ASSESSING EMBODIED AND OPERATIONAL ENERGY IN RESIDENTIAL BUILDINGS: A COMPARATIVE STUDY IN ADAMA TOWN FOR ENERGY-EFFICIENT DESIGN

Bereket Lafraw Dire

A Thesis Submitted to the Department of Architecture,

School of Civil Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in

Environmental Architecture

Office of Graduate Studies

Adama Science and Technology University

Jun,2024

Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled "**Assessing Embodied and Operational Energy in Residential Buildings: A Comparative Study in Adama Town for Energy-Efficient Design** is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation

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I/we, the advisor(s) of this thesis, hereby certify that I/we have read the revised version of the thesis entitled “**Assessing Embodied and Operational Energy in Residential Buildings: A Comparative Study in Adama Town for Energy-Efficient Design”** prepared under my/our guidance by **Bereket Lafraw Id No PGR/28111/15**. Therefore, I/we recommend the submission of revised version of the thesis to the department following the applicable procedures.

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APPROVAL OF BOARD OF EXAMINER

I/we, the advisors of the thesis entitled "**Assessing Embodied and Operational Energy in Residential Buildings: A Comparative Study in Adama Town for Energy-Efficient Design**" and developed by **Bereket Lafraw Id No PGR/28111/15**. Here certify that the recommendations and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis

______________________	______________________	______________________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by **Bereket Lafraw** have read and evaluated the thesis entitled **Assessing Embodied and Operational Energy in Residential Buildings: A Comparative Study in Adama Town for Energy-Efficient Design**" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Environmental Architecture.

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LIST OF ABBREVIATIONS AND ACRONYMS

IEA – International Energy Agency

IEE – Initial embodied energy

REE – Recurrent embodied energy

DEE – demolition embodied energy

LCA – Life cycle assessment

HCB – Hollwe concrete block

HVAC– Heating, Ventilation, and Air Conditioning

EUI – Energy Use Intensity

EPC – Energy Performance Certificate

EEU – Embodied Energy Use

TES – Total Energy Savings

SOO – Specific Operational Energy

SDGs – Sustainable Development Goals

HVAC - Heating, Ventilation, and Air Conditioning

IEE - Initial Embodied Energy

REE - Recurrent Embodied Energy

DEE - Demolition Embodied Energy

EUI - Use Intensity

EPC - Energy Performance Certificate

EEU - Embodied Energy Use

TES - Total Energy Savings

LCEP - Life-Cycle Embodied Performance

BREEAM – Building Research Establishment Environmental Assessment Methodology

BEES – Building For Environmental and Economic Sustainability

LEED – Leadership in Energy And Environmental Design

MJ- Mega joules

WWR- Window to Wall Ratio

ABSTRACT

The energy efficiency of residential buildings is a crucial factor in achieving sustainability and environmental conservation. The construction sector is one of the most energy-consuming sectors, and understanding this industry can help minimize energy waste and the consumption of limited natural resources. The rapid development of residential buildings in Adama town warrants an investigation into the potential for energy efficiency improvements. This research aims to provide recommendations for energy-efficient building designs and appropriate material selection to reduce both embodied and operational energy consumption in residential constructions in Adama town. The primary objective is to assess and compare the energy usage during the construction and operation phases of different residential building typologies. The study was conducted in Dagaga Kebele, where G+0 (ground floor) residential buildings were categorized into four typologies: L-shaped, Villa, Service, and Public houses. A stratified random sampling method was used to select the samples, and an input-output approach was employed to evaluate their energy consumption. The findings indicate that the newly trending L-shaped designs and construction consume more embodied energy (3,549,550 MJ) and operational energy (2463.33 MJ) compared to the other typologies. The Villa design has an embodied energy of (1,122,795.5 MJ) and operational energy of (2,299.36 MJ), while the Public Housing design has an embodied energy of (925,931.3 MJ) and operational energy of (1,555.2 MJ). The Service design has an embodied energy of (478,736 MJ) and operational energy of (291.96 MJ). This highlights the need to upgrade the design and material choices to minimize energy wastage. The study recommends that the construction sector should prioritize energy efficiency and environmental compatibility when planning and constructing buildings, rather than repeating previous designs. The town's construction administration should create an energy-efficient strategy for building, design, and material selection. Architects and construction professionals should prioritize daylighting and ventilation in room design and construction. Avoid high-energy-consuming construction materials to minimize the embodied energy of the building, especially the roof and the massive concrete work, which is the current trend also Maximize the window-to-wall ratio to control operational energy efficiency.

Keywords:- Embodied energy, Operational Energy, Passive design , Energy-Efficient Design, G+0 residential buildings and Dagaga Kebele

CHAPTER ONE

INTRODUCTION

Energy efficiency is a crucial aspect of sustainable building design, encompassing passive design, embodied energy, and operational energy. Passive design techniques, such as utilizing natural lighting, ventilation, and heating/cooling, can significantly reduce a building's energy demand and carbon footprint. (Kumar et al., 2022) Embodied energy, the energy required to extract, process, transport, and assemble building materials, can account for up to 50% of a building's total energy consumption over its lifespan. (Chen et al. (2022) Operational energy, the energy required for heating, cooling, lighting, and powering appliances, accounts for 80-90% of a building's total energy use and 30% of global energy consumption. (IEA, 2022)

The recent surge in G+0 residential development in Adama City has led to a proliferation of similar designs and constructions throughout the town, which have high consumption of concrete and with pitch roof design. This has prompted an examination of the drivers behind these implementations and has piqued interest in assessing this designs and led this study to evaluate this over the scope of energy efficiency. The study seeks to scrutinize whether these designs and constructions are truly energy-efficient, comparing them with previous designs and constructions across Adama based on their design and material selection. As Adama town is an immerging city over the country it have been selected for this study.

1.1 Background of the Study

Embodied energy refers to the energy used in the production and transportation of building materials, the embodied energy of a building or building material serves as a convenient measure of its environmental impact, with a higher embodied energy indicating a greater environmental impact. This energy, like purchased energy, can be linked to the generation of greenhouse gases, particularly CO_2. When considering alternatives to fossil fuels, it's important to recognize that energy sources such as nuclear fission also have associated environmental impacts. The manufacturing process of some building materials can result in greater CO_2 emissions than expected from the embodied energy alone. This occurs when major raw materials like limestone release CO_2 during heating. Replacing high embodied energy components, such as Portland cement, with lower embodied energy alternatives can significantly reduce the overall embodied energy of materials like concrete. (Lawson. B, 2006).

Operational energy refers to the energy used during the building's use. One of the major problems facing residential buildings worldwide is the excessive wastage of operational energy. This issue is particularly concerning as it not only leads to unnecessary financial burden on homeowners but also contributes to environmental degradation and climate change. Operational energy in residential buildings refers to the energy used for heating, cooling, lighting, and powering appliances and electronics. In many cases, this energy is being wasted due to inefficient systems and practices. One of the main reasons for energy wastage in residential buildings is design problems with the lack of adequate lighting and ventilation in a room. Many homes still rely on old heating and cooling systems, outdated insulation, and inefficient lighting, all of which contribute to excessive energy consumption. Another contributing factor to energy wastage is the lack of awareness and education among homeowners about energy-efficient practices. Many people are unaware of the impact of their energy usage and do not take steps to reduce their consumption. Furthermore, poor building design and construction can also lead to energy wastage. Inadequate insulation, air leaks, and improper ventilation can all contribute to higher energy usage and wastage. The impact of this problem is significant. Not only does energy wastage lead to higher utility bills for homeowners, but it also puts unnecessary strain on energy resources and contributes to increased carbon emissions and environmental degradation. To address this issue, there is a need for greater investment in energy-efficient technologies and building practices. (Friedman & Cammalleri, 1994)

The construction and design of buildings play a crucial role in determining energy efficiency. Efficient energy use in buildings involves minimizing heating loads, utilizing solar radiation, and optimizing environmental heat. (Sadriddin, Sayfiddinov. 2023) To achieve carbon-neutral buildings, a comprehensive energy efficiency function model is essential, emphasizing technology energy efficiency over scale and comprehensive energy efficiency. (Rui, Liang., Jia, Liang, Linhui, Hu. 2023) Proper design is vital for energy-efficient buildings, as it requires selecting energy-efficient materials, engineering solutions, and equipment while considering thermal bridges and geographical factors. (O., M., Nazarenko, Nicole, Beiner. 2023)

In the construction industry, energy losses differ between developed and developing countries, with developing nations facing higher transmission and distribution losses.(Uma-Abordagem-Com-Multi-Mochilas-Multidimensionais-Para-o-1akn7uvuwo, 2015) Developing countries like Brazil limit the increase in energy bills due to non-technical losses, encouraging distribution companies to improve their activities and reduce losses.(Dakulagi, 2016) Research highlights the importance of optimizing energy resources in developing countries for sustainable development, particularly in industries like civil construction, where systematic management can lead to improved energy efficiency and quality of production.(Pacheco Paladini et al., 2021) Energy models emphasize the rapid rise in energy consumption in developing countries, distinct from developed nations, necessitating the use of modeling tools like Long-range Energy Alternatives Planning Systems (LEAP) to quantify pathways and address energy challenges. (V. Coyard, 2016)

The increasing need for environmentally friendly building designs across the globe has led to a rise in interest in reducing energy usage in residential buildings. Numerous building materials have been developed over time, but their production and shipment have required a substantial amount of energy and natural resources. Furthermore, a variety of materials, from concrete to bolts, have been collected and processed to meet architectural goals from the foundation to the rooftop, resulting in global energy waste. In light of this, evaluating the operational and embodied energy of buildings has emerged as a crucial component of sustainable design. (Wang, 2022)

The building industry is a significant contributor to global energy consumption and CO_2 emissions, with the sector responsible for 35% of final energy use and 38% of energy-related CO_2 emissions globally. (Niccolò Aste, 2022)Reports highlight the potential for lost efficiency opportunities in the buildings sector, representing a portion of the untapped technical potential for energy efficiency improvements due to lack of resources and attention from programs like the Building Technologies Program (BTP). (Bojana, Petrovic, 2021) Furthermore, the construction industry's energy demand is projected to increase substantially, with a predicted rise of almost 50% between 2010 and 2050, emphasizing the critical need for energy-saving measures and efficiency improvements to mitigate the industry's environmental impact (Dirks et al., 2008). These findings underscore the urgent necessity for targeted efforts to address energy inefficiencies in the building sector to curb energy waste and reduce the industry's overall environmental footprint.

SDG 7, focusing on energy efficiency, plays a crucial role in the building industry's transition towards sustainability and reduced environmental impact.(Energy-Efficiency-in-Commercial-Buildings-Systematic-3k9an1ma, 2023)The construction sector, responsible for nearly half of the world's energy consumption, is a significant contributor to greenhouse gas emissions, emphasizing the importance of energy-efficient practices in buildings.(Khahro et al., 2021) Energy-efficient buildings not only reduce energy consumption but also enhance occupant comfort and operational efficiency throughout the building's lifecycle, from construction to demolition. (Katharina, Reindl., Jenny, Palm. 2020) Professionals in the construction industry, such as architects and engineers, are pivotal in implementing energy-saving measures and driving the adoption of sustainable technologies to achieve highly energy-efficient renovations. (Janmejoy, Gupta., Manjari, Chakraborty, 2021) By aligning energy efficiency initiatives with SDG 7 objectives, the building industry can make substantial strides towards a more sustainable and environmentally friendly future.

The estimate of wasted energy sources in the building construction sector in Africa is a critical concern for sustainable development and energy efficiency. (Ahmed et al., 2014) The construction sector plays a significant role in energy consumption and emissions, making it essential to address inefficiencies and reduce waste in this industry. Studies highlight the potential for substantial reductions in energy consumption and emissions through green practices in construction, emphasizing the importance of transitioning to more sustainable building methods (Davidsson & Hagberg, 2014.). Collaboration between institutions like the African Development Bank and research organizations aims to create mathematical models to optimize energy investments in African countries, focusing on power technologies and fuels that offer the lowest net present value over specific periods (Caggiano, 2023). By estimating infrastructure investment needs and energy demand projections, efforts are being made to ensure a more sustainable and efficient energy supply in the building and construction sector in Africa.

In Ethiopia, rapid urbanization is underway, but there is limited consideration for energy-efficient housing construction practices. Specifically, in Adama City, the environmental impact of resource consumption in residential construction is not well understood. As urban sustainability becomes increasingly important, it is crucial to assess whether Ethiopia's natural resources can sustain current consumption levels. This evaluation will help set targets and explore strategies for promoting energy-efficient housing solutions.(Bulti & Assefa, 2019)

Based on energy efficiency for industry, building, and industry strategy data, the residential sector accounts for the majority of energy consumption in the country, representing nearly 94% of the total demand for energy, while the remaining 6% is met by other sectors like Commercial, Transport, Agriculture and Industry's.

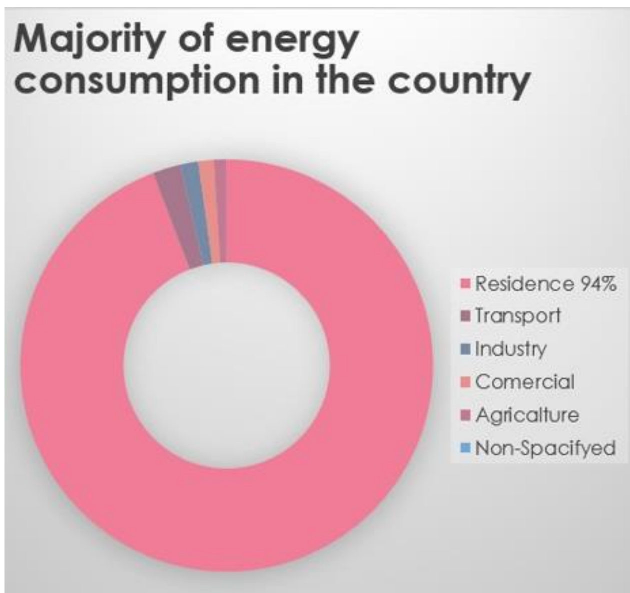

Figure 1: Energy consumption of different industries in Ethiopia *(*Ethiopia_06Directive 005_2011-Energy Efficiency Strategy for Industries_Buildings and Appliance, *n.d.)*

The recent surge in G+0 residential development in Adama town has led to a proliferation of similar designs and constructions throughout the town, which have a high consumption of concrete and pitch roof design. This has prompted an examination of the drivers behind these implementations and has piqued interest in assessing these designs and leading this study to evaluate this over the scope of energy efficiency. The study seeks to scrutinize whether these designs and constructions are truly energy-efficient, comparing them with previous designs and constructions across Adama based on their design and material selection. As the town is an immerging over the country it has been selected for this study. Specifically, the Dagaga Kebele in Adama town has been selected for the study due to the availability of different design and contraction types, material variety, and building age.

In Adama town, various building designs and materials have been utilized across different areas, ranging from traditional brick and earth materials to the more contemporary use of HCB and concrete. However, in recent times, residential building designs in the town have followed a uniform pattern, characterized by massive concrete pergolas and high roofs. This standardized design has resulted in inadequate light and ventilation in some rooms, leading to the extensive use of lighting throughout the day. Additionally, the use of massive concrete structures in the pergolas has led to increased costs and energy wastage during the residential construction process in Adama town. Consequently, these factors have made it challenging for people to afford housing, while also contributing to a lack of diverse and suitable designs for residential buildings in the town.

This research objective aims to conduct a comparative study on the embodied and operational energy of residential buildings in Adama Town, to promote energy-efficient design practices. The findings are expected to inform the architects, urban planners, policymakers, and other stakeholders involved in the construction and development of sustainable communities. By analyzing the energy consumption patterns of different residential buildings. Ultimately, the study aims to promote the adoption of energy-efficient designs that can lead to reduced energy conception in this sector.

1.2 Statement of the Problem

The rapid growth of urbanization in Adama town has led to a surge in the construction of G+0 (ground floor) residential buildings. This trend is driven by the need to provide housing solutions for the increasing population. The prevalence of G+0 residential structures in Adama town makes it a suitable focus for this study, as it allows the establishment of a baseline for future research on residential building energy efficiency.

The primary issue is the high consumption of concrete and the resulting increase in embodied energy in these residential buildings. Additionally, poor building designs with insufficient natural light and ventilation lead to a greater dependency on electrical solutions, consequently increasing operational energy consumption. This problem is further exacerbated by the lack of an energy conservation code and the construction industry's reliance on inspiration and design trends rather than energy-efficient policies. By addressing the energy efficiency of residential buildings in Adama town, this study aligns with the objectives of SDG 7, contributing to the global efforts towards sustainable energy consumption and climate change mitigation.

To address these challenges, this study aims to conduct a comparative analysis of the embodied and operational energy of various G+0 residential building typologies in Adama town. This approach will enable the identification of design solutions and material recommendations to minimize energy consumption in the residential sector. The comparative study is crucial, as it allows the researchers to evaluate the performance of different building typologies, including their design features and material compositions, in terms of energy efficiency.

The research gap in this context is the lack of a comprehensive study that evaluates both embodied and operational energy in Adama town's residential structures. Previous studies have focused primarily on the building envelope and have not provided solutions based on their findings. This research will fill this gap by quantifying the influence of current construction techniques and building designs on energy consumption, and proposing energy-efficient design alternatives. By investigating and comparing the energy performance of different G+0 residential building typologies in Adama town, this study aims to provide insights that will guide policymakers, architects, and industry stakeholders towards more sustainable and energy-efficient residential construction practices contributing to the achievement of SDG 7.

1.3 Objectives

1.3.1. Genera objective

The general objective of the research is to comprehensively assess the embodied and operational energy of different designs of residential buildings in Adama Town, with the overarching goal of contributing to sustainable and energy-efficient design.

1.3.2. Specific objectives

1. To evaluate the embodied energy of different residential building typology's in Adama Town, considering materials, construction processes, and transportation of resources.
2. To analyze the operational energy consumption of different residential buildings in Adama Town.
3. To provide recommendations for energy-efficient design interventions and recommendation initiatives aimed at reducing energy consumption and promoting energy-efficient architectural practices in Adama Town.

1.4 Research Question

1. What are the existing housing typology of G+0 residential buildings in the study area?
2. How is the comparison of embodied energy and operational energy of G+0 residential buildings compares in terms of energy efficiency?
3. What are the elements that cause variations in energy use between diverse building designs in the chosen location?

1.5 Significance of the Study

The outcome of this study is to shed light on energy consumption in the residential building sector, as it is one of the main energy-consuming industries nationwide. This aligns with the objectives of Sustainable Development Goal (SDG) 7, which focuses on energy-efficiency. At the national level, Ethiopia currently has a strategy for energy efficiency in the manufacturing industry, but the residential sector, which is a major energy consumer, has been overlooked. Ethiopia is one of the countries found in the energy poverty index, further emphasizing the need to address energy efficiency in the built environment.

This study examines the operational and embodied energy of various residential building typologies in Adama Town, aiming to provide critical insights that can guide architects, urban planners, and policymakers. The lack of a comprehensive energy conservation code and strategy for the construction industry has led to a reliance on inspiration and design trends, rather than energy efficiency considerations. The findings of this research are expected to serve as an eye-opener, highlighting the importance of incorporating energy efficiency measures into the design, construction, and operation of residential buildings. By quantifying the energy consumption patterns and identifying opportunities for improvement, this study can inform the development of energy-efficient policies, building codes, and design practices that can be implemented at the national level.

Ultimately, the goal of this study is to contribute to the achievement of SDG 7 by addressing the energy efficiency challenges in the residential building sector, which is a significant consumer of energy nationwide. The insights and recommendations generated from this research can guide policymakers, industry professionals, and stakeholders towards more sustainable and energy-conscious residential development practices.

1.6 Scope of the study

1.6.1 Spatial scope

The research examined a range of G+0 residential structures in Adama, with a concentration on Degage Kebele. This kebele has 1200 distinct G+0 residential structures of various designs, which may be classed using a number of criteria. The research was conducted in Dagaga Kebele, which was chosen for several reasons, including the availability of design variation, building life time, and construction materials.

1.6.2 Thematic scope

This study seeks to assess the embodied and operational energy of residential structures in Adama Town, with a particular emphasis on energy-efficient design solutions. The study will assess the environmental impact of both the construction materials utilized (embodied energy) and the energy consumed while the structure is in operation (operational energy). The study examines the energy performance of G+0 residential structures in Adama Town to find the potential for enhancing energy efficiency and sustainability in the local built environment. Building design, construction processes, material choices, and energy systems are all important issues to investigate, with the ultimate goal of encouraging more sustainable practices in Adama Town residential construction. The residential sector consumes a substantial amount of energy, accounting for more than 94% of overall energy consumption in the industry. (Ethiopia: Energy Assessment, n.d.) As a result, using

G+0 residential buildings in Adama will serve as a standard, providing a solid foundation for future research projects.

1.7 Limitations of the Study

One of the key limitations of this study is the lack of precise data on the embodied and operational energy of residential buildings in Adama Town. Acquiring accurate information on the architectural designs, construction materials, and energy consumption patterns of current residential structures has been a challenge. Another limitation relates to the operational energy analysis. Concerns for the privacy of residents and a lack of cooperation in providing the necessary information have posed constraints on the research process. Residents may be reluctant to share detailed data on their energy consumption and usage patterns, which are crucial for the operational energy evaluation. Additionally, the scope of the study is limited to the G+0 (ground floor) residential buildings in Adama Town. While this focus allows for the establishment of a baseline for future research, it may not capture the energy performance of other residential building typologies that may be present in the city. Expanding the scope to include a broader range of residential structures could provide a more comprehensive understanding of the energy landscape in Adama Town.

Furthermore, the study is confined to the Dagaga Kebele, which may not fully represent the diverse residential building characteristics and energy usage patterns across the entire city. Incorporating a larger geographical area or a more representative sample of residential buildings could enhance the generalizability of the findings. These limitations highlight the challenges inherent in conducting a detailed energy assessment of residential buildings, particularly in terms of data availability and accessibility. Nevertheless, the researchers have made every effort to overcome these limitations and provide meaningful insights that can guide Further researchers, policymakers, architects, and industry stakeholders towards more energy-efficient residential development in Adama Town.

1.8 Organization of the paper

The thesis is organized into five chapters. Each chapter conducts a methodical and effective examination of the study's content and data. The following are further examples of the thesis's fundamental chapters.

Chapter One: This research chapter includes a background, statement of the problem, objective, significance of the study, scope of the study, and limitation of the study

Chapter Two: Within the second chapter, the research's border region was explored, appraised, and declared from many sources in the literature review. The introduction, fundamental conceptual definitions, and theoretical, empirical, and deep review of the subject field were extensively reviewed.

Chapter Three: The third chapter outlines the methodology and materials utilized for this particular study. This section covers the study methodology, design, data-gathering techniques, knowledge sources, data analysis, and presentation methods.

Chapter Four: A chapter titled "Results and Discussion" may examine the conclusions of qualitative and quantitative data. The subjective qualitative data is examined and backed by a questionnaire survey, field observation notes, and printed papers from various industries. The quantitative data is examined using field observations, measurements, plans, and actions, aerial photographs, and topography maps.

Chapter Five: The thesis ends with a conclusion and recommendations. The chapter concluded by supporting the conclusions of the literature review, G+0 residential studies in the town, and discussion outcomes. Furthermore, the study advises the most effective design according to energy efficiency

CHAPTER TWO

LITERATURE REVIEW

This section of the literature provides a theoretical, empirical, and in-depth review of publications relating to the subject under research. The study focuses on the embodied and operational energy evaluation of a building in terms of energy efficiency. Using the research questions as a guide, this literature review discusses the definitions of embodied energy, energy efficacy, and operational energy, how to compute both embodied and operational energy, and how to gather information from previous studies.

