, and reflective coatings could be utilized to lower the window's SHGC (solar heat gain coefficient). To achieve appropriate thermal resistance, PVC frame windows can be used.
- The exterior wall, coated with 100-mm thick polystyrene insulation and the inner surface with 50 mm, can lower the wall's steady-state u-value without affecting the structure's original form. In theory, the thermal transmittance value should be

decreased by almost three times; however, the actual u-values before and after the retrofitting solution were 1.52 w/m2 k and 0.513 w/m2 k, respectively. Table 5.16 illustrate the employed retrofit Packages.

Table 5.16 Employed retrofit Packages

Packages		Details
I-	Reduce the SHGC of glass (U-Value =2.82, and SHGC=0.188)	Replacement of baseline clear glass with reflective glass
II-	Reduce the U-Value of the External walls Total: (U-Value 0.513)	Original wall+5 cm EPS (outer side) +25mm cement plaster
III-	Reduce the U-Value of the External walls Total: (U-Value= 0.313)	Original External wall+10 cm EPS (outer side) +2.5cm cement plaster
IV-	Reduce the SHGC of glass and U-Value of the external wall (SHGC=0.188, and U-Value =0.513)	Original External wall + 5cm EPS (outer side) +2.5cm cement plaster, and Replacement of clear window glass with Reflective glass
V-	Reduce the U-Value of roof, wall and SHGC of glass (U-Value =0.351, U-Value= 0.513, SHGC=0.188	Original Roof +5cm XPS+ 0.4cm bitumen sheet + 2.5 cm cement plaster; Original External wall + 5cm EPS+2.5cm cement plaster' Replacement of clear window glass with Reflective glass
VI-	Reduce the U-Value of External) U-Value= 0.313 ,and partition wall. (U-Value=0.533)	Original External wall+10 cm EPS (outer side) +2.5cm cement plaster. Original partition wall +5cm EPS (Inner side) +2.5 cm SG (Soil gypsum) plaster.

5.5 Objective 5: Energy Efficient Envelope for the New Dwellings

5.5.1 The framework

Two contrasting viewpoints are involved in the early-energy design stage of a newly constructed building. The public type, whose main objective is to significantly cut energy consumption and harmful emissions, and the private, which seeks to achieve significant cost savings and interior thermal comfort. The current study focuses on minimizing energy consumption and cost saving, considering the feasibility and material availability. Figure 5.14 illustrates the flowchart of the study process. The iteration of this procedure continues until the predetermined termination condition is met. This process is repeated until the cost and energy requirements are met.

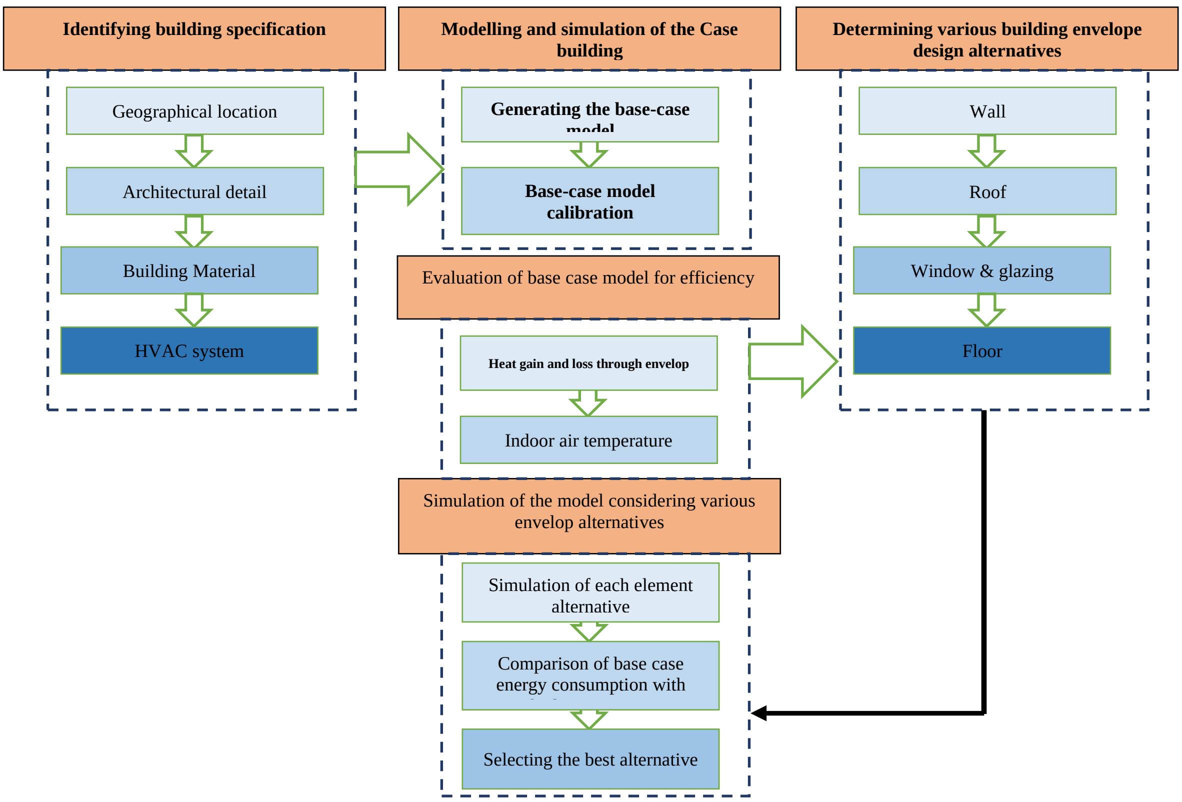
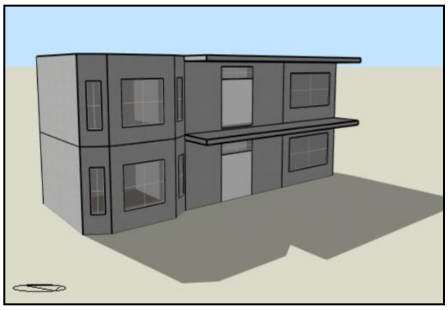


Figure 5.14 The research flowchart

5.5.2 Building model description

The proposed approach is applied to a recently constructed two-story residential house, which its geometrical model is acquired from on-site measurement and is representative of the urban Afghan residence Figure 5.15. The gross floor area is 98.69 m2 (49.34 m2 per storey). Only one façade has glazing covering 9.28 % of the surface of all exterior walls. Table 5.17 lists a typical RCC structure dwelling specification.

(a)



(b)

Figure 5.15 Case study building front view a) real-time photography, b) 3D view

Table 5.17 A typical RCC structure dwelling specification

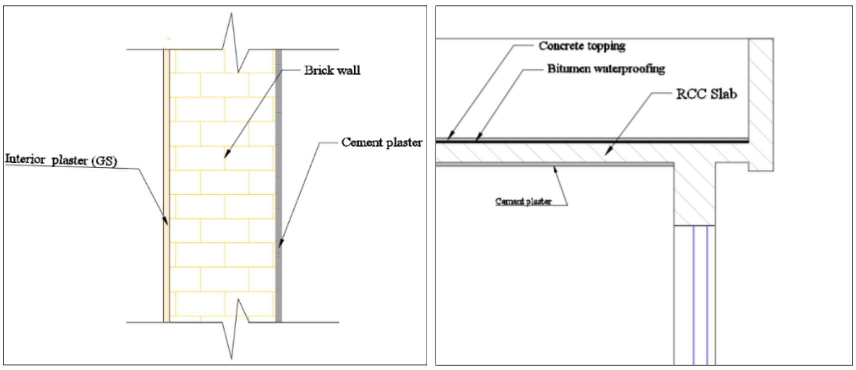
Characteristics	Base-case dwelling description
Building orientation	West direction (Front elevation)
No. of floors	2
Floor hight	3m
Building Area	98.69 m2
Total WWR	9.28 %
Occupancy Density	Two people
Lighting power density	3.2 W/m^2
System type	Split AC
COP	3.2

The purpose of this investigation is, to begin with determining the energy performance of this typical home, then look into the significant deficiencies in the building's existing envelope, and eventually provide insight on envelope improvement that could lower the annual energy demand of new dwellings in the region. Table 5.18 demonstrates the building's physical information.

Table 5.18 Case study building material description

	Material Name	Thickness (m)	Conductivity (W/m·K)	m²·K/W	Cost ($)	U-Value (W/(m²·K)	Toral Cost
External Wall	Cement Plaster (Outer Side)	0.025	1.164	0.021	1.9	1.563	14.6
	Traditional Brick+mortar	0.33	0.703	0.427	10.5		
	GS Plaster (Inner Side)	0.025	1.1	0.021	2.2		
Roof	Concrete topping	0.02	1.020	0.009	1.7	3.44	27.5
	Bitumen waterproofing	0.005	0.500	0.019	3.9		
	RCC Slab	0.12	1.740	0.086	20		
	Layer Plaster	0.025	1.160	0.022	1.9		
Floor	PVC Flooring	0.0095	0.160	0.059	5	2.83	28.8
	Cement Plaster (Outer Side)	0.025	1.160	0.022	1.9		
	RCC	0.15	1.740	0.086	20		
	Cement plaster	0.025	1.160	0.022	1.9		
Partition Wall	Cement Plaster (Outer Side)	0.025	1.160	0.022	1.9	1.72	12.8
	Traditional Brick	0.20	0.703	0.356	9		
	GS Plaster (Inner Side)	0.025	1.164	0.021	1.9		
Glazing	Window-to-wall ratio (WWR)			9.28%		5.11	19
	Shading coefficient of glass (SC)			0.84			
	Solar heat-gain coefficient (SHGC)			0.73			

The traditional approach is used to construct the building's structural elements, such as the roof and wall. Figure 5.16 demonstrates the sample of wall and roof sections for the selected house.



(a) (b)

Figure 5.16 a) Sample of wall section b) roof section

5.5.3 Operational schedules

The living space, which is inhabited during the day, is on the ground floor. Sleeping quarters are located on the first level and are used at night. The air conditioning system is presumed to be on when space is occupied. Internal heat gains from humans, lighting, and machinery affect the indoor climate, influencing energy usage. The occupancy schedule is used based on observations from a typical Afghan dwelling. It should be noted that for model calibration, the actual occupancy is included. As per survey and on-situ measurement, the ground floor is only considered an occupied zone. The first floor is also assumed to be an occupied zone to identify the thermal envelope behavior and the overall building envelope effect on energy consumption.

5.5.4 Model calibration

To calibrate the model, an entire year energy consumption bill is obtained (Appendix F-1). After generating the base-case building model per occupancy, the doweling simulation energy result is compared with actual consumption. The percentage of difference, CV(RMSC), and NMBE indices are used to identify the error presented in equations 5-8, 5-9, and 5-10.

$$Percentage\ Difference = \frac{Simulated\ Results - Measure\ Reasults}{Measured\ Results}\ X\ 100 \quad \text{(5-8)}$$

$$CV\ (RMSE) = \frac{1}{\bar{m}} \cdot \sqrt{\frac{\sum_{i=1}^{n}(\text{mi}-\text{si})^2}{n-p}}\ X100\ (\%) \quad \text{(5-9)}$$

$$NMBE = \frac{1}{\bar{m}} \cdot \frac{\sum_{i=1}^{n}(\text{mi}-\text{si})}{n-p}\ X100\ (\%) \quad \text{(5-10)}$$

Where; m_i =measured value, s_i = simulated/predicted value, n = no. of measured data-points, $\bar{m}$ = mean of measured values, and p = no. of variable model parameters.

5.6 Conclusion

This chapter presents a detailed description of the research philosophy, strategy, and methodology according to which this study has been carried out. The study in both the positivist and the interpretive camps utilizing a mixture of the survey, direct observation, and data analysis. The need for the questionnaire survey, development of the questionnaire, sample selection, minimum sample size, and various tools such as simulation and modeling tools, climate analysis tools, and regression analysis were also discussed in detail. The roadmap of the research is shown in Figure 5-17 The overall research design is presented in the Figure 5-18.

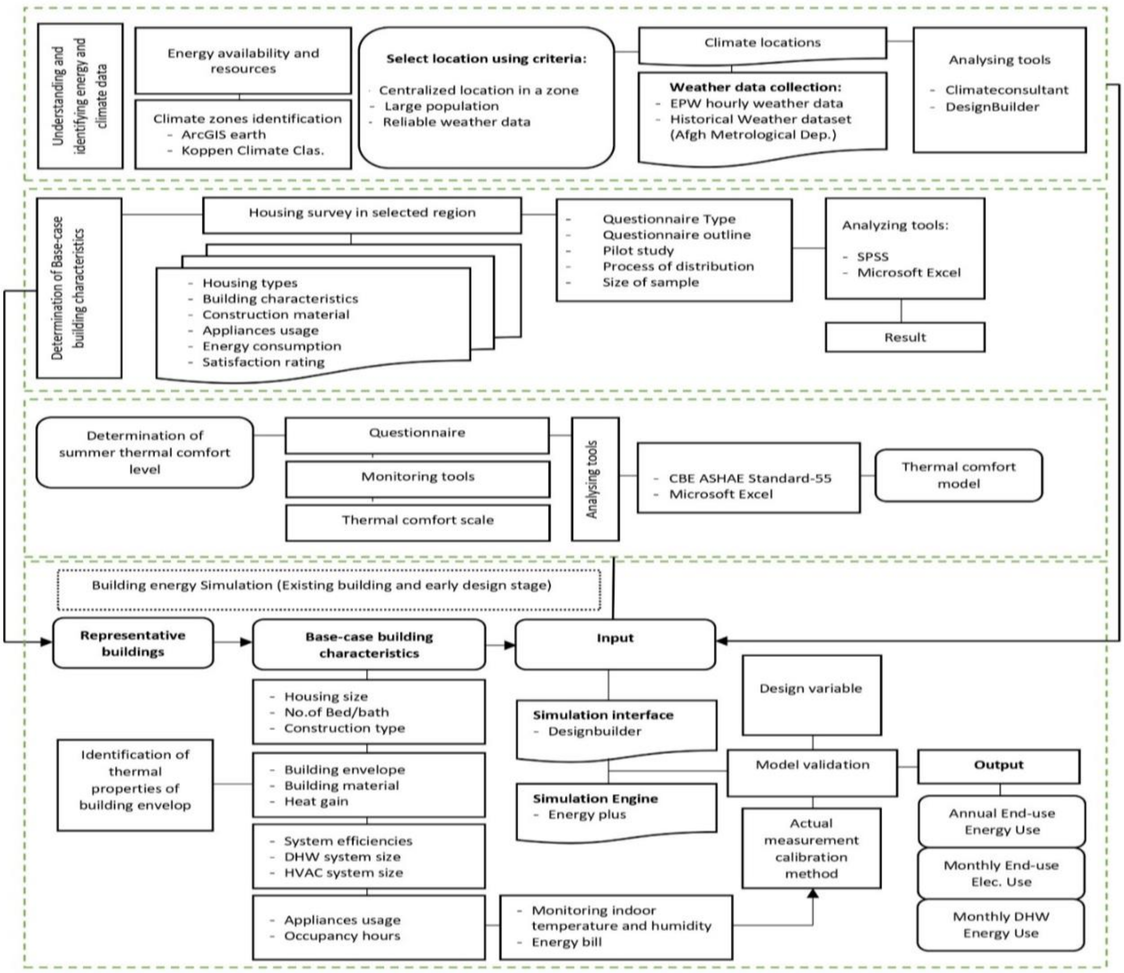


Figure 5.17 Research roadmap

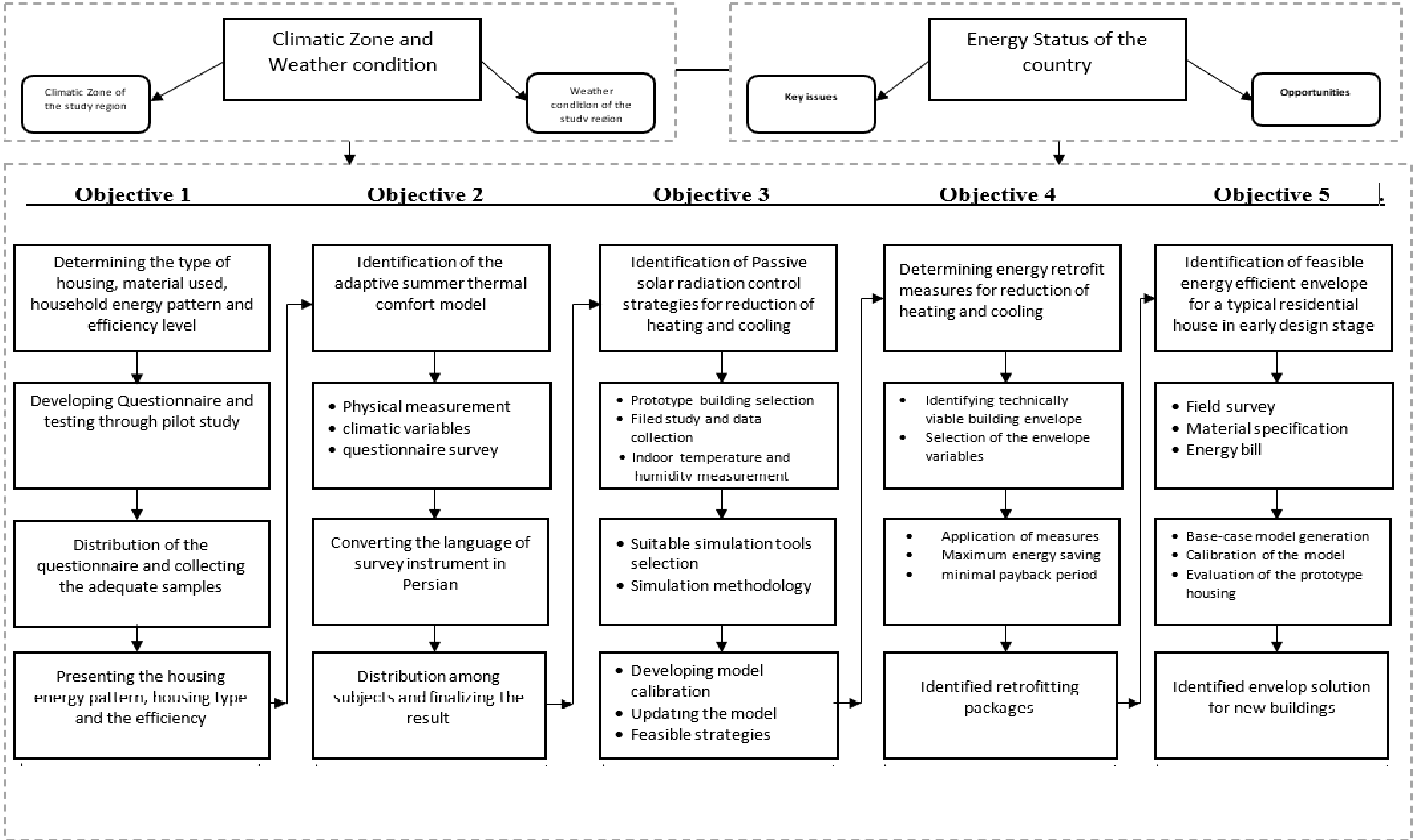


Figure 5.18 Overall research design

CHAPTER 6
RESULTS AND DISCUSSION

This chapter contains the report of each objective of the thesis. The outcome of each study is presented in separate sections and subsections. The chapter ends by summarizing the overall result.

6.1 Residential Buildings Energy Pattern and Characteristics

This section presents the report of the thesis's first objective: to identify household energy-consumption patterns, understand the type and characteristics of urban housing in Afghanistan, and examine household energy efficiency levels.

6.1.1 Dwelling characteristics

The concept of shelter differs between individuals depending on culture, tradition, profession, and way of life. The construction of houses (so-called residential units) was entrusted to architects and mass construction concerning scientific and technological development, the necessities of modern society, and ethnic and cultural gaps. Moreover, in many nations worldwide, sustainable buildings are essential to architectural guidelines and building regulations (Yu and Kim, 2012). There are essentially two types of residential housing in Mazar-I-Sharif:

1) Individual houses,

2) Multi-family apartments/flats.

Individual houses are preferred mainly by residents and have been used for centuries. However, multi-family buildings are currently constructed due to limited available land in the central area, and few of them are constructed using standard material that provides a superior indoor environment. The self-owned and controlled houses are inside multi-story buildings and have several apartments/flats, mainly reinforcement concrete (RCC) structures. Figure 6.1 presents the types of housing in the city.

(a)

(b)

Figure 6.1 (a) Single-family house, (b) multi-family apartment/flat

The individual houses can be categorized as; 1) simple houses, 2) medium houses, and 3) luxurious houses.

1) Simple houses are generally one- or two-floor economic houses constructed with local material (burnt- or mud-brick and wood). Mud houses are an example of simple houses. The walls of the houses are constructed with traditional (burnt) or mud brick, and the roofs are generally flat and built using wooden poles and coated with a mixture of mud and straw.
2) Medium houses: The structure of these low-rises (one or two floors) houses is either masonry (burnt-brick walls, brick roof supported with I-section steel) or RCC.
3) Luxurious houses: These individual houses have RCC structures with scenic exterior façades. Cement plastering is the typical coating on these dwellings'

interior and exterior walls. The most significant advantage these houses offer is the space in and around the house.

For cultural reasons, the privacy of the household is essential for Afghans. Both men and women want privacy and prefer visual segregation from neighbors and the street. Hence, private courtyards isolated from the street are common in individual residences. Figure 6.2 illustrates the different types of individual houses in the city.

(a) (b)

(b) (c)

Figure 6.2 Different types of individual houses

(a) Luxurious house, (b) Medium house, (c) Simple house

In general, 11.3% of the Mazar-I-Sharif residents live in recently built apartments. High-income groups typically live in RCC individual houses, medium-income groups construct brick structure/masonry houses and/or live in apartments, and low-income groups live in mud/brick houses. Each family generally has 6 to 8 family members.

The results reveal that the trend of constructing RCC homes has increased by 50% from 2002 to 2020. However, for the same period, the trend for brick/masonry houses has increased by 8%, and the trend for simple houses with wooden roofs has decreased by 70% in the city.

In terms of insulation, it was found that most of the residential structures in Afghanistan were not insulated. Indeed, 66.71% of the RCC structures were not insulated, or 88.67% of the burnt-brick houses. None of the mud/brick houses were found to be insulated in the survey. However, most of those structures that were found to be insulated used polyurethane foam as an insulator. In RCC structures, PVC and wooden frame-type windows were found to be the most common type. The available PVC frame has double-layer glass primarily, while the traditional wooden, metal, and aluminum frames have only single-layer glass. The types of window frames used in the residential buildings are presented in Figure 6.3. In the burned-brick structure (Masonry houses), 65.09% of the houses have wooden frame windows, 21.7% have metal frame with single layer glass, the rest, most of which are newly constructed homes, have PVC windows. More than 90% of the mud/brick types of houses were found to have wooden-type windows.

Regarding the direction of the façade of houses, the results reveal that most buildings in Afghanistan have not been constructed by considering direction (north, south, east, and west). Irrespective of the type of buildings, the percentage of buildings facing each of the four directions was found to be the same in the survey.

The majority of the RCC-type apartment buildings have a continuous electricity supply (either from the national grid or private generators). Moreover, most individual houses have an intermittent supply of electricity. For example, the city faces electricity shortages in winter due to high demand. People have started fulfilling some of their electricity needs by installing solar panels on the rooftops of their houses.

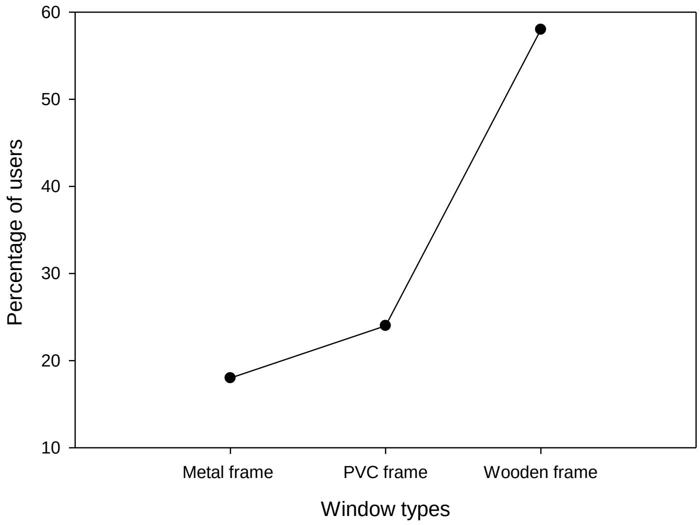


Figure 6.3 Types of window frames used in residential dwellings

As with other countries (Fischer Corinna, 2008), the household sector in Afghanistan has the highest rate of growth in terms of final energy consumption. The overall energy consumption of a household rises concerning a household's income level. The results found that the mean monthly electricity bill of high-income single-family households is between AFN 8,000 to 10,000, with AFN 3,000 to 4,000 and AFN 1,000 to 2,000 for middle- and low-income households, respectively. Therefore, high-income families spend more money on energy than low-income households. Furthermore, whether energy is provided constantly or rationed at particular periods affects home electricity usage.

6.1.2 Energy for space heating and cooling

Climate significantly impacts building design and energy use. Mazar-I-Sharif, the regional hub of northern Afghanistan, is characterized by a dry climate, a scorching summer, and a cold winter (AMD, 2020). Maintaining indoor comfort requires more than six months of space cooling and three months of space heating (ASHRAE, 2021). In Mazar-i-Sharif, various fuels, including electricity, firewood, LPG, coal, and charcoal, are utilized for space heating. The local central-heating systems are rarely used. Dwellings use central heating systems only in new multi-family apartment buildings that predominantly use coal energy due to high electricity rates and power fluctuations in winter. Only 3.54% of dwellings use electrical energy from the city grid for heating purposes. LPG is the most commonly used fuel for heating (35.78% of households). Subsequently, 31.13% of households use coal, and 29.55% use firewood. Figure 6.4 illustrates the types of heating systems commonly used by all types of dwellings in the city.

Figure 6.4 Types of heating systems commonly used in the city

The majority of households use desert coolers for cooling. Around 57.47% of households have desert coolers. With a share of 28.87%, air conditioners are essential household appliances for space cooling, and most of the units studied in the households are split style. In addition, 13.25% of households use only fans for cooling their houses.

6.1.3 Energy for cooking

Cooking is one of the most energy-intensive activities in Mazar-I-Sharif. LPG is the most widely utilized cooking fuel, accounting for 87.1% of all households, whereas firewood is used by just 3.03%. LPG, primarily imported from neighboring countries, such as Uzbekistan, is widely used by all income groups, including high-, middle-, and low-income households, whereas firewood is only used by low-income families trying to make ends meet. In recent years, households have started using electric ovens. The survey found that 9.87% of households are using electricity as fuel for cooking. Figure 6.5 illustrates the percentage of different cooking energy consumed by residents.

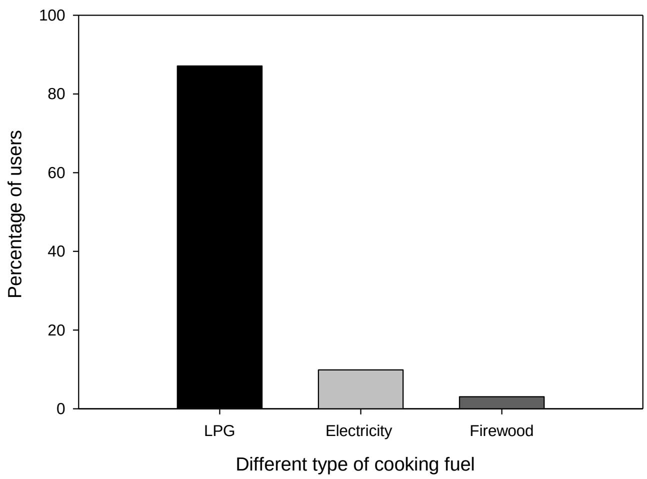


Figure 6.5 Proportions of different types of cooking fuel

6.1.4 Possession of electric appliances

Among electricity appliances, television has the highest penetration rate; 98.88% of households have at least one television. As to other widely owned appliances, washing machines account for 77.27%. The electrical geyser has become necessary for daily use as living conditions have improved, accounting for 68.18%. Additionally, 92.7% of households have a refrigerator, though only 18.56% have a standalone freezer. Figure 6.6 displays the types of hot water supply in urban Afghanistan.

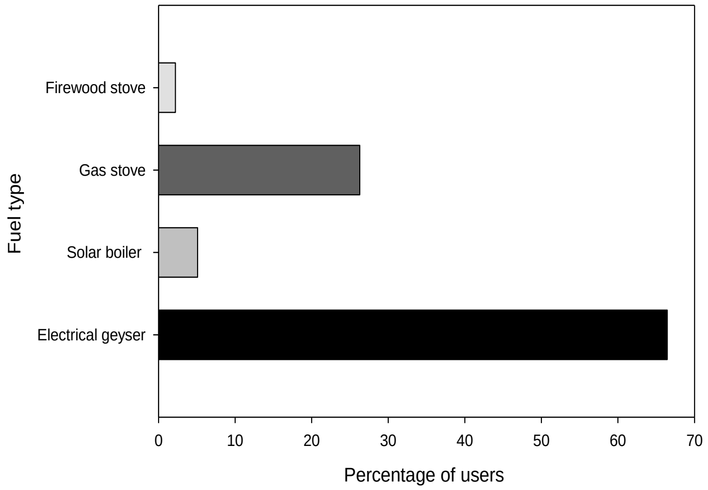


Figure 6.6 Types of hot water supply systems in urban Afghanistan

Concerning cooking appliances, 45.83% of households use an electric oven, and 32.57% have a microwave. The survey indicates that water pumps are widely used, with 64.77% of households using them to collect groundwater from wells owing to the city's lack of an appropriate freshwater delivery network. Figure 6.7 illustrate common appliances and the percentage of users in the urban household.

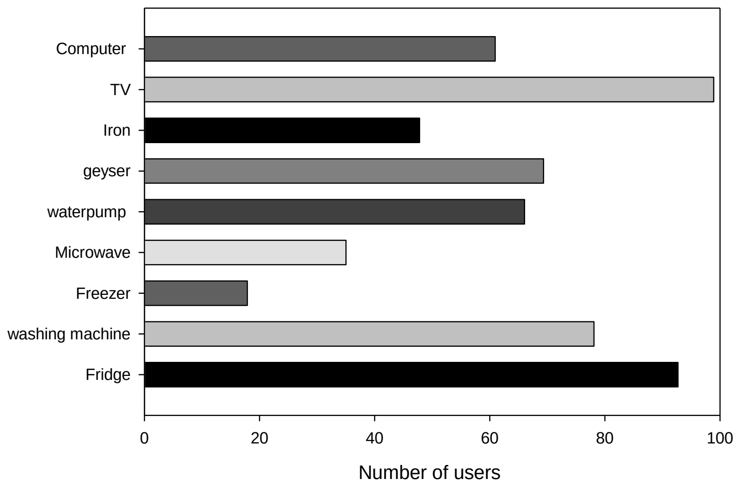


Figure 6.7 Common appliances and the percentages of users in urban households

When electricity fluctuates in the city, kerosene is used to provide electricity for household lighting, electrical heaters, and other appliances commonly used by high-income and rarely by middle-income families.

Regarding lightning appliances, the survey found that 46.67% of households use incandescent bulbs, 30.34% use fluorescent bulbs, 13% use LEDs, and the rest use CFL type of bulbs. It should be noted that households have lately begun using PV panels to generate and store electricity, particularly for lighting when there is a power outage in the city. Therefore, using low-energy bulbs capable of using solar power is a recent trend in the city.

6.1.5 Evaluation of the factors affecting the consumption of energy

Correlation and regression analyses have been conducted to understand the influence of structure type on energy consumption. The results of the correlation analysis are provided in Table 6.1, and the regression analysis results are indicated in Table 6.2.

From the correlation analysis, it is evident that all the types of structures have a significant correlation with the electricity bill. As the type of structure changes, the correlation coefficient also changes. For example, the correlation coefficient of the summer electricity bill with RCC housing is 0.442, with masonry structure, it is 0.274, and with mud/brick houses, it is 0.232. These results mean that electricity consumption is more dominant in RCC structures than in masonry and mud houses. The winter electricity bill presents a similar case. The correlation coefficient of the winter electricity bill with the RCC building is 0.393. With the masonry structure, it is 0.257, and it is 0.195 with the mud/brick house.

Regression analysis was performed to discover the factors that contribute to the electricity bill. From the regression analysis, it can be observed that the electricity bill's primary constituent depends upon the dwelling type. For example, it can be seen from Table 6.1 that, for RCC houses, AC contributes significantly to the electricity bill.

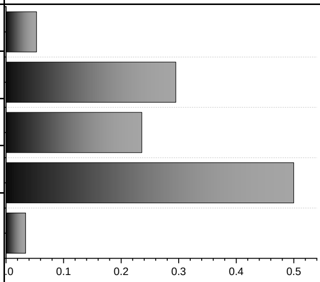
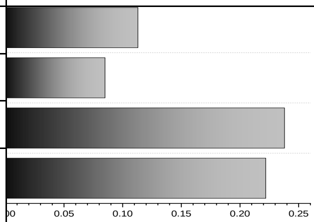
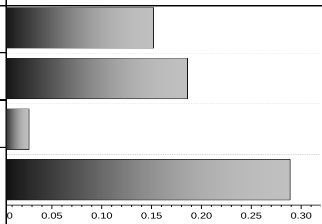
Table 6.1 Correlation between types of dwelling structure and electricity bills in summer and winter

		RCC structure	Masonry structure	Mud/brick house	Electricity bill (summer)	Electricity bill (winter)
RCC structure	Pearson Correlation	1				
	Sig. (2-tailed)					
	N	274				
Masonry structure	Pearson Correlation	-.691**	1			
	Sig. (2-tailed)	.000				
	N	274	274			
Mud/brick houses	Pearson Correlation	-.411**	-.375**	1		
	Sig. (2-tailed)	.000	.000			
	N	274	274	274		
Electricity bill (summer)	Pearson Correlation	.442**	.274**	.232**	1	
	Sig. (2-tailed)	.000	.000	.000		
	N	272	272	272	272	
Electricality bill (winter)	Pearson Correlation	.393**	.257**	.195**	.896**	1
	Sig. (2-tailed)	.000	.001	.000	.000	
	N	272	272	272	272	272

**. Correlation is significant at the 0.01 level (2-tailed).

People living in RCC-structure houses depend more on AC to maintain the internal household temperature. Similarly, for masonry houses, AC and fans are identified as major appliances used for maintaining thermal comfort. In comparison, people living in mud/brick houses primarily use fans and desert coolers to maintain thermal comfort. These results indicate that dwelling type influences the electrical appliance employed to maintain thermal comfort. In other words, it can be deduced that it is challenging to maintain thermal comfort inside RCC buildings without using any electrical appliance compared to maintaining internal thermal comfort in masonry and mud/brick houses.