2.1 Theoretical Review

With the increasing demand for energy-efficient buildings in the world to manage energy resources, it has been necessary to assess the embodied and operational energy of residential buildings to start from the ground. The embodied energy refers to the energy consumed during the production, transportation, and construction of building materials. In contrast, operational energy refers to the energy consumed during the use of the building.

Buildings play a crucial role in the global concerns surrounding high energy consumption and environmental issues. They account for approximately 40% of the world's total energy consumption, primarily for lighting, heating, cooling, and air conditioning (Rahman, Azari, 2019). The energy usage in buildings encompasses both operational and embodied energy, with a growing emphasis on the latter due to the increasing energy efficiency of newer buildings (Mona, Bisadi., Alireza, Akrami., 2018). Improper settings for temperature, lighting, and ventilation in buildings lead to inefficient electricity use, highlighting the need for corrective measures and effective policies to address energy production and consumption challenges (Okon & Okon, 2019). Sustainable energy and utilities management practices are essential to improve energy efficiency in buildings, as demonstrated by studies focusing on professionals in the built environment and their roles in energy consumption and management(IJSRSET151662 |, 2015) . Additionally, tall buildings have the potential to significantly reduce energy consumption through the utilization of renewable energy sources and innovative design approaches, emphasizing the importance of sustainable skyscrapers in energy conservation efforts (Pooya, Lotfabadi, 2014).

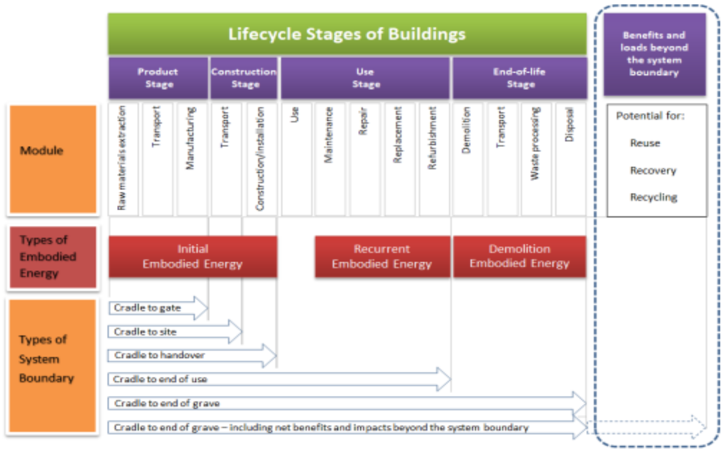

Figure 2: Energy conception of buildings in their lifecycle. Adopted from (Taffese & Abegaz, 2019)

2.1.1 Energy- Efficiency in residential building

Energy efficiency in residential buildings is crucial for reducing energy consumption, improving indoor comfort, and minimizing environmental impact. Various strategies such as implementing energy-efficient systems, utilizing passive solar design, and incorporating modern technologies can significantly enhance the energy performance of buildings. (L., M., Vilinska. 2023) Studies show that factors like thermal mass, insulation materials, and shading devices play a vital role in reducing energy consumption for heating and cooling, with traditional Mediterranean houses demonstrating higher efficiency due to their thermal mass. (Antra, Kundziņa., Ineta, Geipele., M., Auders., S., Lapuķe. 2023) Additionally, the application of green building technologies like Smart Energy Glass windows and solar panels can elevate the energy efficiency class of buildings, resulting in substantial energy and resource savings during operation. National policies also emphasize the importance of improving energy performance in residential buildings to achieve energy-saving targets and promote sustainability.

Life cycle assessments and embodied energy considerations are crucial for achieving holistic energy efficiency in residential buildings. The Life Cycle Energy Analysis Framework assesses energy consumption throughout a building's life, while the Life Cycle Assessment evaluates environmental impacts. The Hybrid Life Cycle Inventory combines elements of LCA and life cycle costing for a balanced view. Embodied Energy Modeling quantifies energy embodied in building materials and construction processes, while the Low Energy Building Design Framework streamlines the design process for low-energy residential buildings. The distinction between operational and embodied energy in residential buildings is essential for achieving energy efficiency. Operating energy can make up to 60% of overall energy consumption, and minimizing operating and embodied energy is crucial for achieving energy efficiency. (Dixit, 2017).

2.1.2 Roof design in energy efficient design

The design of a roof plays a significant role in the energy efficiency of a ground floor residential building. The roof pitch and geometry are crucial factors to consider. Lowering the roof pitch can reduce material usage, but it may also increase heat gain and loss due to reduced ventilation.

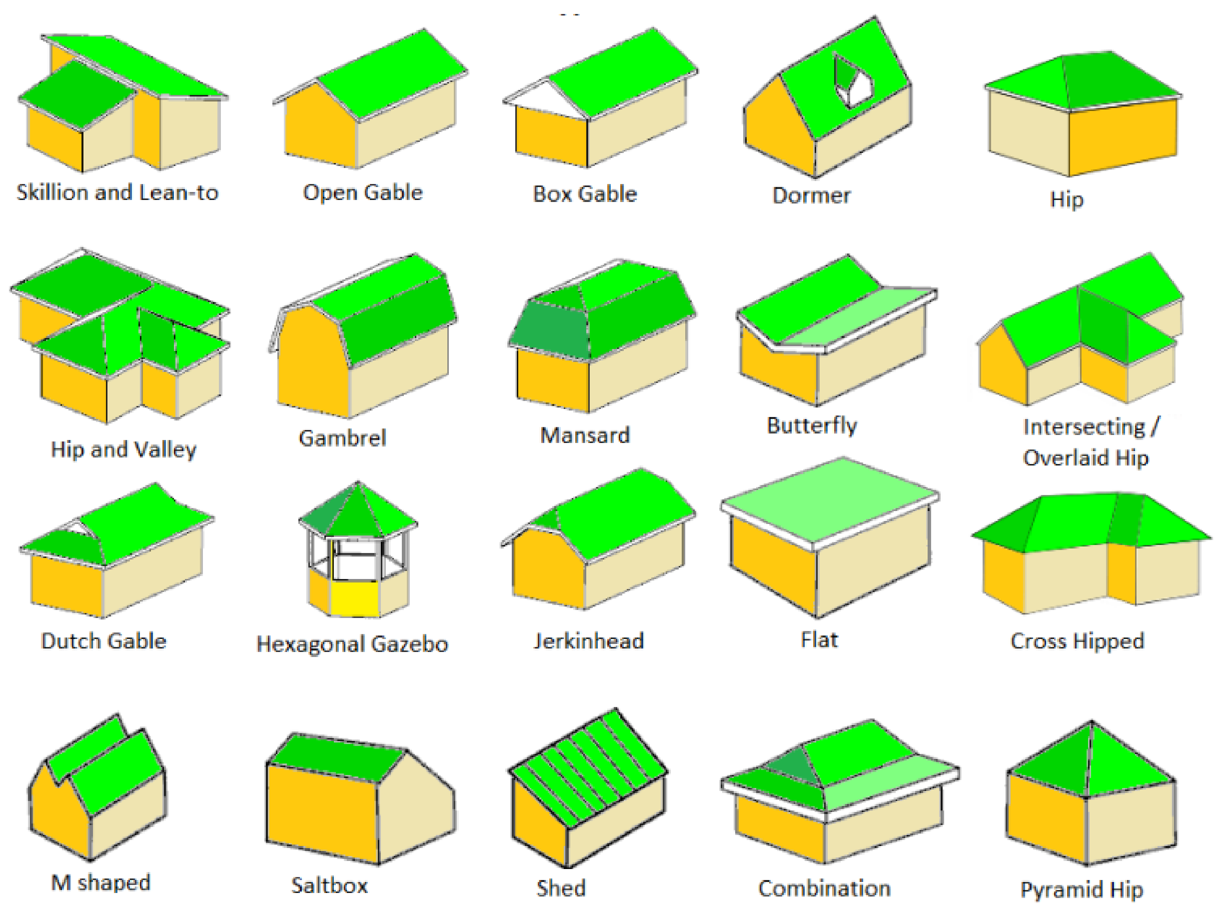

Figure 3: Roof types (Maghiar et al., 2020)

The choice of roof materials is also important, with energy-efficient options such as high-reflectance and high-emissivity roofs that can reduce heat gain and energy consumption. Energy efficiency measures can also be incorporated into the roof design. For example, sealed attics and shade trees can contribute to energy savings. The cost of roof construction should also be considered. Lowering the roof pitch can reduce material costs, but the overall energy efficiency may be compromised. The cost of roof construction can be estimated using tools like the RS Means catalog. (Marcel Maghiar, Ph.D, 2020)

The roof pitch has a significant impact on energy efficiency in different climates. In colder climates, steeper pitches are beneficial as they allow snow to shed more effectively, preventing ice dams and reducing the risk of water damage. This is particularly important in areas with heavy snowfall, as it ensures that the roof can handle the weight of the snow and maintain its structural integrity.(Understanding Roof Pitch: How It Impacts Design And Function - Atlanta Roofing Specialists, 2024)

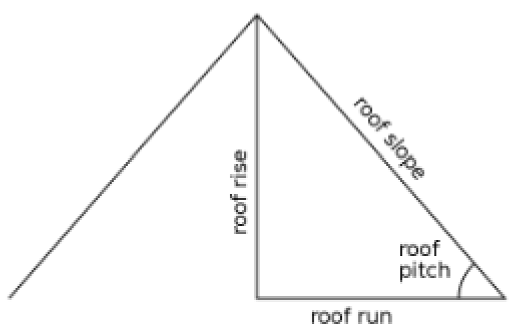

Figure 4: Pitch roof (Understanding Roof Pitch: How It Impacts Design And Function - Atlanta Roofing Specialists, 2024.)

In warmer climates, flat or low-pitched roofs are more suitable as they allow for better insulation and reduce heat gain. This is because flat roofs are more exposed to the sun, which can lead to increased heat gain and higher cooling costs. However, proper insulation and reflective roofing materials can help minimize heat gain and maximize energy efficiency in these climates.Roof Pitch And Energy Efficiency: How Roof Angle Affects Your Energy Bills, 2024.; The Influence of Roofing Choices on Home Energy Efficiency, 2024) In regions with heavy rainfall, steeper pitches are also beneficial as they allow water to run off quickly, reducing the risk of pooling and leaks. This is particularly important in areas with high humidity, as it helps prevent water-related issues and maintains the structural integrity of the roof.(*Roof Pitch And Energy Efficiency: How Roof Angle Affects Your Energy Bills*, n.d.)Ultimately, the choice of roof pitch depends on the local climate and the specific needs of the building. It is essential to consider factors such as snowfall, rainfall, and temperature fluctuations when selecting a roof pitch to ensure optimal energy efficiency and durability

2.1.3 Window to wall ratio in Energy-efficiency of a building

The window-to-wall ratio (WWR) is a crucial factor that significantly affects the energy efficiency of a building. The optimal WWR considers the effects of total energy consumption for cooling, heating, and lighting.(Saber, 2021) A higher WWR allows more daylight to enter a building, reducing the reliance on artificial lighting during daylight hours. However, an excessive ratio can lead to increased heat gain in warmer climates or heat loss in colder regions, impacting energy consumption.

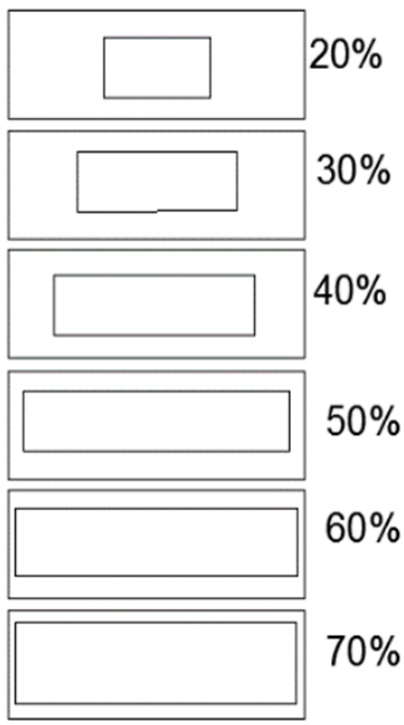

Figure 5: Window-to-Wall Ratio (WWR) and the position of the window on the façade.(Feng et al., 2017)

In hot and humid climates, a lower WWR is recommended to minimize heat gain and reduce cooling loads. In cold climates, a higher WWR can be beneficial for passive solar heating, but it should be balanced with adequate insulation to prevent heat loss. The use of energy-efficient glazing and window treatments can also improve the energy performance of windows.(Feng et al., 2017)

2.1.4 Embodied energy in a building material

Embodied energy in building materials refers to the total energy consumed in their production, transportation, and installation, contributing significantly to a building's overall energy footprint (Dixit & Pradeep Kumar, 2022). This energy includes both direct and indirect energy use, encompassing the energy required for material extraction, processing, manufacturing, and transportation. The embodied energy plays a crucial role in determining the environmental impact of a building, as it influences the building's overall energy efficiency and carbon emissions. Moreover, the embodied energy of building materials is closely linked to their durability and potential for disassembly, highlighting the importance of material selection in reducing environmental impacts. Nanotechnology shows promise in reducing embodied energy by enhancing material durability and decreasing production energy, offering a sustainable solution for lowering the energy intensity of building materials.

Understanding embodied energy is essential for making informed decisions about the environmental impact and energy efficiency of building materials and influencing the energy performance and environmental sustainability of the built environment. It is crucial in sustainable building design through several key points, including life cycle assessment (LCA), energy efficient material selection, energy performance benchmarking, impact on energy renovation measures, sustainable material development, and regulatory compliance and standards.(Dascalaki et al., 2021)

Embodied energy is a crucial aspect of sustainable building design, encompassing the total energy consumed in the extraction, processing, manufacturing, and transportation of building materials and construction activities. It is essential for reducing environmental impact, understanding a building's energy use throughout its lifecycle, selecting energy-efficient materials, making informed decisions, and addressing the unique environmental and contextual factors affecting building performance and energy usage. Incorporating embodied energy assessments helps in assessing a building's environmental footprint, enabling a more accurate picture of a building's environmental footprint. In developing countries, such as Ethiopia, understanding and analyzing embodied energy is even more important due to unique environmental and contextual factors affecting building performance and energy usage. Therefore, considering embodied energy in sustainable building design is essential for minimizing environmental impact, making informed material choices, and ensuring holistic energy efficiency throughout a building's lifecycle.(Taffese & Abegaz, 2019)

2.1.5 Operational energy in residential building

Operational energy consumption in buildings is influenced by factors such as building design, construction, HVAC systems, lighting, appliances, occupancy, and renewable energy integration. Building design and construction, such as orientation, insulation, and energy-efficient materials, can significantly impact energy usage. Properly designed HVAC systems can reduce energy use, while LED fixtures and appliances can also reduce energy consumption. Occupancy and usage, such as residential, commercial, or industrial use, also affect energy consumption. Key energy performance metrics, such as Energy Use Intensity (EUI), Energy Performance Certificate (EPC), Embodied Energy Use (EEU), Total Energy Savings (TES), and Specific Operational Energy (SOO), are crucial for evaluating building energy efficiency. Strategies to reduce operational energy use in buildings include energy-efficient design, high-performance HVAC systems, lighting efficiency, promoting energy-conscious behavior among occupants, integrating renewable energy sources, implementing advanced building management systems, and upgrading to energy-efficient appliances and equipment.(Koezjakov et al., 2018)

2.1.6 Sustainable Building Design

Sustainable building design principles include integrated design approaches, passive design strategies, renewable energy integration, and life cycle assessment methods. It emphasizes the need for a holistic approach to implementing sustainability in building projects, incorporating social, economic, biophysical, and technical aspects. Passive design strategies, such as natural ventilation, vegetation landscaping, water bodies, and building orientation, are crucial for thermal and visual comfort. Highlighting the importance of studying the site's macro and microclimate and applying solar-passive and bioclimatic design features. Renewable energy integration involves developing energy-efficient technological processes for construction, fit-out, and maintenance, and using passive energy design to achieve thermal and visual comfort while reducing energy consumption. So using life cycle assessment methods in conjunction with existing assessment systems like BREEAM, BEES, and LEED to improve decision-making in implementing sustainability in building projects.(Akadiri et al., 2012)

2.2 Empirical literature review

2.2.1 Literature on Embodied Energy Analysis

- Carbon footprint and embodied energy consumption assessment of building construction work in Western Australia

The research conducted by Wahidul K. Biswas at Curtin University in Western Australia focused on assessing the environmental performance of Building 216 in terms of carbon footprint and embodied energy consumption. The study employed a life cycle assessment (LCA) methodology, considering all stages up to the utilization stage, to calculate the life cycle greenhouse gas (GHG) emissions and embodied energy of the building. The results showed that Building 216 had 14,229 tones of CO_2 of GHG emissions and 172 TJ of embodied energy.

The research identified the 'hotspots' in the production and operation of the building that contributed significantly to GHG emissions. The study found that the usage stage of the building produced 63% less GHG emissions than the University average, attributed to the implementation of a Building Management System (BMS). The BMS played a significant role in reducing the total embodied energy consumption of the building, which was 20% less than the University average.

Methodology: included three stages: the supply of construction materials, the construction stage, and the usage stage. The inventory analysis considered the inputs in terms of energy and materials, while the impact assessment calculated the total gases produced in each process and converted them to CO_2-equivalents.

Findings: Building 216's life cycle greenhouse gas emissions were 14,229 tonnes CO_2, with 172 TJ embodied energy. The building's usage stage produced 63% less emissions than the University average, thanks to the Building Management System. The study identified 'hotspots' in production and operation, assessing their environmental performance. It analyzed emissions from mining, processing, construction, and energy consumption of end-use appliances. These findings highlight areas for improvement in environmental management and highlight the environmental impact of building construction.(Biswas, 2014)

Overall, the research highlighted the importance of reducing energy consumption, controlling GHG emissions, and improving environmental management practices in building construction to mitigate the impact of global warming.

- Life cycle embodied energy analysis of residential buildings: A review of the literature to investigate embodied energy parameters

By Manish K. Dixit

Buildings consume 48% of global energy, largely from fossil fuels, which contributes to CO_2 emissions. Embodied energy is utilized during construction by materials, products, processes, transportation, administration, and management, whereas operational energy is required for space cooling, heating, lighting, and appliance power. A comprehensive approach that addresses both embodied and running energy is required to decrease buildings' carbon footprint. Quantifying embodied energy is difficult and resource-intensive, and reported quantities might differ due to methodological and data quality issues. This study tries to close this gap by evaluating the literature and studying the characteristics that influence embodied energy estimations. It presents a two-step strategy to improve the openness and efficiency of embodied energy analysis, including recommendations and an uncertainty calculation model. This promotes sustainable construction methods and energy.

Methodology: The study on life cycle embodied energy analysis of residential buildings uses a comprehensive review of the literature to investigate various parameters influencing calculations. Key aspects of the methodology include data collection and review, identification of methodological issues, and addressing energy inputs and terms. The study emphasizes the importance of reporting energy results in primary energy terms for comparability and accuracy, considering energy components like human and feedstock energy. Data quality assessment is also discussed, emphasizing the need for completeness and accuracy in data used for embodied energy analysis. A proposed solution involves developing guidelines to standardize embodied energy analysis studies, defining terms, computational requirements, and data reporting standards, and quantifying and reporting uncertainties in the analysis to address parameters relying on complete and representative data. This study contributes to advancing the understanding and practice of embodied energy assessment in residential buildings.

Findings: The study examines variations in data quality and methodological parameters in case study buildings across different regions. It focuses on system boundary definitions, life-cycle phases, and embodied energy. The study highlights the subjective selection of system boundaries as a major issue in embodied energy analysis. It also presents embodied energy results for wood-construction residential buildings, revealing variations in IEE and LCE values. The findings emphasize the need for standardized parameters and improved transparency in reporting to enhance the accuracy and comparability of embodied energy calculations.(Dixit, 2017)

- A Building Life-Cycle Embodied Performance Index—The Relationship between Embodied Energy, Embodied Carbon, and Environmental Impact

By Ming Hu

The study investigates the link between environmental effects, embodied energy, and embodied carbon in the building sector. It offers a new metric, life-cycle embodied performance (LCEP), which assesses building performance by taking into account both embodied energy and embodied carbon. To test the approach, the researchers utilize eight buildings in a comparable temperature zone and construction type. Key findings include the use of ozone depletion potential to forecast LCEP values, the need to account for both embodied energy and embodied carbon and the major impact of external wall systems on embodied energy and carbon. The study also shows that environmental effect categories are related to LCEP, with metal and concrete playing a substantial role. The results provide useful insights on building life-cycle assessment and offer a basis for developing standardized metrics to enhance the accuracy and comparability of embodied performance evaluations.

Methodology: The study "A Building Life-Cycle Embodied Performance Index—The Relationship between Embodied Energy, Embodied Carbon, and Environmental Impact" uses a structured approach to evaluate the environmental impact of buildings throughout their life cycle. The methodology includes a life-cycle assessment framework, the development of a new metric called "life-cycle embodied performance (LCEP)," and case studies of eight buildings in the same climate zone with similar construction types. The study quantifies environmental impact across various categories to assess the overall impact of the buildings. The findings provide insights into the importance of considering both embodied energy and embodied carbon in evaluating building sustainability and environmental impact. Recommendations include improving building design practices and enhancing environmental performance through a holistic approach to embodied energy and embodied carbon assessment.

Findings: The study introduces life-cycle embodied performance (LCEP) as a new metric for evaluating building performance, considering the ratio of embodied energy and embodied carbon. It emphasizes the importance of considering both embodied energy and embodied carbon for comprehensive evaluation. The study also highlights the role of exterior wall systems in influencing both embodied energy and embodied carbon. Metal and concrete are identified as key materials in sustainable building design.(Hu, 2020)
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- Visualizing the research of embodied energy and environmental impact research in the building and construction field: a bibliometric analysis

By Ming Hu

This study explores the research on embodied energy and environmental impact in the building and construction industry, focusing on sustainable practices and design strategies. A bibliometric analysis of 320 publications from 1996 to 2019 revealed three main research clusters: embodied energy counting, influential parameters, mitigation strategies, embodied energy significance, and the balance between energy efficiency and environmental impact. The research landscape is diverse, with varying focuses in developing and developed countries. Geographical equality in publication output fosters research collaboration. The study contributes to the ongoing discourse on sustainable building practices and emphasizes the importance of considering embodied energy and environmental impact in shaping the future of the built environment.

Methodology: The study "Visualizing the research of embodied energy and environmental impact research in the building and construction field: a bibliometric analysis" uses a structured approach to analyze the research landscape in this area. The methodology includes a bibliometric analysis framework, data collection and selection, and thematic analysis and trends. The study identifies three primary research clusters in the building sector, including embodied energy counting, influential parameters, mitigation strategies, embodied energy significance, and the balance between energy efficiency and environmental impact. Thematic analysis and trends are also conducted to understand the current status and future directions of research in this domain. The study also compares the research focuses of developing and developed countries in the context of embodied energy and environmental impact research, identifying differences in priorities.

Findings: The study analyzed 320 publications on embodied energy and environmental impact research in the building and construction industry from 1996 to 2019. It identified three primary research clusters, focusing on topics like embodied energy counting, mitigation strategies, and energy efficiency balance. Geographical equality in publication output fostered research collaboration. The study found differences in research focus between developing and developed countries, with developing countries prioritizing methodological accuracy and developed countries balancing energy efficiency and environmental impact.(Hu & Milner, 2020)

- Life cycle embodied energy analysis of higher education buildings: A comparison between different LCI methodologies

By V. Venkatraj , M.K. Dixit

The research "Life cycle embodied energy analysis of higher education buildings: A comparison between different LCI methodologies" looks at the assessment of embodied and operational energy in higher education buildings. It intends to give information about energy efficiency and environmental sustainability in school facilities. The study examines energy consumption patterns and life cycle energy profiles of newly constructed and refurbished buildings, with an emphasis on the link between embodied and operational energy. The study investigates the complexity and variability in estimating embodied energy using several LCI methodologies, such as process-based, aggregated input-output-based hybrid (IOH), and disaggregated IOH approaches. The data will give useful insights into the necessity of standardized procedures for computing embedded energy, the influence of different LCI methods on energy estimates, and the significance of accurate energy performance evaluations in educational infrastructure.

Methodology: The study "Life cycle embodied energy analysis of higher education buildings: A comparison between different LCI methodologies" uses a structured approach to analyze and compare the embodied energy of higher education buildings using various LCI methodologies. The methodology includes data collection and analysis of energy consumption patterns, calculation of embodied energy factors, comparison of LCI methodologies, and analysis of results and interpretation. The findings may offer recommendations for standardizing embodied energy calculations in higher education buildings, guiding energy-efficient design practices, renovation strategies, and operational improvements. The study aims to contribute to understanding energy performance in higher education buildings and provide valuable insights for optimizing energy efficiency and sustainability in educational infrastructure.

Findings: The study examined embodied energy (EE) values using several life cycle inventory (LCI) approaches, indicating considerable differences in EE parameters for educational buildings. The process-based technique overestimated EE, but the IOH-based approaches produced more accurate estimates. Understanding each LCI technique's benefits and limitations is critical for developing successful energy-saving methods and sustainability measures.

Overall, the study's findings emphasize the need to use proper LCI approaches to calculate embodied energy in educational buildings to achieve accurate and trustworthy evaluations. The observed shortcomings highlight the need for better data sources, methodological consistency, and extensive assessments to increase our understanding of energy performance and sustainability in educational infrastructure.(Venkatraj & Dixit, 2021)

2.2.2 Literature on Operational Energy Analysis

- Energy performance analysis of airport terminal buildings by use of architectural, operational information, and benchmark metrics

By Sang-Chul Kim, Hyun-Ik Shin, Jonghoon Ahn

The project "Energy Performance Analysis of Airport Terminal Buildings by Use of Architectural, Operational Information, and Benchmark Metrics" aims to increase energy efficiency and sustainability in airport terminal buildings. The study intends to improve energy performance assessments and forecasting models for present and future airport facilities by examining architectural design, operational features, and benchmark measures. The findings will benefit aviation industry stakeholders, architects, planners, and legislators by paving the road for more sustainable and resource-efficient airport buildings.

Methodology: The study focuses on analyzing the energy performance of airport terminal buildings using architectural, operational, and benchmark metrics. It uses a dataset of 30 existing and simulated airport terminal buildings in North America, along with simulated results from 9 specific space-type models. Benchmark metrics are developed to evaluate the energy performance of both existing and future buildings. A multivariate regression model is used to analyze the data and refine average energy use values. The refined average energy values are then applied to space configurations for new buildings to guide energy-efficient design practices. The study evaluates the improvement in energy performance forecasts, providing insights for optimizing energy efficiency in airport terminal structures.

Findings: The study on energy performance analysis of airport terminal buildings used architectural, operational information, and benchmark metrics. It improved energy performance forecasts by 1.1% to 3.0% using a multivariate regression model. The study highlighted the importance of defining energy baselines based on building characteristics for energy-efficient design practices. The improved benchmark metric can help define energy-efficient design baselines, analyze energy patterns, and make quick decisions for future airport terminal designs.

2.2.3 Literature on both Embodied and Operational Energy Analysis

- Embodied and operational energy and carbon emissions of passive building in HSCW zone in China: A case study

The study focuses on a passive building in the HSCW zone in China, analyzing its embodied and operational energy and carbon emissions. The findings suggest that the passive building has higher embodied energy and carbon emissions than the conventional building, significantly lower operational energy consumption and carbon emissions, and lower total life cycle energy requirement and carbon emissions. The study emphasizes the importance of considering both embodied and operational energy in building design and calls for further research on passive building design in the HSCW zone. However, the study does not address potential uncertainties or limitations in data collection and analysis, reliance on simulation data for operational energy consumption, potential variability in results due to different building designs or construction practices, and the impact of occupant behavior on operational energy consumption.

Methodology: The study looked at the embodied and operational energy, as well as carbon emissions, from passive buildings in China's HSCW zone. It employed the Life Cycle Assessment (LCA) approach to assess the passive building's environmental effect across its entire life cycle. The study discovered that the passive building had an embodied energy usage of 7.31 GJ/m^2 and carbon emissions of 0.98 t CO_2 eq/m^2. It also compared the embodied energy usage to a standard building in the same temperature zone. The findings revealed that passive buildings are more energy efficient and have a lower environmental effect than conventional buildings. The research included suggestions for future passive building design, highlighting the significance of passive cooling systems, high-efficiency cooling equipment, and the use of renewable energy sources.

Findings: The study found that passive buildings have a higher embodied energy consumption of 7.31 GJ/m^2, which is 37.6% higher than conventional buildings. However, they have lower total life cycle energy requirements and carbon emissions of 0.98 t CO_2 eq/m^2, which is 16.2% higher. The study also found that the total life cycle energy requirement of passive buildings is 17.4% lower than conventional buildings, and the total life cycle carbon emissions are 22.7% lower. The study emphasizes the importance of considering both embodied and operational energy consumption in passive building design to achieve energy efficiency and environmental sustainability goals. (Su et al., 2020)

- Embodied and Operational Energy of a Case Study Villa in UAE with Sensitivity Analysis

The study investigated the embodied energy of a residential villa in the United Arab Emirates (UAE) over a 50-year building lifespan using an input-output hybrid approach. The research found that the initial embodied energy was 57% of the villa's life cycle embodied energy and 19% of its recurrent energy. The recurrent embodied energy was 43% and 14% of the villa's life cycle embodied energy. The life cycle embodied energy was 36% over the villa's 50-year life span. The adoption of a solar PV system increased the proportion of embodied energy from 34% to 45%.

Methodology: The study analyzed the embodied and operational energy of a residential villa in the UAE using an input-output hybrid approach. It calculated the energy consumed during the construction phase, including materials and components used. The study also estimated the initial, recurrent, and demolition and disposal embodied energies over a 50-year building life span. A sensitivity analysis was conducted to assess variations related to energy consumption during the villa's life cycle, including the adoption of renewable energy sources. The study compared the initial and recurrent embodied energies to determine their contribution to the overall life cycle energy. The study also evaluated the impact of adding a solar PV system to the villa on embodied energy and overall energy consumption. The study highlighted multiple areas for future research related to embodied energy and its benefits to stakeholders in the building industry. Suggestions were made to explore additional aspects of embodied energy in building construction and design.

Findings: The study found that the initial embodied energy of a case study villa in the UAE was 57%, followed by recurrent energy at 43% and recurrent energy at 14%. The life cycle embodied energy over a 50-year lifespan was 36%. Operational energy consumption constituted 66% of the villa's life cycle energy, emphasizing the need for design and policy strategies to reduce operational energy in residential villas. The study also conducted a sensitivity analysis to understand the impact of renewable energy sources on the villa's embodied and operational energy. The findings highlight the importance of considering both aspects of sustainable building design and energy efficiency strategies.

Overall the study relied on secondary data and the EPIC database, which may introduce limitations in the accuracy and specificity of the findings. Additionally, the study did not address potential limitations or uncertainties associated with the input-output hybrid approach used for the embodied energy assessment. The study provided valuable insights into the embodied and operational energy of residential buildings in the UAE, but the reliance on secondary data and the lack of explicit discussion on potential limitations are important considerations for future research. (Rauf et al., 2022)

2.3 Deep review

- Estimating Embodied Energy in Residential Buildings in a Nigerian Context

By**: -** Isidore Chukwunweike, Olabosipo I. Fagbenle and Abiodun Olukayode /Nov,2015

The International Journal of Applied Engineering Research published an article estimating embodied energy in residential buildings in Nigeria. The study used embodied energy as a measurement index to identify areas that could benefit from innovative strategies. The research used primary data from surveys, observations, and interviews, and adopted the life cycle assessment framework and international energy protocols. The findings highlighted opportunities for embodied energy mitigation, particularly in building frames, walls, and recurring embodied energy components. Recommendations included replacing conventional materials with low-energy and durable ones and adopting innovative construction methods. The study focused on Lagos, Nigeria, known for its active housing sector and rapid urbanization.

The study focused on public housing units in Lagos, Nigeria, focusing on low and medium-income earners. A sample of nine estates, comprising 10,182 housing units, was randomly selected. Data was collected through survey research and the Life Cycle Assessment framework, using 775 questionnaires. Building-specific inventory data was obtained through observation, interviews, and secondary sources. The study estimated the embodied energy of the selected residential building typology using international energy protocols, the Inventory of Carbon and Energy (ICE) database, and local inventory data. The total embodied energy was calculated by considering materials, transportation, construction, recurring embodied energy, and demolition energy. Building typology and description have been described with its bell of quantity to calculate the embodied energy. (Ezema et al., 2015)

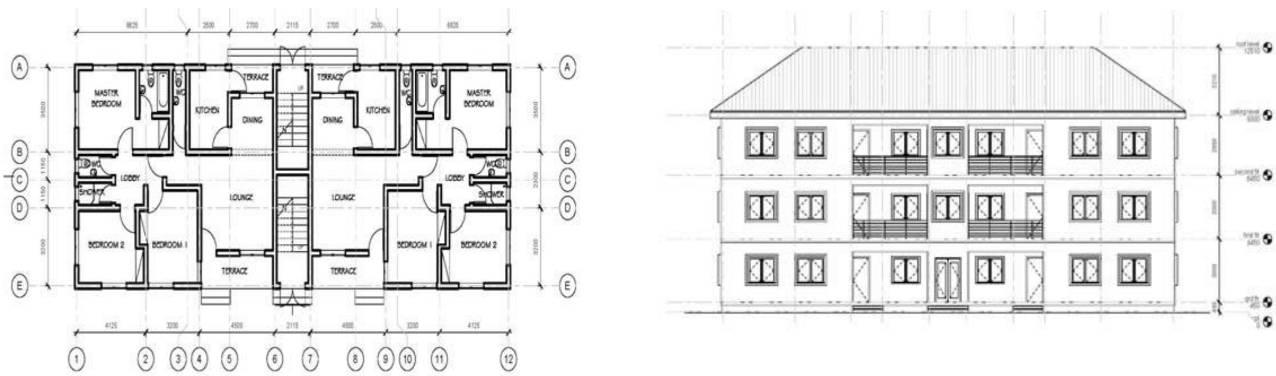

Figure 6: Selected building floor plan and elevation

Table 1: Checklist of materials (Data collected by observation)

Checklist of materials **(**Data collected by observation**)**

Milestone	Component	Material
Substructure	Raft Foundation	Reinforced concrete
	Strip Foundation	Concrete
	Wall in Foundation	225mm concrete-filled Sand-cement blocks
	Columns	Reinforced concrete
	Filling to Level	Lateritic soil
	Hardcore	Broken concrete/stone
	Floor Slab	Concrete with BRC
	Formwork	Timber

Frame, Floor, Wall	Columns	Reinforced concrete
	Beams	Reinforced concrete
	Upper Floors	Reinforced concrete
	Staircases	Reinforced concrete
	External wall	225mm blocks
	Main internal wall	225mm blocks
	Partition walls	150mm blocks
	Formwork	Timber
Roof Structure And Covering	Wall Plate	75x100x3600 timber
	Tie Beam	50x150x3600 timber
	Rafters/Struts	50x100x3600 timber
	Purlins	50x75x3600 timber
	Noggings	50x50x3600 timber
	Fascia Board	25x250x3600
	Roof covering	Aluminum sheets
Finishes	Ceiling	PVC tiles
	Internal walls	Rendering/paint
	External walls	Rendering /paint
	Slab soffits	Rendering/paint
	Wet walls	Glazed ceramic tiles
	Floor finishes	Vitrified tiles
Doors, Windows, Fixtures, Fittings	External doors	Steel
	Internal doors	Timber panel door
	Windows	AAluminumglass
	Anti burglary bars	20x20 hollow steel pipe
	Wardrobe/Cabinets	20mm MDF boards

The study analyzed site construction energy, focusing on equipment and manual energy usage. Contractors were mostly medium-sized firms, mainly labor-intensive. Equipment usage was limited to concrete mixers, hand-held vibrators, welding machines, drilling machines, cutting machines, and office appliances. Earth-moving equipment was leased. (Ezema et al., 2015)

Table 2: Summary of Embodied Energy Calculation

Embodied Energy Category	Embodied Energy (MJ)	Percentage
Cradle-To-Gate	2, 683, 461	50.5
Transportation	100, 201	1.9
Site Construction	60, 138	1.1
Recurring Embodied Energy	2, 468, 307	46.5
Total	5, 312, 107	100

The results were used to identify areas for energy efficiency strategies, such as replacing conventional building materials with low-energy and durable materials and adopting innovative construction methods. Overall The findings suggest areas for energy efficiency strategies, including replacing conventional materials with low-energy alternatives and adopting innovative construction methods.

- Embodied vs. Operational Energy and Carbon in Retail Building Shells: A Case Study in Portugal

By**: -** Ana Ferreira, Manuel Duarte Pinheiro, Jorge de Brito and Ricardo Mateus/ 2023

This paper is a Case Study in Portugal aimed at assessing the environmental impacts of building materials in a European retail building, particularly in Portugal. The specific objectives of the study were to evaluate the embodied energy and carbon emissions of the building, compare them to operational energy use, quantify the material flow in terms of mass, identify materials with higher impacts, and investigate strategies to mitigate these impacts. This study used data from various sources, including the retail group's technical department, Level(s) BSA framework, trade literature, technical datasheets, and SimaPro software. The total mass of building elements was calculated using the Cumulative Energy Demand (LHV) V1.00 methodology, based on the Ecoinvent version 3 database.

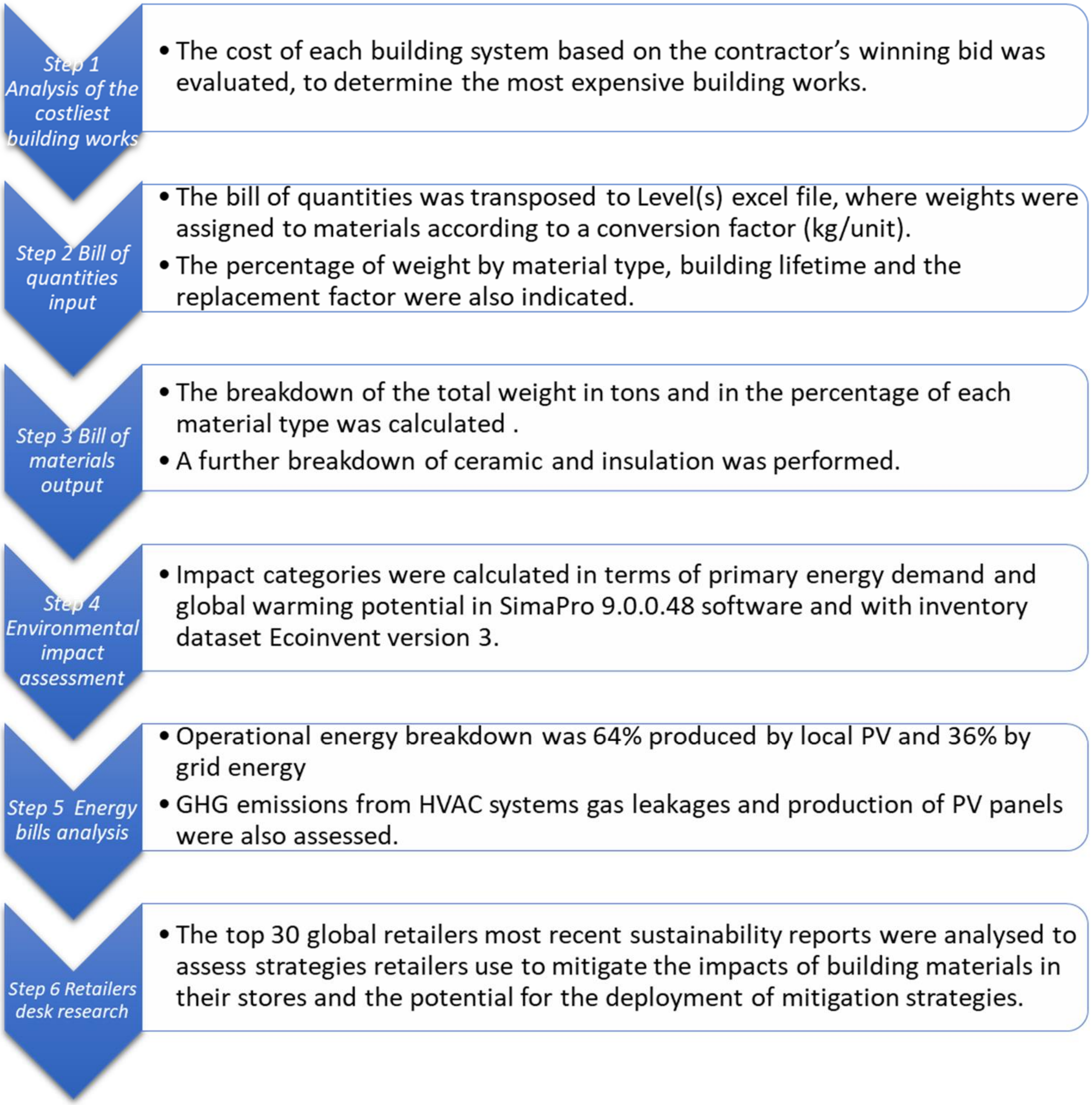

Figure 7: Methodology flow chart that has been used

Table 3: Bill of materials output regarding shell building elements by material type in terms of total weight and percentage of weight.

Material Type Breakdown	Material Total (T)	Material Total (%)

Glass	0.37	0.00%
Plastic	2.19	0.01%
Bituminous Mixtures	86.02	0.20%
Metals	2320.69	5.50%
Electrical And Electronic Equipment	70	0.17%
Concrete, Brick, Tile, Natural Stone, Ceramic	39,415.43	93.44%
Round Gravel	3.74	0.01%
Concrete Block	1509.3	3.58%
Cement Mortar	56.08	0.13%
Screed	326.98	0.78%
Crushed Limestone	7154.82	16.96%
Ceramic Tile	1.38	0.00%
Reinforced Concrete	30,363.13	71.98%
Insulation Materials	289.61	0.69%
Rock Wool	167.93	0.40%
Extruded Polystyrene	121.67	0.29%
Combined Total	42,184.31	100.00%

The cost analysis of building works involves evaluating each system's cost based on the contractor's winning bid. Shell elements, which represent over half of the total construction cost, are chosen for this assessment due to their similar lifetime and low replacement factors. The bill of quantities (BoQ) input is transposed to a Level(s) Excel file, and weights are assigned to building elements' materials based on a conversion factor. The percentage of weight split by material type and assumed building lifetime are also indicated. The bill of materials (BoM) output is calculated, breaking down insulation materials into extruded polystyrene and stone wool, and ceramic materials into round gravel, concrete block, cement mortar, screed, crushed limestone, ceramic tile, and concrete. This process helps retailers prioritize financial gain in their investments.

In conclusion, the study used a simplified Life Cycle Assessment (LCA) method to analyze the shell-building materials in terms of primary energy demand and global warming potential. The findings revealed that the embodied energy represented 32% of the total life cycle energy, while the embodied carbon represented 94%. The study also identified specific building materials, such as cement mortar, steel, concrete, and extruded polystyrene, as having the highest environmental impacts. Additionally, the study highlighted the need to balance the performance of buildings in terms of both embodied and operational aspects to mitigate global environmental impacts, especially in the context of energy-efficient design.(Ferreira et al., 2023)

2.3 Summery and Gaps

The research highlighted several key findings regarding embodied energy and carbon in buildings. Metal and concrete were identified as materials with the highest contribution towards embodied energy and embodied carbon. The increasing significance of buildings' embodied energy in life cycle energy use was emphasized, especially as operating energy decreases due to energy efficiency improvements. The study also highlighted the importance of considering building characteristics in energy performance evaluations to achieve more accurate results. Embodied energy, consumed through construction materials and processes, was found to play a crucial role in the total energy consumption of buildings. The need to standardize parameters for embodied energy calculations was emphasized to ensure consistency and accuracy. Recent research indicated an increasing proportion of embodied energy in total life-cycle energy, especially with the rise of more energy-efficient buildings. However, the proportions of embodied and operational energy were found to vary based on factors like location, climate, and fuel source, making generalizations challenging.

The research highlights several key gaps in the analysis of embodied energy and environmental impact in the building and construction industry. To begin with, there are limitations in the scope of life cycle assessments (LCAs), which often focus only on the supply of construction materials, construction stage, and usage stage, while neglecting other important phases like transportation, construction waste, demolition, and recycling. Furthermore, there is a lack of standardized parameters and methodologies for calculating embodied energy, leading to variations in the coverage of life-cycle components and inconsistencies in data reporting on energy embodied in human labor, transportation, and construction waste. Additionally, there is insufficient research and a lack of established guidelines for evaluating the environmental impact of buildings, with a focus on operational energy efficiency while neglecting embodied energy measurement and reduction. Moreover, there are challenges with data sources and life cycle inventory (LCI) approaches, such as reliance on specialized databases, limited public access, and difficulties in estimating demolition energy and accounting for recycling and reuse costs. Additionally, there are gaps in benchmarking measures, including issues with linking different building zones and the need for improved statistical approaches and broader surveys to analyze energy use for specific building components. Finally, the research emphasizes the need to consider both embodied and operational energy consumption for comprehensive energy reduction in buildings, as high embodied energy can significantly increase the total life cycle energy use, particularly in passive and high-performing buildings.

Table 4: Tabular summary empirical review.

Title Of The Study	Specific Methodology	Key Finding
Carbon Footprint And Embodied Energy Consumption Assessment Of Building Construction Work In Western Australia / 2014 /	- Life Cycle Assessment (LCA	Building 216, with a Building Management System, produced 63% less emissions than the University average, identifying 'hotspots' in production and operation for effective environmental management.
Embodied And Operational Energy And Carbon Emissions Of Passive	- Life Cycle Assessment (LCA	Passive buildings have lower embodied energy consumption and operational energy consumption, highlighting the importance of considering both

Building In Hscw Zone In China /2020/		embodied and operational energy in building design.
Life Cycle Embodied Energy Analysis Of Residential Buildings: A Review Of Literature To Investigate Embodied Energy ParametersUSA Usa / 2017/	- Input-Output Approach	The study highlights the need for standardized parameters and improved transparency in reporting to address variations in data quality and methodological parameters across different regions.
A Building Life-Cycle Embodied Performance Index—The Relationship Between Embodied Energy, Embodied Carbon And Environmental Impact. Switzerland /2020/	- Life Cycle Assessment (LCA	The introduction of life-cycle embodied performance (LCEP) as a new metric for building performance emphasizes the influence of exterior wall systems on embodied energy and carbon.
Visualizing The Research Of Embodied Energy And Environmental Impact Research In The Building And Construction Field, USA/2020/	- Bibliometric analysis	The study identified three research clusters focusing on embodied energy counting, influential parameters, and mitigation strategies, highlighting geographical equality in publication output and differences in research focus between developing and developed countries.