Table 6.2 Influence of cooling system on summer electricity bills based on type of structure

<table>
<tr><th>Types of housing</th><th>Influence factor</th><th>Standardized Coefficients (Beta)</th><th>Significance probability</th></tr>
<tr><td rowspan="5">RCC</td><td>Fan</td><td rowspan="5">
</td><td>.937</td></tr>
<tr><td>AC</td><td>.051</td></tr>
<tr><td>Cooler</td><td>.579</td></tr>
<tr><td>Fan and cooler</td><td>.514</td></tr>
<tr><td>Central cooling</td><td>.596</td></tr>
<tr><td rowspan="4">Masonry</td><td>Fan</td><td rowspan="4">
</td><td>.164</td></tr>
<tr><td>AC</td><td>.077</td></tr>
<tr><td>Cooler</td><td>.670</td></tr>
<tr><td>Fan and cooler</td><td>.579</td></tr>
<tr><td rowspan="4">Mud/brick</td><td>Fan</td><td rowspan="4">
</td><td>.003</td></tr>
<tr><td>AC</td><td>.817</td></tr>
<tr><td>Cooler</td><td>.109</td></tr>
<tr><td>Fan and cooler</td><td>.158</td></tr>
</table>

6.1.6 Satisfaction with internal environmental comfort

Since there are different types of houses and structures in the city, the respondents were asked to express their satisfaction levels regarding the indoor environments of their dwellings in the summer and winter. Moreover, the overall satisfaction of each resident regarding their homes was recorded and analyzed. A graph has been prepared to present the population and their satisfaction level. The peak of the RCC-structure graph is between the satisfaction level of 1 and 2. In addition, the area of over 60% under the graph is below the satisfaction level of 3. This reveals that most people who live in RCC structure houses are not substantially satisfied with the indoor temperature of their houses. The levels of satisfaction with the indoor atmospheres of various types of dwellings during the summer and winter seasons are presented in Figure 6.8. The two graphs (masonry and mud/brick dwelling) are slightly similar in function. However, as the peak of the mud/brick house graph is at 3.5 and there is little dispersion in the distribution of the graph, it can be concluded that the people who live in mud/brick housing are more satisfied (in terms of the thermal environment inside the house) than those who live in masonry and RCC-structure houses.

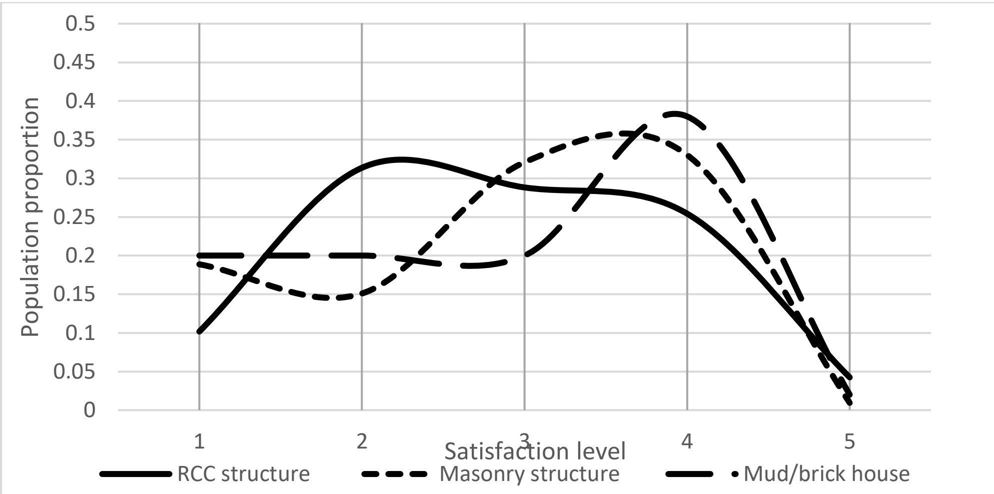


Figure 6.8 Levels of satisfaction with the indoor atmospheres of various types of dwelling during the summer and winter seasons

6.1.7 Validation and reliability of scales

The questionnaire was validated through the smallest space sample by computing Cronbach’s alpha values. The results found Cronbach’s alpha value to be 0.512. In general, most studies have considered Cronbach’s alpha values of 0.7 and above to be acceptable. However, many studies have also accepted the value of Cronbach’s alpha at less than 0.7 but more than 0.5. Such values of Cronbach's alpha are primarily due to the variety of new constructs in the questionnaire (Field, 2013; Tam and Fung, 2012). Therefore, the questionnaire survey used in this study can be considered acceptable, as Cronbach’s alpha value was found to be more than 0.5.

6.2 Assessment of Summer Thermal Comfort Levels of Apartment Residents

This section investigates the thermal comfort level of apartment residents in the extreme summer conditions of Mazar-I-Sharif.

The design of a comfortable house and the choice of building materials depend significantly on the prevailing external climate and criteria for human thermal comfort. As the first step to systematic house design, it is necessary to assess the external climatic variables and articulate the indoor conditions that are likely to be desirable and the conditions that have to be avoided. These conditions serve as guidelines in assessing the range of values of physical parameters in which one would feel thermally comfortable.

6.2.1 Thermal sensation (TS), thermal preference (TP), and thermal acceptance (TA)

Thermal sensation, which conveys warmth or coolness, is among the prime concern psychological aspects of thermal comfort. The average thermal sensitivity of acclimatized individuals in any geographical location is around the neutral point on the ASHRAE thermal sensation scale (ASHRAE, 2005). Individual variations in thermal sensibility (TS) were observed among residents of various apartment complexes. However, 69 % of the individuals were determined to be comfortable in June/July (mean sensation vote = 0), which is consistent with the findings of (Rijal et al., 2002). This was owing to the ample options accessible to apartment occupants who were subjected to a very high-temperature regime in June/July.

The mean interior globe temperature (Tg) in all buildings was around 30–32 ◦C. There was a strong preference for the cooler side of the thermal environment. The TV, TP, and TA is presented in Figure 6.9 - 6.11.

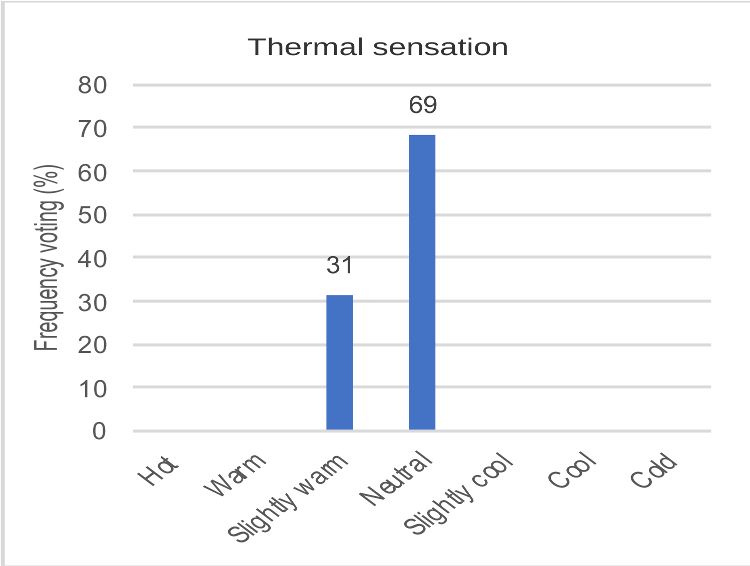


Figure 6.9 Vote distribution for thermal sensation

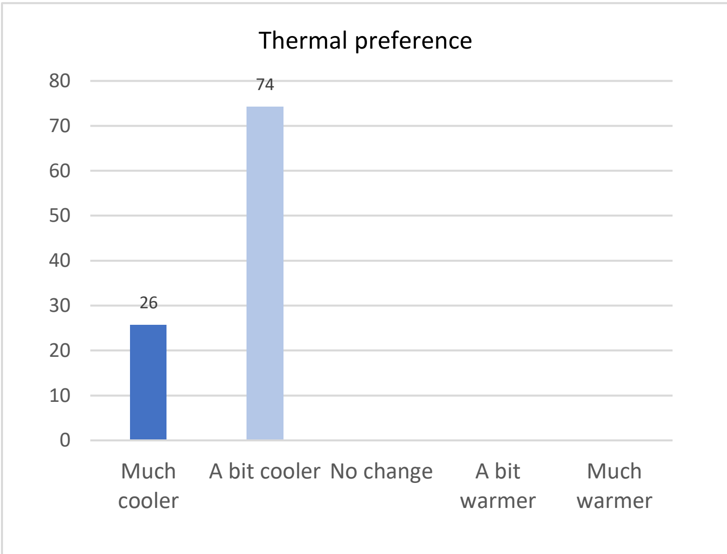


Figure 6.10 Vote distribution for thermal preference

The concept of thermal acceptance is contentious in the field of thermal comfort. Several psychological aspects, such as expectation levels, thermal history, attitudes, control usage, and so on, played a role.

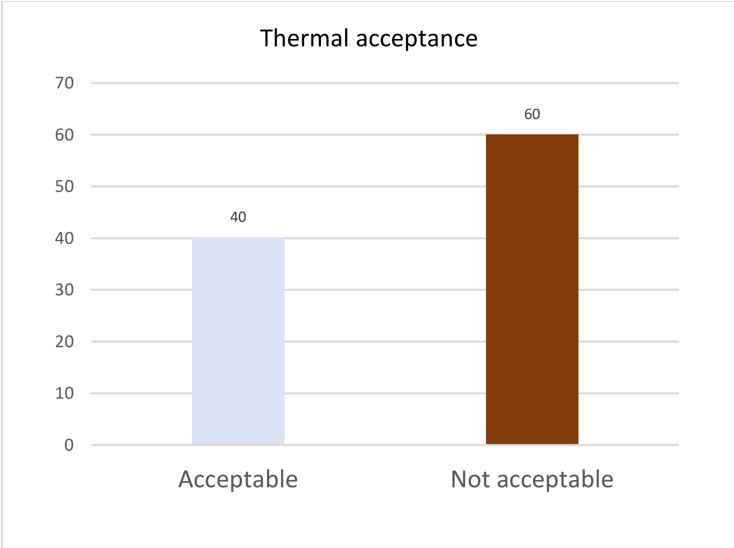


Figure 6.11 Vote distribution for thermal acceptance

6.2.2 Linear regression analysis and comfort zone

The sensation votes were recorded for all six residential buildings consisting of 70 apartments in a regression analysis on operative temperature. The Fanger's predicted mean vote (PMV) for all data sets was determined using the CBE thermal comfort tool (Tartarini et al., 2020). PMV was regressed concerning the operating temperature (Figure 6.12).

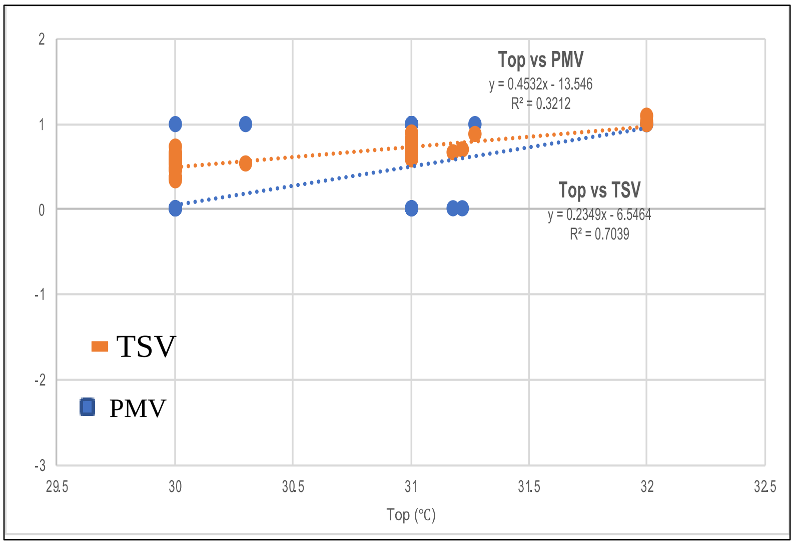


Figure 6.12 The regression of Predicted Mean Vote and Thermal sensation Vote

As demonstrated in Figure 6.12, the PMV was usually more than the sensation itself. Operative temperature (Top) vs. PMV R^2 is 0.6905, while Top vs. thermal sensation vote (TSV) R^2 is 0.4133. Table 6.3 presents the statistics for regression.

Table 6.3 Statistics for regression

Multiple-R	0.56677815
Adjusted R Square	0.31125567
R Square	0.32123747
The Standard Error	0.38804975
Observations	70

Thermal neutrality is 27.86°C with a comfort zone (sensation in the range of -1 to +1) is 23.61 - 32.13°C, which conforms with other studies as compared in Table 6.4.

Table 6.4 Regression correlation among thermal sensation and interior temperature in various research

Author	**Location**	**Regression equation**	**Correlation coefficient (r)**	**Neutral temperature (T_n)**
Present study	Afghanistan	y = 0.2349x - 6.5464	“0.84”	27.86
(Indraganti, 2010)	India	“y = 0.310x-9.060”	“0.65”	29.23
(Ye et al., 2006)	Shanghai	“y = 0.13x-2.92”	“0.69”	22.50
(Ogbonna and Harris, 2008)	Nigeria	“y = 0.313x -8.41”	“0.61”	26.13
(Rijal et al., 2002)	Nepal	“y=0.058x-1.27”	“0.44”	21.90
(Nicol et al., 1999)	Pakistan	“y = 0.154x + 0.09”	“0.74”	25.45

Furthermore, the psychometric chart based on ASHRAE Standard 55-2004 using PMV and analyzed with ClimateConsultant (Appendix…) provides insight into effective design strategies for the arid climate of Mazar-I-Sharif. The design strategies are:

- Traditional passive homes in hot dry climates used high mass construction with small recessed shaded openings, operable for night ventilation to cool the mass;
- An evaporative cooler can provide enough cooling capacity thus reducing or even eliminating air conditioning;

- Window overhangs or operable sunshades (awnings that extend in summer) can reduce or eliminate air conditioning;
- Flat roofs work well in such climate;
- Humidify hot dry air before it enters the building form enclosed outdoor spaces with spray like fountain, misters, wet pavement, or cooling towers;
- Earth sheltering, occupied basements, or earth tubes reduce heat loads in very hot dry climates a the earth stays near average annual temperature;
- Good natural ventilation can reduce or eliminate air conditioning in warm weather, if windows are well shaded and oriented to prevailing breezes;
- On hot days ceiling fans or indoor air motion can make it seem cooler by 5 degrees F (2.8C) or more, thus less air conditioning is needed;
- Heat gain from lights, people, and equipment greatly reduces heating needs so keep home tight, well insulated;
- Use light colored building materials and cool roofs (with high emissivity) to minimize conducted heat gain;
- Keep the building small (right-sized) because excessive floor area wastes heating and cooling energy;
- Sunny wind-protected outdoor spaces can extend living areas in cool weather (seasonal sun rooms, enclosed patios, courtyards, or verandahs)

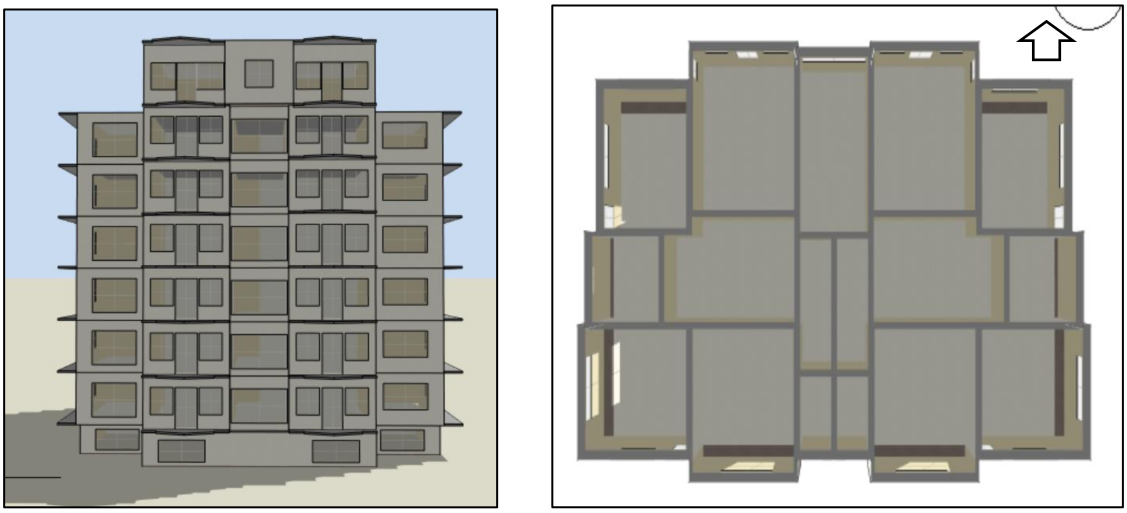
6.3 Passive Solar Radiation Control Strategies for Reduction of Heating and Cooling Energy

This section analyzes and presents Passive solar control strategies resulting in arid and harsh zone concerning Afghanistan Mazar-I-Sharif city weather characterized by scorching summer and cold winter. Since a growing number of residential buildings in

Afghanistan are designed without taking the climate into account sufficiently, following neighboring countries' prototypes, these power guzzler buildings often have a poor indoor climate which affects comfort, health, and efficiency. Since there is a lack of information regarding the effectiveness of solar control measures in such a specific climate, a case study building typical for Afghanistan Mazar-I-Sharif city was selected, modeled, and analyzed using field data and simulation tools to reduce energy consumption and improve thermal performance. This study considers low-cost passive measures with a potentially high impact on energy use, with a shorter payback period.

6.3.1 Base-case simulation

A building model was generated (Figure 6.13) for simulation using DesignBuilder with the EnergyPlus engine. The base-case model simulation was done after all the necessary data was entered into the software. The simulation was performed monthly with the outcome based on the building structure's initial orientation, which was 0° north. Figure 6.13 depicts the energy consumption of base-case buildings over the year.



(a) (b)

Figure 6.13 (a) Building 3D view, (b) Building plan

The energy use in the peak summer month was higher than in other months of the year, primarily due to higher cooling for the apartments (Figure 6.14). To ensure the accuracy and reliability of the model and application of the software, the measured and simulated free-running indoor air temperatures were compared for peak summer months from 1st July 2019 to 12th August 2019.

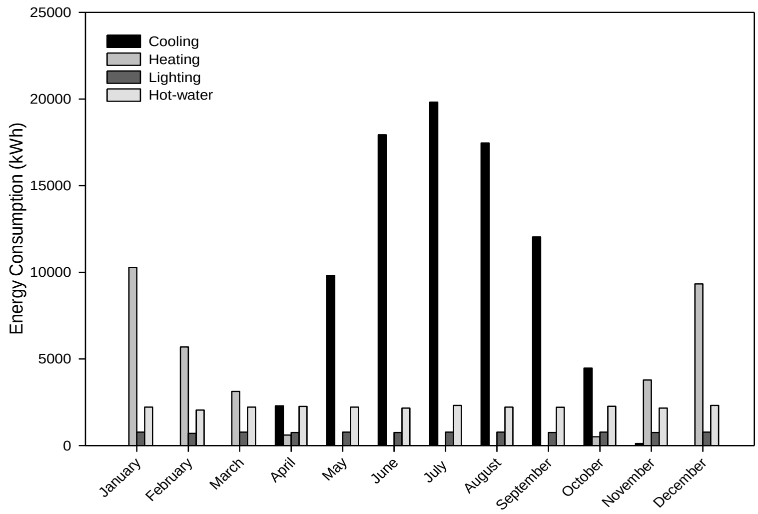


Figure 6.14 Energy consumption of base case building (kWh)

The monitoring room was located on the 6th floor of the residential building. The indoor air temperature of the monitoring room was measured. The instrument used for indoor air temperature measurement was Apresys portable Data-logger (TH 18000436). The room was unoccupied during the monitoring period, with no illumination or equipment. The latest available EPW (EnergyPlus Weather) data (Climate.onebuilding, 2019) was used in the simulation for local outdoor weather. Figure 6.15 represents the comparison graph between measured and simulated temperature and humidity.

The MBE and CV(RMSE) values obtained 4.48% and 9.81%, which fall within the ASHRAE 14 Guide acceptance limit for energy model calibration (Royapoor and Roskilly, 2015). The values indicate the satisfactory level of the generated model.

However, many factors were causing the error in simulation, such as climate and environmental data.

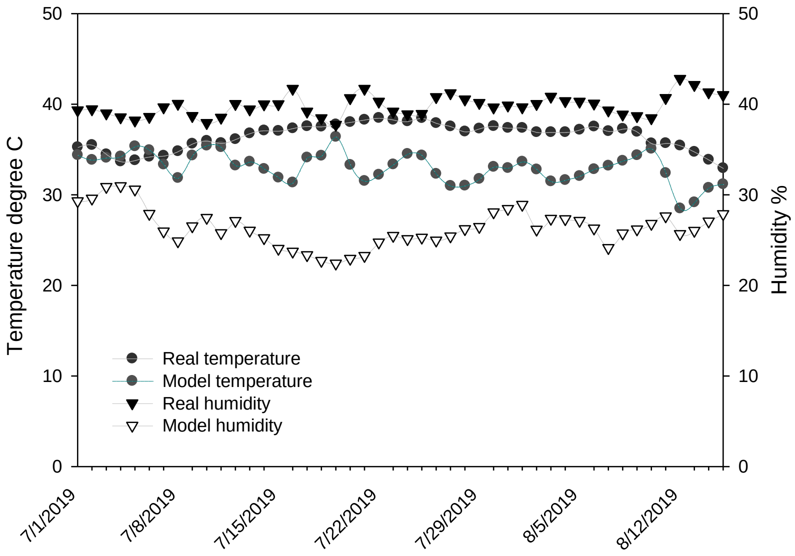
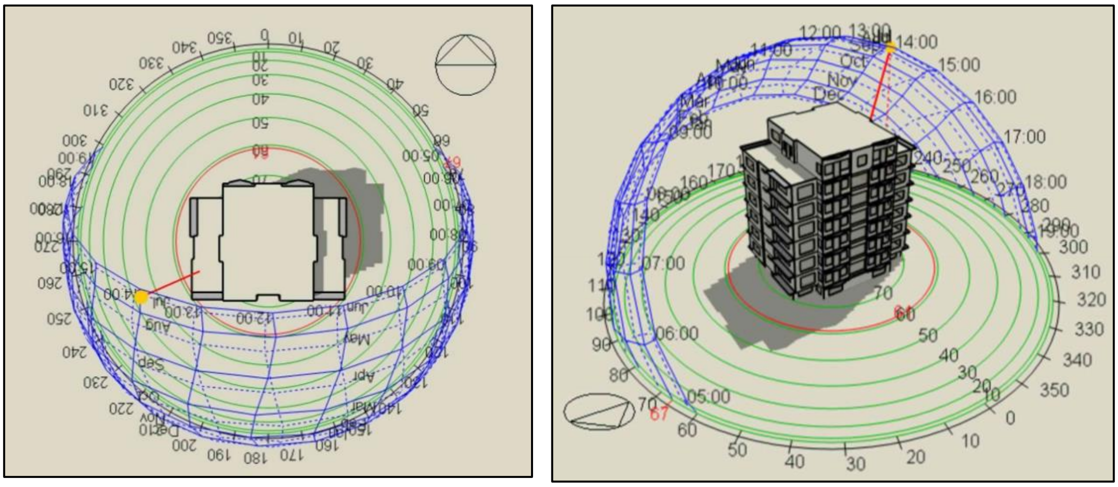


Figure 6.15 Comparison graph between measured and simulated temperature and humidity

The weather data used for simulation was – EPW (Energyplus weather data) of Mazar-I-Sharif city for 2013-2017 (Climate.onebuilding, 2019). Moreover, the case building was in a residential area of the city with surrounding obstructions, which had a noticeable influence on the indoor temperature. Therefore, the base case model can generate approximately the actual operating condition of the building.

6.3.2 Effect of building orientation

Optimum solar orientation can be obtained by analyzing solar paths at various times of the year. One of the significant factors was the amount of solar radiation reaching the site. The sun's high angle means it does not get through the glazing during the hot months if shaded efficiently.



(a) (b)

Figure 6.16 The sun path diagram for case-study building
a) The sun orbits over the year on studied building b) A formation of the seven-floor model and its position to the annual and daily sun path

Figure 6.16 shows the sun's position during the annual period and its influence on energy efficiency performance, where it can be seen that the south receives the most considerable amount of solar radiation during the winter season. Furthermore, the sun warms the east and west facades briefly in the morning and evening, respectively, while the north wall majorly remains in the shade. The three sides of the structure are exposed to the sun which gains heat during the day, while the north side in the shade loses heat; hence, the minimum opening should consider in the north facade of the building to avoid energy loss in winter. Since the building's south facade is more suitable for heating by solar energy in winter; therefore, the larger opening should consider the building's southern side. Furthermore, the southern direction's solar radiation is mostly enough to warm the rooms throughout the day; as soon as solar absorption stops at night, the room may get cold. However, this could be minimized by using thermal mass in building facades to store the collected energy throughout the day and release heat to the inside of the building overnight.

0° and 45° Angle: With the north angle at zero degrees, the cooling load was calculated as 83972.82 kWh, and the heating load as 33313.1 kWh per annum. At 45°, the cooling load of 83972.66 kWh per annum remained constant. Owing to passive solar, which helps warm the building in the winter, the heating load was low compared to the cooling load. The highest cooling load was recorded at 19817.6 kWh in July, while the highest energy load for heating was calculated as 10280.18 kWh in January. Similarly, for a north angle of 0°, July with 19817.63 kWh and January with 10280.17 kWh were recorded, indicating no reduction in energy load.

90° and 135°: The cooling load recorded for 90° was 89514.57 kWh per annum, with a peak of 20801.46 kWh in July and the highest heating load of 10210.92 kWh in January. As compared to a zero-degree angle, this indicates an increase in cooling load. Thus, it can be concluded that there is a correlation between building orientation and its cooling loads.

180° and 225°: In these orientations, cooling and heating loads registered as 82872.14 kWh and 30108.77 kWh, respectively. The 180° value indicates the highest reduction of 5,223.49 kWh per annum in cooling energy compared to 225°. At 225° angle, the peak cooling month was recorded as July with an overall 4.68% cooling energy reduction compared to base-case orientation. The heating load distinction between these orientations was only 1,483 kWh per annum, which could be due to the terraces on the eastern and western sides of the building eliminating direct solar radiation from reaching the indoor spaces.

270° and 315°: The orientation of 270°and 315° resulted in a total heating load of 32625.86 kWh, 33357.4 kWh per annum, and a cooling load of 88977.88 kWh, 83947.47 kWh per annum, respectively, with the highest cooling load of 20681.67 kWh in the peak summer month of July in the orientation of 270°. In this study, the effect of lighting and hot water is not considerable. Figure 6.17 represents energy consumption in four major orientations.

The existing building’s northern side façade has a higher ratio of windows to walls, where the entrance to the apartments is located, followed by the southern side of the base case building façade. Results show that building faces with lower wall window ratios in the west than in the south have a higher operational energy requirement in cooling energy. The finding indicates that the orientation change can be readily incorporated in the design phase to optimize the mid-rise multifamily apartment’s operational energy requirements. The western direction, by having 157866 kWh (kilowatt-hour) energy consumption, is the highest compared to all the other orientations, as shown in Table 6.5.

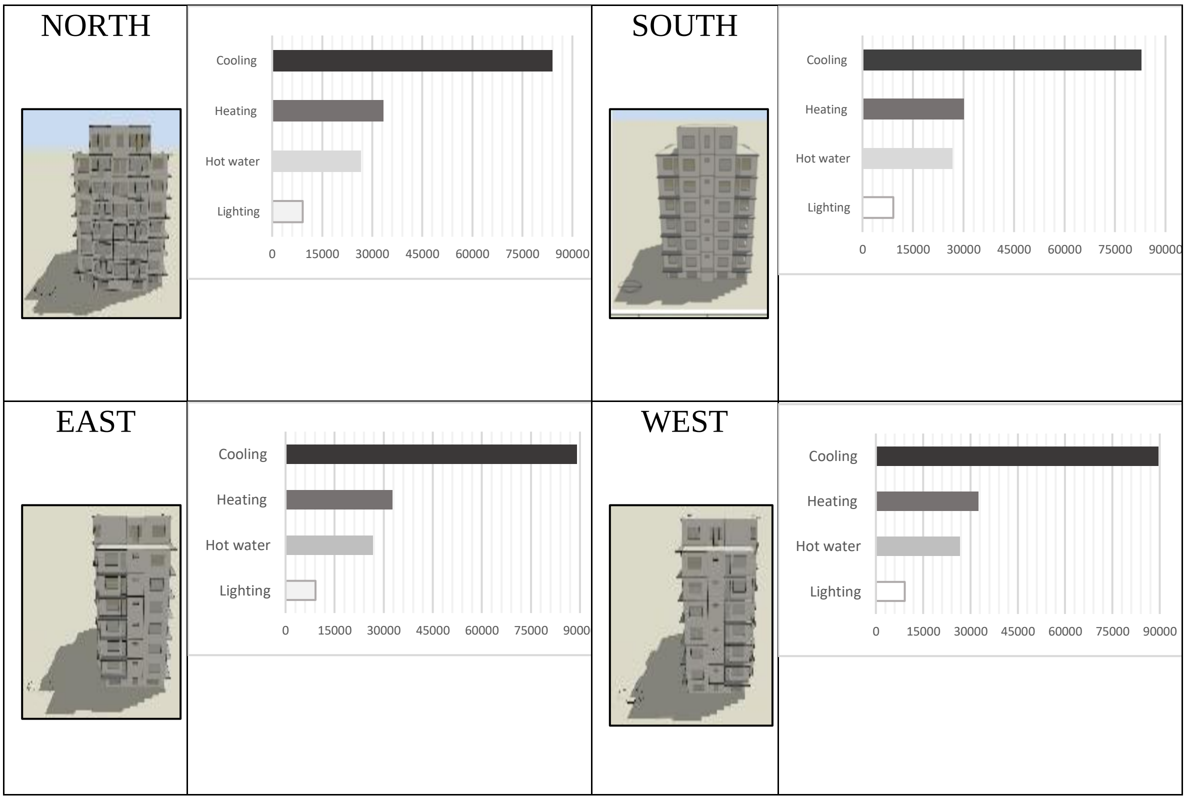


Figure 6.17 Energy consumption in four major orientations (kWh)

Table 6.5 Annual energy consumption concerning each orientation (kWh)

Case	Degree	Cooling	Heating	Lighting	Hot water system	Total electricity (kWh)
Case-1	0◦	83972.82	33313.1	9155.03	26634.09	153075
Case-2	45◦	83972.66	33313.16	9155.03	26634.09	153074.9
Case-3	90°	89514.57	32562.26	9155.03	26634.09	157866
Case-4	135°	88887.57	31554.33	9155.03	26634.09	156231
Case-5	180°	82872.14	30108.77	9155.03	26634.09	148770
Case-6	225°	88095.63	31591.85	9155.03	26634.09	155476.6
Case-7	270°	88977.88	32625.86	9155.03	26634.09	157392.9
Case-8	315°	83947.47	33357.4	9155.03	26634.09	153094

While the sun travels from east to west, during the hottest hours of the day, i.e., 12:00 to 14:00 hrs., the sun is directly overhead and travels towards the west. Hence maximum cooling load is perceived for the Western direction of the building. However, the south façade is the optimal orientation to face the glazed façade of the building. Figure 6.18 illustrates the total energy consumption considering simulated orientation.

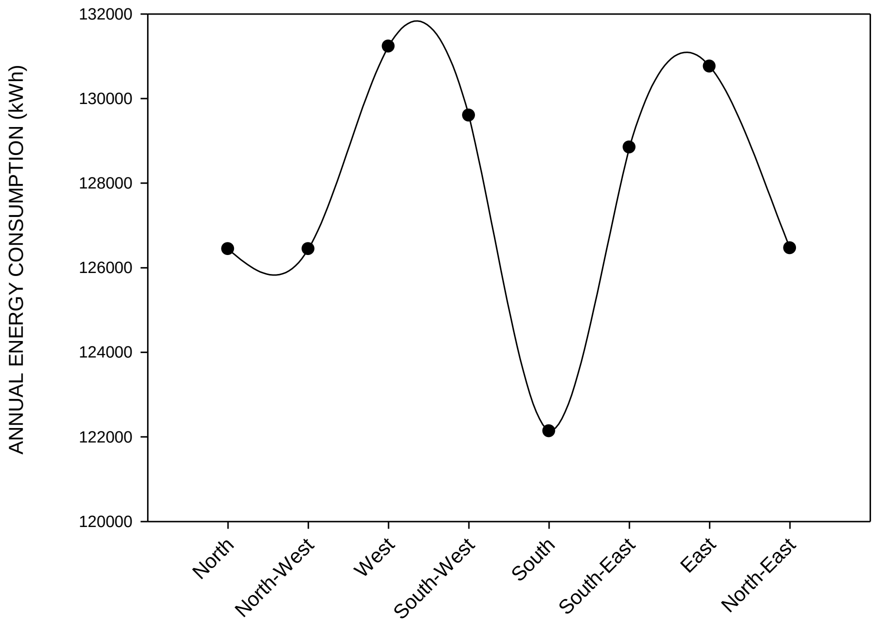


Figure 6.18 Total energy consumed annually for cooling, heating and lighting in a different orientation

When the building orientation lies at a 0° north angle, the energy consumption curve falls in the middle point, and by rotating the building from 0° to 45° angle counter-clockwise, the energy consumption does not experience considerable changes. In comparison, when the building façade turns to the western side or 90°, it increases rapidly and reaches the highest point, which might be due to relatively less solar radiation. Moreover, by rotating the building to 135°, the energy consumption curve starts to decrease, and when it turns to the southern side, it hits the lowest point. In these cases, the window-wall ratio of the front facade is 0.34 and of the rear is 0.21. Furthermore, by rotating the building to 225° with having gradual increment, the curve rises dramatically, and with 270°, it declines sharply. In conclusion, the southern direction has the lowest annual energy demand of 148770 kWh.

6.3.2.1 Impact of neighboring structures on energy demand

Shadings caused by neighboring buildings induce high energy consumption by limiting radiant energy gained and retained by its thermal mass (Compagnon, 2004; Nikoofard et al., 2011). Considering the magnitude of shadow and overshadowing of the neighboring building on the site, the model simulated and analyzed the energy consumption during other months. Sun path analysis figures show that surrounding buildings are significant in winter compared to summer (Figure 6.19). Overshadowing by neighboring buildings is mostly in the east-west compared to the northern façade of the building due to its proximity. Therefore, the site running east-west should be broad enough to avoid overshadowing.

Various types of shading strategies may use to improve the building energy performance. In the cold months, the reduction in shading is preferable, while shading improvement is required in the hot period. Hence, a trade-off is needed to find the most efficient combination and extent of shading for an overall improvement across the year.