Embodied And Operational Energy Of A Case Study Villa In Uae With Sensitivity Analysis /2022/	- Input-Output Approach	The villa's life cycle energy consumption, comprising 66% of its initial and recurrent energy, is crucial for sustainable building design, emphasizing the importance of considering both aspects.
Energy Performance Analysis Of Airport Terminal Buildings By Use Of Architectural, Operational Information, And Benchmark Metrics, South Korea /2020/	- Input-Output Approach	The multivariate regression model improved energy performance forecasts by 1.1% to 3.0%, emphasizing the significance of defining energy baselines for energy-efficient design practices.
Life Cycle Embodied Energy Analysis Of Higher Education Buildings: A Comparison Between Different LCI Methodologies, USA /2021/	- Life Cycle Inventory (LCI)	The study highlighted the significance of proper LCI methodologies in evaluating energy in educational buildings, highlighting significant differences in embodied energy values between process-based and IOH-based techniques.

CHAPTER THREE

MATERIALS AND METHODOLOGY

This chapter describes the research region, the types of information needed for the study, sampling procedures, and the methods utilized to collect various data, as well as the instruments used. The chapter also discusses and analyzes the procedures used to examine the material that leads to answers to research questions and the realization of research objectives.

3.1 Description of the area

The town of Adama is situated in central Ethiopia, located at approximately 8.5264° N latitude and 39.2631° E longitude. It is situated around 100 kilometers southeast of Addis Ababa, the capital city. Adama offers a diverse range of residential options in terms of dwelling types. As a major urban center, Adama is experiencing rapid urbanization, a dense population, and significant economic potential, which is accessible through railway and expressway networks. The area's altitude ranges from 1623 meters above sea level. Adama City experiences an average annual rainfall of approximately 866.25 millimeters, with the majority of precipitation occurring during the rainy season from June to September. The minimum wind speed is observed in September, reaching around 1.65 meters per second, while the highest wind velocities occur during December, January, and February, ranging from 3.05 to 3.2 meters per second. The mean temperature in the city varies from a low of 11.5 degrees Celsius to a high of 31 degrees Celsius (Bulti et al, 2017).

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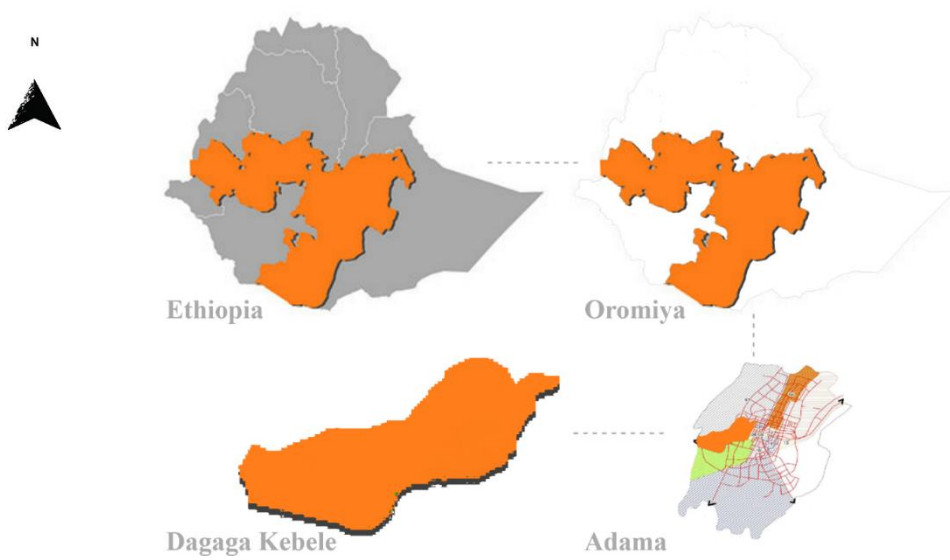

Figure 8: Site location

3.2 Selection of criteria for the site

To select an area for this study based on specific criteria, Dagaga Kabele has been chosen for this study based on the availability of various designs, materials that have been used in the construction of G+0 residential, different times of construction periods, and availability of data. Observations were made based on these selection criteria. This observation examines the overall condition of the site, such criteria that have been listed above and to make this study. Another factor the transformation of informal residences into legal structures in the area (around Ketena 5&6) and the new construction of G+0 residences was also considered for this study.

3.3 Background of study area

The study area was previously known as 05 Kebele, but the administrative structure has since been changed, and the site is now located under the Dambela sub-city, which has been renamed Dagaga Kebele. The site is situated in an area known as Awra Godana. Within the Dagaga Kebele, there are various structures, including schools, hotels, religious compounds, governmental institutions, and industrial compounds.

Figure 9: Selected area image from Google earth

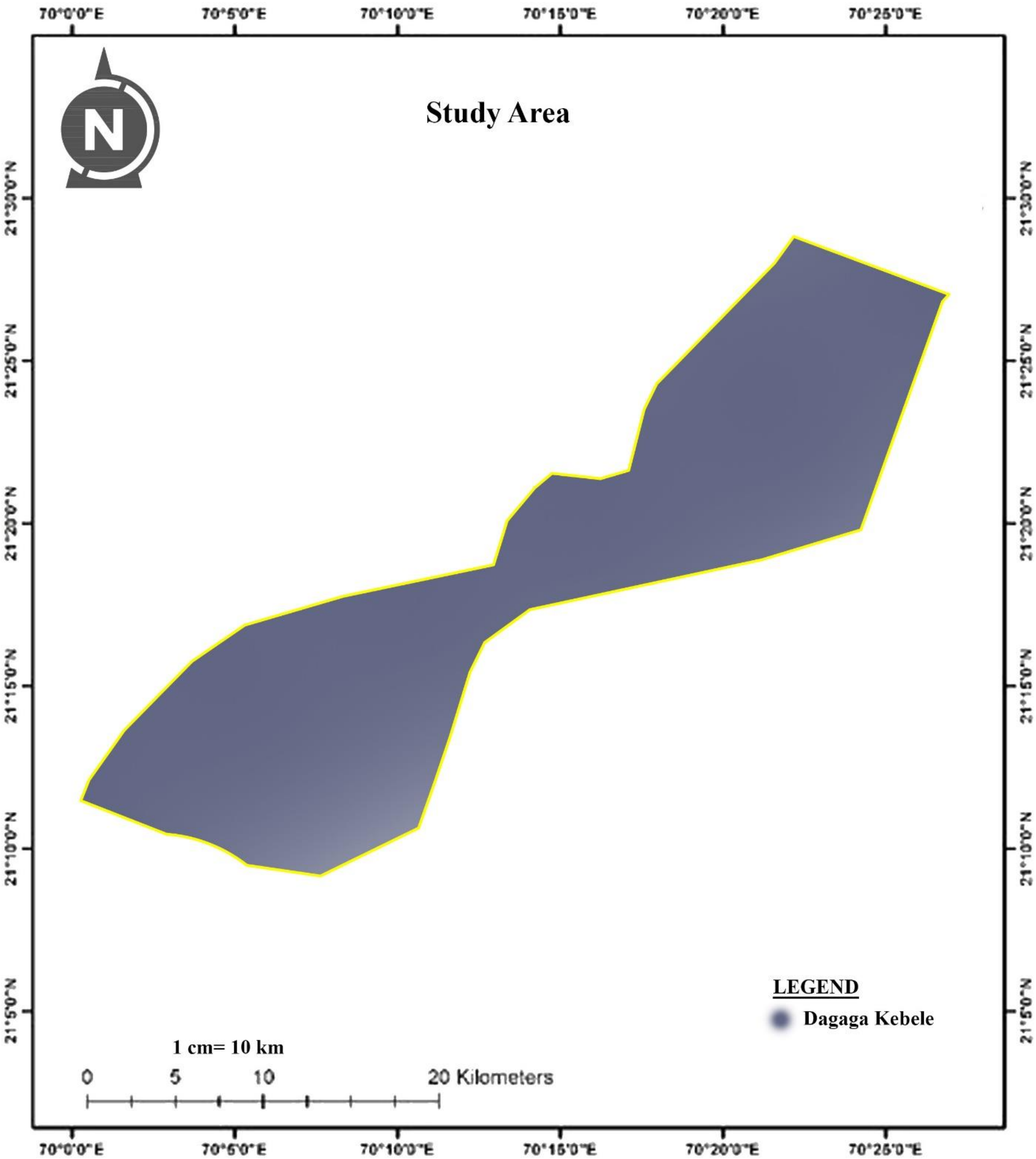

Figure 10: Selected area(Adama City Spatial Text Report, 2017)

This image illustrates the study area for a research project, as indicated by the scale presented: 1 cm = 10 km.

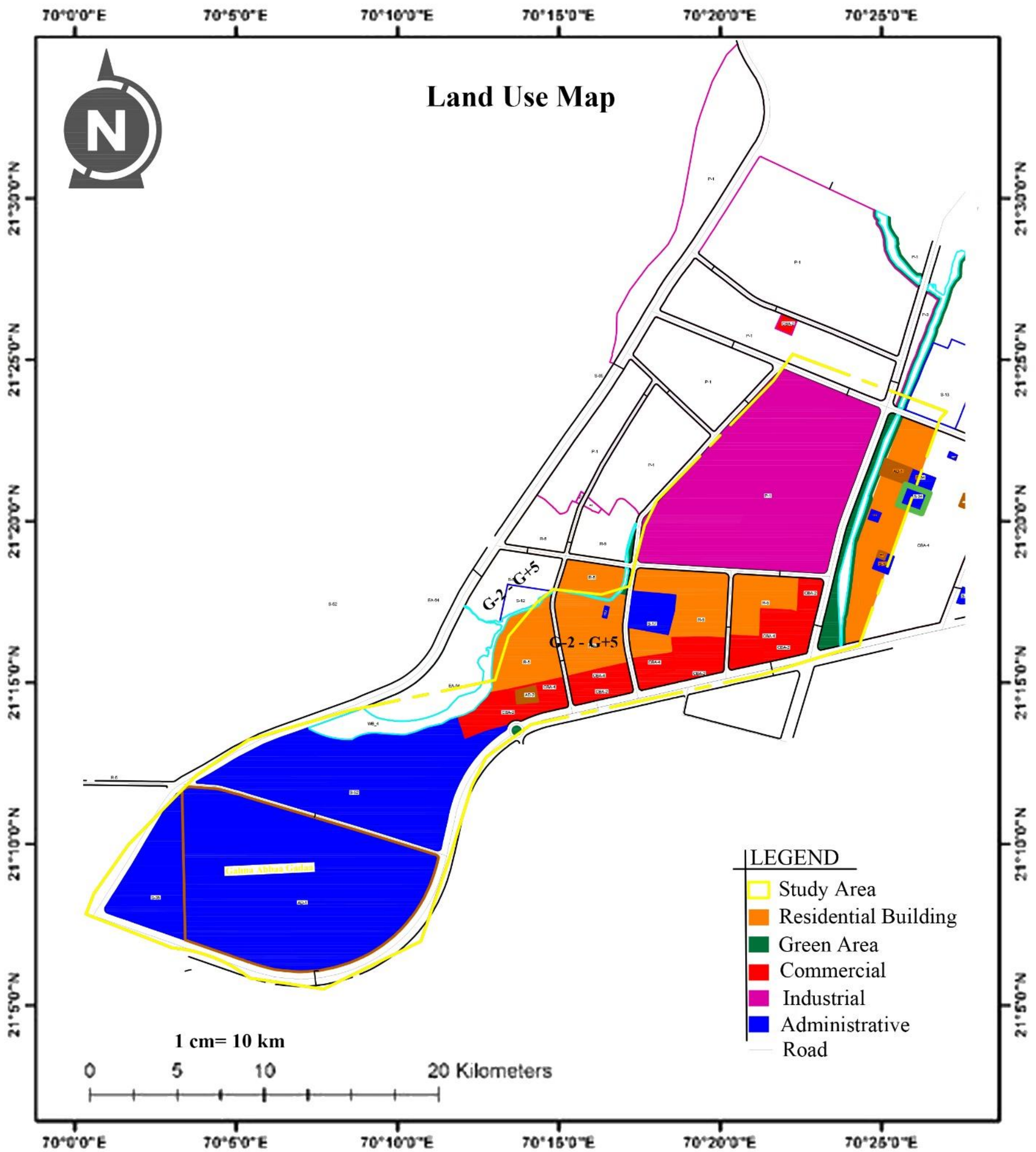

Figure 11: Land use map of the study area (Adama City Spatial Text Report, 2017)

The above image illustrates the existing land use category in the area. The study area contains different land use type which is classified in the legend parts as commercial, residential, Administrative and service, Green space, and industrial. Of the all types of land use the study area is dominated by commercial land use type.

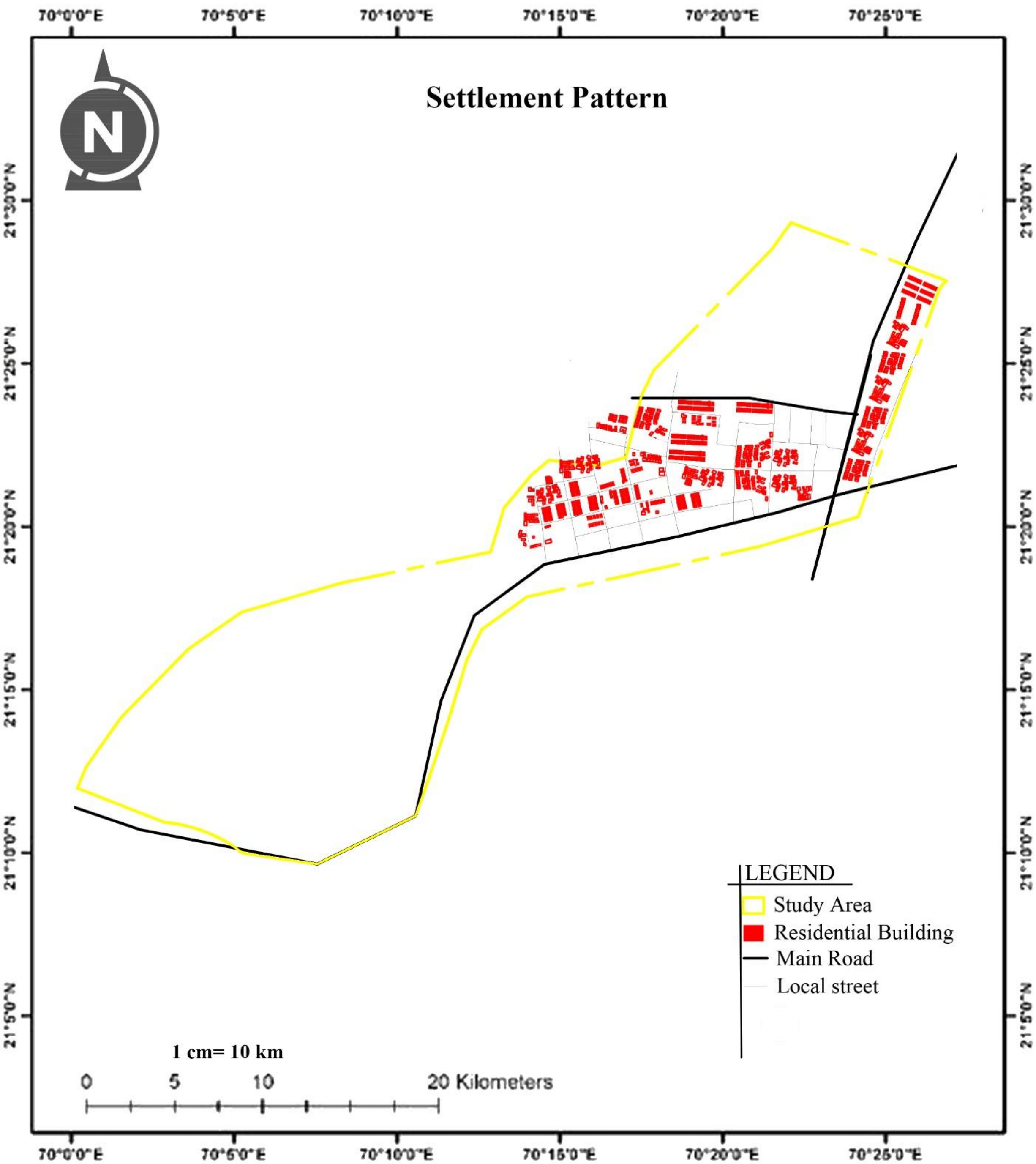

Figure 12: Settlement Pattern of the study area

The image illustrate of the ground floor (G+0) residential buildings, within this settlement pattern. G+0 refers to buildings that have only a ground floor, without any additional stories or floors above it.

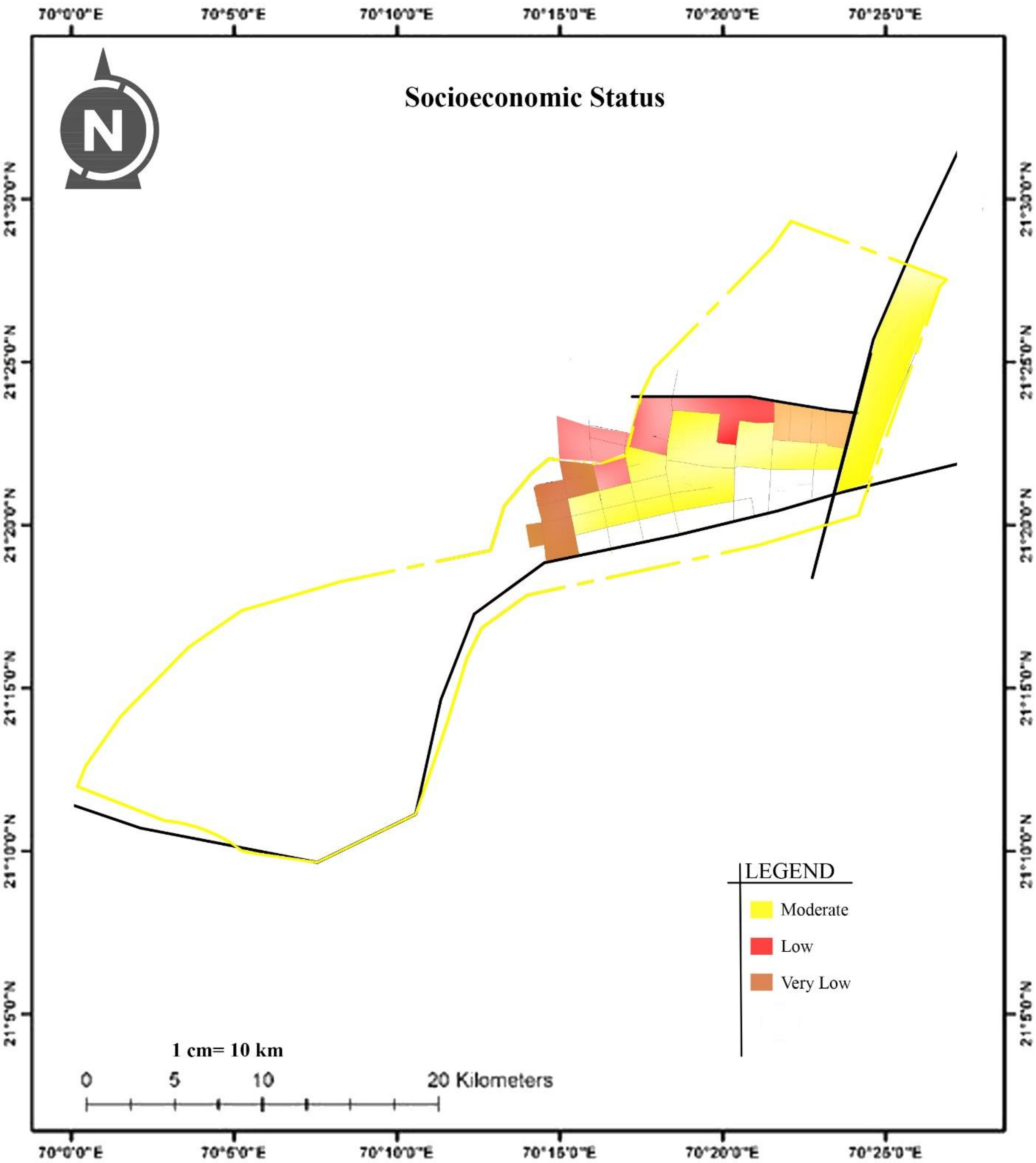

Figure 13: Socioeconomic states of the study area shows data about social and economic conditions

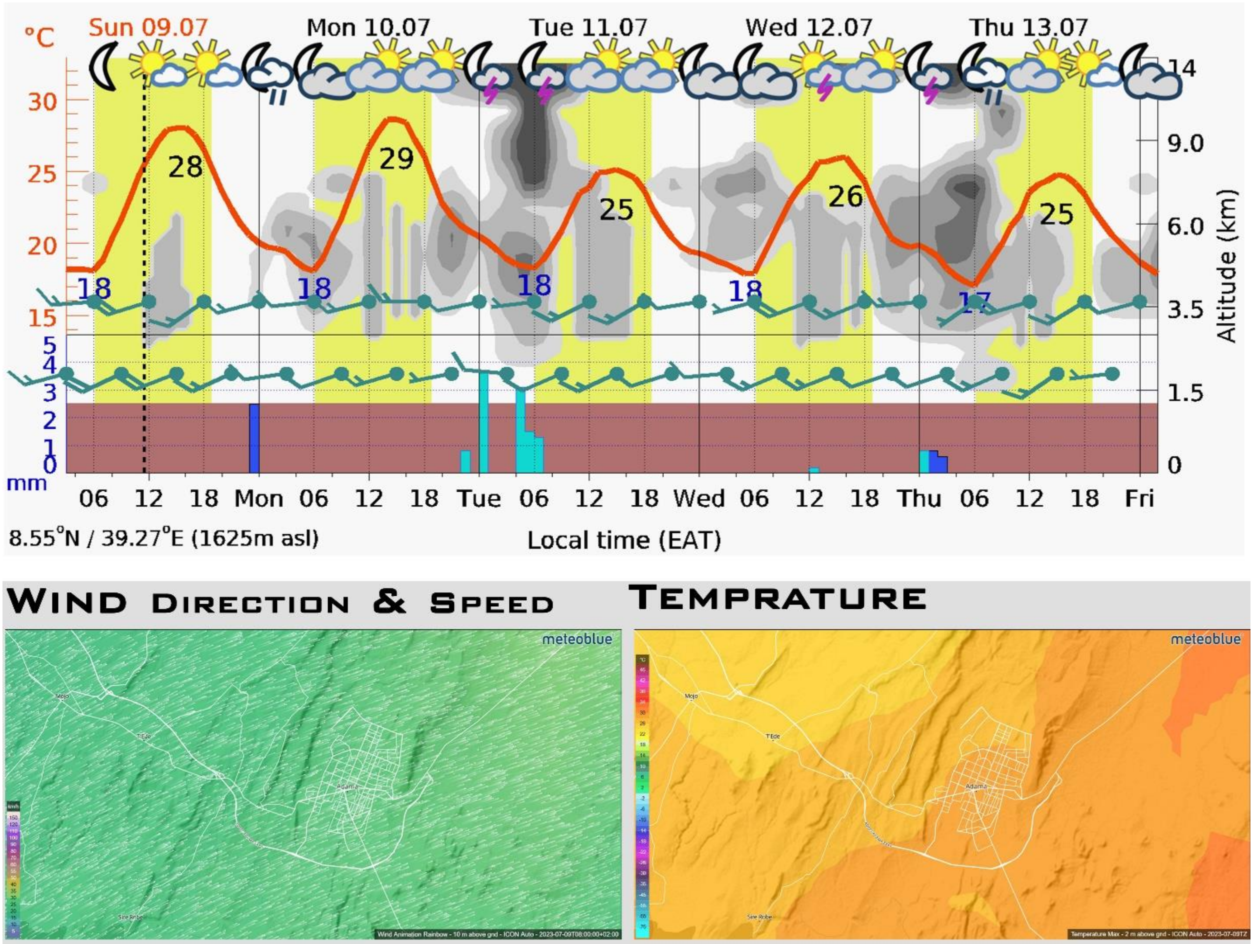

Figure 14: Clemet (Weather Nazrēt(Adama) - Meteoblue, 2024)

The wind direction in Adama town varies throughout the seasons. From October to April, the wind blows predominantly in a northeasterly direction, while from May to September, the wind direction shifts to the southwest. The wind speed during the dry season (the winter season) ranges from 10 km/h to 20 km/h, while in the winter season, it is between 5 km/h to 15 km/h. The average annual temperature in Adama ranges from 12°C (54°F) to 22°C (72°F). The cooler temperatures are typically experienced during the months of November to February, while the warmer temperatures are felt from March to May.(Weather Nazrēt(Adama) - Meteoblue, 2024)

3.4 Study design

The research will employ a mixed-method approach, combining quantitative data collection through building energy audits and material quantity surveys, as well as qualitative data from interviews with building stakeholders and a review of local policies and industry practices. The analysis will focus on both new and existing G+0 residential buildings, representing various construction materials, building forms, and sizes.

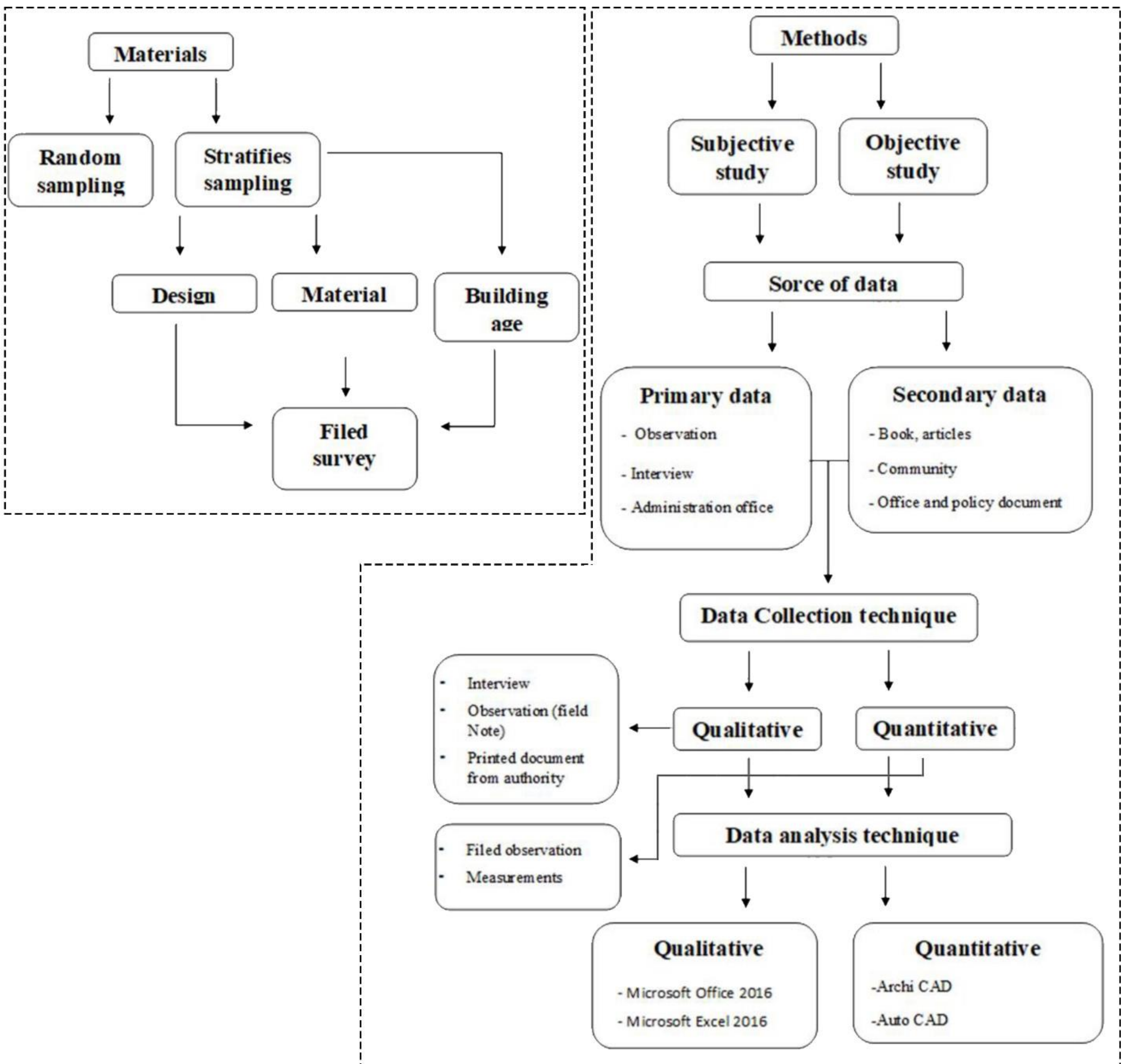

Figure 15: Study design (Source: Own design 2024)

3.5 Study approaches

The research seeks to evaluate the combined energy use and functionality of G+0 structures, in Adama Town focusing specifically on the Dagaga kebele for creating energy-efficient designs. A quantitative approach is employed to measure the energy usage of buildings and Input-output techniques are utilized to assess the embodied energy of construction materials. The embodied and operational energy consumption of several residential building types in Adama Town, including variations in construction methods used across different seasons, are compared using comparative analysis. The analysis of energy-efficient design elements and practices identifies effective approaches to lower energy usage. Software for building energy modeling will be used to simulate energy performance under various design scenarios, and sensitivity analysis will be done to see how design changes may affect energy use. Structured interviews, questionnaires, and focus groups with builders, architects, and homeowners are used in qualitative analysis. Engaging stakeholders is another way to learn about regional construction methods and any implementation roadblocks. To enhance the energy efficiency of Adama Town's residential structures, designs, and recommendations will be created.

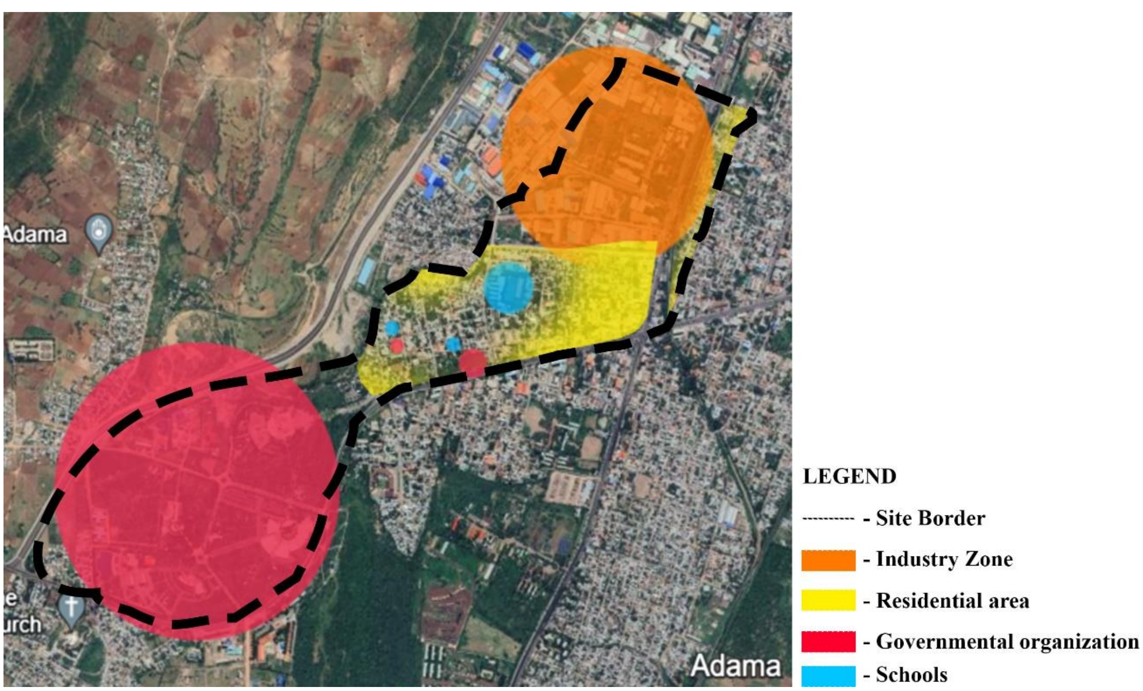

Figure 16: Study area organization

3.6 Data collection methods

Figure 17: Data collection (Source: Own design)

3.7 Research method

To achieve the goal of delivering energy-efficient building design, both qualitative and quantitative research approaches were used. The quality and condition of various G+0 residential structures over the chosen area were investigated using a qualitative approach. For this study, primary data sources were used to gather information. The information from Dagaga kebele in the research area was used to measure the existing documents and information, their conditions as observed and quantified by field surveys, and the scope of services and sample size by demand. The Dagaga Kebele was taken into consideration for this study due to its variation of building designs, building materials, and information availability.

3.7.1 Survey Process:

The first step in the survey process was to identify the target residential neighborhoods in Adama Town for the study. This was done in consultation with local authorities and urban planning departments to ensure that the selected areas were representative of the overall residential building stock in the town. A preliminary survey of the chosen neighborhoods was then conducted to understand the general building typologies, construction practices, and energy use patterns. This involved visual observations, informal interviews with residents, and a review of available secondary data.

Based on the insights gained from the preliminary survey, a comprehensive questionnaire was developed to gather information from the residents of the selected residential buildings. The questionnaire covered a range of topics, including household characteristics, building features, energy usage patterns, occupant behavior, and attitudes towards energy efficiency. The data were gathered by the researcher to ensure effective communication with the respondents. The surveys were conducted in a representative sample of residential buildings, considering factors such as building design typology and age, to ensure a balanced representation of the study area.

3.7.2 Inventory Process:

To complement the survey data, the research team conducted a detailed inventory and assessment of a representative sample of residential buildings identified from the survey data. On-site inspections were carried out to gather information on the operational energy consumption.

Relevant documentation, such as building plans, construction permits, and energy bills, was also collected to supplement the on-site data.

In addition to the on-site assessments, the researcher engaged with local builders, suppliers, and relevant authorities to obtain data on the embodied energy of the construction materials used in the selected residential buildings. This information was crucial for the analysis of the embodied energy associated with the residential buildings.

3.7.2.1 Window to wall ratio (WWR)

The window-to-wall ratio is the ratio between the total window areas to the total wall area. (Sayadi et al., 2021) .This analysis has been taken to evaluate the design according to the energy efficiency of the typologies that are found in the selected site.

$$\text{WWR}\,(\%) = \frac{\sum \text{Glazing area}\,(\text{m}^2)}{\sum \text{Gross exterior wall area}\,(\text{m}^2)}$$

3.7.2.2 Embodied energy calculation

The questionnaire gathered information about the general features of dwelling units. However, building-specific inventory data for embodied energy assessment, such as the types and amounts of building materials and components, as well as the construction procedures and inputs used, were gathered through observation, interviews, and secondary research. The building-specific data was collected by picking a case from the study's variety of dwelling typologies.

The survey and inventory results were combined with relevant international energy protocols, the Inventory of Carbon and Energy (ICE) database, and some local inventory data to estimate energy consumption at the embodied stage of the chosen residential building typology. The quantities of materials received from a standard bill of quantities were estimated in mass (kg) or volume (m^3) before being converted to mass (kg) to make the units of measurement consistent with the ICE inventory. The quantities were also organized based on construction milestones, such as substructure, frame and walls, suspended floors and staircases, roof structure and covering, finishes, fixtures and fittings, and building services, to show the relative materials and energy consumption of each. Given the prevalence of labor-intensive building methods in the research area, manual energy was evaluated using the tropical region's manual energy coefficient.

- Total embodied energy

$$EE = EEM + EET + EEC$$

Where

EE= total embodied energy

EEM = embodied energy of the material

EET = embodied energy of transportation

EEC = embodied energy of construction (Ezema et al., 2015)

- Embodied energy of material

$$EEM = QM\ [EECF]$$

Where

EEM = cradle-to-gate embodied energy of material (MJ)

QM = quantity of material (kg)

EECF = embodied energy coefficient of material (MJ/kg) according to the ICE database and available local inventory data.(Ezema et al., 2015), material quantity has been adopted from the bill of quantity of materials.

- Transportation Energy

$$EET = QF\ [LHV]$$

Where;

EET = embodied energy of material transportation (MJ)

QF = quantity of fuel consumed (liters)

LHV = lower heating value of fuel

On the transportation energy, all of the materials utilized in the construction were manufactured locally. As a result, transportation energy is solely used for local transportation. The most common means of transportation for building supplies in the research area was via road, using diesel-powered heavy-duty vehicles. The majority of the construction materials will be sourced from the Sartra area (Wood, Cement, and Other). Aggregates will be from the Namald area (2 km), and Hardcore and sand will be from the Dabe Soloke or Alem Hotel area (4 km).

The study assumed that all building materials were locally produced. Hence, local transportation of materials was accounted for. Road haulage is the main mode of material transportation in the study area, and the fuel type was found to be predominantly diesel. The quantity of diesel was estimated using 35 liters per 100 kilometers for heavy-duty trucks (Sino Track) and 20 liters per 100 kilometers for light-duty trucks (Chento). (Ezema et al., 2015)

- Embodied energy of construction

  Manual Energy

$$ME = 0.75LT \qquad / EEC = ME \; /$$

Where;

ME = manual energy (MJ)

0.75MJ/hour = human energy coefficient

L = number of labour workers

T = number of hours of work.(Ezema et al., 2015)

3.7.2.3 Operational energy calculation

Energy bills analysis was obtained from the Energy authority office No 2 which is found around Adama Ras area. The data from the surveys helped the research to identify the customer ID and contract account of the households, which in turn helped to find the consumption data of the selected building typologies.

3.8 Data type and sources

3.8.1 Primary data source

The analysis uses an input-output approach based on that for emboded energy data gathered from construction materials volume, transport and energy of construction, operational energy data from electricity bills, on-site measurements, and qualitative data from surveys, bills of quantities, structured interviews, and floor plans are among the data kinds. Local governments, energy companies, suppliers of building materials, and stakeholders are some examples of data sources.

3.8.2 Secondary data source

Secondary sources include previous studies, reports from the Inventory of Carbon & Energy (ICE) data base to calculate the encoded energy and electric consumption bill for operational energy. These resources cast light on occupant behavior, building materials, construction methods, and energy-efficient design. While gathering and utilizing secondary data, it's critical to adhere to privacy regulations and data rights, as well as the proper citation of sources.

3.9 Study Population

The investigation comprises G+0 residential buildings constructed throughout several phases of the city's development specifically in Dagaga Kebele. Stratified random selection will be employed to choose a representative sample of the population that reflects a range of building types, construction techniques, and energy consumption habits. This thorough comparison study will offer insightful recommendations for energy-efficient designs that are customized for Adama Town's unique circumstances. The study will advance knowledge of energy-efficient design techniques and aid in the creation of environmentally friendly and energy-efficient residential structures.

Four design typologies that have been developed and constrained in the town of Adama were chosen for the research. The G+0 designs exhibit many qualities, which are contingent upon the building's age, design, construction material, and construction procedures.

3.10 Sample size

In this study, sampling size was determined by the number of G+0 residential buildings found in Dagaga kebele Adama town, which is 1200. stratified random sampling has been used to represent different types of G+0 residential buildings over the chosen area it also its variability and diversity, these residential buildings are classified into 4 typologies within the study. These buildings that categorized under the one typology have identical floor plans and bill of quantities. From 1200 ground floor residential buildings, to streamline the data on embodied energy to prevent duplication, the study selected a representative typology with the same plot area to compute the total embodied energy for all typologies. This approach is justified because the buildings within the same typology share similar design, construction materials, and quantities. By selecting one representative typology, the study was able to efficiently capture the embodied energy characteristics without the need to analyze each and every building individually. This sampling method allowed for a comprehensive understanding of the embodied energy of the residential buildings in the study area, while keeping the data collection and analysis process manageable.

Table 5: Categories of residential buildings in the study area

Residential Typology Categories	Plot Area m^2
L-Shape	200
Service	200
Villa	200
Public House (Residential)	200

To evaluate the Operational energy stratified random sampling has been used to represent different types of G+0 residential buildings over the chosen site it also its variability and diversity, ensuring it captures the range of building types. In this study, the sampling size was determined using the Yamane formula. This formula calculation is a way to determine the sample size for the study. Based on the calculation out of 1200 G+0 residential buildings targeted population is found using a formula the result is 75 residents which is presented on the site. In this study, the acceptable sampling error is 0.9% to get more reliable information.

$$n = \frac{N}{1+N(e^2)}$$

n = the sampling size
N = the population Size
e = the acceptable sampling error

By having a sample size of 75 residential buildings from each design typology that had been categorized, the L-Shaped typology had 22 buildings overall in the study area, which was less than the target sample size. However, for this the study select 8 buildings form each typology's have been selected to study the average energy consumption of each G+0 residential buildings under the same typology.

3.11 Sampling techniques

The study used a combination of sampling techniques, including stratified random sampling, judgmental sampling, and convenience sampling.

- Stratified random sampling was used to ensure representation from different strata of the residential buildings based on their time of construction in the town, varied building ages, construction materials, building sizes, designs, and diverse neighborhoods. This allowed for better data collection.
- Convenience sampling was used to gather data from accessible residential buildings, identifying trends and variations in energy usage.

3.12 Data analysis and interpretation

The qualitative data interviews, notes, video, audio recordings, images, and text documents were analyzed as follows.

Table 6: Qualitative data analysis technique

Type	Description	Software
Thematic Analysis	Identifying, analyzing, and reporting patterns within the data related to embodied and operational energy in residential buildings.	Excel and Word 2016 were used to evaluate interviews, surveys, and videos.
Content Analysis	Examining and interpreting the content of qualitative data to identify recurring themes and patterns.	
Narrative Analysis	Analyzing the stories or narratives provided by participants to understand their perspectives on energy-efficient design in residential buildings.	

Grounded Theory	Developing theories or explanations based on the data collected during the study.	

Table 7: Quantitative data analysis technique

Type	Description	Software
Descriptive Statistics	Summarizing and describing the characteristics of the data related to energy consumption in residential buildings.	The research utilized AutoCAD 2024 software for overall spatial analysis of the studied region. ArchiCAD 26 is utilized for comprehensive 3D drawings, while Microsoft Word 2016 and PowerPoint 2016 are used for documentation and presentations.

3.13 Data validity and rabidity

To ensure the validity and reliability of the Study, the questionnaires were completed by the researcher, rather than the respondents themselves. The study included interviews and field observations to capture the unique circumstances of housing in the study area, resulting in accurate and trustworthy results.

3.14 Uncertainty Analysis

The potential uncertainty in this study can be a classification of typologies, sampling uncertainty, or data collection uncertainty. This includes the sample size selection of the typologies over the site, and the redundancy trend over the construction and design of G+0 residential buildings leads to these category classifications. In the data collection uncertainty, for each of the residence typologies in the embodied energy data collection to specify the materials and construction technique, the study used a bill of quantities of materials to specify the materials that have been used and the quantities that are used on the site. This information is for one typology, most of the time giving the same quantity, so taking on the rest to avoid the embodied energy calculation. As for the operational energy, it will be taken from the consumption of one year of the electricity bill.

3.12 Ethical consideration

The study provides a sporting letter from the school to gate grant in the data gathering process. The process involved obtaining information about participants, confidentiality, and ensuring privacy. By respecting the socio-cultural and economic background of the society. The study involves interviews, surveys, and group discussions to provide clear information about the research objective. Every participant will be respected and the study will adore all relevant national and local regulations and ethical guidelines.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

This chapter was arranged based on the aims and research questions, as well as the methods and strategy used to achieve the specific goals outlined in previous chapters. The current typologies have been detailed using plans, 3D models, and elevations. They then used an input-output technique to analyze their embodied and operational energy concepts. The residential typologies were examined using field observations and stakeholder files, and this section of the chapter includes a discussion.

4.1 Assessment of Embodied Energy

4.1.1 L-Shape

These types of designs and constructions are all over the town these days. Based on interviews with the occupant’s and stakeholders, this type of design was chosen because of a lack of knowledge about the city. The owners believe that in the market, if the roof is high (5m – 6.40m), the size of the house will increase, and some clients also feel a sense of competition with other residences. The design companies indicate that they suggest this type of design because of the town climate of Adama and the demand of the client.

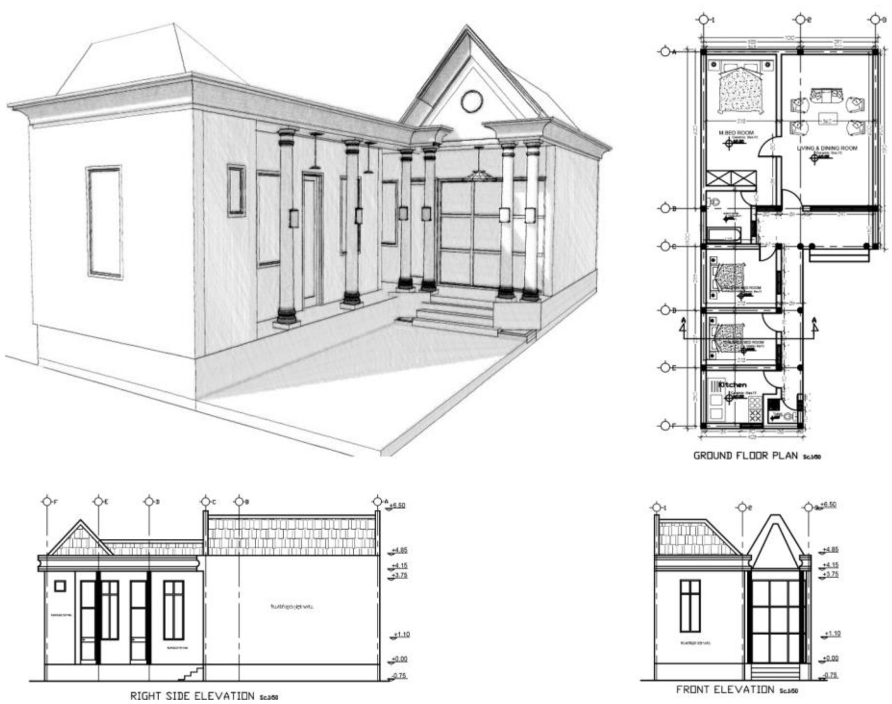

Figure 18: Sample L-shaped G+0 residential building design

Table 8: Embodied energy of material of L-Shape (from bill of quantity)

Sub Structure	Embodied Energy MJ
Excavation & Earth Work	171,558
Concrete Work	59531.3
Masonry Work	80,074

Super Structure	Embodied Energy MJ
Concrete Work	51,526
Block Work	112,651.52
Roofing	1,623,096
Carpentry	1699.3
Aluminum Works	275,989
Plastering And Pointing	15,962
Finishing	46,860
Painting	47,281.66
Sanitary Installation	69,334.08
Electrical Installation	22,561.84
Dry Latrine Septic Tank	944,291.89
Total	3,211,253.292

The overall total embodied energy of materials and construction is EME= 3,522,416 MJ

All of the materials utilized in the construction were manufactured locally. As a result, transportation energy is solely used for local transportation. The most common means of transportation for building supplies in the research area was via road, using diesel-powered heavy-duty vehicles (Sino Truck). The majority of the construction materials will be sourced in the Sartra area.