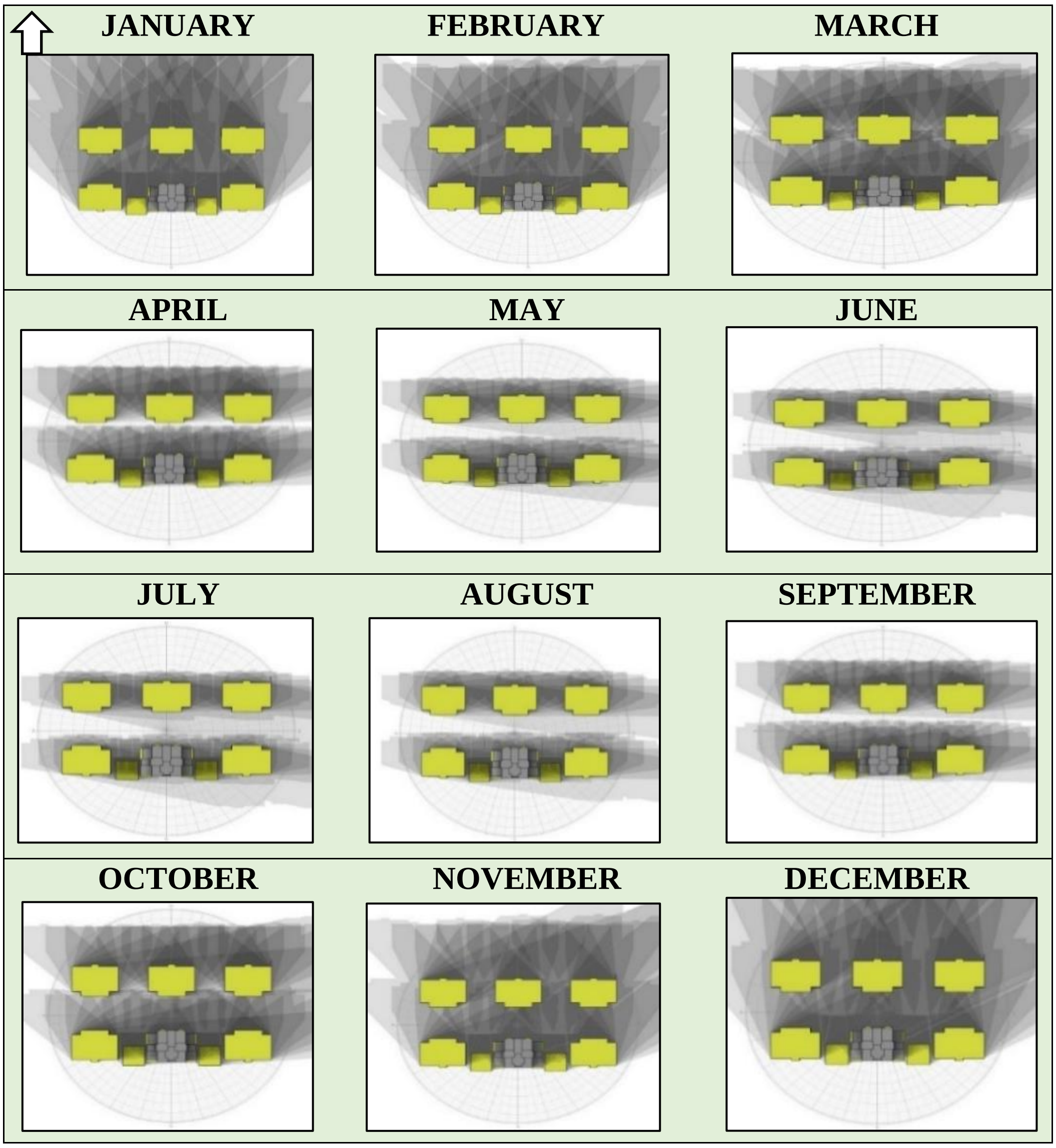


Figure 6.19 Neighbouring building shading effect on the studied building during the year

In contrast, this shading slightly increases energy load in winter, as it somewhat hinders sun energy from entering the indoor environment. Figure 6.20 depicts the energy consumption comparison between neighboring building effects and without neighboring buildings.

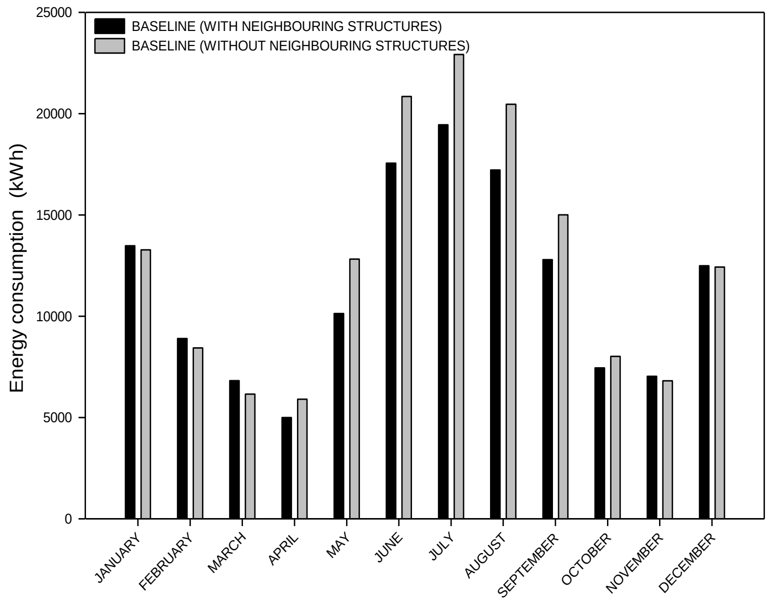


Figure 6.20 Comparison of the building with and without surrounding urban context

6.3.2.2 Effect of fixed and movable shading devices

The arid climate of Mazar-I-Sharif requires both cooling and heating. The selection of a method for decreasing solar gain through shading at the window in summer would also affect solar gain during the winter and increase the heating load. Therefore, an analysis must be made in selecting shading to balance the heating and cooling load. There are various types of shading devices; on sun path-oriented openings, the analysis of useful fixed external and movable internal shading devices is considered to minimize heat gain through windows in the summer.

Getting started, a horizontal fixed louver made of wood has been applied, corresponding to a standard dimension available in the market, and simulated to represent its effect on overall building energy requirement. The impact of louver on overall energy demand depends on various factors. Specifically, the window area, location and inclination angle have a particular magnitude when trying to maintain thermal comfort (Palmero-Marrero and Oliveira, 2010). The elevation and specification of applied louvers to protect the glazed surfaces of the study building are presented in Figure 6.21 and Table 6.6.

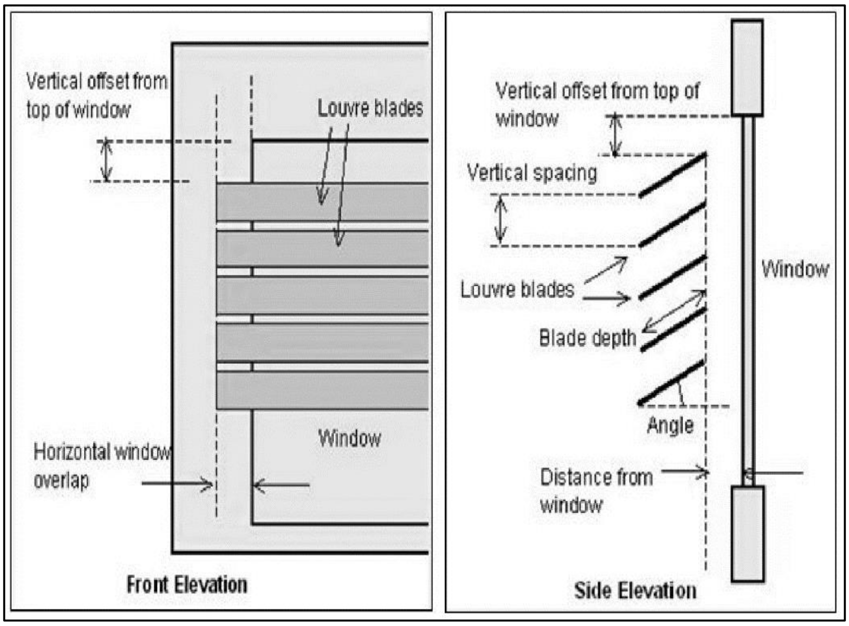


Figure 6.21 Elevation of applied louvers to protect glazed surfaces of the building

Table 6.6 Specification of selected louver

S. No.	Louver Details	
1	Type	0.5 m Projection louvre
2	Blade material	Hardwood
3	Blade thickness	0.1m
4	Angle	15 degrees
5	Distance from window	0.300 m
6	Blade depth	0.200 m
7	Vertical spacing	0.300 m
8	Number of blades	5

Configuration of sunshade has a high influence on decreasing building annual cooling load. The result indicates that 10% of energy could be saved by applying a fixed louver as an external shading device as well as the louver shows efficient performance in the summer season, particularly in June, July, and August, when the heat absorption through the window is high whereas the heating load increases in the winter season that is due to blocking direct solar radiation to enter the indoor environment. The effect of fixed louvers on building energy consumption is presented in Figure 6.22.

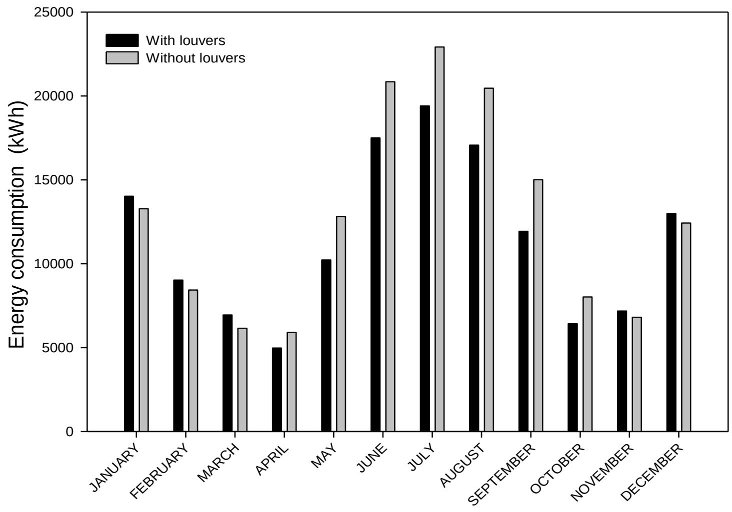


Figure 6.22 Effect of fixed external louvers on overall building energy demand

Figure 8.10 shows that for such a climate, a fixed shading device has a noticeable effect in the summer by saving 13% cooling energy demand but has an adverse influence in the winter since fixed shading raises the heating load by blocking the sunlight. However, by installing movable blinds on the building's southern, eastern and western facades, 21.34% of energy has been saved for both heating and cooling demand. The properties of the applied blind are shown in Table 6.7.

Table 6.7 Properties of applied blind

S. No.	Blind slat properties	
1	Orientation	Horizontal
2	Thickness (cm)	0.1
3	conductivity	0.9 W/mK
4	angle	45°
5	Solar reflectance	0.8

The model consists of full internal shading over southern, eastern and western windows that are compatible with results attained by previous research (Samanta et al., 2014), which unveiled that the cooling load significantly reduces with making use of an efficient shading strategy.

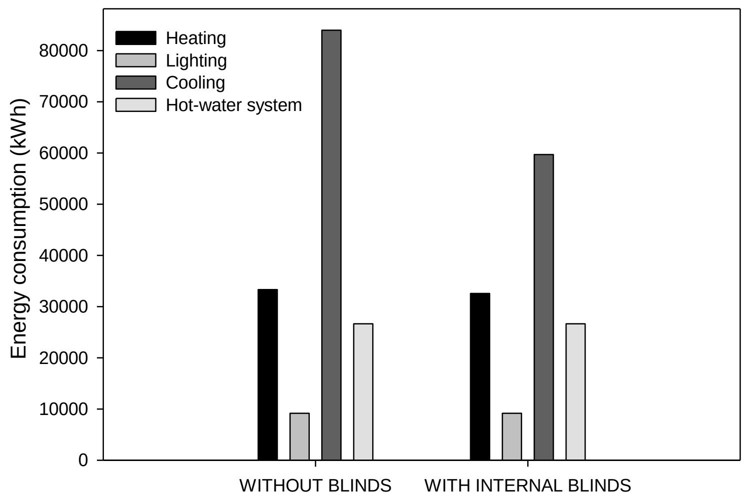


Figure 6.23 Building energy demand with proposed blind and without a blind

Figure 6.23 shows the energy demand of the building with recommended blind and without a blind. The comparison between various types of shading and building energy requirement is shown in Table 6.8.

Table 6.8 Comparison of building heating and cooling demand between various types of shadings (kWh)

No neighboring structures					**Neighboring structures**
Individual load	without overhang	with overhang	with External louvers	with internal blinds	with overhang
Heating	31527.4	33313.1	36956.4	32563.78	35275.74
cooling	83145.5	83972.82	64935.4	59690.31	67232.16

The energy-saving performance for different scenarios with reference orientation is shown in Figure 6.24.

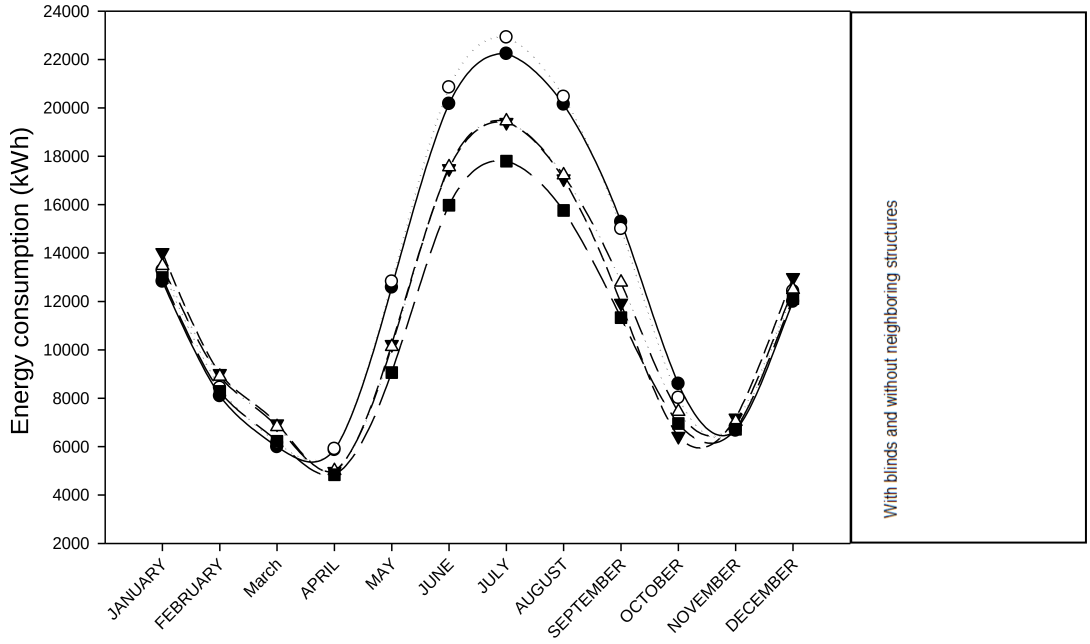


Figure 6.24 Effect of shading elements on building's energy consumption

The overall shading has a positive effect on the energy load, mainly on account of the cooling energy reduction in summer; however, it has partly affected the winter months negatively. The obtained data shows that 22.67% of energy can be saved in cooling demand by applying fixed louvers. Besides, the existing neighboring structures have 19.93%, and the overhang of the case building has a 1.7% effect on the overall energy requirement of the building.

6.3.3 Simple payback period

For the estimated area of 290 m^2, the market value for wooden louver and movable blinds is AFN 1560765 and AFN 171684.15, respectively. The yearly maintenance cost of wooden louvers was considered 2% of the initial investment, and the expected life of the louvers was 20 years. These considerations were calculated by taking values from the local contractors. However, no maintenance cost was assumed for the movable blinds as the payback time is less than a year. The equivalent energy cost and annual energy saving for movable blinds have been estimated as AFN 188448 and 28992 kWh. The result revealed that the louver, as a fixed shading device, would decrease the total energy cost by AFN 100061 (1299.4 USD) annually with an investment of approximately AFN 1591980.3 (20675 USD); therefore, the payback period was estimated to be 0.91 years for blind and 15.9 years for the louvers. The USD exchange rate was taken as AFN 77. Considering this, the payback period for movable shading is relatively short compared to the fixed louver and is technically and economically feasible.

6.3.4 Identifying the thermal properties of local material

Brick and interior plaster GS (Gypsum and Soil) were two major parts of the thermal wall properties used in the studied building and are common construction materials used in the country. MTCoE/SOP (Standard Operating Procedure – ISO:22007-2:2015) method has been used to test the thermal properties of Afghanistan's traditional brick (Burned mud brick) and GS (Gypsum and Soil) plaster, which were used for interior plastering of the case study building. Thermal Constants Analyzer (TPS) was used to test the samples with a scanning rate of 406.184 ms and 423.069 ms for brick and plaster, respectively. An average of ten measurements have been taken on samples to analyze the results. The thermal specification of the studied material (Brick and plaster) are shown in Table 6.9.

Table 6.9 Thermal specification of the studied material

Name	Thickness mm	Temperature (°C)	Thermal Conductivity (W/mK)	Thermal Diffusivity (mm^2 /s)	Specific Heat Capacity (MJ/m^3 K)
Burned Mud Brick	70	24.3	0.7028	0.7313	0.9612
GS Plaster	30	17.83	1.164	0.8807	1.325

6.3.5 Discussion

In general, weather conditions have the most significant effect on the building's thermal efficiency. In the arid climate of Afghanistan, particularly Mazar-I-Sharif city, which is characterized by cold winter and hot summer, a large amount of energy is used to provide cooling and heating. The energy requirement for air cooling in this climate exceeds space heating. In winter, solar radiation can raise the indoor temperature and reduce the overall energy need. On the other hand, the lowest heating demand was obtained by positioning the glazed façade in the southern direction. This finding is consistent with previous research, which showed that the heating energy demand declines to the lowest when the building faces south (Vasaturo et al., 2018).

In contrast, thermal loss in winter increases in the northern side wall since it is always in the shade; hence, if there is a possibility of having an opening on any other three sides of the wall, then a window opening must not be provided in the northern direction. Meanwhile, neighboring structures located on the northern, eastern, and western sides positively affect the cooling energy demand of the building in the summer months. This is due to casting a shadow on the surrounding area and minimizing direct solar penetrating the building envelope.

Moreover, many shading technologies can help block direct solar into the building during the summer; therefore, south glazing requires a suitable shading solution in summer to prevent solar heat. However, it needs an excellent passive design to gain maximum solar radiation in the winter. In such circumstances, flexible mechanisms such as movable blinds are the right solution to manage direct sun radiation entering the building by reducing the demand for 21.34% of cooling and heating. Adjustable shading devices on the building's glazing surfaces positively affect heating and cooling energy use-up as it controls sun heat gain and transmission in the building. Since the low solar angle is problematic, the minimum opening should be considered in the eastern and western directions.

6.4 Sustainable Energy Retrofit Plan for Enhancing Energy Efficiency of Apartments

In this section, the analysis and result of the energy retrofit plan for the existing apartments are discussed. Enhancing the energy efficiency of buildings is critical to the lower energy use of existing structures and the associated emissions (Wei et al., 2018). Existing buildings can be retrofitted to decrease global energy use and greenhouse gas emissions significantly. This has been considered one of the primary strategies to achieve sustainability in the built environment at a low cost and high adoption rate. Building energy retrofits dramatically reduces greenhouse gas emissions at a lower cost and shorter time frames than any other approach (Hoicka and Das, 2021).

Furthermore, energy retrofit to increase energy efficiency is more cost-effective than reconstruction, especially in developing nations. Designing and implementing decarbonization strategies for refurbishment and retrofitting, increasing renovation rates, and encouraging investment should be considered to strengthen the culture of retrofitting buildings in developing countries (IEA, 2020). Residential buildings should be prioritized for retrofitting because, since urbanization is increasing, the construction of residential buildings is increasing. This contributes to a significant increase in CO_2 levels, as residential buildings consume considerable amounts of energy from non-renewable sources to maintain thermal comfort in the interior spaces (Haruna et al., 2021). As a result, thermal retrofitting of existing buildings would be an alternative to achieve the various energy efficiency standards set by many countries to mitigate the environmental impact of buildings (Jagarajan et al., 2017).

Afghanistan, a landlocked country, relies considerably on imported energy from neighboring countries. With 71% of total building energy use, residential buildings are the largest consumers of energy in Afghanistan, and the bulk of this consumption is related to heating, cooling, and ventilation (Temori M.Omar, 2017). Although per capita energy consumption in Afghanistan is lower than in many other developing countries, the energy availability and construction practices differ from those of the rest of the world. Therefore, other countries' experiences or results cannot be applied simply and directly in Afghanistan. However, building energy retrofitting is an excellent way to address these problems economically. Some preliminary studies in Afghanistan have also demonstrated the benefits of energy-saving upgrades to existing residences (GERES, 2015), although these only involved traditional and poorly constructed mud houses and conventional practices rather than thermal simulation theories.

The energy retrofit associated with a renovation process involves using energy solutions to restore the original functioning of a specific building element or improve the energy performance of either a single element or the entire structure. Various metrics could be investigated depending on the designer's expertise and the most common local practices. Thereafter, to incorporate such energy-saving measures, a detailed energy modeling of a building is necessary, considering the structure's dynamics and the occupants' behavior (Menna et al., 2021). Thousands of residential buildings, particularly apartments, were built across Afghanistan during the rebuilding in 2002. At that time, the relevance of building codes, efficiency, and control became apparent due to the construction of several residential and commercial structures. However, due to the late adoption of the energy code (adopted in 2015), its imperfect content, and a lack of execution, the majority of the buildings in the country are energy inefficient and have excessive energy requirements for heating and cooling the indoor environment. Afghanistan has remained unconcerned about the energy crisis, and none of the commercially motivated efficiency techniques adopted in developing nations were adopted there. This partially explains the lack of awareness and the late introduction of energy-related codes, which have not yet been applied. Therefore, it has become increasingly critical to improving the energy performance of housing across the country through retrofitting. This research proposes a methodology to evaluate the viability and applicability of potential energy-saving retrofit measures in residential buildings in Afghanistan. A cost comparison for each measure is performed to construct a compelling case for implementing these measures.

The information presented in this study is intended to provide a basic notion of residential apartment buildings' energy savings in urban Afghanistan and provide some suggestions for the country and developing countries with similar economies.

Cost-effective residential building retrofitting will benefit the country regarding lower buildings' electricity needs. Given the necessity to retrofit a significant number of residential buildings in Afghanistan and to appropriately assess the cost-benefit of various energy-efficient retrofits, approaches that consider the thermal behavior of homes are required for various retrofit scenarios.

6.4.1 Building base model generation

Before analyzing the energy-saving impacts of the chosen measures, the base-case (i.e., before energy retrofit) cooling and heating loads of the subject building were calculated with the EnergyPlus simulation engine and DesignBuilder interface as a benchmark (DesigBuilder, 2022). The heating and cooling loads of the measures were computed with the same approach (i.e., after energy retrofit). The annual cooling and heating energy consumption for the entire building was simulated. Table 6.10 contains tabulated findings obtained directly from the DesignBuilder program after the base-case simulation. The annual cooling and heating energy is expressed in kilowatt-hours (kWh). As expected, space cooling accounts for the bulk of the electrical energy use for the baseline in Mazar-I-Sharif. As indicated in Figure 6.25, space cooling accounts for 57.11% of the building's total annual energy use. Heating is required during winter (primarily in November, December, and January), accounting for approximately 31.66% of annual energy use.

Table 6.10 Base case Scenario annual total energy required (Mazar-I-Sharif City)

Cooling	135086.50 (kWh)
Heating	74902.11 (kWh)
Lighting	7641.48 (kWh)
Domestic Hot Water	18896.19 (kWh)

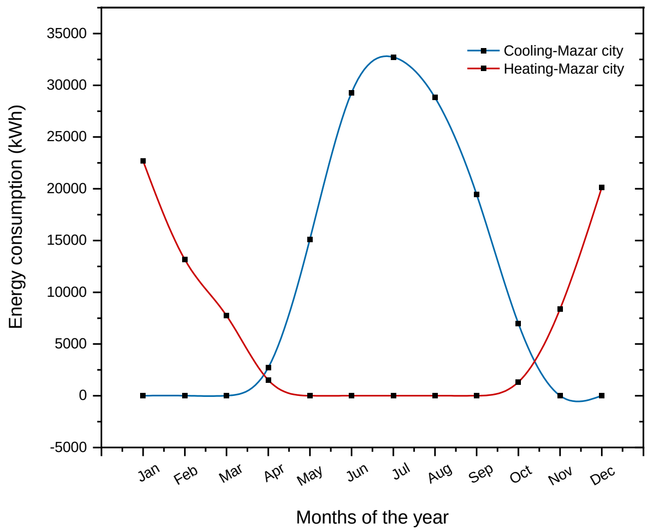


Figure 6.25 Base case-building annual energy consumption for Mazar-I-Sharif city

Since this research examined two regions that require heating and cooling, it is critical to consider ways to improve the efficiency of the envelope to reduce cooling and heating loads through insulation, window glazing, and other specific approaches. The simulation for the climate of Kabul is presented in Figure 6.26, and it illustrates that the heating demand is higher than the cooling energy requirement (Table 6.11).

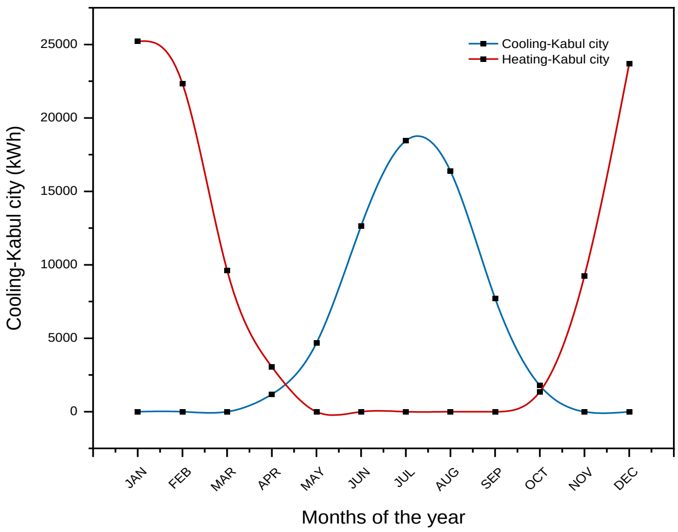


Figure 6.26 Base case-building annual energy consumption for Kabul city

The energy demand for heating, cooling, lighting, and DHW for the base-case scenario that considers the climate of Kabul is presented in Table 6.11.

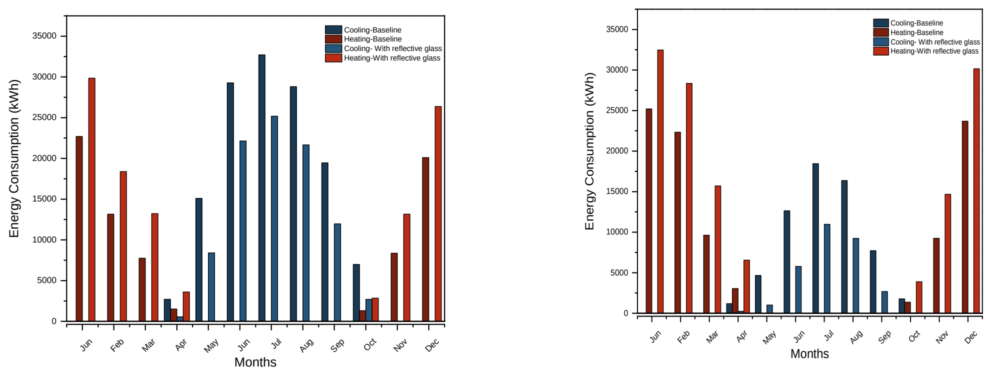
Table 6.11 Base case Scenario annual total energy required (Kabul City)

Cooling	62825.13 (kWh)
Heating	94543.36 (kWh)
Lighting	7641.48 (kWh)
Domestic Hot Water	18896.19 (kWh)

6.4.1.1 The outcome of each scenario

Result for Case 1

The results indicate that replacing the reflective glass with baseline clear glass increases the heating energy requirements by 43.46% and 39.35% in Mazar-I-Sharif and Kabul, respectively. However, it positively impacts cooling demand, which decreased by 4.18 % in the Mazar-I-Sharif scenario; conversely, it caused an increase in overall energy demand in the Kabul scenario. Figure 6.27 represents building energy demands for both the selected cities after applying Case 1, aggregated annually.



(a) (b)

Figure 6.27 Baseline building vs. Case 1: a) Mazar-I-Sharif city, b) Kabul city

The energy demand for heating, cooling, lighting, and DHW for the reference building after applying the retrofit package (Case 1) is presented in Table 6.12 for the Mazar-I-Sharif and Kabul climates, respectively.

Table 6.12 Case 1- Total energy demand annually

Category	Energy demand kWh (Mazar-I-Sharif city)	Energy demand kWh (Kabul city)
Cooling	92641.92	29989.90
Heating	107455.58	131755.06
Lighting	7641.48	7641.48
DHW	18896.19	18896.19

Result for Case 2

Different climatic conditions demand varied ideal thicknesses of EPS for wall insulation to regulate energy consumption for heating and cooling. Fifty mm of EPS and exterior plaster were applied to the original wall to determine the effect of such insulation on the exterior wall of buildings in two different regions. The results indicate that it significantly affects the cooling energy demand in the hot climate of Mazar-I-Sharif. However, it does not considerably affect the cooling energy demand in Kabul. Moreover, the insulation on the exterior walls decreased heating energy demand in both climates by 29.6% and

28.7%, respectively. Figure 6.28 displays annual building energy demands after applying Case 2, considering Mazar-I-Sharif and Kabul city weather conditions.

The energy demand for heating, cooling, lighting, and DHW for the selected buildings after applying the retrofit package (Case 2) is presented in Table 6.13 for the Mazar-I-Sharif and Kabul climates, respectively.

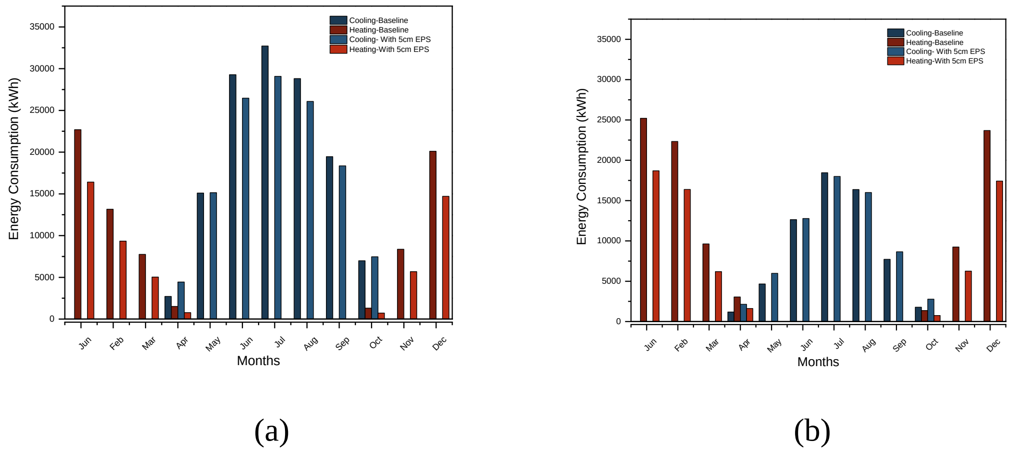


Figure 6.28 Baseline vs. Case 2: a) Mazar-I-Sharif city, b) Kabul city

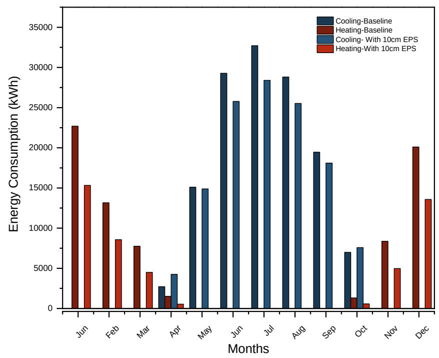
Table 6.13 Case 2- Total energy demand annually

Category	Energy demand kWh (Mazar-I-Sharif city)	Energy demand kWh (Kabul city)
Cooling	127050.94	66327.34
Heating	52687.19	67330.60
Lighting	7487.33	7487.33
Domestic Hot Water	18515.00	18515.00

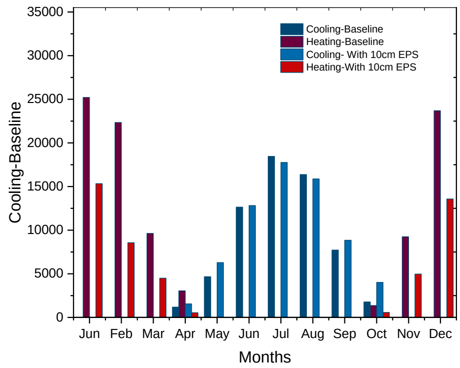
Result for Case 3

The energy-saving retrofit for the external wall of the building was accomplished by applying an external insulating layer of EPS (100 mm) to minimize the heat transfer coefficient. The exterior wall insulation is beneficial in Mazar-I-Sharif in summer and winter, decreasing heating and cooling energy consumption by 35.8% and 7.8%, respectively.

However, the result indicates that the added EPS layer does not significantly affect the cooling energy demand for Kabul housing but can decrease energy consumption for heating by 35.18 % during the winter season. Figure 6.29 demonstrate annual building energy demands for case 3, considering Mazar-I-Sharif and Kabul city weather condition.



(a)



(b)

Figure 6.29 Baseline vs. Case 3: a) Mazar-I-Sharif city, b) Kabul city

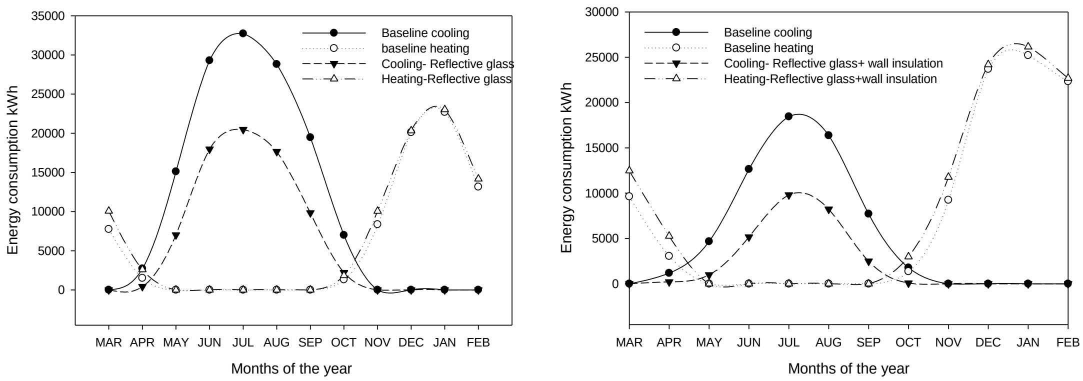
The energy demand for heating, cooling, lighting, and DHW for the reference building after applying the retrofit package (Case 3) is presented in Table 6.14 for the Mazar-I-Sharif and Kabul climates, respectively.