Table 9: Estimated Transport energy of material L-Shape

Material	Quantity	Weight (Kg)	Trips	Distains (Km)
Cement	150 bug	7,500	3	5
Coarse Aggregate		30,000	1	2.5
Sand	8 Sino	240000	8	4
Steel Re-Bars	Berga	3,102.62	1	5
Sawn Timber (Atana)	180 pic	27,000	1	4.5
Hardcore	2 Sino	~ 60,000	2	4
Others	-	~ 500	1	5
Total		128,102 Kg	21	30 Km

The overall transport energy *EET*= 27,026.0 MJ

The average daily labor wage was calculated as 800 birr/day for skilled workmanship work man ship it is 400 birr/day by using an even distribution of skilled and unskilled labor and daily labor wages of 400 birr/day and 350 birr/day, respectively, as acquired from the construction site engineers questioned. As a result, the project required 18 workers (4 skilled and 14 laborers) in total. /By using the human energy coefficient of 0.75 MJ/hour and an average daily working time of 8 hours. (Ezema et al., 2015) /

The total Embodied energy of construction (EEC) is 108 MJ.

Over the embodied energy of L-shaped G+0 residential building will be

- *EE = EEM + EET + EEC*

  EEM= 3,522,416 MJ

  EET= 27,026.0 MJ

  EEC=108 MJ

- *EE* = 3,522,416 MJ + 27,026.0 MJ + 108 MJ

  EE= 3,549,550 MJ

4.1.2 Service

The service typologies are designed following the shape of the site. These typologies have a low-slope roof structure. All rooms in this typology design are directly accessed from the outside, with each room having windows and door access.

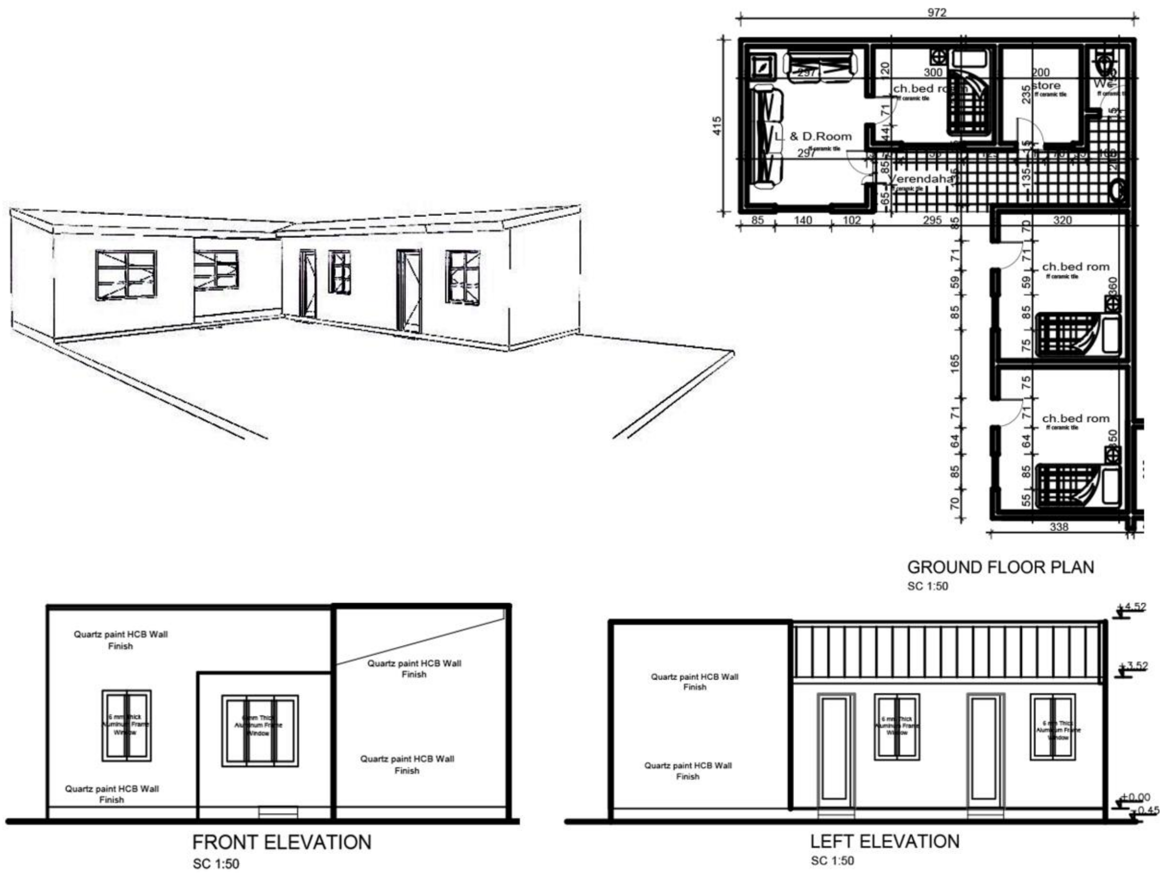

Figure 19: Sample service G+0 residential building design

The study of embodied energy in G+0 service residential buildings shows that both the sub-structure (such as excavation, earthwork, and concrete work) and the super-structure (including concrete work, wall construction, roofing, carpentry, metal works, plastering, glazing, painting, and electrical installation) contribute to the overall embodied energy consumption.

Table 10: Embodied energy of material Service (from bill of quantity)

Sub Structure	Embodied Energy MJ

Excavation & Earth Work	184,516
Concrete Work	44,979
Masonry Work	96,687.00

Super Structure	Embodied Energy MJ
Concrete Work	75,531
Wall Work	1,800
Roofing	49,712
Carpentry And Joinery	165,361
Metal Works	12,909.23
Plastering And Pointing	145,897.34
Glazing	5,722.50
Painting	5,831.15
Electric Installation	1289.2
Total	464,053.42

The overall total embodied energy of materials and construction is EME= 464,053.42MJ

The transportation of these materials involves 9 trips covering a 30 km distance using chanto track. The specific distances for each material vary, ranging from 2.5 km for the coarse aggregate to 5 km for the cement, steel reinforcement bars, and other miscellaneous materials.

Table 11: Estimated Transport energy of material service

Material	Quantity	Weight (Kg)	Trips	Distains (Km)
Cement	50 bug	2,500	1	5
Coarse Aggregate		14,000	1	2.5
Sand	3 cento	42,000	3	4

Steel Re-Bars	Berga	530.20	1	5
Sawn Timber (Atana)	50 pic	9,000	1	4.5
Hardcore	1 chento	1400	1	4
Others	-	~ 100	1	5
Total		69,530.2 Kg	9	30 Km

The overall transport energy *EET*= 14,659.3 MJ

As a result, this project required 4 workers (1 skilled and 3 laborers) in total. /By using the human energy coefficient of 0.75 MJ/hour and an average daily working time of 8 hours. (Ezema et al., 2015) /

The total Embodied energy of construction (EEC) is 24 MJ.

The embodied energy of an L-shaped G+0 residential building will be

- $EE = EEM + EET + EEC$

  EEM= 464,053.42 MJ

  EET= 14,659.3 MJ

  EEC=24 MJ

- *EE* = 464,053.42 MJ + 14,659.3 MJ +24 MJ

  EE= <u>478,736 MJ</u>

4.1.3 Villa

This residential building design features a gabled roof with elevation of 4.45m. The layout includes a living room with a dining area, a kitchen, a master bedroom, a children's bedroom, and a bathroom. All rooms have direct access to daylight, with windows provided in every room.

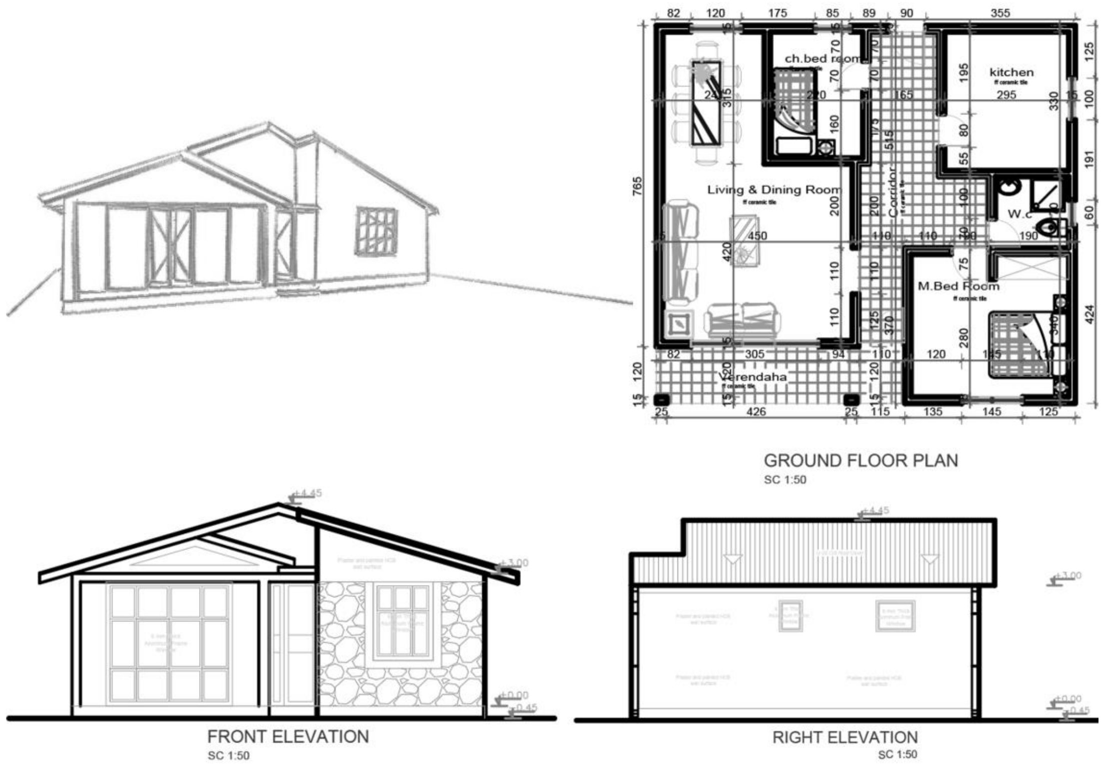

Figure 20: Sample villa G+0 residential building design

The embodied energy of villa residential buildings in Adama Town, based on the construction of various materials and components. The sub-structure includes excavation, earthwork, concrete, and masonry work, which contribute significantly to the overall energy. The super-structure includes roofing, block work, dry latrine septic tank, concrete work, plastering, finishing, sanitary installation, and electrical installation. Other elements like carpentry, joinery, metal works, and painting also contribute to the energy.

Table 12: Embodied energy of material villa (from bill of quantity)

Illustrate the building materials that have been on the design and construction.

Sub Structure	Embodied Energy MJ
Excavation & Earth Work	171,558
Concrete Work	59531.3
Masonry Work	80,074

Super Structure	Embodied Energy MJ
Concrete Work	15,525.5
Block Work	82,996.5
Roofing	220,596
Carpentry And Joinery	1699.302
Metal Works	10,209.23
Plastering And Pointing	15,962
Finishing	46,860
Painting	3581.9
Sanitary Installation	38334.08
Electrical Installation	9561.7
Dry Latrine Septic Tank	344,290
Total	1,100,780

And the overall total embodied energy of materials and construction is EME= 1,100,780 MJ

The main material components consist of cement, coarse aggregate, sand, steel reinforcement bars, sawn timber, and hardcore. The total weight of these materials is 104,002.62 kg sourced from Sartera, Dabesoloke or Alem hotel area, and Namald area. Transporting these materials requires a total of 21 trips covering a distance of 30 km. The distances for each material vary, with the shortest being 2.5 km for coarse aggregate and the longest being 5 km for cement, steel reinforcement bars, and other miscellaneous materials.

Table 13: Estimated Transport energy of villa

Material	Quantity	Weight (Kg)	Trips	Distains (Km)
Cement	100 bug	5,000	3	5
Coarse Aggregate		20,000	1	2.5

Sand	6 Sino	18,000	8	4
Steel Re-Bars	Berga	2,502.62	1	5
Sawn Timber (Atana)	120 pic	18,000	1	4.5
Hardcore	1 Sino and 1 Chento	~ 40,000	2	4
Others	-	~ 500	1	5
Total		104,002.62 Kg	21	30 Km

The overall transport energy *EET*= 21,935.2 MJ

The daily labor wage was computed as 800 birr/day for skilled workmen and 400 birr/day for labored workers based on an equitable distribution of skilled and unskilled labor and daily labor salaries of 400 birr/day and 350 birr/day, respectively, as obtained from the construction site engineers interviewed. As a consequence, the project required a total of ten people (two skilled and eight laborers).

The total embodied energy of construction (EEC) is 60 MJ.

Overall embodied energy of L-an shaped G+0 residential building will be

- $EE = EEM + EET + EEC$

  EEM= 1,100,780 MJ

  EET= 21,955.2 MJ

  EEC=60 MJ

- *EE* = 1,100,780 MJ + 21,955.2 MJ +60 MJ

  EE= <u>1,122,795.2 MJ</u>

4.1.4 Public House

This building typology is a governmental building that has been provided for residential purposes. It has a simple design consisting of a living room with three bedrooms, with an elevation height of 4.20 m. All rooms in this design have access to daylight.

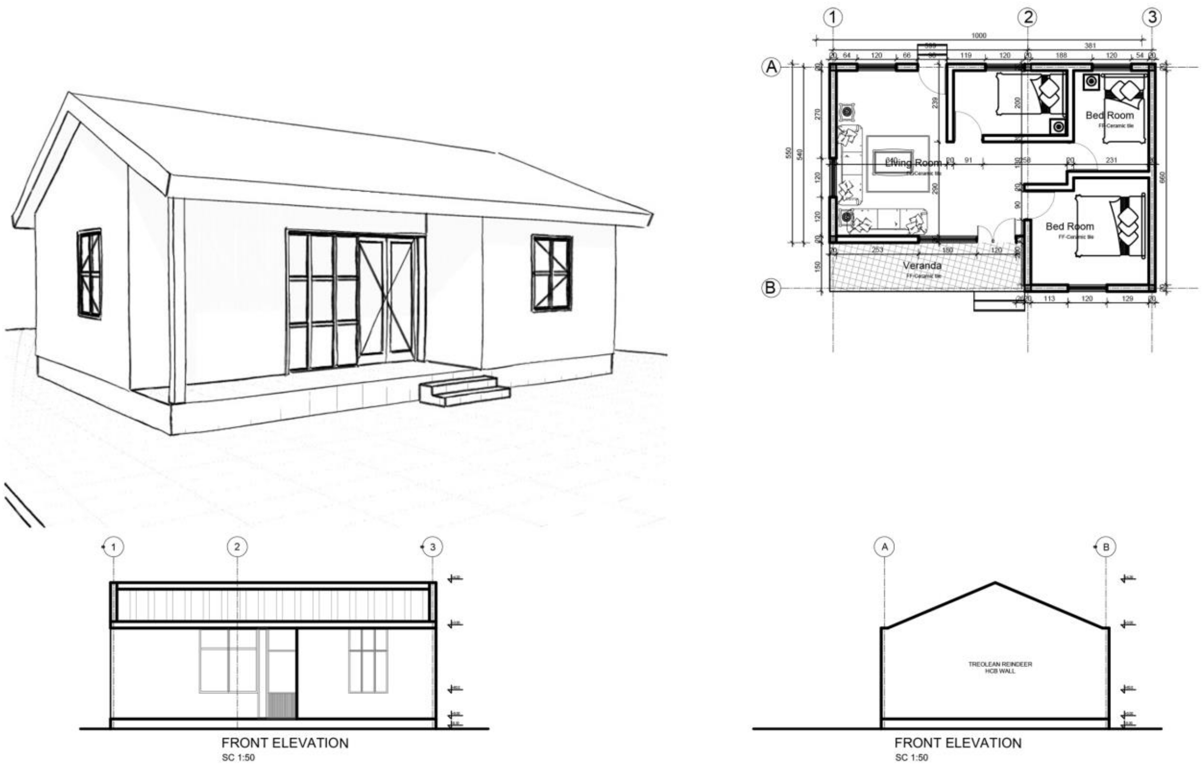

Figure 21: Sample public house building design

Table 14: Embodied energy of material public house (from bill of quantity)

To evaluate the embodied energy of this typology, the researcher conducted a bill of quantities analysis because it is a governmental property that is rented to the public. Field surveys, sketching, and measurements were undertaken to evaluate the materials used in this building typology.

Sub Structure	Embodied Energy MJ
Excavation & Earth Work	150,542
Concrete Work	34,567
Masonry Work	50,149

Super Structure	Embodied Energy MJ
Concrete Work	35,526
Block Work	90,651.52
Roofing	100,596
Carpentry And Joinery	1250
Metal Works	9,509
Plastering And Pointing	10,250
Finishing	26,560
Painting	27281.66
Sanitary Installation	19334
Electrical Installation	2561.7
Dry Latrine Septic Tank	344,290
Total	903,068

Embodied energy of materials and construction is EME= 903,068 MJ

The transportation of these materials involves a total of 9 trips, covering a distance of 30 km. The specific distances for each material vary, ranging from 2.5 km for the coarse aggregate to 5 km for the cement, steel reinforcement bars, and other materials.

Table 15: Transport energy of the material public house

Material	Quantity	Weight (Kg)	Trips	Distains (Km)
Cement	50 bug	2,500	1	5
Coarse Aggregate		14,000	1	2.5
Sand	3 chentai	42,000	3	4
Steel Re-Bars	Berga	530.20	1	5
Sawn Timber (Atana)	50 pic	9,000	1	4.5

Hardcore	1 Sino and 1 Chento	~ 40,000	1	4
Others	-	~ 200	1	5
Total		108,230.2 Kg	9	30 Km

The overall transport energy *EET*= 22,850.8 MJ

As acquired from the construction site engineers questioned. As a result, the project required 8 workers (2 skilled and 6 laborers) in total.
The total Embodied energy of construction (EEC) is 12.5 MJ.

The embodied energy of an L-shaped G+0 residential building will be

- *EE = EEM + EET + EEC*

  EEM= 903,068 MJ

  EET= 22,850.8 MJ

  EEC= 12.5 MJ

- *EE* = 903,068 MJ + 22,850.8 MJ +12.5 MJ

  EE= 925,931.3 MJ

➢ Note that these building typologies have been built over different timelines, and the materials and design trends have made a difference on the resulting embodied energy. This helps the research to evaluate the different building materials that were trending at their specific time and their embodied energy.

4.2 Assessment of Operational Energy

The purpose of the energy billing analysis is to assess the Optional energy. Form the year 2022 the L-shaped design that has been over the area for the previous two years, all the data will be available in this analysis, which has gathered data from interviews, questionnaires, and the mainly from Ethiopian Electric Power Authority (Adama No.2).

4.2.1 L-shaped

The study found that the L-shaped residential buildings had the highest operational energy consumption at 2463.33 MJ. This can be attributed to their poor floor plans designs, increased high lighting demands, and potentially less efficient building envelope and systems design.

Table 16: Energy billing analysis of L-Shape

Energy Bill month	Customer ID							
	90182	101508	18405	90190	101512	67052	101520	90125
	Energy (kWh)							
Jan/22	625	613	673	667	989.92	551	615	598
Feb/22	615.6	621	634	646	1002	562	622	675
Mar/22	695	610	660	650.31	982	589	618	803
Apr/22	870	606	676.16	652	866	577	619	610
May/22	640	642	724	684	767	600	622	619.38
Jun/22	610	667	684	655	605	838	609	750
Jul/22	612	637	665	650	886	584	618	569
Aug/22	697	620	840	576	601	583	638	655
Sep/22	685	612	1005	634	865	554	601	675
Oct/22	860	650	673.55	615.6	1007	588	615	684.86
Nov/22	710	638	1085	567	880	593	622	614
Dec/22	620	640	1020	646	750	551	618	774

The average operational energy is 683.26 KWh / the conversion factor is 1 KWh = 3.6 MJ /

683.26 KWh x 3.6 MJ/KWh = **2463.33 MJ**

4.2.2 Service

In contrast, the service-type residential buildings had the lowest operational energy consumption at 291.96 MJ. This can be explained by their compact design, smaller floor areas, and potentially more efficient opening which help the lighting and ventilation need and also the occupants use optional energy use specifically charcoal helps to minimize their consumption.

Table 17: Energy Billing Analysis of Service

Energy Bill month	Customer ID							
	70182	60412	G-1688	70208	60450	G-1690	70190	60460
	Energy (kWh)							
Jan/22	42.73	69.08	59.27	56.54	81.11	88.16	102.13	52.15

Feb/22	47.9	112.92	119.13	84.79	87.36	65.91	110.21	67.18
Mar/22	40.72	101.69	81.59	66.66	82.42	92.77	116.62	58.84
Apr/22	46.1	68.29	38.95	76.06	87.91	77.88	119.29	56.98
May/22	63.55	72.4	71.75	108.2	119.29	86.75	86.52	67.17
Jun/22	46.07	99.28	67.6	58.59	109.45	92.21	185.6	58.95
Jul/22	63.49	90.75	80.6	87.32	111.27	104.06	46.5	59.95
Aug/22	55.95	91.49	62.64	121.67	104.28	85.13	48.81	59.72
Sep/22	58.88	87.82	70.33	58.95	81.11	98.31	105.19	53.29
Oct/22	130.65	77.2	59.27	83.76	87.36	79.98	102.13	71.26
Nov/22	111.31	87.82	119.13	56.54	82.42	88.16	110.21	52.07
Dec/22	85.55	69.08	81.59	84.79	87.91	65.91	116.62	54.65

The average operational energy is 81.1 KWh / the conversion factor is 1 KWh = 3.6 MJ /

81.1 KWh x 3.6 MJ/KWh = **291.96 MJ**

4.2.3 Villa

The Villa residential buildings had an operational energy consumption of 2299.39 MJ, slightly lower than the L-shaped buildings. This is due to their more efficient layout, design strategies, and better opening (Windows and Doors) organization, although they still had a higher energy demand compared to the service-type buildings.

Table 18: Energy Billing Analysis of Villa

Energy Bill month	Customer ID							
	18360	18362	18181	60318	84614	60320	84613	18350
	Energy (kWh)							
Jan/22	578.57	482.14	464.29	461.61	579.46	524	578	536.21
Feb/22	480	462.14	580	562.5	441.07	479	579	4162.3
Mar/22	569.64	551.79	469.64	473.21	437.5	573	437	620.34
Apr/22	559.29	476.79	578.57	464.29	446.43	482	446	551.11
May/22	564.29	580.36	580.36	563.21	440.36	576	440	649.17
Jun/22	479.46	481.25	463.39	580	424.64	478	562	540.02
Jul/22	476.79	464.29	455.36	579.46	428.57	446	564	436.21
Aug/22	465.18	474.11	579.46	573.71	405.36	580	482	562.3
Sep/22	567.5	539.29	557.14	575	574	552	570	420.34
Oct/22	542.86	460.71	578.57	564.29	507.14	4157	475	651.11
Nov/22	463.21	481.07	5180	563.21	542.86	441	554	449.17
Dec/22	496.43	460.71	479.46	478.57	478.57	475	580	440.02

The average operational energy is 638.72 KWh / the conversion factor is 1 KWh = 3.6 MJ /

638.72 KWh x 3.6 MJ/KWh = **2299.39 MJ**

4.2.4 Public Houses

The public houses, with an operational energy consumption of 1555.2 MJ, performed better than the L-shaped and villa-type buildings, but not as well as the service-type residences. This suggests that the public houses have some energy-efficient design features

Table 19: Energy Billing Analysis of Public House

Energy Bill month	Customer ID							
	301	632	325	310	305	628	640	302
	Energy (kWh)							
Jan/22	359.82	460	339	414.81	451.05	310.97	420.47	427.91
Feb/22	408.93	462	452	383.69	401.42	434	435.5	406.03
Mar/22	401.79	320	348	410.75	3130.5	417.28	430.62	442.73
Apr/22	446.43	464	329	329.81	450.15	421	431.81	431.83
May/22	340.36	340	358	302.49	460.98	400.97	434.09	435.24
Jun/22	424.64	445	345	464	323.67	404.84	413	447.1
Jul/22	328.57	329	439	323.34	443.82	404.98	424.67	458.5
Aug/22	405.36	348	352	443.65	432.29	432.38	419.63	444.39
Sep/22	351.79	370	448	432.26	457.52	412.16	446.07	499.76
Oct/22	439.29	439	334	421.19	440.95	415.68	459.27	408.49
Nov/22	351.79	354	348	411.53	317.08	400.03	429.91	422.4
Dec/22	348.21	339	408.93	423.65	327.01	427.17	420.47	425.39

The average operational energy is 432 KWh / the conversion factor is 1 KWh = 3.6 MJ /

432 KWh x 3.6 MJ/KWh = **1555.2 MJ**

4.3 Window-to-wall ratio analysis

This illustrates the ratio of window to total wall area for the different façades of the various building typologies. This helps us to evaluate the design. The L-shaped residential buildings had the highest WWR at 14.01%. This relatively large window area can contribute to increased heat gains and losses, leading to higher operational energy consumption

Table 20: Window-to-wall ratio analysis of L-shape

	External wall area			Window area			
	Wall length	Wall high	Area	windows	Width of window	High of window	Area
North Wall	7.00	3.60	25.2 m^2	0	0	0	0
South Wall	7.00	3.60	25.2 m^2	3	4.45	6.4	10.67 m^2
East Wall	15.00	3.60	54 m^2	4	3.00	5.20	11.60 m^2
West Wall	15.00	3.60	54 m^2	0	0	0	0
		Total	158.4 m^2			Total	22.20 m^2

- Window to wall ratio (WWR)= (Window Area/ Wall Area) x 100

= (22.20 / 158.4) x100

= **14.01 %**

In contrast, the service-type residential buildings had the lowest WWR at 7.33%. This suggests a more compact design with fewer windows, which, lower the operational energy consumption.