Table 6.14 Annual total energy demand considering Case 3

Category	Energy demand kWh (Mazar-I-Sharif city)	Energy demand kWh (Kabul city)
Cooling	124534.75	67153.97
Heating	48035.68	61277.94
Lighting	7397.14	7397.14
Domestic Hot Water	18291.98	18291.98

Result for Case 4

Figure 13 presents the effect of applying reflective glass and wall insulation (5 cm EPS) on the energy demand for heating and cooling in both climates. The result indicates an overall reduction in energy consumption of 22.48% and 13.9 % for Mazar-I-Sharif and Kabul, respectively, but the energy demand for heating is not appreciably affected. This is due to the reflective glass that blocks the sun from warming the indoor environment, negatively affecting energy consumption in both climates. The energy demand for heating, cooling, lighting, and DHW for the reference building after applying the retrofit package (Case 4) is presented in Figure 6.30 and Table 6.15.



a) b)

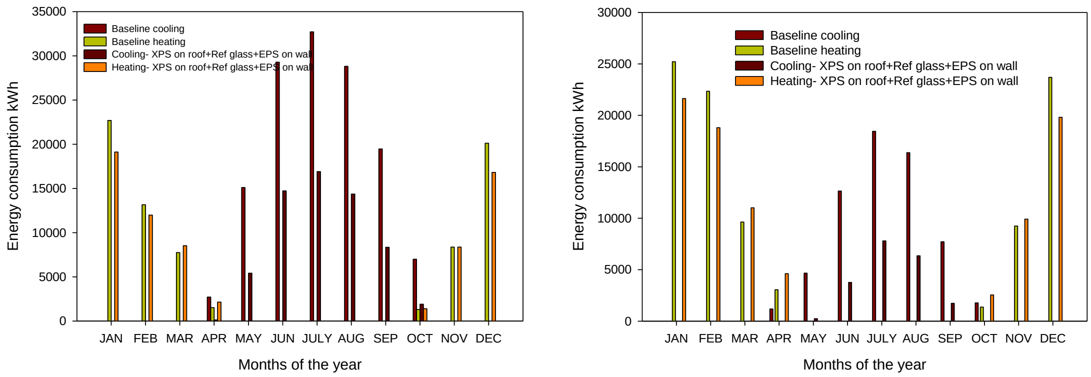
Figure 6.30 Baseline vs. Case 4: a) Mazar-I-Sharif city, b) Kabul city

Table 6.15 Building annual total energy demand- Case 4

Category	Energy demand kWh (Mazar-I-Sharif city)	Energy demand kWh (Kabul city)
Cooling	75585.56	26984.89
Heating	82068.84	105321.19
Lighting	7397.14	7487.33
Domestic Hot Water	18291.98	18515.00

Result for Case 5

This scenario shows that Mazar-I-Sharif and Kabul's overall reduction in energy consumption is 34.11% and 26.9%, respectively. The residential buildings in Afghanistan mainly have flat roofs. Therefore, the XPS board applied to the flat roof and bituminous sheet as an external insulation layer has considerably affected the energy consumption. Figure 6.31 illustrates the energy demand of the reference building after considering the retrofit package for the climates of Mazar-I-Sharif and Kabul, respectively.



(a) (b)

Figure 6.31 Base-case vs. Case 5: a) Mazar-I-Sharif, b- Kabul city

The energy demand for heating, cooling, lighting, and DHW for the reference building after applying the retrofit package (Case 5) is presented in Tables 6.16 for Mazar-I-Sharif and Kabul climates.

Table 6.16 Building annual total energy demand- Case 5

Category	Energy demand kWh (Mazar-I-Sharif city)	Energy demand kWh (Kabul city)
Cooling	61789.70	19926.18
Heating	68354.58	88332.61
Lighting	7397.14	7487.33
Domestic Hot Water	18291.98	18515.00

Result for Case 6

The addition of an external insulating layer, consisting of an EXP coating on the partition and exterior walls, was simulated to study the impact of opaque surfaces on annual energy consumption. With a 17.5% reduction overall and 37.53% reduction in heating energy consumption, Case 6 represents the unique approach to mitigating heat dispersion in winter. Figures 6.32 present the energy consumption for case 6 for the Mazar-I-Sharif and Kabul climates during the year, respectively.

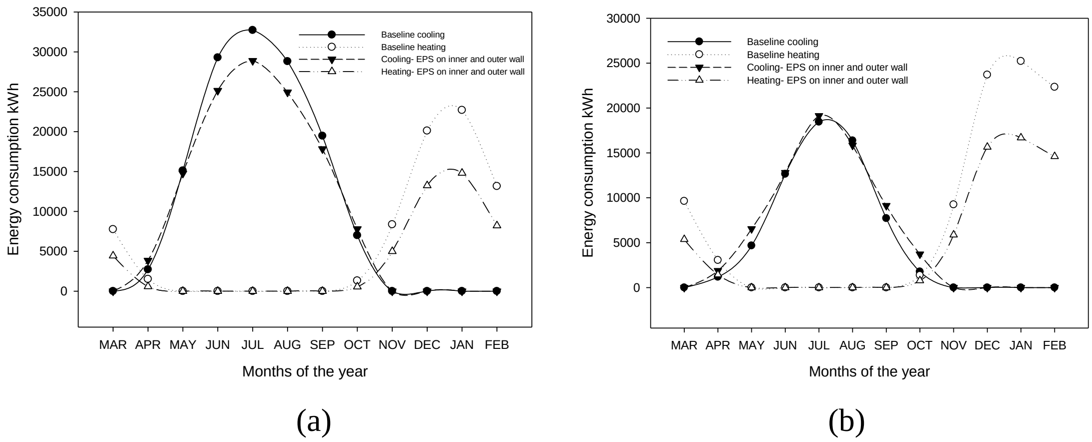


Figure 6.32 Base-case vs. Case 6**:** Mazar-I-Sharif, b- Kabul city

The energy demand for heating, cooling, lighting, and DHW for the reference building after applying the retrofit package (Case 6) is presented in Table 6.17, considering the cities' weather conditions.

Table 6.17 Building annual total energy demand- Case 6

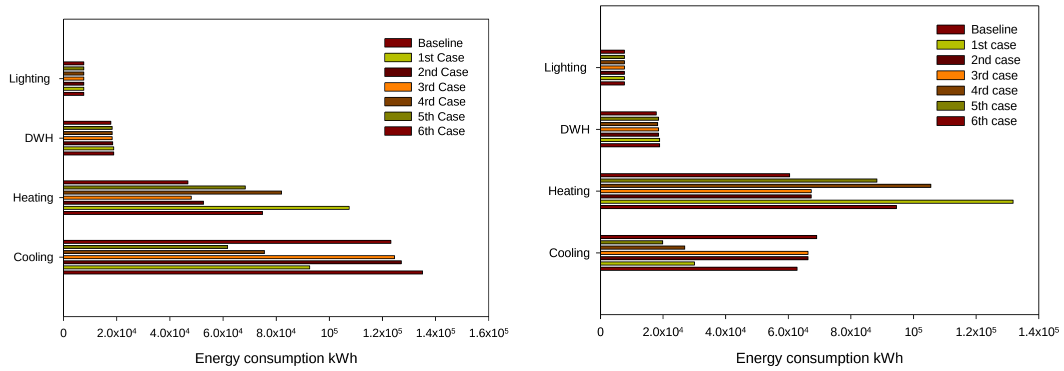
Category	Energy demand kWh (Mazar-I-Sharif city)	Energy demand kWh (Kabul city)
Cooling	123195.27	69049.40
Heating	46790.78	60400.97
Lighting	7207.69	7207.69
Domestic Hot Water	17823.48	17823.48

6.4.2 Comparison of the best retrofit packages for various energy-saving targets

Table 6.18 demonstrates that retrofitting the walls constantly improves a building's energy efficiency regardless of the energy-saving goal. The results shown in Figure 6.33 demonstrate that when insulation is applied to both the walls and the roof, more energy savings are achieved than when only one of the building envelope components is insulated. Moreover, the result indicates that reflective glass is not feasible in Kabul as it increases energy consumption.

Table 6.18 Energy savings chart for all the envelope parameters

Retrofit packages	City	Peak Energy month	Peak energy kWh	Annual total heating and cooling energy kWh	Percentage of Savings
Baseline	Mazar-I-Sharif	JULY	32717.270	209988.6039	0 %
	Kabul	JAN	26787.610	157368.49	0 %
Case 1 - reflective glass	Mazar-I-Sharif	JAN	29853.962	200097.4981	4.7 %
	Kabul	JAN	33919.680	161744.96	-2.78 %
Case 2 – 5 cm EPS on external wall (Inner side)	Mazar-I-Sharif	JULY	29078.53	179738.1	14.4 %
	Kabul	JAN	20243.056	133657.94	15.06 %
Case 3 – 10 cm EPS on external (Outer side)	Mazar-I-Sharif	JULY	28395.79	172570.4	17.81 %
	Kabul	JAN	18655.607	128431.91	18.38 %
Case 4- Reflective glass+ 5cm EPS on external wall (outer side)	Mazar-I-Sharif	JAN	23021.73	157654.4	24.92 %
	Kabul	JAN	27679.010	132306.08	15.92 %
Case 5 – 5cm XPS on roof+ Reflective glass+ 5cm EPS on external wall	Mazar-I-Sharif	JAN	19116.1	130144.3	38.02 %
	Kabul	JAN	23171.112	108258.79	31.2 %
Case 6 – 5cm EPS on internal wall + 10cm EPS on external wall (outer side)	Mazar-I-Sharif	JULY	28883.260	169986.0442	19.04 %
	Kabul	JAN	18171.364	129450.37	17.74 %



(a) (b)

Figure 6.33 Building energy consumption baseline building vs. each case: a) Mazar-I-Sharif, b) Kabul

Figure 6.34 compares the baseline and each case energy requirement considering Kabul and Mazar-I-Sharif City weather conditions.

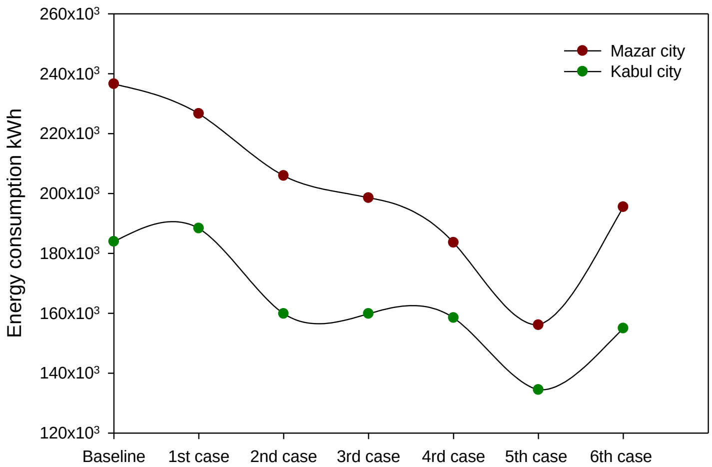


Figure 6.34 Comparison between baseline and each case building energy requirement

6.4.3 Estimating the benefits

There are different benefits from building energy efficiency retrofit measures based on the building and the economic status of households. Furthermore, electricity prices and implementation costs significantly influence the cost-effectiveness of residential buildings' energy-efficient retrofit techniques. Since Afghanistan relies mainly on imported energy from neighboring countries, energy prices are high and vary depending on the region. However, building retrofits can provide direct and indirect economic benefits (e.g., increased property value or rental level of existing structures, improved living comfort) (Liu et al., 2018). Indirect effects are difficult to define and translate into monetary terms, so the current study focused on direct economic advantages. However, improving the thermal performance of dwellings also provides noneconomic benefits to residents, such as the comfort given by energy-efficient homes. It enhances various areas of everyday living, including well-being, productivity, health, and mood (resulting in improved family relations) (Preciado-pérez and Fotios, 2017). This study presents the benefit of decreasing energy use through any alternative measure while maintaining the same degree of comfort. Ten local suppliers (retailers, contractors, construction companies, and real estate developers) were engaged for cost advice and to ensure that the suggested features were doable and financially feasible in local practice. External variables may influence the energy demand of buildings. A heat island effect that increases cooling requirements in hot climates is often found in densely populated metropolitan areas (Yang et al., 2021).

6.4.3.1 Payback time

Although upgrading energy efficiency is always beneficial in terms of decreasing energy use, the payback times vary depending on the form and source of funding (Preciado-pérez and Fotios, 2017). Allocating resources necessitates relying on the future to reap the rewards, and the future is, by definition, unpredictable. Understandably, consumers want to receive and enjoy products and services sooner rather than later, so they are prepared to pay interest on money (purchase of fuel) in exchange for earlier purchases of products and services (Morrissey and Horne, 2011).

A simple payback method for an operating year was used to choose the best retrofit solutions. Da Afghanistan Breshna Sherkat (DABS) services determined the electrical unit cost in each region. The average energy consumption for both locations was then assessed, and the annual energy savings were determined and used to establish the simple payback. The payback period was calculated by dividing the cost of any retrofit measure by the savings realized for the specific retrofit in a year. The energy efficiency measures' costs were computed in US dollars ($) and Afghani (AFN) and were based on market rates. The exchange rate that was determined at the end of 2021 was used. Therefore $/AFN is equal to 1/96.

It should be noted that the payback period for the retrofitting of the building, considering the Kabul climate, is comparatively high; however, in Mazar-I-Sharif, which has scorching summers and cold winters, most of the retrofit packages are economically viable with a short payback period. Moreover, the electricity price in the two regions also affects the economic viability of retrofit packages. Table 6.19 presents the top minimum retrofit scenarios considering a simple payback period.

Table 6.19 Retrofit packages considering minimum simple payback period

Region	Packages	Payback period (years)	Investment cost ($)	Return of investment (%)	Annual total energy saving ($)
Mazar-I-Sharif Hot-dry (2B)	II	1.84	3,842	54%	2,084
	III	1.54	3,991	64%	2,590
	IV	8	28,884	12.4%	3,600
	V	5.7	31,128	17.5%	5,463
	VI	3.7	10,477	26.8%	2,810
Kabul Mixed-dry (4B)	II	6	3,842	16.4%	631
	III	5	3,991	19.4%	775
	VI	13.6	10,477	7.3%	766

6.5 Energy Saving Potential of Building Envelope in Early-Design stage

This section presents the outcome of the envelope's effect on the energy demand of dwellings in the early design stage. The level of data input uncertainty significantly influences the simulation result. The simulation program will offer a trustworthy database list for input requirements. Other input data, however, are suppositions, and they occasionally retain their default values. Therefore, to ensure the accuracy and reliability of the outcomes, comparing the output results to actual results is required. For this research, the energy consumption of the dwelling in the form of electrical bills has been collected for a year (Appendix F-1). The simulation results were then compared with the overall energy bill to confirm the accuracy of the simulation. The absolute value of the percentage of differences (PDs) Simulated and measured data is 9.34%, within the accepted range, less than 15%. For calibrating the model, the actual occupancy is considered. As per the field survey and the actual occupant behavior, only the house's ground floor was occupied. However, for analyzing the building's thermal efficiency before applying an alternative efficient envelope option, the house on both floors is assumed as occupied.

6.5.1 Evaluation of case building model

As presented in Figure 6.35, the heat gain and loss via building envelope are high during the summer and winter. Moreover, the temperature contour of the base-case model (Figure 6.36) indicates the heat gain through roofs and floors. In addition, the result reveals no significant difference between indoor and outdoor temperature during the year in the analyzed base case building model. Moreover, the outdoor temperature influences the indoor temperature of the building significantly, which affects building heating and cooling energy requirements. Meanwhile, the air temperature in the conditioned area is affected by the outside dry bulb temperature and exhibits a comfort range. It ranges from 15-16 ˚C in the winter to 31 ˚C in the summer. According to ASHRAE standard 55-2010 (ASHRAE, 2010), the comfort band for summer and winter is between 27.77 ˚C and 19.44 ˚C. Furthermore, the AEEC (ANSA, 2015) thermal comfort recommended range for the summer and winter months is 25.5-26.6°C and 22.2-23.3°C, respectively.

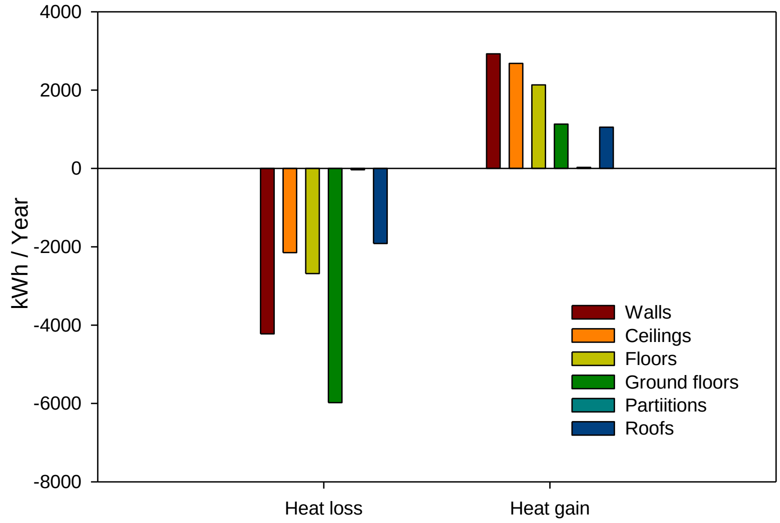


Figure 6.35 Heat gain and loss through the building envelope

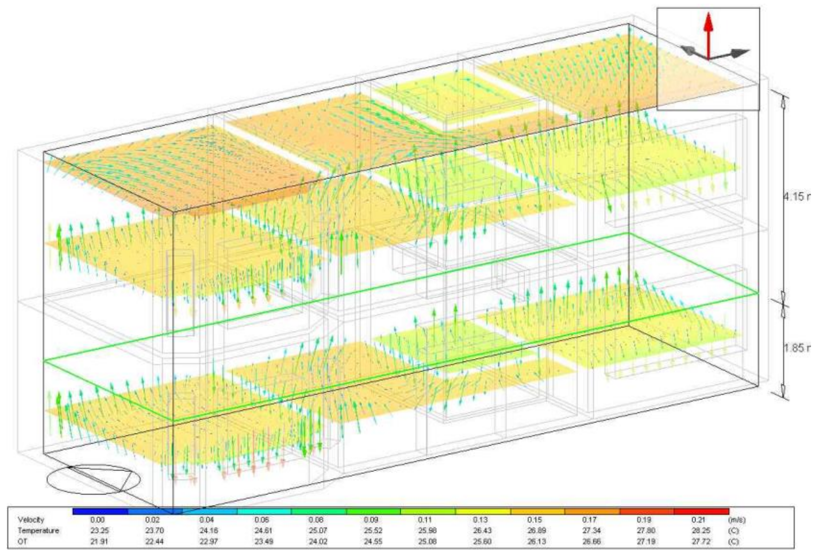


Figure 6.36 Temperature contour

In addition, as per identified summer thermal comfort model the neutral temperature is 27.86°C. Consequently, it is evident that the indoor thermal comfort in these types of housing units is not adequately maintained during the summer months. Figure 6.37 presents a Comparison of building conditioned and unconditioned air temperatures. The preceding demonstrates that the case building, which represents contemporary housing practice in urban Afghanistan, is thermally inefficient and has insufficient indoor comfort due to heat gain and loss throughout the year and hence does not comply with any code or norms.

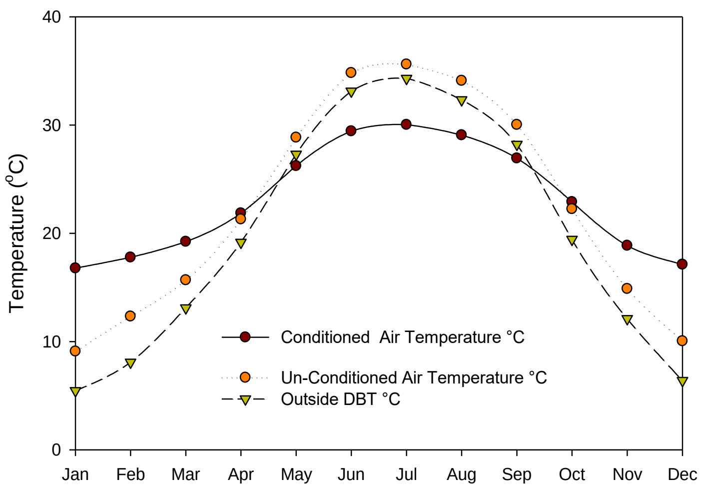


Figure 6.37 Comparison of building conditioned and unconditioned air temperature

6.5.2 Energy-efficient envelope design options

Many envelope design techniques may be assessed to enhance the thermal performance of residential buildings. The energy efficiency will be increased due to improving the thermal performance of specific architectural components. Heat transfer, heat storage, thermal mass, solar heat acquisition through transparent outside envelopes like windows, and air penetration are the main exterior envelope features that affect the room temperature and energy usage (Fazio et al., 1997). These features should be carefully analyzed to increase a building's energy efficiency. A collection of possible energy-efficient options for walls, roofs and floors, and windows for the typical dwelling in urban Afghanistan are shown in Table 6.20 to Table 6.23.

Table 6.20 Glazing option

Glazing type	Layers and thickness	SHGC	U-Value	Cost $
Single glaz base	Clear 6mm	0.81	5.7	19
Double glazing	Tint 6mm 13mm air	0.35	2.6	23
Triple glazing	Clear3mm/6mm air	0.682	2.17	27.5

Table 6.21 Design options for walls

Design Option	Description	Thickness	Conductivity (W/m.K)	Cost ($)	U-Value (W/m^2K)	Total cost
Red tile brick on the wall	Red brick tile	0.01	0.800	10.6	1.53	25.2
	Cement plaster	0.025	1.16	1.9		
	Burned brick	0.33	0.703	10.5		
	GS paster	0.025	1.16	2.2		
External wall-Option 1	Cement Plaster (Outer Side)	0.025	1.164	1.9	1.563	14.6
	Burned brick	0.33	0.703	10.5		
	GS plaster (Inner side)	0.025	1.1	2.2		
External wall - option 2	Cement plaster	0.025	1.6	1.9	0.354	19.1
	EPS (adhesive +mesh)	0.11	0.046	4.5		
	Burned brick	0.33	0.7	10.5		
	GS plater	0.02	1.16	2.2		
Cavity wall	Cement plaster	0.025	1.16	1.9	0.355	18
	Burned brick	0.15	0.7	5.1		
	EPS	0.1	0.046	4		
	Burned brick	0.15	0.7	5.1		
	Cement plaster	0.025	1.16	1.9		
Thick brick wall	Cement plaster	0.025	1.16	1.9	1.17	17
	Burned brick	0.45	0.7	13.2		
	Cement plaster	0.025	1.16	1.9		
AAC block wall	Cement plaster	0.025	1.16	1.9	0.563	16.6
	AAC block	0.25	0.16	12.8		
	Cement plaster	0.025	1.16	1.9		

Partition wall	Cement plaster	0.025	1.16	1.9	0.59	16.1
	EPS+ adhesive	0.05	0.046	3		
	Brick	0.22	0.7	9		
	GS plaster	0.02	1.16	2.2		

Table 6.22 Design option for roof and floors

Roof/Floor	Material Name	Thickness	conductivity	Cost $	T. Cost	U-val.
Cool roof	Cool tile	0.015	0.84	6.9	33.9	3.2
	Cement mortar	0.02	1.02	1.2		
	Bitumen	0.005	0.5	3.9		
	RCC slab	0.12	1.74	20		
	Cement plaster	0.02	1.16	1.9		
Roof with metal cladding	Light.w metallic cladding	0.002	0.29	9.5	40.5	0.49
	Air-gap	0.5	-	-		
	Cement plaster	0.025	1.16	1.7		
	Vapor permeable felt	0.003	0.01	1		
	EPS	0.07	0.046	2.5		
	Bitumen	0.005	0.5	3.9		
	RCC	0.12	1.04	20		
	Plaster	0.025	1.16	1.9		
Insulated roof	Roof cement plaster	0.02	1.16	1.9	31.8	0.40
	Bitumen sheet	0.003	0.23	4.5		
	EPS	0.1	0.046	3.5		
	Bitumen	0.005	0.5	3.9		
	RCC slab	0.12	1.74	20		
	Cement plaster	0.025	1.16	1.9		
Insulated roof with brick tile	Clay tile	0.01	1	4	35.5	0.27
	Tile bedding	0.02	1.4	1.2		
	Vapor permeable flet	0.003	0.01	1		
	Xps board	0.1	0.03	3.5		
	Bitumen sheet	0.005	0.5	3.9		
	RCC slab	0.12	1.74	20		
	Internal cement plaster	0.025	1.16	1.9		
Painted oak floor	Oak painted	0.02	0.19	24	50.8	2.28
	Vapor permeable	0.03	0.01	1		
	Cement plaster	0.025	1.16	1.9		
	RCC slab	0.12	1.74	22		
	Cement plaster	0.025	1.16	1.9		
	Vinyl flooring	0.005	5	5		

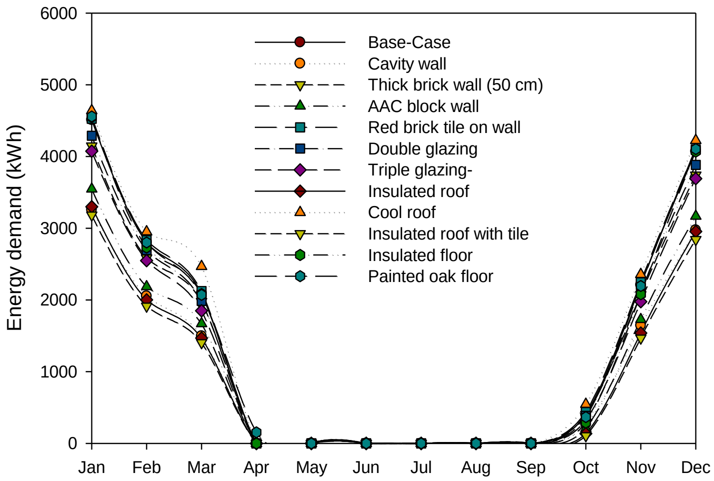
Roof/Floor	Material Name	Thickness	conductivity	Cost $	T. Cost	U-val.
Insulated floor	XPS board	0.05	2.8	2.8	30.7	0.49
	Vapor barrier	0.003	1	1		
	RCC slab	0.12	20	20		
	Cement plaster	0.025	1.9	1.9		

Table 6.23 Proposed envelope design

Proposed element	Material	Thickness (m)	Cost $	Total cost	U-Value W/m^2-K
Proposed External wall	Cement plaster	0.025	1.9	19.1	0.354
	EPS +adhesive +mesh	0.1	4.5		
	Brick	0.33	10.5		
	GS plaster	0.02	2.2		
Proposed partition wall	Cement plaster	0.025	1.9	16.1	0.59
	EPS+ adhesive mortar	0.05	3		
	Brick	0.22	9		
	GS plaster	0.02	2.2		
Proposed Roof	Lightweight metallic roof cladding	0.002	9.5	40.5	0.49
	Air gap	0.5	0		
	Cement mortar	0.02	1.7		
	Vapor permeable felt	0.003	1		
	EPS	0.07	2.5		
	Bitumen sheet	0.005	3.9		
	RCC slab	0.12	20		
	Cement plaster	0.025	1.9		
Proposed Floor	Vinyl flooring	0.005	5	30.7	0.49
	XPS board	0.05	2.8		
	Vapor barrier	0.003	1		
	RCC slab	0.12	20		
	Cement plaster	0.025	1.9		
Double glazing PVC window	Tint 6mm -13mm air	SHGC 0.35	23	23	2.6

6.5.3 Effect of individual measures on monthly and yearly energy demand

Since recommended set point values of the HVAC system, for such a conventional construction, do not meet the occupant comfort level due to heat loss, particularly from vertical walls and the roof. Thus, walls and roofs are the main envelope components for energy-efficient design with higher energy savings. A comparison amongst the measures, including the base case, has been made for the heating demand of the prototype building.



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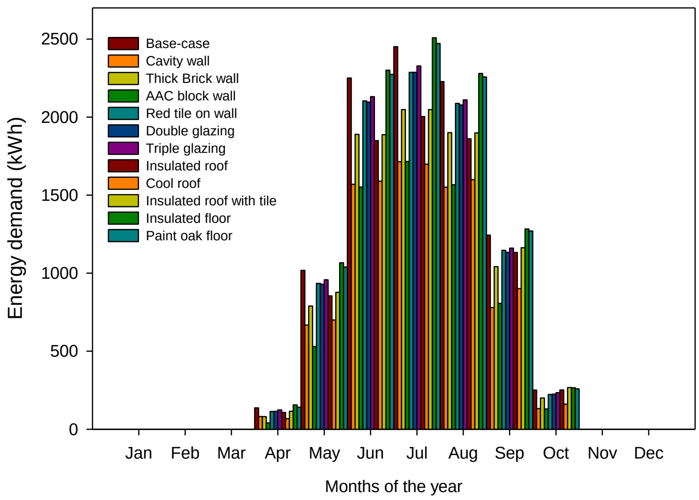

(b)

Figure 6.38 (a) Heating energy demand, (b) cooling energy demand

After applying each option, the heating and cooling load varies between 19868 kWh and 29282 kWh per year. Moreover, depending on the type of measure and its effect on the building, the cooling load of the prototype building varies between 5554 kWh and 9712kWh per year (Figure 6.38).

Adding insulation is a common technique for reducing the energy needed for space heating and cooling. The thickness of the insulation and the surface area has the most impact on how much energy is saved by insulation. The result demonstrates that among all strategies, applying energy efficiency measures on the wall is the most efficient way of reducing the energy demand of dwellings, with energy savings of 12 to 30.8 %. In addition, the roof has a high impact on the house's energy demand, which can save up to 21% of the energy requirement of the building if adequately insulated. Figure 6.39 illustrates the influence of each design option on various energy requirements of the dwelling.

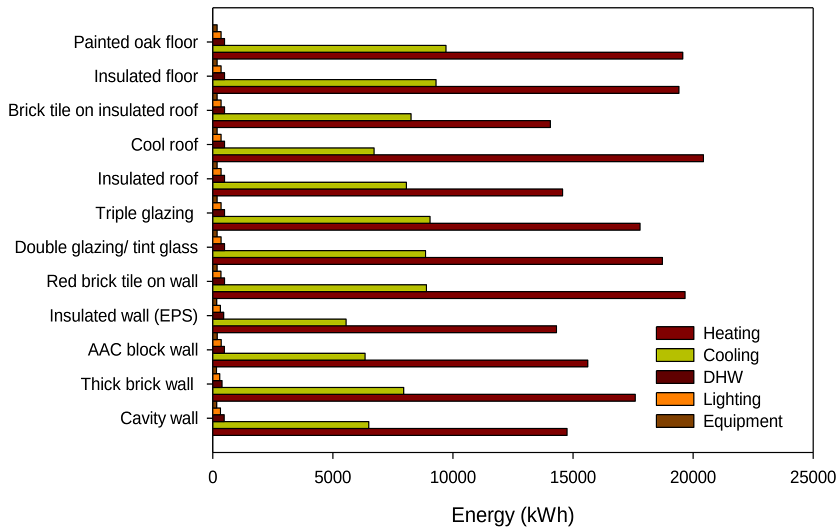

Figure 6.39 Overall energy demand of house considering each measure

The thermal transmittance of windows is generally much higher than that of other envelope components. Therefore, applying any of the above-mentioned measures on windows can save 4-7% of the energy requirement of a case-study dwelling. As presented in Table 10.4, the proposed case is a set of measures applied to the prototype dwelling's wall, roof, floor, and glazing.

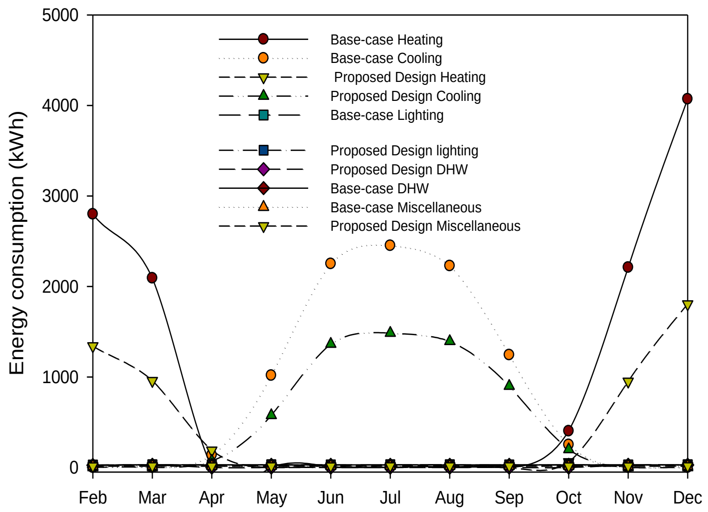

Figure 6.40 Heating and cooling energy demand considering each measure

The result suggests that considering the aforementioned measures, the building will perform more energy efficiently (Figure 6.40). Moreover, it has been revealed that there is more than 53% energy saving potential through efficient envelope design in the early design stage of a typical Afghan dwelling. Figure 6.41 depicts the comparison of total energy demand between the base case and the proposed design.

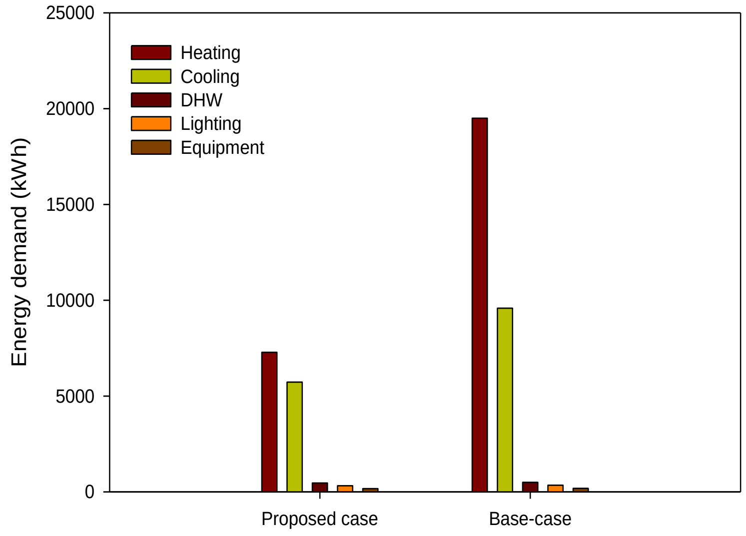

Figure 6.41 Comparison of total energy demand, base-case vs. proposed design

Figure 6.42 Compare heating and cooling energy demand between base-case and proposed design

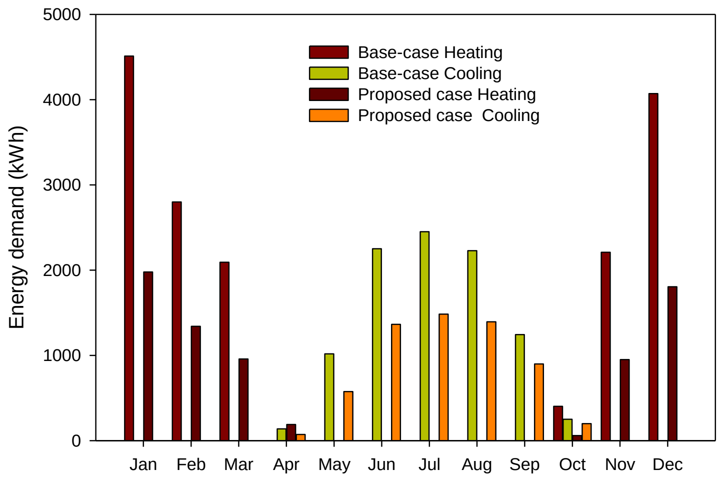

Figure 6.42 Comparison of heating and cooling energy demand between base-case and proposed design

To better comprehend the overall findings, Figure 6.43 displayed a comparison of all parameters' total energy loads.

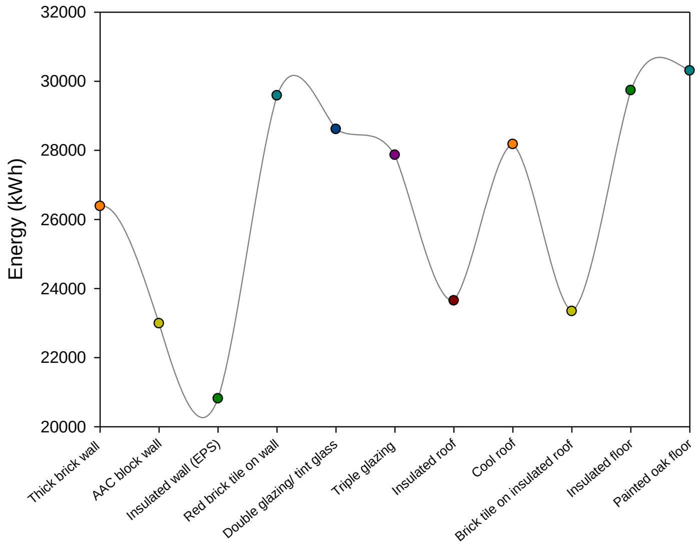

Figure 6.43 Overall energy demand considering each measure

6.5.4 Payback period

A simple payback method for an operating year was used for each measure. The costs of measures were computed in US dollars ($). The per unit of electricity price was selected as per electricity bill, which was 2.6 AFN. The exchange rate for electricity price was determined at the end of 2022 was used. Therefore $/AFN is equal to 1/85. Table 6.24 presents the payback time for each measure.

Table 6.24 Payback period result for each measure

Options	Payback period (Years)	
1	Cavity wall	1.4
2	Thick brick wall	2.7
3	AAC block wall	1.1
4	Insulated wall (EPS)	1.7
5	Red brick tile on wall	59
6	Double glazing /tint glass	4.6
7	Triple glazing	3.6
8	Insulated roof	1.9
9	Cool roof	3.4

Options	Payback period (Years)	
10	Brick tile on insulated roof	1.1
11	Insulated floor	-
12	Painted oak floor	-
13	Proposed Envelope Design	2.2

It has been determined through economic calculations with payback analysis that the proposed design is technically and economically feasible for the typical Afghan dwelling, with a minimum payback period of 2.2 years.

6.5.5 Conclusion

The first section of this chapter presented the outcome of the energy patterns, characteristics, and efficiency of housing in urban Afghanistan. The majority of current urban housing, constructed with RCC, requires more energy for heating and cooling to maintain thermal comfort. Liquefied petroleum gas (LPG) was found to be the primary fuel used in urban Afghanistan, followed by coal and firewood. Furthermore, 50% of the people use desert coolers for cooling purposes. Due to extensive load-shedding problems, many households use expensive fuels like diesel and kerosene to generate electricity.

Regarding the thermal comfort level of apartment residences in the summer season, the neutral temperature was found 27.86°C, and the comfort zone (responses in the range of -1 and +1) was 23.61 - 32.13°C based on linear regression data analysis. Since summer was hot and dry, relative humidity did not significantly affect comfort perception. The actual thermal sensation response was always found to be lower than Predicted Mean Vote (PMV).

Building energy modeling and simulation for evaluating the impact of different shading and orientation underlines the vast research scope in customizing building designs to Afghanistan's climatic conditions and other developing countries, thus contributing to buildings' sustainability. Findings demonstrated that neighboring structures have a positive correlation with cooling demand. Meanwhile, south is the optimal orientation to face the building's glazed façade, saving up to 7.4% of cooling and 9.7% of heating energy. Moreover, movable shading devices installed on the building's openings in the summer season reduce the building energy load by up to 19%.

Research on retrofitting apartment buildings proposes a cost-effective approach for retrofitting existing buildings. Based on the quantitative findings of energy modeling, a priority guide was created for the most viable and practical retrofitting solutions for residential buildings, and financial analysis of initial investment versus return was done. The result shows that retrofitting existing buildings has substantial advantages and significantly increases the energy efficiency of buildings.

Regarding the study on building envelope design, it has been revealed that there is more than 53% energy saving potential through efficient envelope design in the early design stage of typical Afghan dwellings. Moreover, a thermal insulation layer for vertical walls allows for greater energy savings (more than 30%) if 0.1m thick polyurethane layer applied on external walls and 0.05m on partition walls, since applying on external side of the wall encircle thermal bridges which are one of the main thermal loss points, however, considering the economic aspects, the optimal wall design is identified as cavity wall filled with 0.1m polyurethane layer with payback period of 1.4 years.

CHAPTER 7
SUMMARY AND CONCLUSION

7.1 Summary of Research Work

This research is set in the context of energy deficiency in Afghanistan, the need for high heating and cooling energy for residential buildings in the country due to extreme climatic conditions, and the scope of increasing energy efficiency of the existing and new buildings. The research began with an aim to develop measures for improving the energy efficiency of residential buildings in Afghanistan's urban region and provides valuable measures for improving building efficiency through feasible measures.

The study has five objectives: (i) identification of energy pattern and housing characteristics, (ii) determination of summer thermal comfort, (iii) devise passive solar control strategies, (iv) sustainable retrofit plan for reduction of heating and cooling, and (v) energy-efficient envelop for a new dwelling. Due to the muti-facet research problem, each objective required a different research method. The energy pattern and housing characteristics were determined in this study by using a questionnaire survey combined with statistical analyses. Before administering the questionnaire, a pilot study was conducted with the help of experts. The study also tried to identify the summer thermal comfort model in apartment residents. In this regard, a field investigation was carried out in the summer of 2019 in apartment buildings in Mazar-I-Sharif using Class-II protocols. A specific questionnaire was administered to investigate six mid-rise residential buildings.

Identification of passive solar radiation control strategy is grounded on the modeling and simulation of a case study residential apartment building in Mazar-I- Sharif, Afghanistan. The case study building was selected on various factors to act as a representative of multi-apartment residential buildings in Afghanistan. Some of the factors are – the use of local material, construction on standard code of practice, conventional design, and high quality of construction. The sun path diagram for the locality under investigation and the overheated period is plotted accurately. Eight major building orientations were investigated, and the monthly and annual energy consumption was obtained through DesignBuilder software with EnergyPlus simulation engine, and control strategies were applied. In simulations, the values of the thermal properties of construction materials such as brick and internal plasters from Afghanistan were obtained through Lab testing in India. All the location-specific data were collected from the city of Mazar-I-Sharif, including case studies of a seven-storied residential building and two typical storied houses. Regarding the building energy retrofit, the study's primary goal was to develop a technique to accurately select and evaluate intervention packages consisting of several retrofit solutions that can be applied to an existing building to lower energy consumption. A case study was done on a residential apartment complex in Mazar-I-Sharif in, Afghanistan. The approach was based on dynamic simulations of the thermal behavior of the building. The simulations consider a base-case scenario and a succession of retrofit intervention packages, and the results were compared from the energy and cost perspective. Since it is impractical to examine all possible combinations of the measures, appropriate retrofit options for the building envelope, such as thermal insulation and retrofitting of the glazing, were selected. Similarly, for the early design stage of a building, the influence of the envelope on the energy consumption of buildings is examined through a dynamic analysis of a typical residential house which has been selected as a baseline model. The model was then calibrated using a yearly energy consumption bill.

The research work led to valuable conclusions and contributions as summarized subsequently.

7.2 Conclusions Based on Research

Due to extreme climatic conditions in Afghanistan, especially arid climatic zone, a large proportion of energy is consumed for cooling and heating in residential buildings. Such energy consumption practice is further affected by the non-consideration of scientific principles and energy efficiency in designs. This thesis argues that there is significant scope for improving the energy efficiency of buildings to reduce energy consumption and substantially influence national energy consumption levels. Hence, the research proposes technically feasible energy-saving solutions by improving the energy efficiency of building designs and analysis of realistic and practical approaches. The research also takes into account the unique challenges regarding awareness, construction practices, and affordability for building energy efficiency in Afghanistan.

Important conclusions emerging from various research objectives are as follows:

Energy consumption patterns and housing characteristics findings revealed that energy usage in households is affected by dwelling and household types. Most (67%) urban residential buildings were constructed after 2002 without considering energy-efficiency codes and practices. About 71% of housing does not have any type of thermal insulation, and they did not consider building ‘direction/orientation’ an essential aspect of design and construction, resulting in the requirement for higher energy to maintain comfort inside household dwellings. Around 35.78% of households use LPG for heating, which is primarily imported from neighboring countries and is a primary source of cooking energy in urban Afghanistan. Moreover, 31% of households use coal for heating while 29% use firewood, which reveals urban residents are still significantly dependent on solid biomass for generating heat. Around 57% of households use desert coolers for cooling purposes, 28% use AC, and 13% use fans. Though most households in Mazar-I-Sharif are connected to the national electric grid, they face extensive load-shedding problems.

Regarding the thermal comfort levels for residents, the neutral temperature in summer was found as 27.8°C, and the comfort zone (responses in the range of -1 and +1) from 23.6 - 32.1°C. The south is the optimal orientation to face the building's glazed façade, saving up to 7.4% of cooling and 9.7% of heating energy. Movable shading devices installed on the building's openings in the summer can reduce the building energy load by up to 19%, with a total energy cost saving of AFN 188448 (USD 2447) annually.

The research on passive solar control strategies highlighted that energy performance in a mid-rise multifamily residential building with similar wall-to-window ratios varies with the building's orientation and mainly contributes to reducing the active cooling and heating in buildings. The optimal orientation was when the building with higher WWR (window-to-wall ratio) faced the south. 9.7% and 7.4% of annual kWh energy savings for heating and cooling were observed compared to other building orientations. Having a glazed façade to the west increases energy demand making it the worst orientation. Being a fixed device, a wooden louver in external windows could provide 22.6% of energy saving in cooling but was disadvantageous during winter. A movable blind is technically and economically viable with 18.9% overall energy saving and a 0.91-year payback period. Since investment in shading can be offset by the savings in energy consumption associated with mechanical cooling. Therefore, the simplicity and low initial cost are important issues that make the movable blind more feasible in Mazar-I-Sharif, where cooling and heating requirements are almost balanced, and the building must be designed for proper orientation.

The research findings on improving the energy efficiency of existing and new buildings considering the building envelope reveal that applying relatively low-cost wall and roof insulation is the most cost-effective way to minimize building energy consumption. On the other hand, replacing clear windows glass with tint one is not feasible in the Kabul climate; however, it has a relatively positive impact on cooling energy demand in the dry and hot climate of Mazar-I-Sharif. Wall insulation is beneficial at every level. Thermal bridges are eliminated by insulating the entire perimeter of the building with EPS, which can save up to 18% of the building's energy demand. This measure is the most effective retrofit option for the building envelope. Although window glass replacement is a frequent retrofit option in hot climate countries, it is not the most effective option in Afghanistan for a low payback time.

Furthermore, it has been revealed that the cost of enhancing the thermal performance of Afghan houses is recouped in a reasonable timeframe because the cost of modifying building requirements is compensated by the energy savings associated with a decreased demand for mechanical cooling. The study has shown that there are various advantages to enhancing the energy efficiency of Afghanistan's building stock, including reduced power consumption. Moreover, retrofitting existing buildings is highly cost-efficient, considering the economic advantages of decreased fuel consumption and a decreased demand for electricity production capacity.

A thermal insulation layer for vertical walls allows for greater energy savings (more than 30%) if 0.1m thick polyurethane layer is applied on external walls and 0.05m for interior walls since it encircles thermal bridges. However, considering the economic aspects, the optimal wall design is identified as cavity wall filled with 0.1m polyurethane layer with a payback period of 1.4 years. Floor insulation is typically not considered the best solution. It has been identified that there is more than 53% energy saving potential through efficient envelope design in the early design stage of a typical Afghan dwelling with a minimum payback period of 2.2 years.

7.3 Contribution

This research has delved into an important social and global issue of increasing building energy efficiency and subsequently contributing to a better environment. In the process, the research has made valuable contributions to new knowledge and recommendations for practical purposes.

Theoretical contributions to the body of knowledge are as follows:

- The research identifies critical gaps in building energy efficiency studies in Afghanistan, and the research is a step to the direction. Future researchers can use similar approaches for commercial and public buildings in the country.
- The research demonstrates the experimental process for determining the thermal properties of construction material that has critical values for the buildings, which will further inform the building modeling.
- The research identifies critical trains in energy usage patterns and housing characteristics. The majority of newly constructed buildings in urban Afghanistan are RCC structures without any insulation and considering the region's climate and any passive measures, leading to uncomfortable summer and winter indoor environments and higher energy demand. The study contributes to the body of knowledge that there is a potential to improve building energy efficiency by up to 53% by enhancing the thermal efficiency of the building envelope.

- Based on the research, in the arid climate of Afghanistan, south-facing buildings are the most efficient, which can be included in the country code.
- The study brings together a vast amount of information on building energy which has the potential to inform the construction practices, materials, and building codes, and the authorities can use the information to inform policies better.

Key contributions for practical purposes and recommendations are as follow:

The academic contribution of the study lies in creating a database containing different types of fuels/appliances used for heating and cooling purposes in Afghanistan. This database helps in providing recommendations to policymakers and practitioners. The policymakers must formulate policies through which more environmentally friendly and energy-efficient techniques can be used in constructing residential housing.

The findings of this study will aid the designers in using the measures while designing the energy-efficiency new dwellings in the region. The results of this research will also assist stakeholders in determining the most efficient and suitable thermal retrofit solution for a particular set of targeted buildings and allow Afghan residents to weigh the benefits of improved energy performance from envelope retrofit and the associated capital outlay.

Passive solar strategies offer a verified workflow for building orientation considering energy saving, and it is helpful for building and energy professionals, architects, and engineers who are obligated for decision making in the course of the design stage of the building to make it energy-efficient, which directs toward sustainability in building design in Afghanistan.

7.4 Recommendation

The energy efficiency strategies must be strictly implemented in buildings as a large amount of energy is consumed in residential buildings. In an Arid climate (hot summer and cold winter), the solar heat gains during winter reduce heating demand. Thus for passive solar heating, the glazed facade of the building should face in the southern direction in order to maximize winter sun exposure. However, in the summertime, appropriate shading devices should be applied over the window. In this geographical location, the building's optimal orientation is when the minimum glazing is used in the west. In other words, limiting or eliminating west-facing glazing may reduce heat gain during summer and fall afternoons. Moreover, if there is a provision for opening on the other sides, the windowless wall should be directed to the north to prevent energy loss in winter.

Building retrofits have direct and indirect benefits, especially in residential buildings in developing countries like Afghanistan. The essential direct benefits include cost savings for heating and cooling in the winter and summer. Due to a large number of newly constructed, uncomfortable, and power-hungry residential buildings that do not meet the energy efficiency standards, it is necessary to assess the financial viability of an energy building retrofit plan and the suggested feasible retrofit measures. One of the critical goals of the energy performance of buildings in Afghanistan should be to promote cost-effective improvements to the overall energy performance of existing buildings. Furthermore, given the high cost and scarcity of electricity, households and other private entities should consider energy efficiency retrofit measures, as demonstrated in the study, that is less expensive and enable property owners and/or users to invest in energy conservation at a reasonable cost. As such, it is highly recommended that the country must promote the research and development ecosystem and incentivize those contractors who construct energy-efficiency buildings.

Based on the psychometric chart of the region, enough cooling can be provided using an evaporative cooler. Since water is accessible in both urban and rural areas, air conditioning use may be decreased or even eliminated when there is less heat gain through the envelope. Since the ground keeps close to its normal yearly temperature in the Mazar-I-Sharif climate, earth sheltering and basements use less energy when they are used. The study also recommends to the practitioners that, instead of importing cheap and inefficient heating/cooling equipment from neighboring countries, they should promote energy-efficient equipment in the local market. To accomplish this, the government should encourage practitioners by subsidizing the manufacture and importation of energy-efficient equipment.

7.5 Limitations and Direction for Future Research

Despite ambitious efforts by the Ph.D scholar, the research is limited by practical and financial constraints of conducting field research. The scholar acknowledges six important limitations of the study.

First, the study is limited to the data collected from a major city in northern Afghanistan having an arid climate. Further research would be required to extend the findings to other climatic zones and cities of Afghanistan.

Second, the study covers the analysis of summer thermal comfort, and due to unavoidable circumstances, a similar analysis of winter could not be done within the time limits of Ph.D. Future researchers may attempt the same.

Third, parts of the study where data was collected using questionnaires, the language of the questionnaires was Persian, and respondents were adult respondents. It is possible that children and the elderly might have different comfort levels and affect the overall building design.

Fourth, there are different approaches to achieving energy efficiency of buildings like efficient HVAC systems or photovoltaic energy. However, it was consciously decided to focus on building envelope, considering technological and economic challenges in implementing other solutions in Afghanistan.

Fifth, the energy modeling uses experimental data from brick and plaster samples from Afghanistan tested in India. However, more rigorous experiments of larger material samples are required to achieve more generalizable modeling. Sixth, the results can be validated by replicating the same methodology in other cities in developing countries similar to Afghanistan. Moreover, the results of this study provide information regarding the energy patterns used in different types of residential buildings. Therefore, this information can be used by future studies in quantifying the inefficiencies of buildings in terms of cost or environmental effects.

Despite this limitation, the thesis provides substantial addition to the body of knowledge that can be used to improve the energy efficiency of residential buildings in developing and less developed countries.

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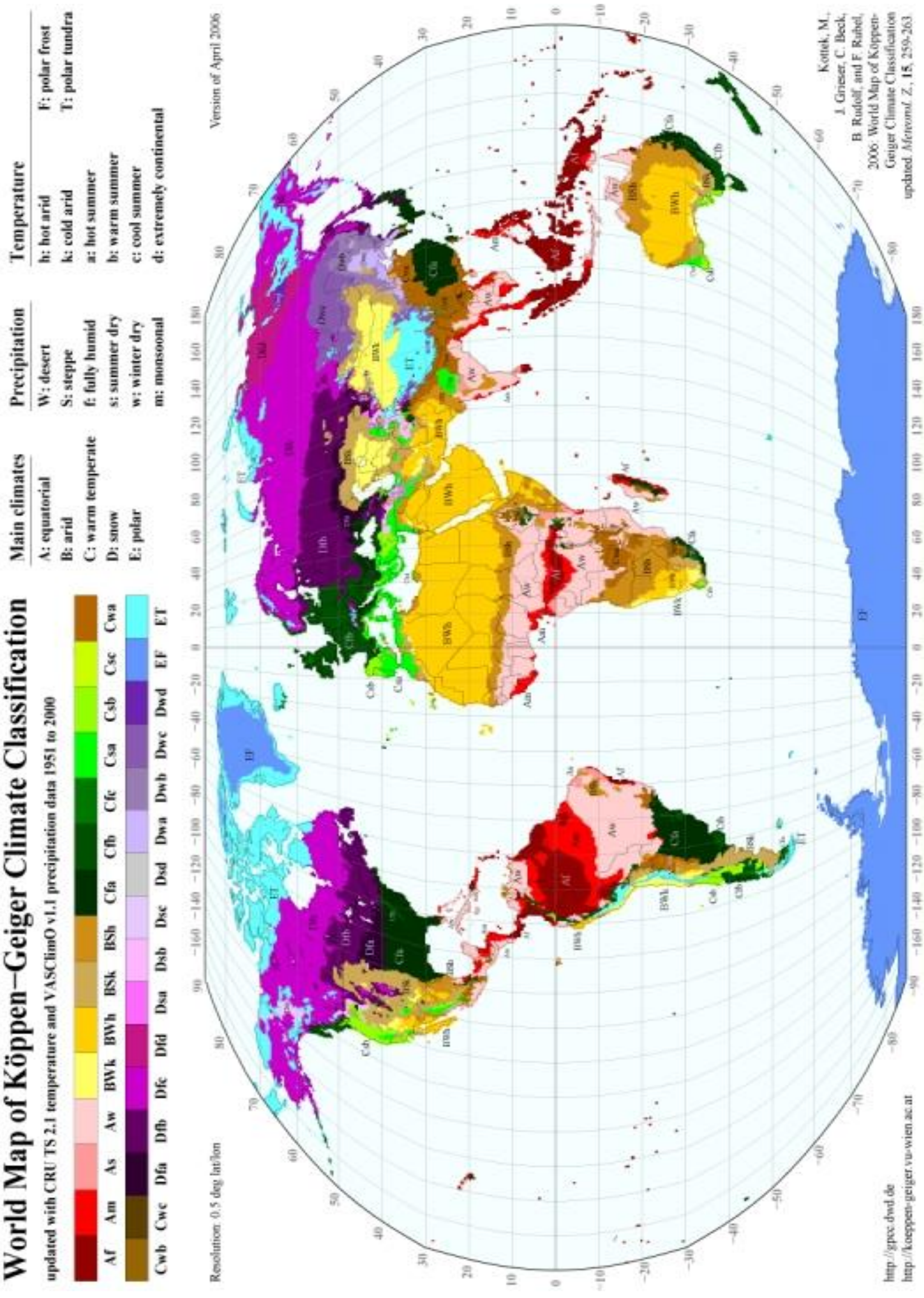
APPENDIX A-1

KOPPEN CLIMATE CLASSIFICATION

Class (A) Tropical: Consistently high temperatures define such climates.		
Af	Fully humid equatorial rainforest (P_{min} ≥60 mm and all seasons are rainy)	
Am	Equatorial Monsoon [P_{ann} ≥25 (100 − P_{min})]	
Aw	Equatorial savannah with dry winter (P_{min} < 60 mm in winter)	
As	Equatorial savannah with dry summer (P_{min} < 60 mm in summer)	
Class (B) Dry climate (Arid and Semiarid): The propensity for evaporation and transpiration to surpass precipitation is a feature of Class B climates.		
Bs	Semi-arid Steppe climate (P_{ann} > 5 P_{th})	
BSh		Hot steppe/desert (T_{ann} ≥ + 18 °C)
BSk		Cold steppe/desert (T_{ann} ≤+ 18 °C)
Bw	Desert climate (P_{ann} 5 P_{th})	
BWh		Hot steppe/desert (T_{ann} ≥ + 18 °C)
BWk		Cold steppe/desert (T_{ann} ≤+ 18 °C)
Class (C) Temperate (Mesothermal): In the spring/summer months (April to September in the northern hemisphere), such climates have an average monthly maximum temp of 10°C (50°F) or more, and a mean monthly low temperature of -3°C (27°F).		
Cs	Warm temperate climate with dry summer (Psmin < Pwmin, Pwmax > 3 Psmin and Psmin < 40 mm)	
Csa		Hot summer (Tmax ≥ + 22 °C)
Csb		Warm summer (not 'a' and at least 4 Tmon ≥ + 10 °C)
Cw	Warm temperate climate with dry winter (Pwmin < Psmin and Psmax > 10 Pwmin)	
Cwa		Hot summer (Tmax ≥ + 22 °C)
Cwb		Warm summer (not 'a' and at least 4 Tmon ≥ + 10 °C)
Cwc		
Cf	Neither Cs nor Cw (Moist all seasons)	
Cfa		Hot summer (Tmax ≥ + 22 °C)
Cfb		Warm summer (not 'a' and at least 4 Tmon ≥ + 10 °C)
Cfc		Cool summer and cold winter (not 'b' and Tmin > − 38 °C)
Class (D) Continental climate (Microthermal): The average temperature in these climates is above 10°C (50°F) in the warmest months and below -3°C in the coldest months (or 0OC). Group D climates are exceedingly rare in the southern Hemisphere due to the limited land masses in the middle latitudes and the lack of land between 40 and 60 °C latitude, with the exception of a few highland regions.		
Ds	Snow climate with dry summer (Psmin < Pwmin, Pwmax > 3 Psmin and Psmin < 40 mm)	
Df	Snow climate, fully humid (neither Ds nor Dw)	
Dsa		
Dsb		
Dsc		
Dsd		
Dw	Snow climate with dry winter (Pwmin < Psmin and Psmax > 10 Pwmin)	
Dwa		Hot summer (Tmax + 22 °C)
Dwb		Warm summer (not 'a' and at least 4 Tmon + 10 °C)
Dwc		Cool summer and cold winter (not 'b' and Tmin > − 38 °C)
Dwd		Extremely continental (like 'c' but Tmin − 38 °C)
Dfa		Hot summer (Tmax + 22 °C)
Dfb		Warm summer (not 'a' and at least 4 Tmon + 10 °C)
Dfc		Cool summer and cold winter (not 'b' and Tmin > − 38 °C)
Dfd		Extremely continental (like 'c' but Tmin − 38 °C)
Class E - Polar and Alpine Climates (Tmax < + 10 ° C)		
ET	Short summers allow tundra vegetation to flourish. (0 ° C Tmax < + 10 °C)	
EF	Frost climate (perpetual ice and snow) (Tmax < 0 °C)	

APPENDIX A-2

WORLD MAP OF KOPPEN



APPENDIX B-1

THERMAL SIMULATION STUDIES (EXISTING BUILDINGS)

Authors / Year	Research objectives	Location and the Climate	Base case model	Calibration	Parameter considered	Simulation tools	Conclusion
Feitosa (2018)	Retrofitting a green roof and a green wall to reduce heat stress	1A Rio de Janeiro (warm and humid climate), 3A Sydney (temperate)	-	Calibrated through literature comparison	Block work and timber framed drywall structures	Experimental	The findings show that green roof and green wall retrofits may significantly reduce heat stress in residential buildings.
Evangelisti (2015)	To investigate residential building envelope energy retrofit options.	Itlay Climatic Zone D (Continental climates) 3A	Real, Building Total Surface: 2948.4 sq m, Residential Units: 24	Actual Temperature Mesurement, RMSE, MBE	External Insulation , Windows , HVAC set point.	TRNSYS	Higher thermal insulation provides for the greatest savings in heating demand, however during the summer, the window solar gain factor is crucial.
Lee (2018)	Analysis of thermal performance of PCM-enhanced cellulose insulation in passive solar residential building walls	U.S. (DOE Region 4)	Real (Test Bed) The test houses had dimensions of 1.83m×1.83m×1.52m and used typical residential frame wall construction and geometry.	Experimental using Differential scanning calorimeter (DSC)	Orientation, PCMs	Experimental	The findings demonstrates daily average peak heat flux reduction for individual walls was 25.4%, while the hourly average peak heat flux reduction for the sum of all four walls was 20.1%.
Zubiaga (2016)	To study the role of the design and operation of individual heating systems for the energy retrofits of residential buildings	3C Bilbao (northern Spain)	Real A 60 m2 dwelling of the building was selected for the purpose.	Not Validated	heat production unit; terminal units and) control system.	TRNSYS	The findings suggested that the temperature set-point resulted in the most effective to reduce the energy consumption.
Zubiaga (2015)	To analyse energy and economic assessment of the envelope	3C Bilbao (northern Spain)	Real The building contains 36	Actual measurement	Wall, window and roof	TRNSYS	The findings suggested that the thermal improvement of roof and

Authors / Year	Research objectives	Location and the Climate	Base case model	Calibration	Parameter considered	Simulation tools	Conclusion
	retrofitting in residential buildings		dwellingunits, each of which has a net floor area of 50–55 m2and a floor toceiling height of 2.47 m.				facade is beneficial from the energyand economic points of view.
Gugul (2018)	Techno-economical analysis of building envelope and RE technology retrofits	4A (mix humid) Ankara, 3A (warm humid) Istanbul , and 3A (warm humid)Izmir	Real The total area of the house is 700 m2, however only 500 m2 is heated regularly during the heating season.	Actual Energy Consumption	wall, window, and roof improvements and the retrofit of solar domestic water heating	ESP-r	The results indicate that applyingwindowglazing, roof, and a combination ofwindow,wall, and roof improvements reduce heating energy demand by 21%, 34%, and 50%, respectively, with favorable payback periods
Cascio (2017)	Residential building retrofit through numerical simulation	3A (warm humid) Wollongong, Australia climate zone 5	Real The case study examined is a 7000 m2 student accommodation at the University of Wollongong, Australia.	Validated against energy audit report.	Wall, window, roof, Light, Solar DHW	DesignBuilder	The study reports saving from the implementation of the most cost-effective ECMs to be about 58.4 MWh per year concerning the electricity consumption and 19.6 MWh per year referring to the natural gas consumption.
Kotti (2017)	To Quantify Thermal Bridge Effects and Assessing Retrofit Solutions in a Greek Residential Building	3B (warm-dry) Thessaloniki Greece warm temperate	Real The selected case study building is a typical, semi-detached, three-storey, single family house with parking spaces on the ground floor and a flat roof.	Not Validated	Wall, window, roof	THERM & TRNSYS	The impact of thermal bridging on the overall annual heating load was estimated at 13%. The investigated retrofit solutions achieved a decrease of the annual heating energy requirement of 4-10%.
Giovanardi (2015)	Integrated solar thermal facade system for building retrofit	3A (warm-humid) Rome, Italy	Real, the total heated floor surface area of the room is 24 m2, the fac¸ade has a net opaque surface of 13.7 m2 and a window area of 2.5 m2.	Not Validated	solar facade implementation	Energyplus, TRNSYS	The findings demonstrates that the low-cost, the versatile modularity and the easy installation make this active solar fac¸ade an innovative and promising technology for the building stock transformation, despite of the low quality of the produced energy due to the low outcome temperature of the unglazed collector.

Authors / Year	Research objectives	Location and the Climate	Base case model	Calibration	Parameter considered	Simulation tools	Conclusion
Galle (2017)	Integrating Scenarios into Life Cycle Assessment: Understanding the Value and Financial Feasibility of a Demountable Building	4A (Mixed -humid) Belgium	Virtual	Not Validated	Floor replacement Wall replacement Space alteration	NPV LCC	Financial justification for alterations is difficult to attain
Neroutsou (2016)	A case study for Lifecycle costing of low energy housing refurbishment	4A (mixed-humid) London, UK	Real, The case study house is a Victorian semi – detached end terrace house built before1919. witha total usable floor area of approximately 167 m2	Not Validated	Wall Insulation, Floor Insulation Window Insulation, Natural Lighting, Air Tightness, Efficient Lighting	Simple Payback NPV Sensitivity Analysis	The payback is not justifiable except based in an annual increment in energy. Only structural intact and long-life buildings should be retrofitted
Chen (2015)	Evaluation on Retrofit of One Existing Residential Building in North China: Energy Saving, Environmental and Economic Benefits	4A (Mixed-humid) Tangshan, China	Real, one brick-concrete structure with 6 floors and 72 families.	Actual Energy Consumption	Wall exterior insulation Roof insulation Doors and windows	Simple Payback NPV	The findings demonstrates the full-scale retrofit in this building can meet the 50% energy saving target set by the government. Indoor thermal environment achieved a good improvement after the full-scale retrofit as well.
Asadi (2012)	Optimization model for building retrofit strategies using TRNSYS simulations, GenOpt and MATLAB	3A (warm-humid) Portugal	Real, the building has a ground floor and a basement. The two stories are connected by a staircase. The gross floor area of the house is 97 m2 . The glazing area represents 10% of the floor area.	Not Validated	External walls insulation materials; roof insulation, windows type; solar collector type.	TRNSYS , GenOpt and MATLAB	The results demonstrate its practicability to provide decision support in an actual setting
Yao (2014)	Investigation of movable solar shades on energy, indoor thermal and visual comfort improvements	3A (warm-humid) Ningbo, China,	Real, the investigated building in this paper is a six-story residential building (2100 m2)	Actual Measurement	Solar Shades	Energyplus	The findings demonstrates that movable solar shades used for south-facing windows not only reduce building energy demand by 30.87%, but also improve indoor thermal comfort by 21% in summer as well as reduce dramatically extremely uncomfortable risks by 80.4%, and meanwhile the visual comfort condition is also improved by 19.9%.

Authors / Year	Research objectives	Location and the Climate	Base case model	Calibration	Parameter considered	Simulation tools	Conclusion
Ortiz (2016)	Comfort and economic analysis for passive measures for the energy refurbishment of residential buildings	Barcelona and Tarragona (Spain) C2 and B3 As per ASHRAE 3A (warm-humid)	Real, Only two floors are included in the simulation, inorder to simulate the building with more detail: the standard floorand the under roof floor.	Not Validated	Façade, wall, roof	Trnsys3D, GoogleSketchUp	The method provides technical and economic information about a set of passive energy efficiency measures, with the objectiveto help to make decisions for choosing the appropriate combination of passive measures.
Ortiz (2016)	developing cost-optimal studies for the energy refurbishment of residential buildings.	Barcelona and Tarragona (Spain) C2 and B3 As per ASHRAE 3A (warm-humid)	Real, Only two floors are included in the simulation, inorder to simulate the building with more detail: the standard floorand the under roof floor.	Not Validated	Façade, wall, Roof heating and DHW system,, cooling system, ,lighting system , integration of PV system	Trnsys3D, GoogleSketchUp	The method provides technical and economicinformation to help taking decisions of the users, experts and politi-cians, considering not only economic and energy aspects, but alsocomfort parameters.
AlFaris (2016)	Energy retrofit strategies for housing sector in the arid climate	0B Abu Dhabi ,UAE Arid climate	Real, study has selected 10 villas to implement these techniquesof energy efficiency	Actual Mesurement	Wall,roof, windows and efficien appliences.	RETScreen Simple Payback for LLCA	The potential of improvement of energy performance in the housing sector by increasing the energy efficiency by 25.1% in average through lowand medium cost techniques. The percentage of savings varies from 14.4% to 47.6% of the total electricityaccording
Lauck (2014)	Evaluation of phase change materials for improving thermal comfortin a super-insulated residential building	Portland, Oregon, USA ASHRAE Climate Zone 4C, mixed marine	Real, two-story building, Each apartment has a total floor area of 145 m2,consisting of three bedrooms, two bathrooms, a common livingroom and kitchen, and an unconditioned workshop with an area of 11.6 m2	Validated with observed data	Wall, roofs, floor.	Energyplus	The findings demonstrates that installationof the PCM had a positive effect on thermal comfort, reducing the estimated annual overheated hoursfrom about 400 to 200.
Aldawi (2012)	Thermal performance modelling of residential house wall systems	3A(warm-humid) Melbourne, 2A(hot-humid) Brisbane, 0A Darwin, 4A (mixed-humid) Hobart, 3B (warm-dry) Adelaide and 3A (warm-humid)Sydney.	Real, The house has three bedrooms with the total floor area and physical volume of approximately 161.33 m² and 460 m3 respectively.	Not Validated	Wall,roof,floors	AccuRate	Using the new house wall system energy savings ranging from 14% to 33% various climate zones is achieved. This will reduce the greenhouse gas emission, enhance sustainable environment and energy security. However, further study is required to understand the full potential of the new house wall system.