Table 21: Window to wall ratio analysis of service

	External wall area			Window area			
	Wall length	Wall high	Area	Number of windows	Width of window	High of window	Area
North wall	9.96	3.50	34.86m^2	2	2.40	1.90	4.56 m^2
South wall	9.96	3.50	34.86m^2	2	4.50	4.90	11.90 m^2

East wall	9.00	3.50	31.5 m^2	1	0.60	0.80	0.48 m^2
West wall	9.00	3.50	31.5 m^2	0	0	0	0
		Total	158.4 m^2			Total	16.94 m^2

- Window to wall ratio (WWR)= (Window Area/ Wall Area) x 100

= (7.99 / 108.9) x100

= **7.33 %**

The villa-style residential buildings had a WWR of 12.70%, which is lower than the L-shaped buildings but higher than the service-type. This intermediate WWR when we compare it with the other typology's which are in the study.

Table 22: Window to wall ratio analysis of villa

	External wall area			Window area			
	Wall length	Wall high	Area	Number of windows	Width of window	High of window	Area
North wall	10.00	3.00	30.00m^2	3	3.60	2.00	4.56 m^2
South wall	10.00	3.00	30.00m^2	2	3.00	2.00	6.00 m^2
East wall	7.00	3.00	21.00m^2	0	0	0	0
West wall	7.00	3.00	21.0m^2	1	1.20	2.00	2.40 m^2
		Total	102 m^2			Total	12.96 m^2

- Window to wall ratio (WWR)= (Window Area/ Wall Area) x 100

= (12.96 / 102) x100

= **12.70 %**

The public houses had a WWR of 10.69%, which is higher than the service-type buildings but lower than the L-shaped and villa-style residences

Table 23: Window-to-wall ratio analysis of public house

	External wall area			Window area			
	Wall length	Wall high	Area	Number of window	Width of window	High of window	Area
North wall	13.30	3.00	39.9 m^2	0	0	0	0
South wall	13.30	3.00	39.9 m^2	3	3.65	1.50	5.44 m^2
East wall	11.55	3.00	14.55 m^2	0	0	0	0
West wall	11.55	3.00	14.55 m^2	2	1.70	1.50	2.55 m^2
		Total	108.9 m^2			Total	7.99 m^2

- Window to wall ratio (WWR)= (Window Area/ Wall Area) x 100

= (16.94 / 158.4) x100

= **10.69 %**

4.3 Comparative study

The study examines G+0 residential structures in Adama town specifically, using Dagaga kebele as an example. Based on the analysis, there have been four design typologies on the site: L-shaped, Service, Villa, and Public House. The analysis considers both the embodied and operational energy of the typologies to offer a complete picture of their energy efficiency. Residential building typologies range in terms of design, transportation usage, layout, energy consumption, and construction process, all of which have an impact on the energy performance of residential structures. The study discovered significant differences in embodied and operational energy across the four dwelling building styles.

4.3.1 Embodied energy comparison

The comparative analysis of the embodied energy in the selected typologies includes the outcomes related to the sub-structure, superstructure, transportation, and construction energy required.

4.3.1.1 Sub-structure

The embodied energy levels of the sub-structure components in the selected four typologies, including Excavation, Concrete, and Masonry work on the site, were assessed. During the evaluation of embodied energy in the excavation phase, both the L-shape and Villa typologies consumed 171,558 MJ, while the service typology used 184,516 MJ and the Public Houses typology utilized 150,542 MJ of embodied energy.

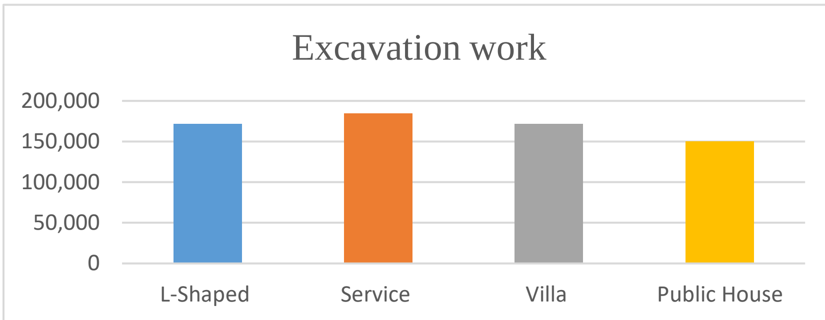

Figure 22: Comparative analysis of excavation work in ground floor residential buildings at the study area.

For concrete work in the sub-structure, the L-shape and Villa typologies had the same embodied energy consumption at 59,531.3 MJ, followed by the service typology with 44,979 MJ, and the Public Houses typology with 34,567 MJ of embodied energy consumption.

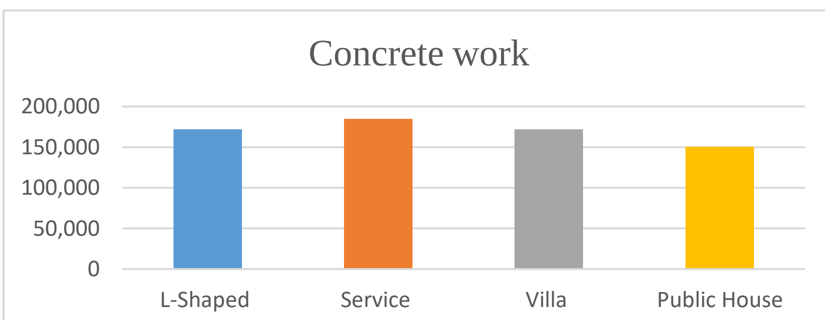

Figure 23: Comparative analysis of concrete work in ground floor residential buildings at the study area.

In terms of masonry work, the L-shape and Villa typologies consumed 80,074 MJ, the service typology used 96,687 MJ, and the Public Houses typology consumed 50,149 MJ of embodied energy.

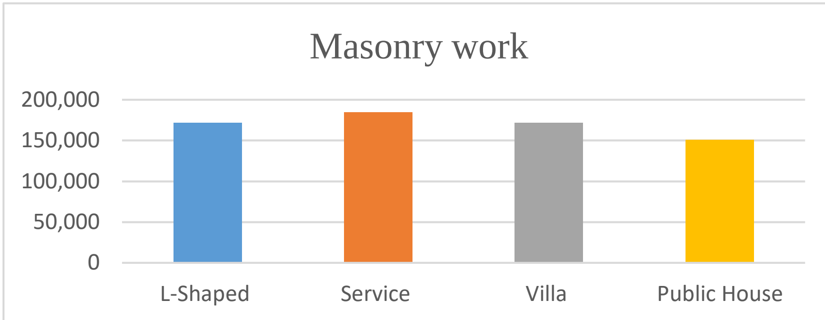

Figure 24: Comparative analysis of masonry work in ground floor residential buildings at the study area.

4.3.1.2 Super-structure

The construction of the super-structure typically involves materials such as concrete, blocks, roofing materials, metalwork, carpentry, plastering, and finishing products. The variation in embodied energy can be attributed to the quantity of construction materials used in the selected typologies. In terms of the super-structure construction using concrete, the L-shape typology consumed 51,526 MJ, the Villa typology consumed 15,525.5 MJ, and the Public Houses typology utilized 35,526 MJ of embodied energy on the service residential building almost there is no concrete work rather than the structural work. Here we can see that the L-shape have more energy consumption than the others. This occurs by the highly consumption of conceit specifically in parfait work of this design typology.

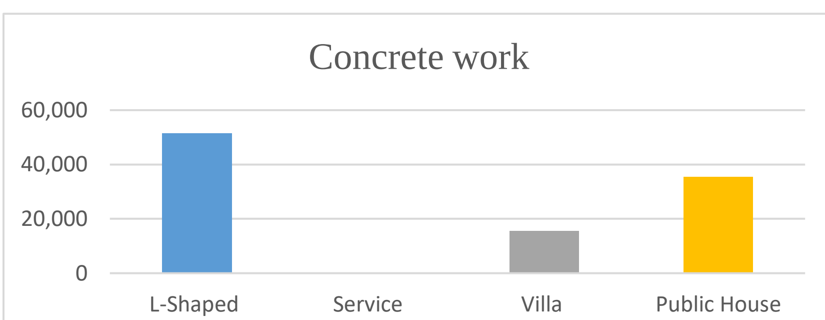

Figure 25: Comparative analysis of concrete work on super-structure of ground floor residential buildings at the study area.

When it comes to block work, the L-shape typology used 112,651.52 MJ, the Service typology utilized 1,800 MJ, the Villa typology consumed 82,996.5 MJ, and the Public Houses typology consumed 90,651.52 MJ of embodied energy. Class B 200mm thick HCB with the designed compressive strength, bedded in cement mortar (1:3). Price shall include mortar bed. And 150 mm thick HCB wall for internal partition

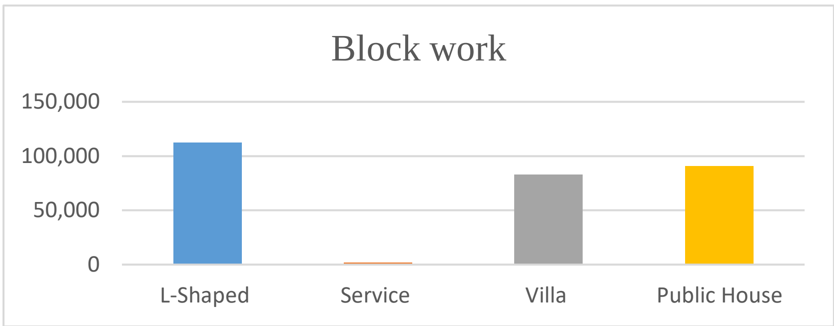

Figure 26: Comparative analysis of block work on super-structure of ground floor residential buildings at the study area.

The roofing in the L-shape typology required 1,623,096 MJ, the Service typology consumed 49,712 MJ, the Villa typology used 220,596 MJ, and the Public Houses typology needed 100,596 MJ of embodied energy. In this evaluation we can clearly see the trending roofing structure or pitched roof of the L-shape building exiled than the other typology's that are in the study area.

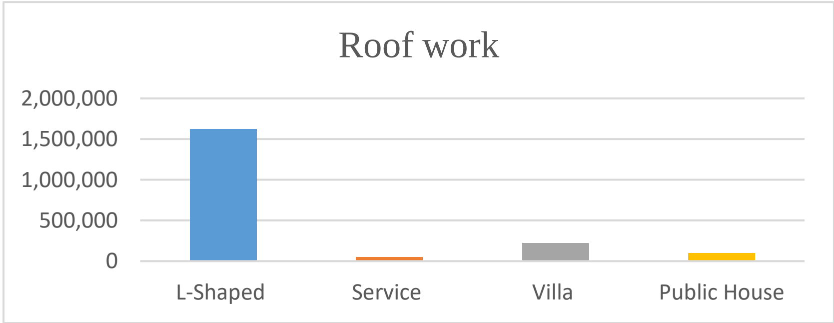

Figure 27: Comparative analysis of roof work on super-structure of ground floor residential buildings at the study area.

In terms of carpentry work, the L-shape typology utilized 1,699.3 MJ, the Service typology used 165,361 MJ, the Villa typology consumed 1,699.3 MJ, and the Public Houses typology required 1,250 MJ of embodied energy.

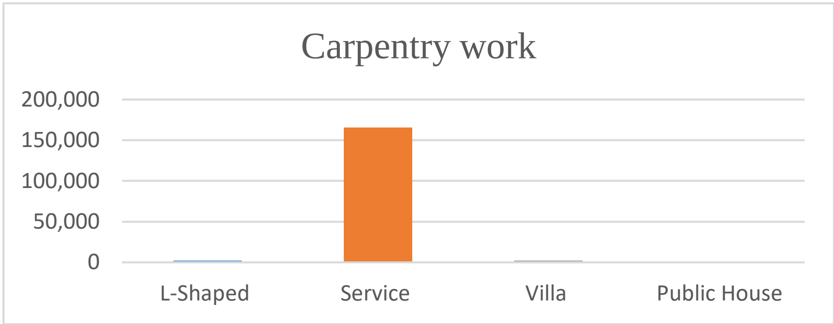

Figure 28: Comparative analysis of carpentry work on super-structure of ground floor residential buildings at the study area.

Aluminum work in the L-shape typology used 275,989 MJ, the Service typology required 12,909.23 MJ, the Villa typology consumed 10,209.23 MJ, and the Public Houses typology used 9,509 MJ of embodied energy. The L-shaped windows and doors manufactured from steel aluminum imitation profile and all as per the engineering approval and window door schedule. Price shall include 5mm thick clear glazing window and door stopper, approved quality cylinder lock with handle.

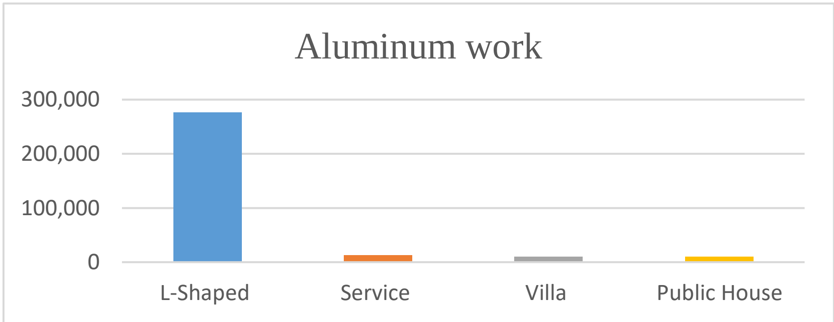

Figure 29: Comparative analysis of Aluminum work on super-structure of ground floor residential buildings at the study area.

Plastering work in the L-shape typology consumed 15,962 MJ, the Service typology used 145,897.37 MJ, the Villa typology used 15,962 MJ, and the Public Houses typology needed 10,250 MJ.

Figure 30: Comparative analysis of plastering work on super-structure of ground floor residential buildings at the study area.

For finishing work, the L-shape typology utilized 46,860 MJ, and the Villa typology utilized 46,860 MJ. the L-shape and the Villa have the same result in this evaluation as the service and the public residential houses doesn't have this in there constriction list.

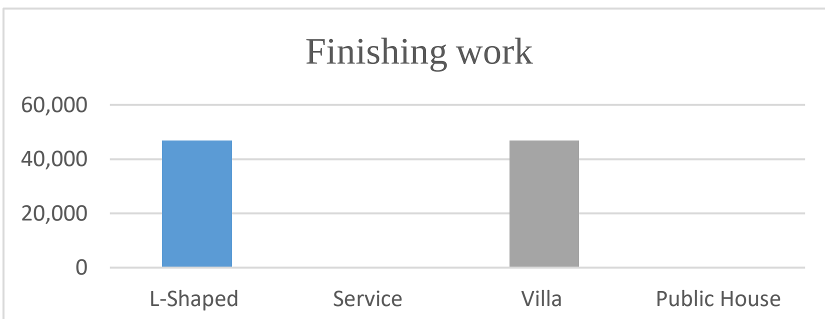

Figure 31: Comparative analysis of finishing work on super-structure of ground floor residential buildings at the study area.

Regarding painting, the L-shape typology consumed 47,281.66 MJ, the Service typology used 5,831 MJ, the Villa typology consumed 3,581.9 MJ, and the Public Houses typology required 27,281.66 MJ of embodied energy.

Figure 32: Comparative analysis of painting work on super-structure of ground floor residential buildings at the study area.

In the context of sanitary work, the L-shape typology utilized 69,334.08 MJ of embodied energy, the Villa typology consumed 38,334.08 MJ, and the Public Houses typology utilized 19,334 MJ. Specifically for the service building, the sanitary facilities are external to the main structure, with access provided directly from the septic layer.

Figure 33: Comparative analysis of sanitary work on super-structure of ground floor residential buildings at the study area.

For electricity work, the embodied energy for the four typologies are as follows: L-shape 22,561.84 MJ, Service 1,289 MJ, Villa 9,561 MJ, and Public Houses 2,561.7 MJ.

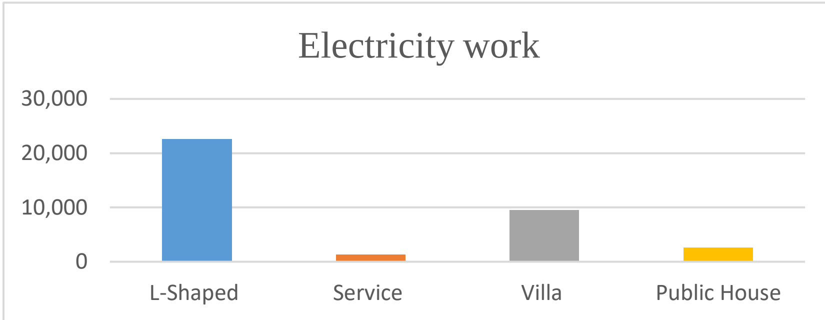

Figure 34: Comparative analysis of electricity work on super-structure of ground floor residential buildings at the study area.

Finally, for septic tank work, the L-shape typology required 944,291.89 MJ, the Villa typology utilized 344,290 MJ, and the Public Houses typology consumed 344,290 MJ of embodied energy. It is important to note that the service residential building does not have a septic tank in its construction, so this particular section has been omitted from the bill of quantity of material data during the sanitary analysis.

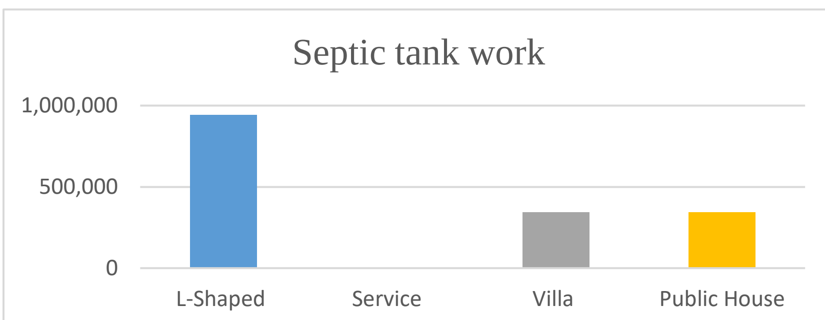

Figure 35: Comparative analysis of electricity work on septic tank work of ground floor residential buildings at the study area.

4.3.1.3 Transport embodied energy consumption

All construction materials used in the project were locally manufactured, necessitating transportation energy only for local transport. The primary mode of transporting building supplies in the research area was via road, utilizing diesel-powered heavy-duty vehicles such as Sino Truck and Chento. The majority of the construction materials, including wood, cement, and other items, were sourced from the Sartra area, while aggregates were obtained from the Namald area (2km) and hardcore and sand from either the Dabe Soloke or Alem Hotel area (4km).

In terms of transport energy consumption, the L-Shape structure utilized 27,026.0 MJ for transporting 128,102 kg of materials over 21 trips covering 30 km using Sinotrack vehicles exclusively. The Service Building required 14,659.3 MJ for transporting 69,530.2 kg of materials over 9 trips covering the same distance, using Chento vehicles as the main mode of transport. Similarly, the Villa project consumed 21,935.2 MJ for transporting 104,002.62 kg of materials over 21 trips covering 30 km, utilizing both Sinotrack and Chento vehicles. On the other hand, the Public Houses project used 22,850.8 MJ for transporting 108,230.2 kg of materials over 9 trips covering 30 km, employing both Sino and Chento vehicles for hardcore transport.

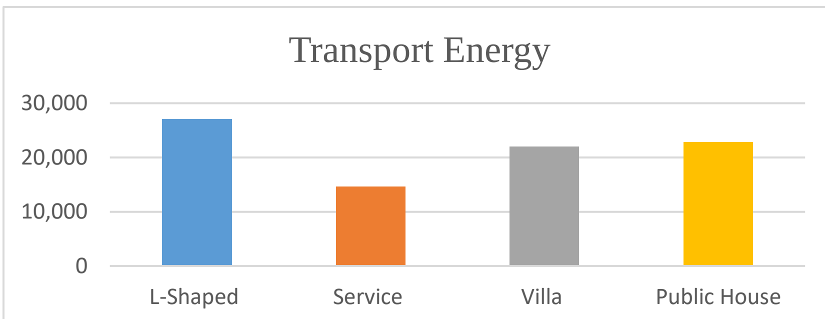

Figure 36: Comparative analysis of transport energy for construction of ground floor residential buildings at the study area.

The analysis shows that the L-shape building is in consume much of the transport energy for construction rather than the other typologies have been specified.

4.3.1.4 Constriction embodied energy consumption

In the construction projects analyzed, the average daily labor wages and workforce compositions varied. For the L-Shape project, it necessitated a total of 18 workers (4 skilled and 14 laborers) with average daily wages set at 800 birr for skilled workers and 400 birr for laborers. The total Embodied Energy of Construction for this project was calculated to be 108 MJ. The Service project, in contrast, required 4 workers (1 skilled and 3 laborers), with an Embodied Energy of Construction of 24 MJ. For the Villa project, ten workers were employed (two skilled and eight laborers) with daily wages of 800 birr for skilled workers and 400 birr for laborers, resulting in an Embodied Energy of Construction of 60 MJ. Lastly, the Public Houses project involved 8 workers (2 skilled and 6 laborers) and had an Embodied Energy of Construction of 12.5 MJ, as determined by the construction site engineers.

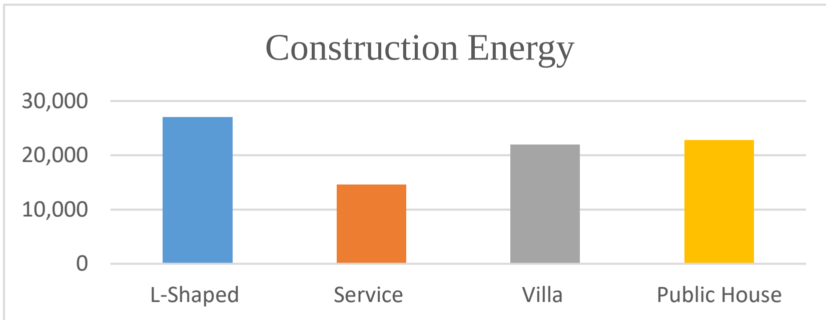

Figure 37: Comparative analysis of construction energy for ground floor residential buildings at the study area.