Authors / Year	Research objectives	Location and the Climate	Base case model	Calibration	Parameter considered	Simulation tools	Conclusion
He et al. 2020	To develope a sustainable retrofit decision-making model to uncover the optimal set of retrofit solutions according to local climatic conditions, building features, and retrofit costs.	temperate and hot summer-cold winter zones, Yunnan ,China	Real: apartment of a residential building	Sensitivity analysis	Wall, window,shading, HVAC,Lighting, control system, renewable energy	Mathematical	the optimal NPV can be obtained by pursuing a 40% energy saving, as it can result in energy saving of up to 50 kWh/m2 /year and 95 kWh/m2 /year at an average retrofit cost of approximately USD 1.30 and 3.20 m2 /year in the temperate and hot summer-cold winter zones respectively.

APPENDIX B-2

THERMAL SIMULATION STUDIES (EARLY DESIGN STAGE)

Authors / Year	Research objectives	Location and the Climate	Base case model	Calibration	Parameter considered	Simulation tools	Conclusion
ANDERSSON (1985)	To calculate heating and cooling loads at different orientations	cold climate: Madison (4A) A hot climate: - Miami (4A) mixed climate: Nashville (3A) passive solar climate: Albuquerque	Real: one floor house	-	Orientation	BLAST	Total loads are much lower in all climates when the more extensively glazed exposure is directed to the south than when the identical building is oriented east or west.
Abaza (2002)	To suggest general design guidelines for improving the energy performance of buildings and enhancing thermal comfort	4A. Humid subtropical (Blacksburg, Virginia, USA)	Real floor area of Beliveau House is approximately 580m²	House was field monitored to calibrate building energy simulation.	Thermal mass, insulation, solar heat gain coefficient (SHGC)	EnergyPlus	The most significant influencer on building thermal performance was thermal insulation. The only way to keep cool during the night was using direct ventilation.
Cheung et al. (2005)	To reduce the cooling load	3A: Subtropical (Hong Kong, China)	Real: The public rental flats were developed by the housing authority	Calibrated using actual data of the building (within 8% per annum of published survey data)	(6) Insulation, thermal mass, glazing type, window size, color of external wall, and external shading devices.	Energy-10	The techniques for increasing the thermal performance of the exterior wall were more effective than the strategies for improving the thermal performance of the windows.
Al-ajmi (2008)	to arrive at a building design that is both energy-efficient and typical of local design, which may provide further guidance to enhance Kuwait's building code.	1B Very Hot-Dry (Kuwait)	(single storey building) are 10 m x 8.2 m	sensitivity analysis	building envelope, window type, size and direction, infiltration and ventilation.	TRNSYS	The simulation results have revealed the ideal characteristics that need be included in domestic buildings in order to modify the energy conservation code. Furthermore, the traditional wall has been demonstrated to be more energy efficient than the AAC wall, both of which are widely utilised in Kuwait.

Authors / Year	Research objectives	Location and the Climate	Base case model	Calibration	Parameter considered	Simulation tools	Conclusion
Tubus-Dubrow and Krati (2010)	To optimizze the builidng shape and building envelope features	5B: Temperate (Boulder, CO, USA)	Virtual: Building America Research Benchmark Model	-	(6) building shapes, wall, roof, and foundation type, window type, window area	DOE-2 and genetic algorithm	The south-facing trapezoid was the most efficient for yearly heating energy usage, while the north-facing trapezoid was the most efficient for cooling. The best form, according to the energy and Life Cycle Cost, is square.
Morrissey(2011)	to investigate life cycle costs of residential building thermal efficiency	3A- Warm-Humid Melbourne, Australia	Virtual: Residential house	-	ceiling insulation, infiltration control, shading, external wall insulation, window glazing and internal wall insulation	AccuRate/ LCC	The cost savings from improved efficiency requirements are considerable over time spans of 25 and 40 years, especially in light of rising energy prices. The energy cost reductions associated with more thermally efficient building designs balance the higher construction costs after the first few years of occupancy.
Dhaka et al. (2011)	To utilize energy conservation measures(ECMs) recommended by the National Energy Conservation Building Code (ECBC)	1A: Composite climate (Hyderabad, India)	Real: Part of a building's fourth floor, with a room size of 3.6m x 2.4m	Calibrated using the actual data of the building	(4) Wall and roof U-Factor, glazing type and set point temperature	EnergyPlus	In a composite climate, the building becomes comfortable for an additional 313 hours, 133 hours in a hot and dry environment, and 192 hours in a warm and humid climate.
Lai and Wang, (2011)	To investigate how different types of roof construction, window glasses, and sunshield types affect the energy consumption	IA: Humid subtropical (Tainan, Taiwan)	Real: Four-story building	Calibrated using annual monthly energy consumption trends	(2) shading devices and window glazing	eQuest	Annual power consumption savings of roughly 15.1 percent were realised by adopting low-e glass and 1.5mx1.5m box shading.
Dhaka et al. (2012)	To evaluated improvement in the energy efficiency of an air-conditioned building b8lock by employing EC9Ms recommended by ECBC	1A: Composite (Hyderabad, India)	Real: part of building's fourth floor,room size of 3.6x2.4m	Calibrated: MBE and CVRMSE	(4) Wall and roof U-factor, glazing type, and set point temperature	DesignBuilder	Small buildings' energy consumption can be decreased by 40% and energy savings of up to 16% can be achieved by adopting adaptive thermostat settings.
Pisello (2012)	To define different performance levels by proper non-dimensional indexes named thermal deviation indexes (TDI).	3A Warm – Humid (Palermo), 4A Mixed-Humid (Perugia), 4A Mixed-Humid (Bolzano) ,Italy	Real: experiment and virtual. three free-floating houses	Calibrated: TDI results are compared with those obtained from existing procedures.	External wall inertia, Roof reflectance, Envelope transmittance, SHGCwindows, Shieldings transmittance.	EnergyPlus	SC summer values, in particular, are more than 40% higher than winter values, and the greatest sensitivity correlates to SHGCw for Perugia and Bolzano, and shieldings transmittance for Paler.

Authors / Year	Research objectives	Location and the Climate	Base case model	Calibration	Parameter considered	Simulation tools	Conclusion
Gulati (2012)	To optimize the building envelope for minimizing the heat gain and resultant energy demand	1A: Composite, New Delhi, India)	Virtual	-	(6) Building orientation, WWR, roof, wall, glass and shading devices	eQuest	The heat load was reduced by around 71 percent via the envelope.
Mata et al (2013)	to assess the effects of applying a set of ESMs to all residential buildings in Sweden.	In Between 5A to 7 (Cold-humid to very cold) Sweden	Virtual	-	(12) Windows, ventilation systems, lighting, roofs, facades, hydro pumps,temp st point.	Simulink	The use of the chosen ESMs has the potential to cut the Swedish residential sector's final energy demand by 53%. Heat recovery systems and lowering the indoor temperature are the most cost-effective strategies, saving 22% and 14% of energy, respectively.
Iwaro and Mwasha (2013)	To investigate the impacts of sustainable envelope design on building sustainability by using the integrated performance model.	3C: Mediterranean (sanFemando, CA, USA)	Real: Housing development corporation, Single-family units	Calibrated using the actual data of the building	(7) Roof, Wall, Windows, external door, floor, ceiling, and envelope area	Graph iSOFT	The high energy efficiency of a building envelope design option equates to good long-term performance.
Fang et al. (2014)	To demonstrate that the use of an external wall insulation system can improve a building's energy efficiency	3A:Humid subtropical (Chongqing, China)	Real: An energy efficient chamber was constructed using a thermal insulation system for the external wall, and a basic chamber was constructed according to the general design for the 1980s and 1990s	-	Wall insulation	-	The external environment had a limited impact on the internal thermal environment of an energy efficient chamber, which allowed it to be kept at more pleasant temperatures with less energy use than the basic chamber.
Ferrara et al. (2014)	To investigate the possibilities provided by the use of simulation based optimization methods within the context of application of the cost optimal methodology	4A: Warm and temperate (Rhone-Alpes,France)	Real: Two-story high performance single-family house	The model was calibrated through trial and error by using a set of measured	Wall, roof, slab, window and width of window	TRNSY/ GenOpt/ Particle swarm optimizatio n	A light wooden envelope with triple glazing, a great width of the south window, and no window on the roof is the ideal solution.
McKeen and Fug (2014)	To examine the energy consumption under various aspect ratios	6A: Semi continental cold (Toronto, Canada)	Real/Virtual: 10-storey buildings with a gross floor area	Represent typical configurations of new and	Aspect ratio	eQuest	For cooling load reduction, a 1:2 aspect ratio is preferable.

Authors / Year	Research objectives	Location and the Climate	Base case model	Calibration	Parameter considered	Simulation tools	Conclusion
			of 6000m2 and aspect ratio of 1:1, representative of several newly constructed residential building	existing residential buildings; 10-storey buildings with a gross floor area of 6000m2			
Sang et al. (2014)	Energy-efficient Building Envelope Design	3A: Hot-humid subtropical (Hong Kong, China)	Virtual: A 40-floor building with a floor area of 462 ft2	against benchmark published by Hong Kong Electrical and Mechanical Service Department	window-to-wall ratio (WWR), solar heat gain coefficient (SHGC), wall construction and roof construction	eQuest	The cooling demand was cut in half, or 46.81 %. The SHGC is essential for lowering the cooling burden. Analyzing dwelling energy consumption, highlighting the outside construction environment, exploring window and wall systems and material features, and suggesting prospective design measures are all steps in the process of making appropriate design decisions.
Stazi et al. (2014)	To determine the energy consumption , comfort levels, and environmental sustainability of adoping three energy-efficient envelopes	4A:Mediterranean (Ancoa, Italy)	Real: proposed north-south oriented four storey residential building	-	Wall and floor masonry, cement and wood	Thermal performanc e/EnergyPl us (comfort) simaPro (LCA)	High internal masses and thick insulation should be paired (masonry).
Yi (2014)	To discuss the total ecological impact of a building, which encompasses the process energy and environmental cost represented by the energy	4A: Temperate (South Korea)	Real: single-family house with an average size of 101.9m2	Window size , orientation , and wall material	Nonparametric simulation: Multivariate	eQuest and Ecotec	According to the results of the energy synthesis, more indirect energy investment during construction is necessary to reach the lowest operating energy scenario. As a result, the increased material flows are likely to outweigh the efficiency advantages.
Samuelson (2014)	Parametric energy simulation in early design stage for a high-rise residential buildings in urban contexts	4A, Mixed - Humid (USA New York-Central Park) 1A, Very Hot - Humid (China, Shenzhen) 4A, Mixed - Humid (China Beijing)	Virtual Square shape (1200 m2) Rectangle (1200m2) T-shape (1200m2)	Not Validated	WWR, Glass Type, Building Rotation, Building Shape, and Wall Insulation	Energy Plus	The impact of the urban environment as a source of solar shade has a significant impact on design optimization.
Ahmad (2014)	to reduce the operational costs of comfort air conditioning.	(2A, Hot – Humid) Islamabad, Pakistan	Real: two storey	Not validated	windows area, windows glazing type, Area lighting, heating ventilating, thermostat set point and Energy Efficiency ratio of	eQuest	In comparison to the baseline model, there was a 38.5 % reduction in energy use.

Authors / Year	Research objectives	Location and the Climate	Base case model	Calibration	Parameter considered	Simulation tools	Conclusion
					the HVAC .		
Abdallah (2015)	To optimize building measures to minimize energy consumption of aging buildings.	Between 4A and 5 A (Mixed – Humid & Cool – Humid) Illinois, USA	This building has an area of 3,500 square feet and was built in 1980	Not Validated	equipment that minimizes energy consumption and carbon emissions	eQuest	The created model provides new and unique features that enable decision makers, building owners, and operators to choose the best building upgrade measures from a variety of viable options, assisting them in their continuing work of optimising the sustainability of their structures.
Pennaa (2015)	To investigates the relationship between the initial characteristics of residential buildings and the definition of optimal retrofit solutions in terms of cost and energy	4A (Mixed – Humid), 3A (Warm – Humid) Milan and Messina, Italy	Real: a single storey module with a square floor of 100 m2	-	external insulation of the walls,roof and floor, glazing replacement, substitution of heating generator, mechanical ventilation	TRNSYS and genetic algorithm (NSGA-II)	The energy optima are pretty close to the Zero-Energy condition in Messina and quite close in Milan, but the economical profitability is reached for few cases with higher heating demand. The solutions with the best thermal comfort are those that require the highest investment costs and consequently, the highest NPV.
Balaji et al. (2015)	To investigate the influence of building envelope material on indoor thermal comfort and their suitability for different climatic condition	1A: Tropical moderate (Bangalore), composite (Jaipur), and warm-humid (Challaker) India.	Real:Multifloor house in selected cities	Calibrated using the actual monthly data of the building, (MBE,RMSC,a nd CVRMSE)		DesignBuil der	For a composite climate, AAC is advised, while fly ash and CSSB are recommended for a moderate climate, and CSSD is indicated for a warm and humid environment.
Fallahtaft i (2015)	to optimise building orientation in Tehran, as well as determining the impact of its shape, relative compactness (RC) and glazing percentage on its optimised orientation.	3B, Warm – Dry (Tehran,Iran)	Virtual : Volume: 8x 8 =64 m3	Calibrated	Shape, orientation , relative compactness, percentage of glazing	Ecotect	The optimal orientation is primarily influenced by the passive solar heat gain elements; also, among the examined parameters, the glazing percentage amount plays the most critical function in establishing a building's orientation.
Eisabeglo o (2016)	to model and simulate a complex traditional building.	2B, (Hot arid, Yazd, Iran)	Real: traditional house	Calibrated recorded temperature with simulation	Thermal mass	DesignBuil der	The simulation results might provide a decent estimate of indoor thermal conditions for most rooms; however, there are certain issues with utilising this programme for traditional building thermal modelling in hot and dry climates. The most serious flaw in this programme is its inability to calculate the effect of evaporative cooling.
Asadi et al (2016)	To study thermal behaviour of Yazd traditional homes	2B,(Hot arid, Yazd, Iran)	Real: Tradational house	Validated : RMSE of expremental and simulated	Thermal mass	EnergyPlus	In all seasons, the inside temperature of summer portions fluctuates less than the ambient temperature. In comparison to places at the ground floor, the weather temperature in underground spaces is closer to the comfort temperature.

Authors / Year	Research objectives	Location and the Climate	Base case model	Calibration	Parameter considered	Simulation tools	Conclusion
Ascione et al. (2016)	To determine the building envelope design variables that minimize winter and summer energy demand without compromising on thermal comfort	4A: Mediterranean Climate (Madrid, Nice, Naples, and Athens)	Virtual: Single-Storey building, with a rectangular shape and net conditioned building area of approximately 140m2	-	Thermal properties of the building envelope, adoption of phase change materials (PCMs) with different melting temperature, cool roof solutions, several WWR values, and shading systems	DesignBuilder/GenOpt (Based on the NSGA-II algorithm)	Aerated concrete blocks or bricks with integrated insulation should be selected. Brick-concrete roof with external insulation is recommended. Optimal WWR changes greatlyon the selection of triple glazing windows with selective coating and external shading. PCM adoption of melting temperature of 25OC on the inner side allows a reduction of the cooling demand in each city.
An-Naggar (2017)	To analyse energy Performance Simulation in Residential Buildings	2B, Hot - Dry (Cairo, Egypt)	Real Residential building is considered to consist of three floors and six apartments of 100 sq m floor area for each apartment;	Not Validated	different wall and roof materials	Designbuilder	When thermal insulation (Glass wool blanket) with a thickness of 0.05 m was applied in the walls and roof of the final storey, it saved around 40% of the energy consumed by the air conditioner.
Alwetaishi (2018)	To investigates the impact of each of these aspects with respect to the hot and dry climate of the capital of Riyadh.	1B, (Very Hot -Dry) Hot and Arid, Riyadh, Saudi Arabia	Virtual: Two floor building	-	thermal mass, thermal insulation, CY and glazing to wall ratio	(TAS EDSL)	For building zones facing south, west, and east, it is conceivable to achieve near-zero carbon building in the hot and dry region during the winter with little dependency on energy loads. Furthermore, employing a courtyard rather than putting construction materials to the building façade is more effective. In hot and dry climates, a glazing to wall ratio of 10% is suggested, with a maximum of 30% in all directions.
Shabunko (2018)	Benchmarking of residential buildings	0A (Brunei Darussalam) Tropical equatorial	Real- three housing estates have been chosen. These are the Mentiri (Type A), Panaga (Type B) and Meragang (Type C) housing estates.	verified against the power con-sumption data, and data from selected door-to-door survey	window-to-wall ratio (WWR), solar heat gain coefficient (SHGC), wall construction and roof construction	EnergyPlus	The results, when compared to the previous EnergyPlus simulation results, show that for each kind of building, yearly energy consumption reductions of 15–19.2% are possible.

Authors / Year	Research objectives	Location and the Climate	Base case model	Calibration	Parameter considered	Simulation tools	Conclusion
Kosir et al. (2018)	A study of interconnectedness of building form, orientation and window area in regard to energy consumption for heating and cooling	4A: Temperate, Slovenia.	Virtual-volume 10mx10mx10m	-	-	EnergyPlus	An elongated building shape is preferable than a compact one.
Simon (2018)	investigates the energy use in a reference household referred to as the base-case home (BCH) considering the building's layout, the envelope materials and the climate conditions of seven designated locations across Chile.	Between 3B and 6A (Warm – Dry and Cold-Humid) subtropical desert, very mild Mediterranean , semi-arid climate, mild oceanic ,7 cities of Chile	Virtual: one floor house with 12 x 6 m2 conditioned area	Validated: by comparing with energyplus result, percentage deviation	wall and ceiling insulation, window and door U-values and infiltration/ ventilation rate.	MEEDI	The result of improved envelope U-values and air tightness in the BCH vs the LEH is a reduction in electricity consumption of 45 to 59 percent and a reduction in CO_2 emissions of 0.542 to 4.198 tCO_2 per year, depending on the location and energy system scenario.
Ashmawy (2018)	To identify the effect of building orientation on the amount of energy consumption within buildings.	2B, Hot - Dry hot arid, Cairo, Egypt	Virtual :one floor house	-	Orientation	Energy-plus	A building with a southern facade consumes less energy than one with a northern face. The yearly energy consumption of a western facade, on the other hand, is 26% more than that of a southern front. In Cairo, Egypt, the northern and southern orientations of a two-facade building result in the lowest energy use.
Dodoo (2019)	To optimize the cost of energy-efficient building envelope measures for a multi-storey residential building in a cold climate	6A, (Cold-Humid) Sweden city of Växjö Cold Climate	Real The building used for this analysis is a constructed six-storey multi-family house with 24 apartments and total heated floor area of 1686 m2.	Validated by the IEA BESTEST, ASHRAE 140-2007 and CEN-15265	Insulation levels for the attic floor/roof, ground floor and exterior walls	VIP-Energy simulation program (v. 4.0.3)	When the proper insulation thicknesses are applied, significant energy and cost savings can be realised.
Albatayneh (2019)	to find the effect of the building orientation on the overall thermal performance.	3B (warm and dry), Amman,Jordan	Real: 10m length and 15m width	-	Building orientation	DesignBuilder	In the northern hemisphere, the larger windows should be in the southern walls to provide the maximum heat to the building through the window, which allows the sun to enter and warm it up in the winter. This will save about 35% on heating costs every year.

Authors / Year	Research objectives	Location and the Climate	Base case model	Calibration	Parameter considered	Simulation tools	Conclusion
Albayyaa (2019)	To determine the influence of various parameter on the total energy required to achieve thermal comfort in the house.	3A (Warm - Humid) Sydney, Australia	Real: 2 two floors detached residential house 200 m2,	Validated: percentage errors between the simulated and actual energy consumptions	Glazing , shading device, ventilation and infilteration	IDA-ICE	Passive Solar and Energy Efficiency Design Strategies for constructing typical fibro and brick veneer houses, respectively, lower the total energy used for heating during the winter by 37 and 36 %.
Yarramsetty et al. (2020)	To assess the influence of the orientation of the buildings.	4B (Mixed – Dry climate)	Real:2 floor house	Validated: percentage errors between the simulated and actual energy consumptions	Orientation	BIM	"t is observed from the analysis of data collected that a saving of $1393 from the best orientation (+315° clockwise) to the worst orientation (+165° clockwise)."
Dehwah (2021)	To analyse energy performance of integrated adaptive envelope systems (AES) for residential buildings	2B (Hot - Humid) (Phoenix), 3C (Warm - Marine) (San Francisco), 5B (Cool – Dry) (Boulder), 6A (Cold-Humid) (Burlington)	Virtual An energy model for a single-family detached house, developed by DOE , encompassing a 220 m2 floor area is considered.	Not Validated	cool roofs, movable PV-integrated shading devices (MPVISDs) and switchable insulation systems (SISs)	Energy Plus	The integrated AES has a huge amount of potential for conserving energy in residential buildings when it comes to cooling. Depending on the climate in the United States, cooling energy savings range from 234 to 949 kWh per year.
Zou (2021)	To predict the life cycle energy performance of residential buildings in different climate zones of China	China (15 locations) severely cold area, cold area, hot summer and cold winter area, hot summer and warm winter area, temperate area	Virtual Number of floors – 2.00 Total floor area 250 m2	Not Validated	window-to-wall ratio (WWR), solar heat gain coefficient (SHGC), wall construction and roof construction	Grasshopper with Ladybug Tools (simulation engine EnergyPlus) GISS-E2-R (for generating future weather data)	The more the impact of climatic change (temperature), the more the building's heating and cooling energy changes.

APPENDIX C

ENERGY PATTERN AND BUILDING CHARACTERISTICS SURVEY QUESTIONNAIRE- PERSIAN LANGUAGE

ارزیابی مصرف انرژی در ساختمان های رهایشی

شماره مبایل:(......................................)   ایمیل: (..................................)   اسم :(.............................)
آدرس: (..) ناحیه: (....................................)   شهر : (............................)

(نوت: لطف نموده جواب تان را با ☑ نشانی کنید)

1. نوعیت مسکن:

☐ ساختمان رهایشی مستقل   ☐ آپارتمان رهایشی

2. مساحت زیربنای ساختمان (........................)

3. تعداد طبقه:

☐ یک طبقه   ☐ دوطبقه   ☐ سه طبقه   ☐ بیشتر از سه طبقه

4. تعداد اطاق نشیمن و خواب:

☐ سه اتاق   ☐ چهار اتاق   ☐ بنج اتاق   ☐ شش اتاق   ☐ بیشتر از شش

5. تعداد ساکنان بزرگ در منزل:

☐ دو نفر   ☐ چهارنفر   ☐ شش نفر   ☐ بیشتر از شش نفر

6. تعداد اطفال در منزل :

☐ دوتن   ☐ چهارتن   ☐ شش تن   ☐ بیشتر از شش تن

7. سال ایجاد ساختمان:

☐ 2000   ☐ 2005   ☐ 2010   ☐ 2019

8. نوعیت ساختمان:

☐ آهنکانکریتی   ☐ خشت و ضربی   ☐ خشت و چوب پوش

9. در ساختمان شما کدام نوع عایق حرارتی استفاده شده است؟

☐ پشم شیشه   ☐ پشم سنگ   ☐ فوم   نوع دیگر(..........)   ☐ هیچکدام

10. اوسط مصارف ماهانه بل برق شما در تابستان چند افغانی است؟
(................... افغانی)

11. اوسط مصارف ماهانه بل برق شما در زمستان چند افغانی است؟
(................... افغانی)

12. ازکدام سیستم سردکننده در ساختمان تان استفاده میکنید؟

☐ پکه   ☐ ایرکاندیشنر AC   ☐ کولر آبی   ☐ سیستم سردکننده ی مرکزی

13. تعداد سرد کننده ها در ساختمان
(......................)

14. بنجره (کلکین) ساختمان شما چه نوع است؟

☐ فلزی   ☐ PVC   ☐ چوبی   ☐ المونیمی

15. شیشه ی بنجره های ساختمان شما چه نوع است؟

☐ یک لایه   ☐ دو لایه   ☐ دو لایه Low-e

16. برای گرم کردن ساختان تان از کدام نوع انرژی استفاده میکنید؟

انرژی برقی ☐ گاز ☐ چوب ☐ زغال سنگ ☐ تیل ☐

17. مصارف ماهان ی گاز برای گرم کردن ساختمان تان ؟

5 کیلو گرام ☐ 10 کیلو گرام ☐ 20 کیلو گرام ☐ 40 کیلو گرام ☐

18. وسایل برقی منزل تان را مشخص کنید

یخچال ☐ فریزر ☐ ماشین لباس شویی ☐ Microwave ☐ واترپمپ ☐ بایلر ☐ داش ☐ تلویزیون ☐ کمپیوتر ☐

19. سیستم آب گرم منزل تان چه گونه است؟

بایلر برقی ☐ بایلر گازی ☐ بایلر آفتابی ☐ نوع دیگر(مشخص کنید)...............

20. برای پخت غذا از کدام نوع انرژی استفاده میکنید؟

برق ☐ گاز ☐ تیل ☐ چوب ☐ نوع دیگر(مشخص کنید)....................

21. به طور معمول از چه تعداد گروپ در ساختمان استفاده میکنید؟
(.............................)

22. برای تنویر منزل تان از کدام نوع گروپ استفاده میکنید؟

☐ Incandescent یا گروپ های معمول ☐ Fluorescent فلورسنت ☐ LED ☐ CFL

23. بیشتر انرژی مورد استفاده ی شما در کدام بخش است؟

پخت غذا ☐
گرم کردن و سرد ساختن ساختمان ☐
استفاده از وسایل الکترونیکی ☐
تنویر ساختمان ☐

دیگر مورد (مشخص کنید).................

24. اتاق های خواب و نشیمن در کدام سمت ساختمان شما قرار دارد؟

غرب ☐ شرق ☐ جنوب ☐ شمال ☐

25. آب و هوای داخل ساختمان شما در فصل گرما (تابستان) چگونه است؟

خیلی گرم ☐ گرم ☐ اندکی گرم ☐ معتدل ☐ اندکی سرد ☐ سرد ☐ خیلی سرد ☐

26. آب و هوای داخل ساختمان شما درفصل سرما (زمستان) چگونه است؟

خیلی سرد ☐ سرد ☐ اندکی سرد ☐ معتدل ☐ اندکی گرم ☐ گرم ☐ خیلی گرم ☐

27. آیا از آب و هوای کنونی داخل ساختمان تان رضایت دارید؟
بلی ☐
نخیر ☐

APPENDIX D-1

INVESTIGATION OF SUMMER THERMAL COMFORT SURVEY QUESTIONNAIRE

Transvers Survey

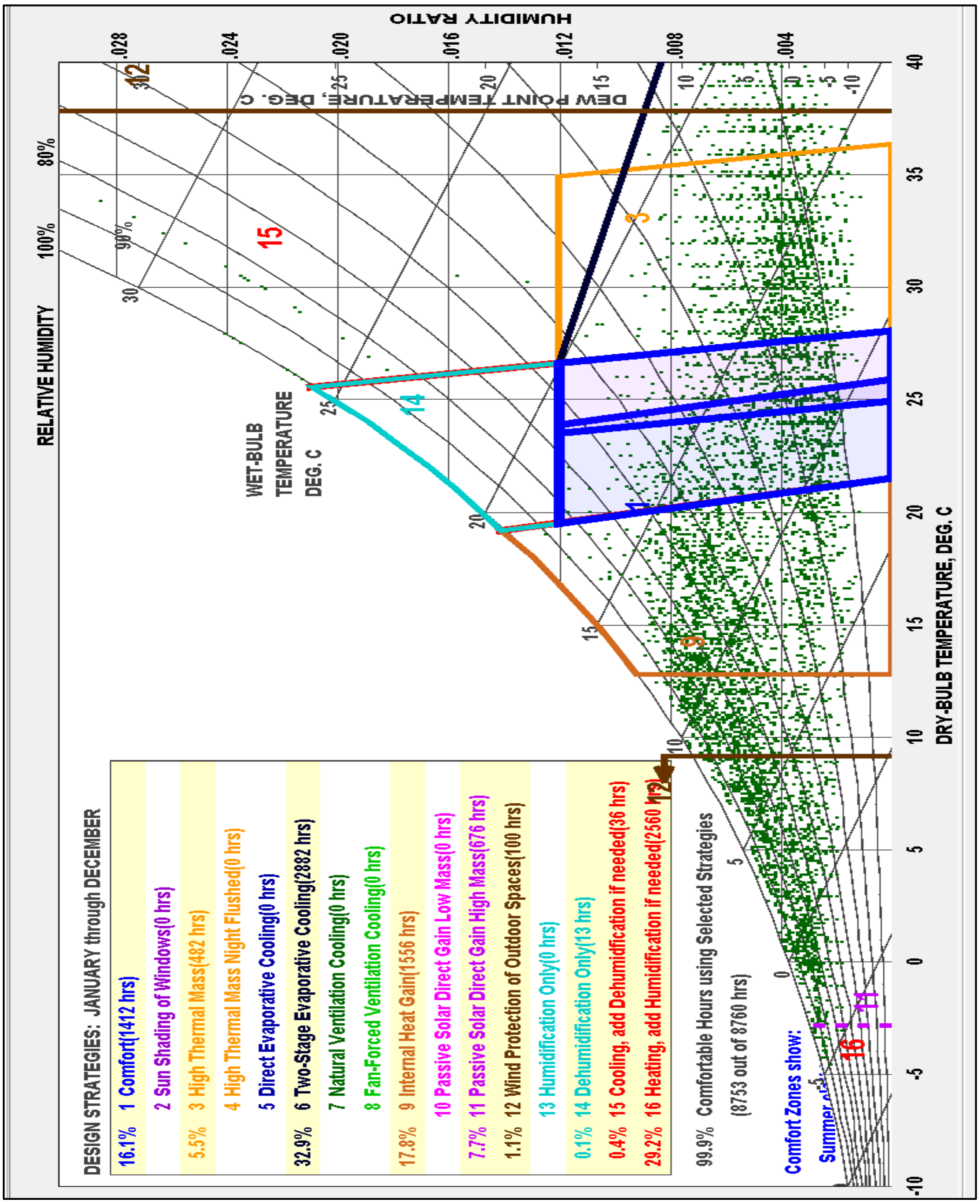
Sex: Male /Female	Block____Flat No._____	Time:
Date: / /	Age:	Weight:

Please tick an appropriate box.			
FEELINGS		***PREFERENCE***	
1. How do you feel?		2. How would you prefer to feel?	
Hot		Much warmer	
Warm		A bit warmer	
Slightly warm		No change	
Neutral		Much cooler	
Slightly cool		Much warmer	
Cool			
Cold			
FEELINGS		***PREFERENCE***	
3. How do you find the air movement?		4. What would you prefer to have?	
Very high		Much more air movement	
High		A bit more air movement	
Slightly high		No change	
Neither high nor low		A bit less air movement	
Slightly low		Much loess air movement	
Low			
Very low			
FEELINGS		***PREFERENCE***	
5. How do you find the humidity?		6. What do you prefer to have?	
Very humid		Much drier	
Humid		A bit drier	
Slightly humid		No change	
Neither humid nor dry		A bit humid	
Slightly dry		Much more humid	
Dry			
Very dry			
FEELINGS		***PREFERENCE***	
7. How do you find the lighting level?		8. What would you prefer to have?	
Very bright		Much dimmer	
Bright		A bit dimmer	
Slightly bright		No change	
Neither bright nor dim		A bit brighter	
Slightly dim		Much brighter	
Dim			
Very dim			
FEELINGS		***PREFERENCE***	
9. How do you find the background noise level?		10. What would you prefer to have?	
Very noisy		Much quieter	
Noisy		A bit quieter	
Slightly noisy		No change	
Neither noisy nor quiet		A bit noisier	
Slightly quiet		Much noisier	
Quiet			
Very quiet			
FEELINGS			
11. How do you find the air quality?		12. How would you rate the overall comfort?	
Very bad		Very comfortable	
Bad		Moderately comfortable	
Slightly bad		Slightly comfortable	
Neither bad nor good		Comfortable	
Slightly good		Slightly uncomfortable	
Good		Moderately uncomfortable	
Excellent		Very uncomfortable	

Please tick an appropriate box.			
PRODUCTIVITY			
11. How is your productivity being affected by the surrounding environmental conditions?		12. Do you have any hot part in your body now?	
Much higher than normal		Neck	
Slightly higher than normal		Back	
Normal		Chest	
Slightly lower than normal		Arm	
Much lower than normal		Feet	
SWEETING		***CLOTHING***	
13. how are you sweating now?		14. What is your clothing material now?	
No sweating		Cotton	
Slightly		Woollen	
Moderate		Polyester	
Profusely		Others (specify)	
ACTIVITY		***CONTROLS***	
15. What have you been doing in the last 15 minutes?		16. Which of the following environmental controls are you using now?	
Lying down		External door open/ closed	
Sitting resting		Balcony door open /closed	
Sitting working		Internal door open/closed	
Standing		Window open/closed	
Standing working		Blinds/curtains open/closed	
Moving around		General lighting on/off	
Sitting and light activity		Local lighting on/off	
Moving around		Local fan on/off	
Sitting and light activity		Air cooler on/ off	
		Air conditioning on/off	
CONTROLS		***CONTROLS***	
17. Which of the following semi-permanent controls are you using now?		18. When feeling hot which of the following actions have you undertaken now?	
Plants in the interior		Sleeping	
Wetted khus mats		Doing something less vigorously	
Extension of shade to windows		Changing posture	
Wetting the floor		Sitting on the floor	
Wetting the roof		Staying in airy places	
Plants in the interior		Avoiding direct sunlight	
		Staying away from heat sources	
		Using hand fan	
		Removing clothing	
		Taking cold shower	
		Drinking cold beverages	
19. Is the current indoor air and temperature acceptable for you?			
Yes			
No			

APPENDIX D-2

PSYCHROMETRIC CHART OF MAZAR-I-SHARIF CITY



APPENDIX E-1

RECORDED INDOOR WEATHER DATA (SAMPLE OF ONE DATA LOGGER)

Device Configuration | **Serial Number**

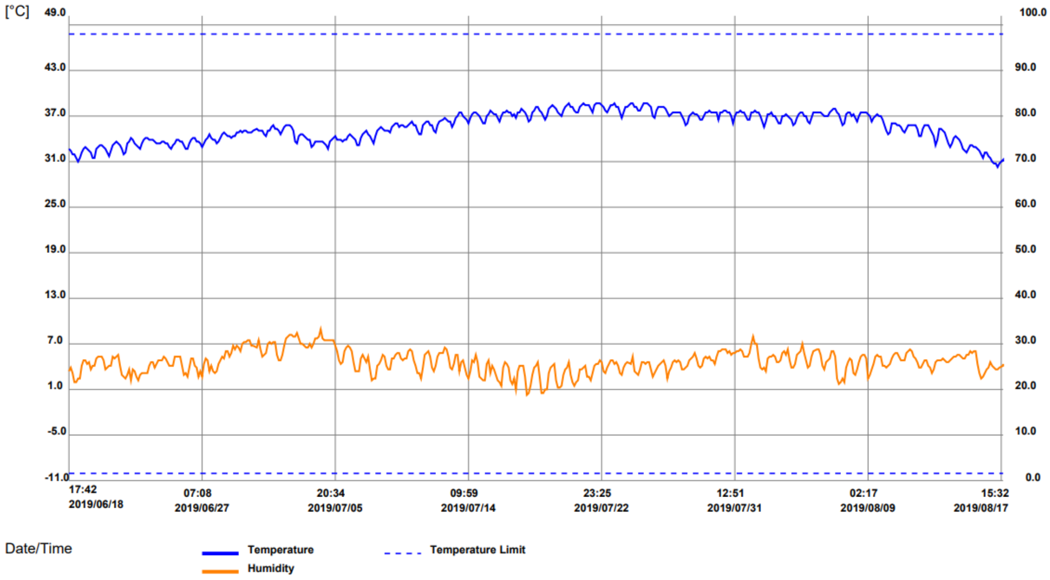
Start Delay:	0 min	Interval Time:	10 min 0 sec	TH 18000436 V1.02
Temp. Limit:	48.0°C /-10.0°C	Humidity Limit:	--/--	

Logging Summary

Max Temp.:	39.0°C	Max Humidity:	35.4%	Start Time:	2019/06/18 17:42:50
Min Temp.:	30.2°C	Min Humidity:	17.6%	Stop Time:	2019/08/17 15:32:50
Average Temp.:	35.7°C	Average Humidity:	26.2%	Total Time:	29 day 21 hr 50 min
MKT:	35.9°C			Data Points:	8628

Note:

Apresys Graph



Temperature/Humidity

Date	Time	°C	%
06/18/2019	17:42:50	32.9	24.1
06/18/2019	17:52:50	32.6	25.1
06/18/2019	18:02:50	32.6	24.7
06/18/2019	18:12:50	32.6	24.5
06/18/2019	18:22:50	32.6	24.4
06/18/2019	18:32:50	32.6	24.5
06/18/2019	18:42:50	32.6	24.5
06/18/2019	18:52:50	32.6	24.5
06/18/2019	19:02:50	32.6	24.6
06/18/2019	19:12:50	32.6	24.7
06/18/2019	19:22:50	32.6	24.7
06/18/2019	19:32:50	32.6	24.7
06/18/2019	19:42:50	32.6	24.7
06/18/2019	19:52:50	32.6	24.5
06/18/2019	20:02:50	32.6	25.8
06/18/2019	20:12:50	32.5	26.0
06/18/2019	20:22:50	32.4	26.0
06/18/2019	20:32:50	32.3	25.7
06/18/2019	20:42:50	32.2	25.6
06/18/2019	20:52:50	32.1	24.7
06/18/2019	21:02:50	32.1	24.6
06/18/2019	21:12:50	32.1	24.4
06/18/2019	21:22:50	32.1	23.9
06/18/2019	21:32:50	32.1	24.3
06/18/2019	21:42:50	32.1	24.2
06/18/2019	21:52:50	32.1	24.0
06/18/2019	22:02:50	32.1	24.0
06/18/2019	22:12:50	32.1	23.2
06/18/2019	22:22:50	32.1	23.7
06/18/2019	22:32:50	32.1	23.4
06/18/2019	22:42:50	32.1	23.9
06/18/2019	22:52:50	32.1	23.1
06/18/2019	23:02:50	32.1	23.6
06/18/2019	23:12:50	32.1	22.9
06/18/2019	23:22:50	32.1	22.9
06/18/2019	23:32:50	32.1	22.7
06/18/2019	23:42:50	32.1	21.6
06/18/2019	23:52:50	32.1	22.1
06/19/2019	00:02:50	32.1	22.2
06/19/2019	00:12:50	32.1	20.7
06/19/2019	00:22:50	32.1	22.3
06/19/2019	00:32:50	32.1	22.4
06/19/2019	00:42:50	32.1	22.6
06/19/2019	00:52:50	32.1	22.2
06/19/2019	01:02:50	32.1	21.5
06/19/2019	01:12:50	32.0	22.2
06/19/2019	01:22:50	32.1	22.6
06/19/2019	01:32:50	32.1	21.9
06/19/2019	01:42:50	32.1	20.8
06/19/2019	01:52:50	32.0	20.9
06/19/2019	02:02:50	32.0	21.8
06/19/2019	02:12:50	31.9	20.8
06/19/2019	02:22:50	31.9	21.9
06/19/2019	02:32:50	31.8	22.3
06/19/2019	02:42:50	31.8	21.4
06/19/2019	02:52:50	31.7	22.4
06/19/2019	03:02:50	31.7	21.8
06/19/2019	03:12:50	31.6	21.5
06/19/2019	03:22:50	31.6	22.0
06/19/2019	03:32:50	31.6	22.3
06/19/2019	03:42:50	31.6	21.8
06/19/2019	03:52:50	31.5	22.2
06/19/2019	04:02:50	31.5	21.8
06/19/2019	04:12:50	31.5	21.2
06/19/2019	04:22:50	31.4	21.1
06/19/2019	04:32:50	31.3	21.7
06/19/2019	04:42:50	31.3	22.8
06/19/2019	04:52:50	31.3	22.3
06/19/2019	05:02:50	31.2	21.5
06/19/2019	05:12:50	31.2	21.7
06/19/2019	05:22:50	31.2	21.7
06/19/2019	05:32:50	31.1	22.1
06/19/2019	05:42:50	31.2	22.5
06/19/2019	05:52:50	31.2	23.5
06/19/2019	06:02:50	31.1	21.7
06/19/2019	06:12:50	31.0	22.5
06/19/2019	06:22:50	31.0	21.7
06/19/2019	06:32:50	31.0	22.0
06/19/2019	06:42:50	31.0	22.8
06/19/2019	06:52:50	30.9	21.7
06/19/2019	07:02:50	31.0	22.6
06/19/2019	07:12:50	31.0	22.1
06/19/2019	07:22:50	31.0	22.5
06/19/2019	07:32:50	31.0	23.4
06/19/2019	07:42:50	31.1	23.7
06/19/2019	07:52:50	31.2	23.8
06/19/2019	08:02:50	31.3	23.5
06/19/2019	08:12:50	31.3	21.6
06/19/2019	08:22:50	31.4	22.7
06/19/2019	08:32:50	31.4	21.8
06/19/2019	08:42:50	31.4	22.2
06/19/2019	08:52:50	31.5	23.3
06/19/2019	09:02:50	31.5	22.8
06/19/2019	09:12:50	31.6	23.0
06/19/2019	09:22:50	31.7	22.9
06/19/2019	09:32:50	31.8	22.8
G2TOP
06/19/2019	16:02:50	32.9	26.6
06/19/2019	16:12:50	32.9	26.6
06/19/2019	16:22:50	32.9	26.6
06/19/2019	16:32:50	32.9	25.3
06/19/2019	16:42:50	33.0	26.6
06/19/2019	16:52:50	33.0	26.7
06/19/2019	17:02:50	33.0	26.7
06/19/2019	17:12:50	33.0	26.8
06/19/2019	17:22:50	33.0	26.2
06/19/2019	17:32:50	33.0	26.6
06/19/2019	17:42:50	33.0	26.8
06/19/2019	17:52:50	33.0	26.9
06/19/2019	18:02:50	33.0	26.8
06/19/2019	18:12:50	33.0	26.9
06/19/2019	18:22:50	33.0	25.2
06/19/2019	18:32:50	33.1	26.9
06/19/2019	18:42:50	33.1	26.8
06/19/2019	18:52:50	33.1	24.8
06/19/2019	19:02:50	33.1	26.5
06/19/2019	19:12:50	33.1	27.2
06/19/2019	19:22:50	33.1	27.1
06/19/2019	19:32:50	33.1	26.8
06/19/2019	19:42:50	33.0	26.9
06/19/2019	19:52:50	33.0	26.8
06/19/2019	20:02:50	32.9	26.9
06/19/2019	20:12:50	32.9	26.6
06/19/2019	20:22:50	32.8	26.5
06/19/2019	20:32:50	32.8	26.5
06/19/2019	20:42:50	32.7	25.8
06/19/2019	20:52:50	32.7	24.9
06/19/2019	21:02:50	32.6	25.4
06/19/2019	21:12:50	32.6	24.5
06/19/2019	21:22:50	32.6	24.3
06/19/2019	21:32:50	32.6	24.7
06/19/2019	21:42:50	32.6	25.3
06/19/2019	21:52:50	32.6	25.1
06/19/2019	22:02:50	32.6	25.1
06/19/2019	22:12:50	32.5	26.2
06/19/2019	22:22:50	32.5	26.0
06/19/2019	22:32:50	32.5	26.4
06/19/2019	22:42:50	32.6	26.2
06/19/2019	22:52:50	32.6	26.8
06/19/2019	23:02:50	32.6	27.3
06/19/2019	23:12:50	32.7	27.5
06/19/2019	23:22:50	32.7	26.9
06/19/2019	23:32:50	32.7	27.4
06/19/2019	23:42:50	32.7	26.5
06/19/2019	23:52:50	32.7	26.3
06/20/2019	00:02:50	32.6	25.7
06/20/2019	00:12:50	32.6	25.8
06/20/2019	00:22:50	32.6	26.4
06/20/2019	00:32:50	32.6	24.8
06/20/2019	00:42:50	32.6	25.1
06/20/2019	00:52:50	32.7	25.0
06/20/2019	01:02:50	32.7	23.9
06/20/2019	01:12:50	32.6	25.4
06/20/2019	01:22:50	32.6	24.2
06/20/2019	01:32:50	32.6	25.1
G3TOP
06/20/2019	08:02:50	31.5	25.6
06/20/2019	08:12:50	31.6	25.4
06/20/2019	08:22:50	31.7	25.4
06/20/2019	08:32:50	31.8	25.1
06/20/2019	08:42:50	32.0	25.1
06/20/2019	08:52:50	32.1	26.0
06/20/2019	09:02:50	32.1	26.4
06/20/2019	09:12:50	32.3	24.8
06/20/2019	09:22:50	32.3	25.6
06/20/2019	09:32:50	32.5	26.7
06/20/2019	09:42:50	32.6	26.8
06/20/2019	09:52:50	32.7	27.0
06/20/2019	10:02:50	32.8	27.0
06/20/2019	10:12:50	32.8	27.1
06/20/2019	10:22:50	32.9	27.1
06/20/2019	10:32:50	32.9	27.2
06/20/2019	10:42:50	32.9	27.2
06/20/2019	10:52:50	32.9	27.2
06/20/2019	11:02:50	33.0	27.2
06/20/2019	11:12:50	33.0	27.2
06/20/2019	11:22:50	33.0	27.2
06/20/2019	11:32:50	33.0	27.2
06/20/2019	11:42:50	33.0	27.2
06/20/2019	11:52:50	33.0	27.2
06/20/2019	12:02:50	33.1	27.2
06/20/2019	12:12:50	33.1	27.3
06/20/2019	12:22:50	33.1	27.3
06/20/2019	12:32:50	33.1	27.3
06/20/2019	12:42:50	33.1	27.3
06/20/2019	12:52:50	33.1	27.3
06/20/2019	13:02:50	33.1	27.3
06/20/2019	13:12:50	33.1	27.3
06/20/2019	13:22:50	33.1	27.3
06/20/2019	13:32:50	33.1	27.3
06/20/2019	13:42:50	33.1	27.3
06/20/2019	13:52:50	33.1	27.3
06/20/2019	14:02:50	33.1	27.3
06/20/2019	14:12:50	33.1	27.3
06/20/2019	14:22:50	33.1	27.3
06/20/2019	14:32:50	33.1	27.3
06/20/2019	14:42:50	33.1	27.3
06/20/2019	14:52:50	33.2	27.3
06/20/2019	15:02:50	33.2	27.3
06/20/2019	15:12:50	33.2	27.3
06/20/2019	15:22:50	33.2	27.4
06/20/2019	15:32:50	33.2	27.4
06/20/2019	15:42:50	33.2	27.3
06/20/2019	15:52:50	33.3	27.1
06/20/2019	16:02:50	33.3	27.3
06/20/2019	16:12:50	33.3	27.3
06/20/2019	16:22:50	33.3	27.3
06/20/2019	16:32:50	33.3	27.3
06/20/2019	16:42:50	33.3	27.3
06/20/2019	16:52:50	33.3	27.3
06/20/2019	17:02:50	33.3	27.2
06/20/2019	17:12:50	33.4	27.2
06/20/2019	17:22:50	33.4	27.2
06/20/2019	17:32:50	33.4	27.2
G4G5G6

Temperature/Humidity

Date	Time	°C	%	Date	Time	°C	%	Date	Time	°C	%	Date	Time	°C	%	Date	Time	°C	%	Date	Time	°C	%
06/22/2019	17:42:50	34.4	24.7	06/23/2019	09:42:50	33.5	24.8	06/24/2019	01:42:50	34.1	26.7	06/24/2019	17:42:50	33.8	27.0	06/25/2019	09:42:50	33.1	23.7	06/26/2019	01:42:50	33.6	21.6
06/22/2019	17:52:50	34.3	25.0	06/23/2019	09:52:50	33.6	23.0	06/24/2019	01:52:50	34.1	26.8	06/24/2019	17:52:50	33.8	27.1	06/25/2019	09:52:50	33.2	24.8	06/26/2019	01:52:50	33.5	22.6
06/22/2019	18:02:50	34.2	24.9	06/23/2019	10:02:50	33.7	25.2	06/24/2019	02:02:50	34.1	26.9	06/24/2019	18:02:50	33.8	27.0	06/25/2019	10:02:50	33.2	24.7	06/26/2019	02:02:50	33.5	24.3
06/22/2019	18:12:50	34.2	23.8	06/23/2019	10:12:50	33.7	25.3	06/24/2019	02:12:50	34.1	26.8	06/24/2019	18:12:50	33.8	27.1	06/25/2019	10:12:50	33.2	25.1	06/26/2019	02:12:50	33.5	24.7
06/22/2019	18:22:50	34.2	25.1	06/23/2019	10:22:50	33.8	25.1	06/24/2019	02:22:50	34.0	26.8	06/24/2019	18:22:50	33.8	26.9	06/25/2019	10:22:50	33.3	25.0	06/26/2019	02:22:50	33.4	22.5
06/22/2019	18:32:50	34.2	23.7	06/23/2019	10:32:50	33.8	25.3	06/24/2019	02:32:50	34.0	26.9	06/24/2019	18:32:50	33.8	26.9	06/25/2019	10:32:50	33.3	25.5	06/26/2019	02:32:50	33.3	23.4
06/22/2019	18:42:50	34.2	25.3	06/23/2019	10:42:50	33.8	25.1	06/24/2019	02:42:50	34.0	26.9	06/24/2019	18:42:50	33.8	27.2	06/25/2019	10:42:50	33.4	25.6	06/26/2019	02:42:50	33.3	22.4
06/22/2019	18:52:50	34.2	25.5	06/23/2019	10:52:50	33.9	25.2	06/24/2019	02:52:50	34.0	26.9	06/24/2019	18:52:50	33.8	27.4	06/25/2019	10:52:50	33.4	26.4	06/26/2019	02:52:50	33.3	23.1
06/22/2019	19:02:50	34.1	25.6	06/23/2019	11:02:50	33.9	25.1	06/24/2019	03:02:50	34.0	27.0	06/24/2019	19:02:50	33.8	27.4	06/25/2019	11:02:50	33.4	27.2	06/26/2019	03:02:50	33.2	24.3
06/22/2019	19:12:50	34.1	25.6	06/23/2019	11:12:50	33.9	25.0	06/24/2019	03:12:50	34.0	27.0	06/24/2019	19:12:50	33.8	27.4	06/25/2019	11:12:50	33.5	26.8	06/26/2019	03:12:50	33.2	22.8
06/22/2019	19:22:50	34.1	25.6	06/23/2019	11:22:50	33.9	24.1	06/24/2019	03:22:50	34.0	27.0	06/24/2019	19:22:50	33.8	26.1	06/25/2019	11:22:50	33.5	27.4	06/26/2019	03:22:50	33.1	23.5
06/22/2019	19:32:50	34.1	24.8	06/23/2019	11:32:50	33.9	24.2	06/24/2019	03:32:50	34.0	25.8	06/24/2019	19:32:50	33.8	26.5	06/25/2019	11:32:50	33.5	27.4	06/26/2019	03:32:50	33.1	24.4
06/22/2019	19:42:50	34.1	25.6	06/23/2019	11:42:50	34.0	22.6	06/24/2019	03:42:50	34.0	24.4	06/24/2019	19:42:50	33.8	26.0	06/25/2019	11:42:50	33.5	27.4	06/26/2019	03:42:50	33.1	22.7
06/22/2019	19:52:50	34.1	22.9	06/23/2019	11:52:50	34.0	24.7	06/24/2019	03:52:50	33.9	24.5	06/24/2019	19:52:50	33.7	26.4	06/25/2019	11:52:50	33.6	27.4	06/26/2019	03:52:50	33.1	23.2
06/22/2019	20:02:50	34.1	24.9	06/23/2019	12:02:50	34.0	25.0	06/24/2019	04:02:50	33.8	22.5	06/24/2019	20:02:50	33.7	28.3	06/25/2019	12:02:50	33.6	27.5	06/26/2019	04:02:50	33.0	24.2
06/22/2019	20:12:50	34.0	22.8	06/23/2019	12:12:50	34.0	23.5	06/24/2019	04:12:50	33.8	22.8	06/24/2019	20:12:50	33.7	28.0	06/25/2019	12:12:50	33.6	27.5	06/26/2019	04:12:50	33.0	24.1
06/22/2019	20:22:50	34.0	24.8	06/23/2019	12:22:50	34.0	24.7	06/24/2019	04:22:50	33.8	26.4	06/24/2019	20:22:50	33.6	28.0	06/25/2019	12:22:50	33.6	27.4	06/26/2019	04:22:50	32.9	24.2
06/22/2019	20:32:50	33.9	23.9	06/23/2019	12:32:50	34.0	22.7	06/24/2019	04:32:50	33.8	24.5	06/24/2019	20:32:50	33.6	27.9	06/25/2019	12:32:50	33.6	26.9	06/26/2019	04:32:50	32.9	23.4
06/22/2019	20:42:50	33.9	23.2	06/23/2019	12:42:50	34.0	19.8	06/24/2019	04:42:50	33.8	24.7	06/24/2019	20:42:50	33.6	27.9	06/25/2019	12:42:50	33.6	27.6	06/26/2019	04:42:50	32.8	22.4
06/22/2019	20:52:50	33.8	24.7	06/23/2019	12:52:50	34.1	22.9	06/24/2019	04:52:50	33.8	26.2	06/24/2019	20:52:50	33.6	27.9	06/25/2019	12:52:50	33.6	27.5	06/26/2019	04:52:50	32.7	23.2
06/22/2019	21:02:50	33.8	24.0	06/23/2019	13:02:50	34.1	24.1	06/24/2019	05:02:50	33.8	26.6	06/24/2019	21:02:50	33.6	27.9	06/25/2019	13:02:50	33.6	27.7	06/26/2019	05:02:50	32.7	24.7
06/22/2019	21:12:50	33.7	24.9	06/23/2019	13:12:50	34.1	23.5	06/24/2019	05:12:50	33.8	26.6	06/24/2019	21:12:50	33.6	28.2	06/25/2019	13:12:50	33.7	27.7	06/26/2019	05:12:50	32.8	24.1
06/22/2019	21:22:50	33.7	24.5	06/23/2019	13:22:50	34.1	23.3	06/24/2019	05:22:50	33.8	24.7	06/24/2019	21:22:50	33.6	28.0	06/25/2019	13:22:50	33.7	27.7	06/26/2019	05:22:50	32.9	22.6
06/22/2019	21:32:50	33.7	23.8	06/23/2019	13:32:50	34.1	23.4	06/24/2019	05:32:50	33.7	23.1	06/24/2019	21:32:50	33.6	29.1	06/25/2019	13:32:50	33.7	27.7	06/26/2019	05:32:50	32.9	21.8
06/22/2019	21:42:50	33.7	24.8	06/23/2019	13:42:50	34.1	24.3	06/24/2019	05:42:50	33.7	24.3	06/24/2019	21:42:50	33.6	27.9	06/25/2019	13:42:50	33.7	27.7	06/26/2019	05:42:50	32.9	25.5
06/22/2019	21:52:50	33.7	24.6	06/23/2019	13:52:50	34.1	24.2	06/24/2019	05:52:50	33.7	23.6	06/24/2019	21:52:50	33.6	27.6	06/25/2019	13:52:50	33.7	27.8	06/26/2019	05:52:50	32.9	25.1
06/22/2019	22:02:50	33.7	24.5	06/23/2019	14:02:50	34.1	23.6	06/24/2019	06:02:50	33.7	26.1	06/24/2019	22:02:50	33.6	27.5	06/25/2019	14:02:50	33.7	27.7	06/26/2019	06:02:50	32.9	24.0
06/22/2019	22:12:50	33.7	24.9	06/23/2019	14:12:50	34.2	24.4	06/24/2019	06:12:50	33.7	24.2	06/24/2019	22:12:50	33.6	26.9	06/25/2019	14:12:50	33.7	27.6	06/26/2019	06:12:50	32.9	24.2
06/22/2019	22:22:50	33.7	24.9	06/23/2019	14:22:50	34.2	24.3	06/24/2019	06:22:50	33.6	23.5	06/24/2019	22:22:50	33.6	27.4	06/25/2019	14:22:50	33.7	27.6	06/26/2019	06:22:50	32.9	23.4
06/22/2019	22:32:50	33.7	25.7	06/23/2019	14:32:50	34.2	24.3	06/24/2019	06:32:50	33.5	24.1	06/24/2019	22:32:50	33.6	26.0	06/25/2019	14:32:50	33.7	27.5	06/26/2019	06:32:50	32.9	23.7
06/22/2019	22:42:50	33.7	23.8	06/23/2019	14:42:50	34.2	22.6	06/24/2019	06:42:50	33.5	25.2	06/24/2019	22:42:50	33.6	26.4	06/25/2019	14:42:50	33.7	27.7	06/26/2019	06:42:50	32.7	25.0
06/22/2019	22:52:50	33.7	24.1	06/23/2019	14:52:50	34.2	24.0	06/24/2019	06:52:50	33.5	25.3	06/24/2019	22:52:50	33.6	26.7	06/25/2019	14:52:50	33.8	27.7	06/26/2019	06:52:50	32.7	23.4
06/22/2019	23:02:50	33.6	24.6	06/23/2019	15:02:50	34.2	24.0	06/24/2019	07:02:50	33.5	25.1	06/24/2019	23:02:50	33.6	26.3	06/25/2019	15:02:50	33.8	27.5	06/26/2019	07:02:50	32.5	23.1
06/22/2019	23:12:50	33.6	24.4	06/23/2019	15:12:50	34.2	23.6	06/24/2019	07:12:50	33.5	26.2	06/24/2019	23:12:50	33.6	26.0	06/25/2019	15:12:50	33.9	27.6	06/26/2019	07:12:50	32.5	23.0
06/22/2019	23:22:50	33.5	24.0	06/23/2019	15:22:50	34.2	24.1	06/24/2019	07:22:50	33.5	26.5	06/24/2019	23:22:50	33.6	26.7	06/25/2019	15:22:50	33.9	27.5	06/26/2019	07:22:50	32.5	23.7
06/22/2019	23:32:50	33.5	22.7	06/23/2019	15:32:50	34.2	24.1	06/24/2019	07:32:50	33.5	26.5	06/24/2019	23:32:50	33.7	26.1	06/25/2019	15:32:50	34.0	27.7	06/26/2019	07:32:50	32.4	24.3
06/22/2019	23:42:50	33.5	24.1	06/23/2019	15:42:50	34.2	24.0	06/24/2019	07:42:50	33.6	24.8	06/24/2019	23:42:50	33.7	27.7	06/25/2019	15:42:50	34.0	27.3	06/26/2019	07:42:50	32.4	23.6
06/22/2019	23:52:50	33.5	24.3	06/23/2019	15:52:50	34.2	24.0	06/24/2019	07:52:50	33.6	26.5	06/24/2019	23:52:50	33.7	27.7	06/25/2019	15:52:50	34.0	27.4	06/26/2019	07:52:50	32.5	24.4
06/23/2019	00:02:50	33.5	24.7	06/23/2019	16:02:50	34.3	23.9	06/24/2019	08:02:50	33.6	26.6	06/25/2019	00:02:50	33.7	26.2	06/25/2019	16:02:50	34.0	27.6	06/26/2019	08:02:50	32.5	23.4
06/23/2019	00:12:50	33.5	24.3	06/23/2019	16:12:50	34.3	23.9	06/24/2019	08:12:50	33.6	26.5	06/25/2019	00:12:50	33.7	27.5	06/25/2019	16:12:50	34.0	27.7	06/26/2019	08:12:50	32.6	22.5
06/23/2019	00:22:50	33.5	24.2	06/23/2019	16:22:50	34.3	23.9	06/24/2019	08:22:50	33.6	26.5	06/25/2019	00:22:50	33.7	26.9	06/25/2019	16:22:50	34.0	27.2	06/26/2019	08:22:50	32.6	23.4
06/23/2019	00:32:50	33.4	24.0	06/23/2019	16:32:50	34.3	23.8	06/24/2019	08:32:50	33.6	26.7	06/25/2019	00:32:50	33.7	27.0	06/25/2019	16:32:50	34.0	27.3	06/26/2019	08:32:50	32.6	23.4
06/23/2019	00:42:50	33.4	24.0	06/23/2019	16:42:50	34.3	23.8	06/24/2019	08:42:50	33.6	26.2	06/25/2019	00:42:50	33.7	27.7	06/25/2019	16:42:50	34.1	27.7	06/26/2019	08:42:50	32.7	22.2
06/23/2019	00:52:50	33.4	22.9	06/23/2019	16:52:50	34.3	23.8	06/24/2019	08:52:50	33.5	24.8	06/25/2019	00:52:50	33.7	27.6	06/25/2019	16:52:50	34.1	27.6	06/26/2019	08:52:50	32.8	23.1
06/23/2019	01:02:50	33.4	23.3	06/23/2019	17:02:50	34.3	23.8	06/24/2019	09:02:50	33.5	24.5	06/25/2019	01:02:50	33.7	27.6	06/25/2019	17:02:50	34.1	27.8	06/26/2019	09:02:50	32.9	23.0
06/23/2019	01:12:50	33.3	22.1	06/23/2019	17:12:50	34.3	23.9	06/24/2019	09:12:50	33.5	25.0	06/25/2019	01:12:50	33.7	26.2	06/25/2019	17:12:50	34.1	27.8	06/26/2019	09:12:50	32.9	23.2
06/23/2019	01:22:50	33.2	22.4	06/23/2019	17:22:50	34.3	23.9	06/24/2019	09:22:50	33.5	26.1	06/25/2019	01:22:50	33.7	25.8	06/25/2019	17:22:50	34.1	27.6	06/26/2019	09:22:50	33.0	21.9
06/23/2019	01:32:50	33.2	21.9	06/23/2019	17:32:50	34.3	23.9	06/24/2019	09:32:50	33.5	26.4	06/25/2019	01:32:50	33.7	25.5	06/25/2019	17:32:50	34.1	27.7	06/26/2019	09:32:50	33.1	21.7
06/23/2019	01:42:50	33.2	21.1	06/23/2019	17:42:50	34.3	23.9	06/24/2019	09:42:50	33.5	26.7	06/25/2019	01:42:50	33.6	25.2	06/25/2019	17:42:50	34.2	27.6	06/26/2019	09:42:50	33.2	22.3
06/23/2019	01:52:50	33.2	21.8	06/23/2019	17:52:50	34.3	23.9	06/24/2019	09:52:50	33.5	26.1	06/25/2019	01:52:50	33.6	25.0	06/25/2019	17:52:50	34.2	27.0	06/26/2019	09:52:50	33.2	21.9
06/23/2019	02:02:50	33.2	22.4	06/23/2019	18:02:50	34.3	23.9	06/24/2019	10:02:50	33.5	26.9	06/25/2019	02:02:50	33.5	25.4	06/25/2019	18:02:50	34.2	27.7	06/26/2019	10:02:50	33.3	22.4
06/23/2019	02:12:50	33.2	21.5	06/23/2019	18:12:50	34.3	24.0	06/24/2019	10:12:50	33.6	26.5	06/25/2019	02:12:50	33.5	25.2	06/25/2019	18:12:50	34.2	27.8	06/26/2019	10:12:50	33.4	21.3
06/23/2019	02:22:50	33.2	21.4	06/23/2019	18:22:50	34.2	24.1	06/24/2019	10:22:50	33.6	26.8	06/25/2019	02:22:50	33.4	25.1	06/25/2019	18:22:50	34.2	27.9	06/26/2019	10:22:50	33.5	21.8
06/23/2019	02:32:50	33.2	22.4	06/23/2019	18:32:50	34.2	24.1	06/24/2019	10:32:50	33.6	26.9	06/25/2019	02:32:50	33.2	25.1	06/25/2019	18:32:50	34.2	28.0	06/26/2019	10:32:50	33.5	21.9
06/23/2019	02:42:50	33.2	21.8	06/23/2019	18:42:50	34.2	24.2	06/24/2019	10:42:50	33.6	26.9	06/25/2019	02:42:50	33.2	24.8	06/25/2019	18:42:50	34.2	28.0	06/26/2019	10:42:50	33.6	22.7
06/23/2019	02:52:50	33.1	22.6	06/23/2019	18:52:50	34.2	24.2	06/24/2019	10:52:50	33.6	25.7	06/25/2019	02:52:50	33.1	25.7	06/25/2019	18:52:50	34.2	27.9	06/26/2019	10:52:50	33.7	25.3
06/23/2019	03:02:50	33.1	23.8	06/23/2019	19:02:50	34.2	24.2	06/24/2019	11:02:50	33.6	26.3	06/25/2019	03:02:50	33.1	25.6	06/25/2019	19:02:50	34.2	28.0	06/26/2019	11:02:50	33.7	25.2
06/23/2019	03:12:50	33.1	21.8	06/23/2019	19:12:50	34.2	24.3	06/24/2019	11:12:50	33.6	26.8	06/25/2019	03:12:50	33.1	25.1	06/25/2019	19:12:50	34.2	25.0	06/26/2019	11:12:50	33.7	25.9
06/23/2019	03:22:50	33.1	21.5	06/23/2019	19:22:50	34.2	24.3	06/24/2019	11:22:50	33.6	26.7	06/25/2019	03:22:50	33.1	25.4	06/25/2019	19:22:50	34.1	24.8	06/26/2019	11:22:50	33.7	25.5
06/23/2019	03:32:50	33.1	22.4	06/23/2019	19:32:50	34.2	23.1	06/24/2019	11:32:50	33.6	26.3	06/25/2019	03:32:50	32.9	25.3	06/25/2019	19:32:50	34.1	25.0	06/26/2019	11:32:50	33.7	26.1
06/23/2019	03:42:50	33.1	21.9	06/23/2019	19:42:50	34.1	24.4	06/24/2019	11:42:50	33.6	27.1	06/25/2019	03:42:50	32.9	24.6	06/25/2019	19:42:50	34.1	26.8	06/26/2019	11:42:50	33.8	26.3
06/23/2019	03:52:50	33.1	22.5	06/23/2019	19:52:50	34.1	24.4	06/24/2019	11:52:50	33.6	27.1	06/25/2019	03:52:50	32.9	24.9	06/25/2019	19:52:50	34.1	27.8	06/26/2019	11:52:50	33.8	26.3
06/23/2019	04:02:50	33.1	22.4	06/23/2019	20:02:50	34.1	24.6	06/24/2019	12:02:50	33.6	27.1	06/25/2019	04:02:50	32.8	23.8	06/25/2019	20:02:50	34.0	28.1	06/26/2019	12:02:50	33.8	26.4
06/23/2019	04:12:50	33.1	21.2	06/23/2019	20:12:50	34.0	25.0	06/24/2019	12:12:50	33.6	26.1	06/25/2019	04:12:50	32.7	23.0	06/25/2019	20:12:50	34.0	27.9	06/26/2019	12:12:50	33.8	26.5
06/23/2019	04:22:50	33.2	22.6	06/23/2019	20:22:50	34.0	24.1	06/24/2019	12:22:50	33.6	27.1	06/25/2019	04:22:50	32.8	26.0	06/25/2019	20:22:50	33.9	27.8	06/26/2019	12:22:50	33.8	26.6
06/23/2019	04:32:50	33.1	21.9	06/23/2019	20:32:50	34.0	25.2	06/24/2019	12:32:50	33.6	26.7	06/25/2019	04:32:50	32.9	25.4	06/25/2019	20:32:50	33.9	27.8	06/26/2019	12:32:50	33.9	26.6
06/23/2019	04:42:50	33.1	21.3	06/23/2019	20:42:50	34.0	25.3	06/24/2019	12:42:50	33.6	27.1	06/25/2019	04:42:50	33.0	24.8	06/25/2019	20:42:50	33.8	27.9	06/26/2019	12:42:50	33.9	26.7
06/23/2019	04:52:50	33.1	22.8	06/23/2019	20:52:50	34.0	25.4	06/24/2019	12:52:50	33.6	24.9	06/25/2019	04:52:50	33.0	26.8	06/25/2019	20:52:50	33.8	27.8	06/26/2019	12:52:50	33.9	26.7
06/23/2019	05:02:50	33.0	22.7	06/23/2019	21:02:50	34.0	25.5	06/24/2019	13:02:50	33.6	26.9	06/25/2019	05:02:50	33.2	27.2	06/25/2019	21:02:50	33.8	27.9	06/26/2019	13:02:50	33.9	26.7
06/23/2019	05:12:50	32.9	21.9	06/23/2019	21:12:50	33.9	25.4	06/24/2019	13:12:50	33.6	26.6	06/25/2019	05:12:50	33.2	26.4	06/25/2019	21:12:50	33.7	28.1	06/26/2019	13:12:50	33.9	26.8
06/23/2019	05:22:50	32.8	21.6	06/23/2019	21:22:50	33.9	25.5	06/24/2019	13:22:50	33.6	26.9	06/25/2019	05:22:50	33.3	26.9	06/25/2019	21:22:50	33.7	27.3	06/26/2019	13:22:50	34.0	26.8
06/23/2019	05:32:50	32.9	22.5	06/23/2019	21:32:50	34.0	25.6	06/24/2019	13:32:50	33.6	27.0	06/25/2019	05:32:50	33.3	26.6	06/25/2019	21:32:50	33.7	26.7	06/26/2019	13:32:50	34.0	26.9
06/23/2019	05:42:50	32.8	23.3	06/23/2019	21:42:50	33.9	25.8	06/24/2019	13:42:50	33.6	26.5	06/25/2019	05:42:50	33.4	27.3	06/25/2019	21:42:50	33.7	26.2	06/26/2019	13:42:50	34.0	27.0
06/23/2019	05:52:50	32.9	22.6	06/23/2019	21:52:50	33.9	25.9	06/24/2019	13:52:50	33.6	26.6	06/25/2019	05:52:50	33.4	26.0	06/25/2019	21:52:50	33.7	26.1	06/26/2019	13:52:50	34.0	26.7
06/23/2019	06:02:50	32.9	22.6	06/23/2019	22:02:50	33.9	25.9	06/24/2019	14:02:50	33.6	26.9	06/25/2019	06:02:50	33.3	26.2	06/25/2019	22:02:50	33.7	26.3	06/26/2019	14:02:50	34.0	26.9
06/23/2019	06:12:50	32.9	22.4	06/23/2019	22:12:50	34.0	26.0	06/24/2019	14:12:50	33.7	27.1	06/25/2019	06:12:50	33.3	24.9	06/25/2019	22:12:50	33.7	26.3	06/26/2019	14:12:50	34.0	27.0
06/23/2019	06:22:50	32.9	23.5	06/23/2019	22:22:50	34.0	26.0	06/24/2019	14:22:50	33.7	27.1	06/25/2019	06:22:50	33.2	25.8	06/25/2019	22:22:50	33.7	26.3	06/26/2019	14:22:50	34.0	26.8
06/23/2019	06:32:50	32.8	23.3	06/23/2019	22:32:50	34.0	26.0	06/24/2019	14:32:50	33.7	27.0	06/25/2019	06:32:50	33.1	25.6	06/25/2019	22:32:50	33.7	27.3	06/26/2019	14:32:50	34.0	26.9
06/23/2019	06:42:50	32.9	23.1	06/23/2019	22:42:50	34.0	26.0	06/24/2019	14:42:50	33.7	26.5	06/25/2019	06:42:50	32.9	25.3	06/25/2019	22:42:50	33.7	27.5	06/26/2019	14:42:50	34.1	26.6
06/23/2019	06:52:50	33.0	23.6	06/23/2019	22:52:50	34.0	26.0	06/24/2019	14:52:50	33.7	26.8	06/25/2019	06:52:50	32.9	25.7	06/25/2019	22:52:50	33.8	26.8	06/26/2019	14:52:50	34.1	27.0
06/23/2019	07:02:50	33.0	23.1	06/23/2019	23:02:50	34.1	26.1	06/24/2019	15:02:50	33.7	26.9	06/25/2019	07:02:50	32.9	25.3	06/25/2019	23:02:50	33.8	25.9	06/26/2019	15:02:50	34.1	26.5
06/23/2019	07:12:50	33.0	23.2	06/23/2019	23:12:50	34.1	26.1	06/24/2019	15:12:50	33.7	27.0	06/25/2019	07:12:50	32.9	25.0	06/25/2019	23:12:50	33.8	26.9	06/26/2019	15:12:50	34.1	26.9
06/23/2019	07:22:50	33.0	23.9	06/23/2019	23:22:50	34.1	26.1	06/24/2019	15:22:50	33.7	24.4	06/25/2019	07:22:50	32.8	22.8	06/25/2019	23:22:50	33.8	27.0	06/26/2019	15:22:50	34.1	26.9
06/23/2019	07:32:50	33.0	23.7	06/23/2019	23:32:50	34.1	26.1	06/24/2019	15:32:50	33.7	26.9	06/25/2019	07:32:50	32.5	23.4	06/25/2019	23:32:50	33.8	25.1	06/26/2019	15:32:50	34.1	27.0
06/23/2019	07:42:50	33.0	23.0	06/23/2019	23:42:50	34.1	26.2	06/24/2019	15:42:50	33.7	26.6	06/25/2019	07:42:50	32.5	25.3	06/25/2019	23:42:50	33.8	24.7	06/26/2019	15:42:50	34.1	27.1
06/23/2019	07:52:50	33.0	23.8	06/23/2019	23:52:50	34.1	26.3	06/24/2019	15:52:50	33.7	26.7	06/25/2019	07:52:50	32.5	25.4	06/25/2019	23:52:50	33.8	24.7	06/26/2019	15:52:50	34.1	27.2
06/23/2019	08:02:50	33.1	23.0	06/24/2019	00:02:50	34.1	26.3	06/24/2019	16:02:50	33.7	26.3	06/25/2019	08:02:50	32.7	25.7	06/26/2019	00:02:50	33.7	25.0	06/26/2019	16:02:50	34.2	27.2
06/23/2019	08:12:50	33.1	23.8	06/24/2019	00:12:50	34.1	26.4	06/24/2019	16:12:50	33.7	26.8	06/25/2019	08:12:50	32.8	25.4	06/26/2019	00:12:50	33.7	25.1	06/26/2019	16:12:50	34.2	27.2
06/23/2019	08:22:50	33.1	23.1	06/24/2019	00:22:50	34.1	26.5	06/24/2019	16:22:50	33.7	25.3	06/25/2019	08:22:50	32.9	25.1	06/26/2019	00:22:50	33.7	26.5	06/26/2019	16:22:50	34.2	27.2
06/23/2019	08:32:50	33.1	22.5	06/24/2019	00:32:50	34.1	26.8	06/24/2019	16:32:50	33.8	26.3	06/25/2019	08:32:50	33.0	26.9	06/26/2019	00:32:50	33.7	24.6	06/26/2019	16:32:50	34.2	27.2
06/23/2019	08:42:50	33.1	23.3	06/24/2019	00:42:50	34.1	26.5	06/24/2019	16:42:50	33.8	25.0	06/25/2019	08:42:50	33.1	25.5	06/26/2019	00:42:50	33.7	24.9	06/26/2019	16:42:50	34.2	26.4
06/23/2019	08:52:50	33.1	21.3	06/24/2019	00:52:50	34.1	26.5	06/24/2019	16:52:50	33.8	25.1	06/25/2019	08:52:50	33.2	27.1	06/26/2019	00:52:50	33.7	24.5	06/26/2019	16:52:50	34.2	27.2
06/23/2019	09:02:50	33.2	21.7	06/24/2019	01:02:50	34.1	26.5	06/24/2019	17:02:50	33.8	26.3	06/25/2019	09:02:50	33.2	26.2	06/26/2019	01:02:50	33.7	24.2	06/26/2019	17:02:50	34.3	27.2
06/23/2019	09:12:50	33.2	21.6	06/24/2019	01:12:50	34.1	26.8	06/24/2019	17:12:50	33.8	26.6	06/25/2019	09:12:50	33.2	23.8	06/26/2019	01:12:50	33.6	24.2	06/26/2019	17:12:50	34.3	27.3
06/23/2019	09:22:50	33.3	22.2	06/24/2019	01:22:50	34.1	26.7	06/24/2019	17:22:50	33.8	26.7	06/25/2019	09:22:50	33.1	25.0	06/26/2019	01:22:50	33.6	23.8	06/26/2019	17:22:50	34.3	27.0
06/23/2019	09:32:50	33.4	23.2	06/24/2019	01:32:50	34.1	26.7	06/24/2019	17:32:50	33.8	27.0	06/25/2019	09:32:50	33.1	24.6	06/26/2019	01:32:50	33.6	26.3	06/26/2019	17:32:50	34.3	25.7

APPENDIX E-2

LOCAL CONSTRUCTION MATERIAL SAMPLES

a) Plaster sample b) brick sample

b) Testing instrument (Hot disk)

APPENDIX E-3

THERMAL SPECIFICATION REPORT OF TRADITIONAL BRICK

Mahindra TERI Centre of Excellence

teri | MahindraLIFESPACES

Building A Greener Urban Future

ilac-MRA

MTCoE/TR/F.01, Issue No.-02

TC-8746

Test Report

ULR No.: TC874620000000030F

Report No. MT-B-TPS-062001

Date of issue: 19/06/2020

This test report has been generated at the Mahindra TERI Center of Excellence Material Testing Laboratory. The test specimen has been tested for its Thermal Conductivity, Thermal Diffusivity and Specific Heat Capacity.

1. CUSTOMER INFORMATION

Name of the Organization	:	Delhi Technological University
Contact Person	:	Shambalid Ahady
Address	:	DTU, Shahabad Dawlatpur, Rohini, Delhi-110042
Phone Number	:	8826940811
Email	:	Shambalid.ahady_phd2k18@dtu.ac.in

2. SAMPLE DETAILS

a.	Description of Sample	:	Afghanistan Traditional Brick
b.	Date of Receipt	:	12/06/2020
c.	Sample IDs	:	MT-B-TPS-12062001
d.	Date of Testing	:	15/06/2020
e.	Sample Thickness	:	70mm
f.	Density of the sample (as reported by customer)	:	-
g.	Test Method[1]	:	MTCoE/SOP/01:01-02-2019
h.	Machine Used	:	Thermal Constant Analyzer TPS
i.	Sample Conditioning	:	25±4ºC
j.	Sensor used in the Measurement	:	Kapton 5501
k.	Measurement time	:	40 s
l.	Power	:	114.89 mW
m.	Time Window	:	36.836 s
n.	Scanning rate	:	406.184 ms

[1] Test Method MTCoE/SOP/01:01-02-2019 is based upon ISO:22007-2:2015

Mahindra TERI Centre of Excellence, TERI Gram, Gual Pahari, Gurgaon - Faridabad Road, Gurugram - 122 102, Haryana, India.
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3. **RESULTS:**

Sample Name	Sample Temperature (°C)	Thermal Conductivity* (W/mK)	Thermal Diffusivity* (mm^2/s)	Specific Heat Capacity* (MJ/m^3K)
Afghanistan Traditional Brick	24.3	0.7028	0.7313	0.9612

** Reported Result is average of ten measurements*

-------------- End of Report--------------

Bhushan Sharma
Quality Manager

Megha Behal
Area Convenor
Authorized Signatory

Disclaimers

- The above results refer only to the tested sample(s) and applicable parameters submitted by the customer.
- Samples will be destroyed after 15 days from the date of issue of test report unless otherwise specified.
- This report shall not be reproduced, wholly or in part and cannot be used as evidence in the court of law and should not be used in any advertising media without special permission in writing from Laboratory.
- In case any reconfirmation of contents of the test report is required, please contact the authorized signatory of the test report within 15 days of the issue of the report.

APPENDIX E-4

THERMAL SPECIFICATION REPORT OF GS PLASTER

Test Report

ULR No.: TC874620000000001F **Date of issue: 31/01/2020**
Report No. MT-A-TPS-012001

This test report has been generated at the Mahindra TERI Center of Excellence Material Testing Laboratory. The test specimen has been tested for its Thermal Conductivity, Thermal Diffusivity and Specific Heat Capacity.

1. CUSTOMER INFORMATION

Name of the Organization	:	Delhi Technical University
Contact Person	:	Shambalid Ahady
Address	:	Delhi Technical University, Rohini, Sec-17, New Delhi-110042
Phone Number	:	8826940811
Email	:	Shambalid.ahady@gmail.com

2. SAMPLE DETAILS

a.	**Description of Sample**	:	Plaster
b.	**Date of Receipt**	:	14/01/2020
c.	**Sample IDs**	:	MT-B-TPS-14012001
d.	**Date of Testing**	:	22/01/2020
e.	**Sample Thickness**	:	30mm
f.	**Density of the sample** (as reported by customer)	:	-
g.	**Test Method**[1]	:	MTCoE/SOP/01:01-02-2019
h.	**Machine Used**	:	Thermal Constant Analyzer TPS
i.	**Sample Conditioning**	:	25±4ºC
j.	**Sensor used in the Measurement**	:	Kapton 5465
k.	**Measurement time**	:	10 s
l.	**Power**	:	44.25 mW
m.	**Time Window**	:	8.616 s
n.	**Scanning rate**	:	423.069 ms

[1] Test Method MTCoE/SOP/01:01-02-2019 is based upon ISO:22007-2:2015

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3. **RESULTS:**

Sample Name	Sample Temperature (°C)	Thermal Conductivity* (W/mK)	Thermal Diffusivity* (mm^2/s)	Specific Heat Capacity* (MJ/m^3K)
Plaster	17.83	1.164	0.8807	1.325

* *Reported Result is average of ten measurements*

----------- End of Report-----------

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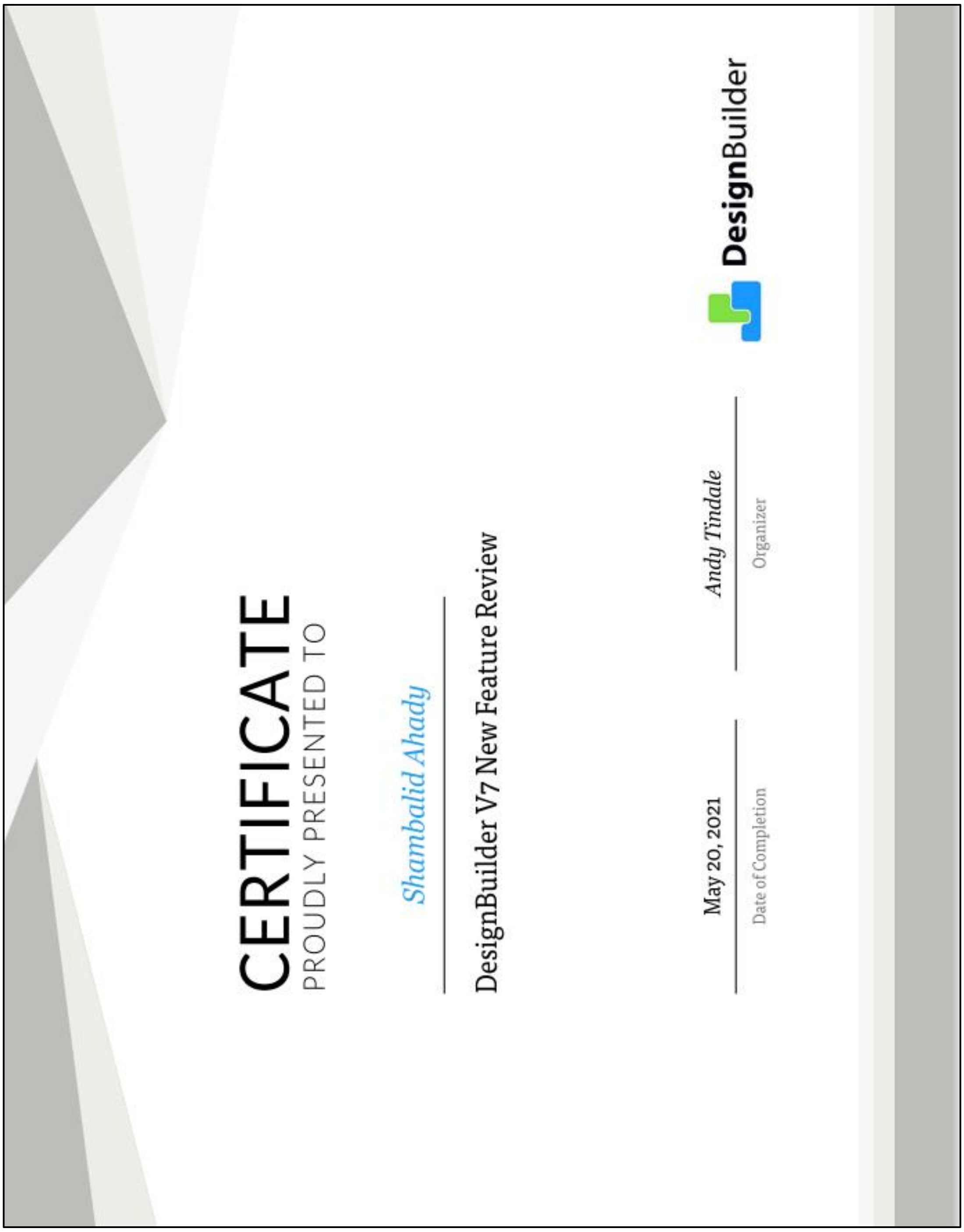
Authorized Signatory

Disclaimers

- The above results refer only to the tested sample(s) and applicable parameters submitted by the customer.
- Samples will be destroyed after 15 days from the date of issue of test report unless otherwise specified.
- This report shall not be reproduced, wholly or in part and cannot be used as evidence in the court of law and should not be used in any advertising media without special permission in writing from Laboratory.
- In case any reconfirmation of contents of the test report is required, please contact the authorized signatory of the test report within 15 days of the issue of the report.

APPENDIX E-5

DESIGNBUILDER SOFTWARE CERTIFICATE


CERTIFICATE
PROUDLY PRESENTED TO
Shambalid Ahady
DesignBuilder V7 New Feature Review
May 20, 2021
Date of Completion
Andy Tindale
Organizer
DesignBuilder

APPENDIX F-1

ENERGY BILL FOR RESIDENTIAL HOUSE FOR DURATION OF A YEAR

APPENDIX F-2

ENERGYPLUS SIMULAITON OUTPUT (SAMPLE OF SINGLE FAMILY DWELLING BASE-CASE SIMULATION)

Program Version: **EnergyPlus, Version 9.4.0-998c4b761e, YMD=2022.05.31 23:40**
Tabular Output Report in Format: **HTML**
Building: **Building**
Environment: **MAZAR (01-01:31-12) ** Mazar i Sharif AP BAL AFG ISD-TMYx WMO#=409110**
Simulation Timestamp: **2022-05-31 23:40:25**

Report: **Annual Building Utility Performance Summary**
For: **Entire Facility**
Timestamp: **2022-05-31 23:40:25**
Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	30097.87	304.97	304.97
Net Site Energy	30097.87	304.97	304.97
Total Source Energy	84014.95	851.30	851.30
Net Source Energy	84014.95	851.30	851.30

Building Area

	Area [m2]
Total Building Area	98.69
Net Conditioned Building Area	98.69
Unconditioned Building Area	0.00

End Uses

	Electricity [kWh]	Natural Gas [kWh]	Other Fuel 1 [kWh]	District Cooling [kWh]	District Heating [kWh]	Water [m3]
Heating	0.00	0.00	0.00	0.00	19494.25	0.00
Cooling	0.00	0.00	0.00	9580.08	0.00	0.00
Interior Lighting	345.81	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	183.06	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	494.68	7.75
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	528.87	0.00	0.00	9580.08	19988.93	7.75

Note: District heat appears to be the principal heating source based on energy usage.

Normalized Metrics

Utility Use Per Conditioned Floor Area

	Electricity Intensity [kWh/m2]	Natural Gas Intensity [kWh/m2]	Other Fuel Intensity [kWh/m2]	District Cooling Intensity [kWh/m2]	District Heating Intensity [kWh/m2]	Water Intensity [m3/m2]
Lighting	3.50	0.00	0.00	0.00	0.00	0.00
HVAC	0.00	0.00	0.00	97.07	202.54	0.08
Other	1.85	0.00	0.00	0.00	0.00	0.00
Total	5.36	0.00	0.00	97.07	202.54	0.08

Utility Use Per Total Floor Area

	Electricity Intensity [kWh/m2]	Natural Gas Intensity [kWh/m2]	Other Fuel Intensity [kWh/m2]	District Cooling Intensity [kWh/m2]	District Heating Intensity [kWh/m2]	Water Intensity [m3/m2]
Lighting	3.50	0.00	0.00	0.00	0.00	0.00
HVAC	0.00	0.00	0.00	97.07	202.54	0.08
Other	1.85	0.00	0.00	0.00	0.00	0.00
Total	5.36	0.00	0.00	97.07	202.54	0.08

Electric Loads Satisfied

	Electricity [kWh]	Percent Electricity [%]
Fuel-Fired Power Generation	0.000	0.00
High Temperature Geothermal*	0.000	0.00
Photovoltaic Power	0.000	0.00
Wind Power	0.000	0.00
Power Conversion	0.000	0.00
Net Decrease in On-Site Storage	0.000	0.00
Total On-Site Electric Sources	0.000	0.00
Electricity Coming From Utility	528.867	100.00
Surplus Electricity Going To Utility	0.000	0.00
Net Electricity From Utility	528.867	100.00
Total On-Site and Utility Electric Sources	528.867	100.00
Total Electricity End Uses	528.867	100.00

Report: Input Verification and Results Summary
For: Entire Facility
Timestamp: 2022-05-31 23:40:25

General

	Value
Program Version and Build	EnergyPlus, Version 9.4.0-998c4b761e, YMD=2022.05.31 23:40
RunPeriod	MAZAR (01-01:31-12)
Weather File	Mazar i Sharif AP BAL AFG ISD-TMYx WMO#=409110
Latitude [deg]	36.71
Longitude [deg]	67.21

Elevation [m]	391.40
Time Zone	4.50
North Axis Angle [deg]	0.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	224.45	27.00	86.15	27.00	84.30
Above Ground Wall Area [m2]	224.45	27.00	86.15	27.00	84.30
Window Opening Area [m2]	20.82	0.00	20.02	0.00	0.80
Gross Window-Wall Ratio [%]	9.28	0.00	23.24	0.00	0.95
Above Ground WWR[%]	9.28	0.00	23.24	0.00	0.95

Skylight-Roof Ratio

	Total
Gross Roof Area [m2]	65.09
Skylight Area [m2]	0.00
Skylight-Roof Ratio [%]	0.00

PERFORMANCE

Zone Summary

	Area [m2]	Conditioned (Y/N)	Volume [m3]	Multipliers	Above Ground Gross Wall Area [m2]	Window Glass Area [m2]	Lighting [W/m2]	People [m2 per person]	Plug and Process [W/m2]
BLOCK2:ZONE1	13.39	Yes	40.19	1.00	37.50	4.44	3.2000	9.77	1.5000
BLOCK3:ZONE1	5.31	Yes	15.92	1.00	7.05	0.30	3.2000	9.77	0.0000
BLOCK4:ZONE1	14.19	Yes	42.56	1.00	27.15	0.71	3.2000	9.77	0.0000
BLOCK6:ZONE1	13.39	Yes	37.84	1.00	37.50	4.44	0.0000	9.77	0.0000
BLOCK7:ZONE1	5.31	Yes	14.99	1.00	7.05	0.30	0.0000	9.77	0.0000
BLOCK8:ZONE1	14.19	Yes	40.08	1.00	27.15	0.71	0.0000	9.77	0.0000
BLOCK1:ZONE1	16.46	Yes	49.37	1.00	40.53	3.74	3.2000	43.67	1.5000
BLOCK5:ZONE1	16.46	Yes	46.49	1.00	40.53	3.74	0.0000	43.67	0.0000
Total	98.69		287.44		224.45	18.39	1.6000	13.18	0.4537
Conditioned Total	98.69		287.44		224.45	18.39	1.6000	13.18	0.4537
Unconditioned Total	0.00		0.00		0.00	0.00			
Not Part of Total	0.00		0.00		0.00	0.00			

Report: **Climatic Data Summary**
For: **Entire Facility**
Timestamp: **2022-05-31 23:40:25**

Design Day

	Maximum Dry Bulb [C]	Daily Temperature Range [deltaC]	Humidity Value	Humidity Type	Wind Speed [m/s]	Wind Direction
SUMMER DESIGN DAY IN	37.20	16.80	15.20	Wet-bulb	0.00	0.00

MAZAR (01-01:31-12) JUL						
SUMMER DESIGN DAY IN MAZAR (01-01:31-12) AUG	36.20	16.30	15.00	Wet-bulb	0.00	0.00
SUMMER DESIGN DAY IN MAZAR (01-01:31-12) SEP	33.90	16.60	14.50	Wet-bulb	0.00	0.00
WINTER DESIGN DAY IN MAZAR (01-01:31-12)	-10.90	0.00	-10.90	Wet-bulb	7.00	0.00

Report: **Envelope Summary**
For: **Entire Facility**
Timestamp: **2022-05-31 23:40:25**

Opaque Exterior

	Construction	Reflectance	U-Factor	Gross Area (m2)	Net Area (m2)	Azimuth (deg)	Tilt (deg)	Cardinal Direction
WALL_2_0_0	EXTERNAL WALL	0.30	1.614	13.50	13.50	0.00	90.00	N
WALL_3_0_0	EXTERNAL WALL	0.30	1.614	12.00	12.00	270.00	90.00	W
WALL_5_0_0	EXTERNAL WALL	0.30	1.614	12.00	7.20	90.00	90.00	E
GROUNDFLOOR_0_0_0	GROUND FLOOR	0.40	3.275	18.00	18.00	270.00	180.00	
WALL_3_0_0	EXTERNAL WALL	0.30	1.614	7.05	6.65	270.00	90.00	W
GROUNDFLOOR_0_0_0	GROUND FLOOR	0.40	3.275	7.05	7.05	270.00	180.00	
WALL_5_0_0	EXTERNAL WALL	0.30	1.614	10.05	10.05	270.00	90.00	W
WALL_7_0_0	EXTERNAL WALL	0.30	1.614	17.10	12.62	89.99	90.00	E
GROUNDFLOOR_0_0_0	GROUND FLOOR	0.40	3.275	10.05	10.05	270.00	180.00	
GROUNDFLOOR_0_0_1	GROUND FLOOR	0.40	3.275	8.54	8.54	269.99	180.00	
WALL_2_0_0	EXTERNAL WALL	0.30	1.614	13.50	13.50	0.00	90.00	N
WALL_3_0_0	EXTERNAL WALL	0.30	1.614	12.00	12.00	270.00	90.00	W
WALL_5_0_0	EXTERNAL WALL	0.30	1.614	12.00	7.20	90.00	90.00	E
ROOF_1_0_0	PROJECT ROOF_1	0.40	3.524	18.00	18.00	90.00	0.00	
WALL_3_0_0	EXTERNAL WALL	0.30	1.614	7.05	6.65	270.00	90.00	W
ROOF_1_0_0	PROJECT ROOF_1	0.40	3.524	7.05	7.05	90.00	0.00	
WALL_5_0_0	EXTERNAL WALL	0.30	1.614	10.05	10.05	270.00	90.00	W
WALL_7_0_0	EXTERNAL WALL	0.30	1.614	17.10	12.76	89.99	90.00	E
ROOF_1_0_0	PROJECT ROOF_1	0.40	3.524	3.52	3.52	89.99	0.00	
ROOF_1_0_1	PROJECT ROOF_1	0.40	3.524	15.08	15.08	89.99	0.00	
WALL_2_0_0	EXTERNAL WALL	0.30	1.614	2.87	2.07	56.64	90.00	E
WALL_4_0_0	EXTERNAL WALL	0.30	1.614	13.05	13.05	270.00	90.00	W
WALL_5_0_0	EXTERNAL WALL	0.30	1.614	13.50	13.50	180.00	90.00	S
WALL_6_0_0	EXTERNAL WALL	0.30	1.614	3.00	2.20	121.79	90.00	E
WALL_7_0_0	EXTERNAL WALL	0.30	1.614	8.10	5.38	90.00	90.00	E
GROUND-F_0_0_0	GROUND FLOOR	0.40	3.275	21.44	21.44	236.64	180.00	
WALL_2_0_0	EXTERNAL WALL	0.30	1.614	2.87	2.07	56.64	90.00	E
WALL_4_0_0	EXTERNAL WALL	0.30	1.614	13.05	13.05	270.00	90.00	W
WALL_5_0_0	EXTERNAL WALL	0.30	1.614	13.50	13.50	180.00	90.00	S
WALL_6_0_0	EXTERNAL WALL	0.30	1.614	3.00	2.20	121.79	90.00	E
WALL_7_0_0	EXTERNAL WALL	0.30	1.614	8.10	5.38	90.00	90.00	E
ROOF_1_0_0	PROJECT ROOF_1	0.40	3.524	21.44	21.44	121.79	0.00	

Opaque Interior

	Construction	Reflectance	U-Factor	Gross	Net	Azimuth	Tilt	Cardinal

				Area (m2)	Area (m2)	(deg)	(deg)	Direction
PARTITION_4_0_0	R-PARTITION WALL	0.30	1.763	9.00	8.46	180.00	90.00	S
PARTITION_4_1_0	R-PARTITION WALL	0.30	1.763	4.50	4.50	180.00	90.00	S
CEILING_1_0_0	R-GROUND FLOOR_	0.30	2.423	18.00	18.00	90.00	0.00	
PARTITION_2_0_10001	R-PARTITION WALL	0.30	1.763	9.00	8.46	0.00	90.00	N
PARTITION_4_0_0	R-PARTITION WALL	0.30	1.763	9.00	9.00	180.00	90.00	S
PARTITION_5_0_0	R-PARTITION WALL	0.30	1.763	7.05	7.05	90.00	90.00	E
CEILING_1_0_0	R-GROUND FLOOR	0.30	2.423	7.05	7.05	90.00	0.00	
PARTITION_2_0_10003	R-PARTITION WALL	0.30	1.763	4.50	4.50	0.00	90.00	N
PARTITION_4_0_10005	R-PARTITION WALL	0.30	1.763	9.00	9.00	0.00	90.00	N
PARTITION_3_0_10006	R-PARTITION WALL	0.30	1.763	7.05	7.05	270.00	90.00	W
PARTITION_6_0_0	R-PARTITION WALL	0.30	1.763	13.50	13.50	180.00	90.00	S
CEILING_1_0_0	R-GROUND FLOOR	0.30	2.423	3.52	3.52	89.99	0.00	
CEILING_1_0_1	R-GROUND FLOOR	0.30	2.423	15.08	15.08	89.99	0.00	
PARTITION_4_0_0	R-PARTITION WALL	0.30	1.763	9.00	9.00	180.00	90.00	S
PARTITION_4_1_0	R-PARTITION WALL	0.30	1.763	4.50	4.50	180.00	90.00	S
FLOOR_0_0_10000	R-GROUND FLOOR	0.40	2.423	18.00	18.00	0.00	180.00	
PARTITION_2_0_10010	R-PARTITION WALL	0.30	1.763	9.00	9.00	0.00	90.00	N
PARTITION_4_0_0	R-PARTITION WALL	0.30	1.763	9.00	9.00	180.00	90.00	S
PARTITION_5_0_0	R-PARTITION WALL	0.30	1.763	7.05	7.05	90.00	90.00	E
FLOOR_0_0_10004	R-GROUND FLOOR	0.40	2.423	7.05	7.05	0.00	180.00	
PARTITION_2_0_10011	R-PARTITION WALL	0.30	1.763	4.50	4.50	0.00	90.00	N
PARTITION_4_0_10012	R-PARTITION WALL	0.30	1.763	9.00	9.00	0.00	90.00	N
PARTITION_3_0_10013	R-PARTITION WALL	0.30	1.763	7.05	7.05	270.00	90.00	W
PARTITION_6_0_0	R-PARTITION WALL	0.30	1.763	13.50	13.50	180.00	90.00	S
FLOOR_0_0_10007	R-GROUND FLOOR	0.40	2.423	3.52	3.52	0.00	180.00	
FLOOR_0_0_10008	R-GROUND FLOOR	0.40	2.423	15.08	15.08	360.00	180.00	
PARTITION_3_0_10009	R-PARTITION WALL	0.30	1.763	13.50	13.50	360.00	90.00	N
CEILING_1_0_0	R-GROUND FLOOR	0.30	2.423	21.44	21.44	121.79	0.00	
PARTITION_3_0_10014	R-PARTITION WALL	0.30	1.763	13.50	13.50	360.00	90.00	N
FLOOR_0_0_10015	R-GROUND FLOOR	0.40	2.423	21.44	21.44	0.00	180.00	

Exterior Fenestration

	Construction	Area (m2)	U-Factor	SHGC	Parent Surface
WALL_5_0_0_0_0_0_WIN	1001	4.35	5.778	0.819	BLOCK2:ZONE1_WALL_5_0_0
WALL_3_0_0_0_0_0_WIN	1001	0.28	5.778	0.819	BLOCK3:ZONE1_WALL_3_0_0
WALL_7_0_0_0_0_1_WIN	1001	0.67	5.778	0.819	BLOCK4:ZONE1_WALL_7_0_0
WALL_5_0_0_0_0_0_WIN	1001	4.35	5.778	0.819	BLOCK6:ZONE1_WALL_5_0_0
WALL_3_0_0_0_0_0_WIN	1001	0.28	5.778	0.819	BLOCK7:ZONE1_WALL_3_0_0
WALL_7_0_0_1_0_0_WIN	1001	0.67	5.778	0.819	BLOCK8:ZONE1_WALL_7_0_0
WALL_2_0_0_0_0_0_WIN	1001	0.60	5.778	0.819	BLOCK1:ZONE1_WALL_2_0_0
WALL_6_0_0_0_0_0_WIN	1001	0.60	5.778	0.819	BLOCK1:ZONE1_WALL_6_0_0
WALL_7_0_0_0_0_0_WIN	1001	2.40	5.778	0.819	BLOCK1:ZONE1_WALL_7_0_0
WALL_2_0_0_0_0_0_WIN	1001	0.60	5.778	0.819	BLOCK5:ZONE1_WALL_2_0_0
WALL_6_0_0_0_0_0_WIN	1001	0.60	5.778	0.819	BLOCK5:ZONE1_WALL_6_0_0
WALL_7_0_0_0_0_0_WIN	1001	2.40	5.778	0.819	BLOCK5:ZONE1_WALL_7_0_0

LIST OF PUBLICATIONS BASED ON THESIS

Peer reviewed international journals

1. Ahady, Shambalid., Dev, Nirendra., Mandal, Anubha. (2022). Solar radiation control passive strategy for reduction of heating and cooling energy use in arid climate: Case of Afghanistan. *Indoor and Built Environment*, *31*(4), 955-971. https://doi.org/10.1177/1420326X211050114
2. Ahady, Shambalid., Dev, Nirendra., Mandal, Anubha. (2022). Urban Residential Buildings' Energy Consumption Pattern and Efciency. *Iranian Journal of Science and Technology, Transactions of Civil Engineering, online on*. https://doi.org/10.1007/s40996-022-00848-3
3. Ahady, Shambalid., Dev, Nirendra., Mandal, Anubha. (2022) Sustainable energy retrofit plan for enhancing energy efficiency of residential apartments in arid climate: case of afghanistan. Sådhanå 47:131. https://doi.org/10.1007/s12046-022-01896-1
4. Ahady, Shambalid., Dev, Nirendra., Mandal, Anubha. (2020). An overview of the opportunities and challenges in sustaining the energy industry in Afghanistan. *E3S Web of Conferences*, *173*. https://doi.org/10.1051/e3sconf/202017303006
5. Ahady, Shambalid., Dev, Nirendra., Mandal, Anubha. (2019) Toward Zero Energy : Active and passive design strategies to achieve net zero Energy Building. *International Journal of Advance Research and Innovation*, *7*(1), 229–232. ISSN 2347-3258

Peer reviewed international conferences

1. An overview of the opportunities and challenges in sustaining the energy industry in Afghanistan. 5th International Conference on Advances on Clean Energy Research (ICACER 2020), 9 June, Barcelona polytechnic university, Spain.
2. Toward Zero Energy : Active and passive design strategies to achieve net zero Energy Building. International conference of advance research and innovation.(ICARI-2019). Jan 20th 2019Delhi state center, Institute of engineers, India
3. Net zero: Design and strategies. International conference , empowering and enabling women in science.oct.2018, India.