The construction energy of this selected residential building shows that the L-shaped need much man power than the rest of the typologies specifically the construction of contrite part needed to have more man power.

4.3.2 Operational energy comparison

The study shows that L-shaped building consumes the most operational energy, at 2463.33 MJ, mainly from electricity use. This is because of its heavy reliance on electricity for lighting through the daily base, appliances, and other home needs. The Service Building uses less energy, largely by using charcoal for cooking and heating, along with electricity for lighting and electronics. The Villa Building's energy consumption is almost as much, at 2299.36 MJ, showing similar use norms. The Public House displays an even use of energy with 1555.2 MJ indicating a balanced approach to energy use. The Service building has a distinctive pattern of using both electricity and charcoal which lowers its total operational energy usage.

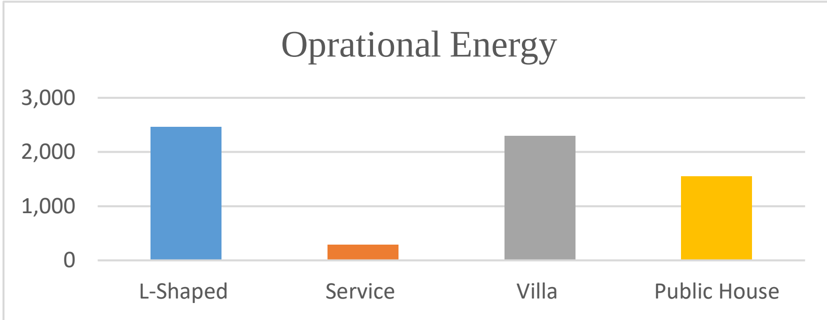

Figure 38: Comparative analysis of operational energy for ground floor residential buildings at the study area.

Comparatively, the L-shaped and Villa buildings depend more on electricity leading to higher operational energy consumption. However, the villas did not have lighting problems in the daytime whereas the L-shaped typology has a problem with this aspects.

4.3.3 Overall energy consumption comparison

The embodied energy analysis revealed that the L-Shape project had 3,549,550 MJ, the Villa project had 1,122,795.2 MJ, the Public House project had 925,931.3 MJ, and the Service project had 478,736 MJ of embodied energy. In terms of operational energy consumption, the L-Shape project utilized 2463.33 MJ, the Villa project used 2299.36 MJ, the Public House project consumed 1555.2 MJ, and the Service project required 291.96 MJ. Consequently, the overall energy consumption for each project was as follows: L-Shape project used 3,552,013.33 MJ, Villa project utilized 1,125,094.36 MJ, Public House project consumed 927,486.5 MJ, and the Service project required 479,027.96 MJ.

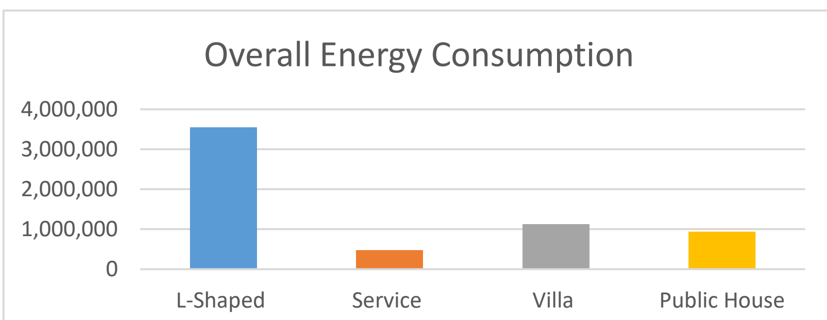

Figure 39: Comparative analysis of overall energy consumption of selected ground floor residential buildings at the study area.

The residential buildings in the study area have different lifespans. The L-Shaped design is the recent trending design and construction. In the study area, this type of design and construction has been implemented recently due to the legalization of the previously illegalized land properties. This construction has taken place from 2021 to the present. The Villas are the most dominant design features around the selected area, and these residential buildings are estimated to have a lifespan of 19-20 years. The public houses are estimated to have a lifespan of 25 years and above. The service buildings are the oldest on the site, and these buildings are estimated to have a lifespan of 35 years and above.

To evaluate the total energy consumption (Operational energy), the study uses a 50-year period to assess the long-term energy consumption of each typology.

Let's compare four typology’s houses:

- L-shaped:
    - Embodied Energy: 3,549,550 MJ
    - Annual Operational Energy: 2,463.33 MJ/year
    - Lifespan: 50 years
    - Total Operational Energy: 2,463.33 MJ/year x 50 years = 123,166 MJ
    - Total Energy: 3,549,550 MJ + 123,166 MJ = **3,672,716 MJ**
- Service:
    - Embodied Energy: 479,736 MJ
    - Annual Operational Energy: 291.1 MJ/year
    - Lifespan: 50 years
    - Total Operational Energy: 291.1 MJ/year x 50 years = 14,555 MJ
    - Total Energy: 479,736 MJ + 14,555 MJ = **494,291 MJ**
- Villa:
    - Embodied Energy: 1,122,795 MJ
    - Annual Operational Energy: 2,299.36 MJ/year
    - Lifespan: 50 years

- Total Operational Energy: 2,299.36 MJ/year x 50 years = 114,968 MJ
- Total Energy: 1,122,795 MJ + 114,968 MJ = **1,237,763 MJ**

- Public house:
  - Embodied Energy: 925,931 MJ
  - Annual Operational Energy: 1,555.2 MJ/year
  - Lifespan: 50 years
  - Total Operational Energy: 1,555.2 MJ/year x 50 years = 77,750 MJ
  - Total Energy: 925,931 MJ + 77,750 MJ = **1,003,681 MJ**

Overall the L-shape building consume more energy than the other typologies that have been selected on the study.

4.3.4 Window to wall ratio analysis comparison

This analysis shows that the L-shaped building has a high window-to-wall ratio of 14.01% than the other typologies specified in the study but also this building typology consumes much of the energy. Whereas the service building typology has a lower window-to-wall ratio of 7.33 % and still has a low energy consumption over the embodied and operational energy

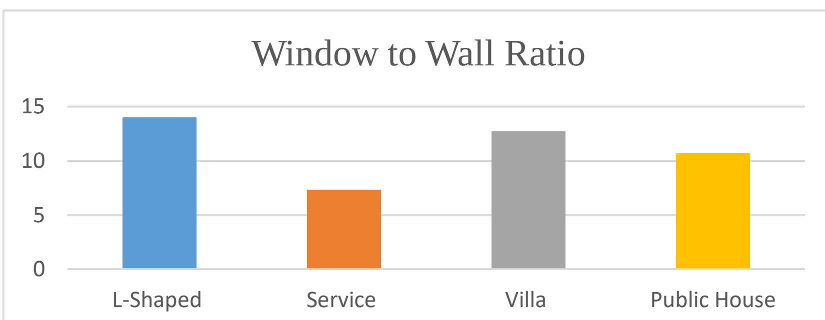

Figure 40: Comparative analysis of overall energy consumption of selected ground floor residential buildings at the study area.

Within this design typology, certain rooms lack adequate access to daylight and ventilation in both the design and construction phases. Specifically, the rooms located in the corners of the L-shaped layout may be enclosed within other rooms without windows. These rooms are typically designated as the Master bedroom and master bathroom.

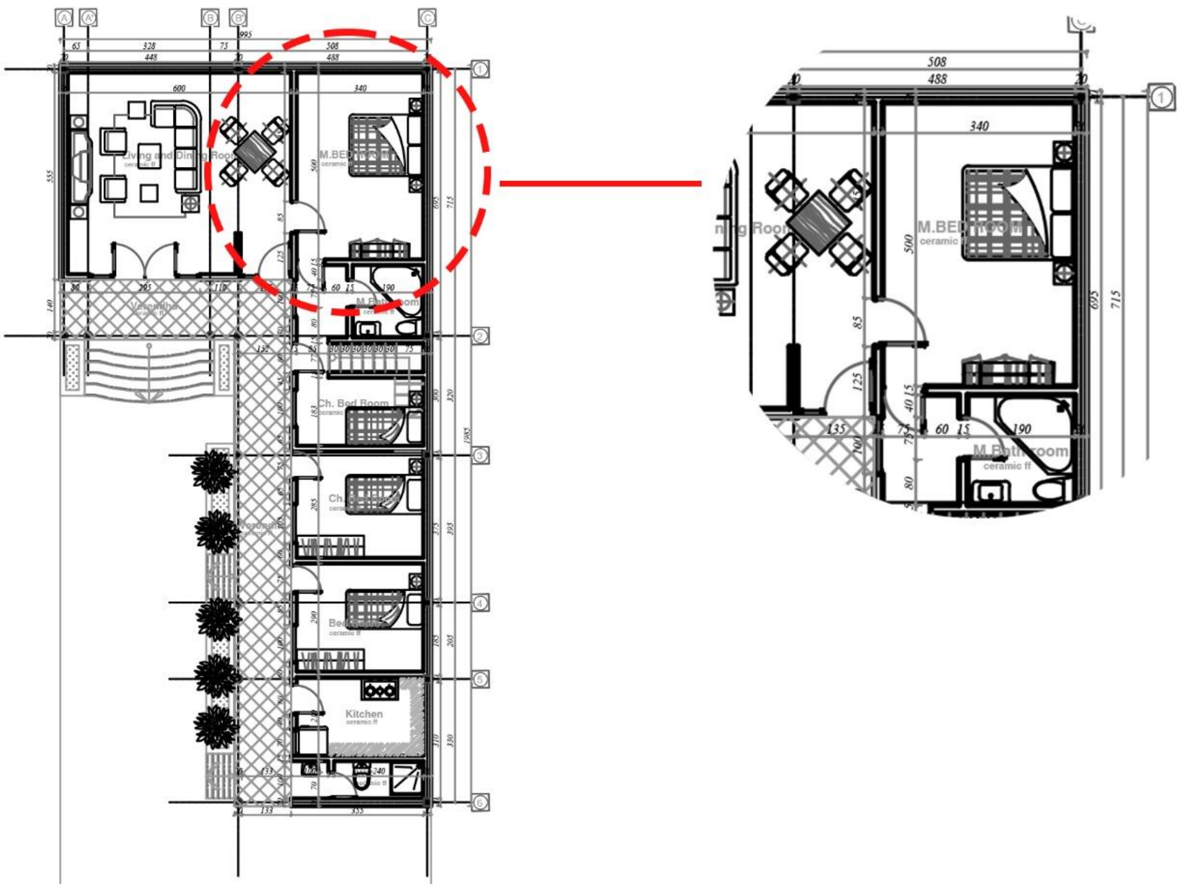

Figure 41: Sample plan of L-shaped building daylight problem

4.4 Discussion

Based on the study over the analysis of the embodied and operational energy consumption of the selected typologies the newly trended L-shaped typology consumed more embodied energy than the rest of the building design and construction. These results are shown in Figure 39, this analysis specifically shows that the use of excessive building material especially on the roofing (Figure 27) and block work (Figure 26) of this typology made the embodied energy go higher than the other selected typology. The operational energy analysis shows that having a high percentage of window-to-wall ratio again (Figure 40) the L-shaped building has a higher consumption rate than the others. In the research of using electrical applications the L-shaped and the villas have almost the same output but in some rooms of the L-shaped residential building design, there has been a lack of daylighting which led them to have more operational energy consumption rather than the others (Figure 41).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study aims to the assessment of embodied and operational energy in residential buildings, focusing on Adama Town for energy-efficient design. Through a comparative analysis, valuable insights were gained regarding the energy performance of buildings in the selected site. Based on the study made there are four topologies of G+0 residential buildings in the study area these are L-shaped, Service, Villa, and Public houses, these typologies have their energy consumption. This paper will make a valuable contribution to the residential building industry. The research shed light on the importance of considering both embodied and operational energy in the design and construction phases to achieve sustainable and energy-efficient buildings.

The study results of the analysis of embodied and operational energy overall results are L-Shaped have 3,550,129.62 MJ which is the largest energy consumption from the overall typology whereas the Villa comes up with 1,123,371.7 MJ, then the Public housing has a result of 926,406.2 MJ and at last the Service building have lowest energy conception of 480,027.96 MJ. In terms of operating energy usage, the L-Shape has 2463.33 MJ, the Villas have 2299.36 MJ, the Public House has 1555.2 MJ, and the Service has 291.96 MJ. And the total energy consumption of this typology's are L-shape (3,672,716 MJ), Villa (1,237,763 MJ), Public house (1,003,681 MJ) and Service (494,291 MJ).The L-shaped building typology has higher energy consumption than the rest of the typology. By evaluating the embodied energy associated with building materials and the operational energy consumed during the building's lifecycle, designers and stakeholders can make informed decisions to promote sustainable practices in the construction industry. In the study the limited sample size the study tries to defend this problem by categorizing the building through Design, construction materials, and ways of construction, This helps the sample narrow to four typologies. in the L-shaped typology, most of the energy variation comes from Embodied energy analysis, when we see this in detail spatially in the higher embodied energy value the roofing component makes the embodied energy consumption rocket high when compared to the other typologies. Over the sub-substructure, almost all typologies have similar results. Over the operational energy analysis, almost all have minimum difference over the L-Shaped enhance with the operational energy because of the light use in the daytime in some rooms that have been in the corner rooms mostly in the design those rooms be Bedroom or Bathroom, whereas the other typologies have good lighting in their rooms. Whereas have a higher window-to-wall ratio rather than the others.

The study's recommendations emphasize the need for continuing research and implementing energy-saving techniques in residential construction. Together, architects, engineers, and legislators may create structures that not only fulfill functional requirements but also contribute to the creation of enduring and environmentally friendly built environments.

In conclusion, for the analysis of energy-efficient G+0 building design, the results of the comparative analysis shows that the service building is more energy-efficient than the others design. Specifically over the embodied energy. This construction of this typology requires low construction, materials, transport, and manual energy.

5.2 Recommendation

According to the research findings, the present trend of construction of G+0 residential structures consumes more energy than rest building typologies. A well-designed, complete, and sustainable residential building will result in more energy-efficient and sustainable buildings across town and the country. There the following recommendations were devised from the research.

- The town's construction administration should create an energy-efficient strategy for building, design, and material selection as the country is in the energy poverty index.
- The construction sector should prioritize energy efficiency and environmental compatibility when planning and constructing buildings, rather than repeating previous designs.
- Architects and construction professionals should prioritize daylighting and ventilation in room design and construction. The administrator should also be responsible for overseeing

and verifying the design and construction processes. Construction materials must be utilized carefully, with experience and functionality.

- Successful programs require effective community participation in conceptualization, design, and execution. It may also foster a sense of belonging because each individual's perspective differs, allowing us to construct unique ideas and plans for their placement. According to study findings, the construction sector should prioritize minimizing energy consumption in building superstructures to improve energy efficiency.

5.3 Design recommendation

- The structure will be built in a 105-m^2 area according to the local administration's cadastral plan, which spans the G+0 residence. (Adama City Spatial Text Report, n.d.)
- The height of the building is above 4.00 m to provide good indoor air quality.
- Reduce high-energy-consuming construction materials to minimize the embodied energy of the building. Especially the roof, which is the trend these days. Maximizing the window-to-wall ratio to control operational energy efficiency.

Figure 42: Proposal Design

The proposed design features a layout that focuses on meeting the programmatic requirements of the L-shaped typology. It has also merged the building heights and roofing of the Villa spacificaly on the living room area and roofing of Service building typologies to optimize the consumption of materials. The design includes a living room with an outdoor patio, 1 bedroom with a bathroom, 2 bedrooms with a common toilet, a kitchen, and a space for parking. All the interior walls are proposed to be constructed with gypsum blocks. This design approach aims to avoid the excessive roofing and mass of concrete over the exterior of the building.

Figure 43: Floor Section, Human eye perspective, and patio of the proposed design

5.3.1 Evaluation of Embodied Energy on Proposed Design

The proposed design for G+0 residential building have a significantly lower embodied energy of 1,823,245 MJ. This represents a substantial reduction compared to the L-shaped design, indicating that the proposed design has been optimized to minimize the energy required for the production of the building materials. The lower embodied energy of the proposed design suggests a more environmentally-friendly approach to construction, with a focus on material selection, design optimization, and efficient construction practices.

Table 24: Embodied energy of material proposed design (Forecasted)

Sub Structure	**Embodied Energy MJ**
Excavation & Earth Work	171,558
Concrete Work	59531.3
Masonry Work	80,074

Super Structure	**Embodied Energy MJ**
Concrete Work	23,526
Block Work	84,497.22
Gypsum block interior wall	95.76 MJ
Roofing	150.447
Carpentry And Joinery	1699.3
Aluminum Works	166,696.13
Plastering And Pointing	15,962
Finishing	46,860
Painting	47,281.66
Sanitary Installation	69,334.08
Electrical Installation	22,561.84
Dry Latrine Septic Tank	944,291.89
Total	1,823,245

By assuming that all materials are fabricated and obtained locally, the same local transportation routes used for the existing typologies will be utilized.

Table 25: Transport energy of material proposed design (Forecasted)

Material	Quantity	Weight (Kg)	Trips	Distains (Km)
Cement	100 bug	5,000	3	5
Coarse Aggregate		20,000	1	2.5
Sand	6 Sino	18,000	8	4
Steel Re-Bars	Berga	2,502.62	1	5
Sawn Timber (Atana)	120 pic	18,000	1	4.5
Hardcore	1 Sino and 1 Chento	~ 40,000	2	4
Others	-	~ 500	1	5
Total		104,002.62 Kg	21	30 Km

The overall transport energy *EET*= 21,935.2 MJ

The daily labor wage was computed as 800 birr/day for skilled workmenship and 400 birr/day for labored workers based on an equitable distribution of skilled and unskilled labor and daily labor salaries of 400 birr/day and 350 birr/day, respectively, as obtained from the construction site engineers interviewed. As a consequence, the project required a total of ten people (two skilled and eight laborers).

The total Embodied energy of construction (EEC) is 60 MJ.

Overall forecasted embodied energy of an L-shaped G+0 residential building will be

- *EE = EEM + EET + EEC*

EEM= 1,823,245 MJ

EET= 21,955.2 MJ

$EEC = 60$ MJ

- EE = 1,100,780 MJ + 21,955.2 MJ +60 MJ

EE= <u>1,845,260 MJ</u>

The proposed design provides a high window-to-wall ratio to make all rooms have abdicated light and ventilation.

Table 26: Window-to-wall ratio analysis of the proposed design

	External wall area			Window area			
	Wall length	Wall high	Area	Number of windows	Width of window	High of window	Area
North wall	2.98 410	360 500	31.79m^2	1	0.90	1.80	1.62 m^2
South wall	4.92	4.95	34.86m^2	2	~	~	10.13 m^2
East wall	7.30	3.55	25.91m^2	4	~	~	12.27 m^2
West wall	12.23	4.00	78.08m^2	0	0	0	0
		Total	112.9m^2			Total	24.02 m^2

- Window to wall ratio (WWR)= (Window Area/ Wall Area) x 100

= (24.02 / 112.94) x100

= <u>21.26 %</u>

The proposed villa-style residential design in Adama Town features a window to wall ratio of 21.26%, indicating a significant focus on providing daylight access and natural ventilation throughout the building.

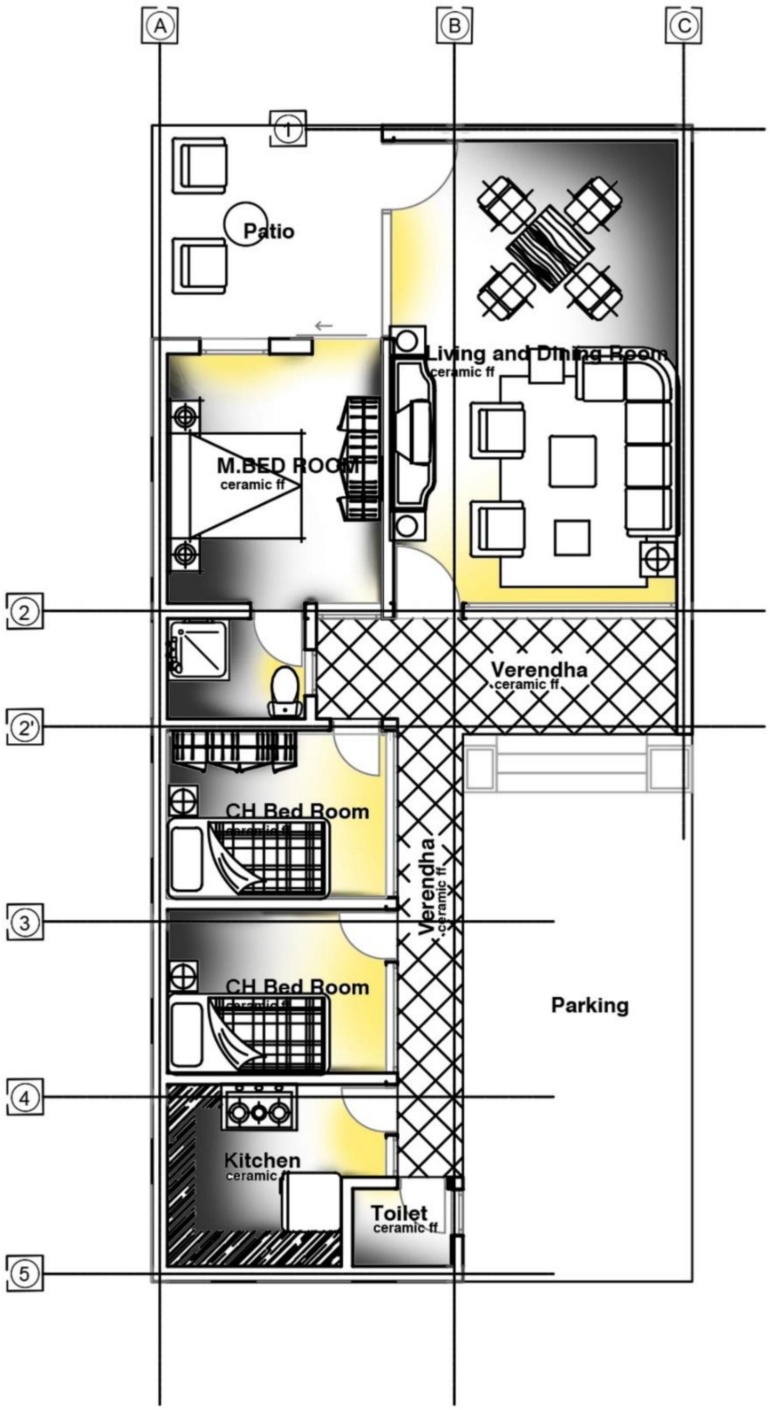

Figure 44: Daylighting in the Proposed Design

The operational energy of the proposed design when it is forecasted based on the study like villa typology this proposed design also has 3 beds with direct daylight accesses, like L-Shape typology has 2 bathrooms with abdicate natural light and has kitchen has abdicated daylight so we do not need using electricity in a day time for lighting but in operational energy consumption almost all typology's have the same out-put only difference is in L-Shaped to gate some light in some rooms specifically in the rooms that are found in the corner are in the need of daylight.

- Total energy conception of newly proposed design :
    - Embodied Energy: 1,845,260 MJ
    - Annual Operational Energy: 2305.5 MJ/year (forecasted)
    - Lifespan: 50 years
    - Total Operational Energy: 2305.5 MJ/year x 50 years = 115,275 MJ
    - Total Energy: 1,845,260 MJ + 115,275 MJ = **1,960,535 MJ**

Let's see the result of the proposed design and other typologies that have been specified in the research

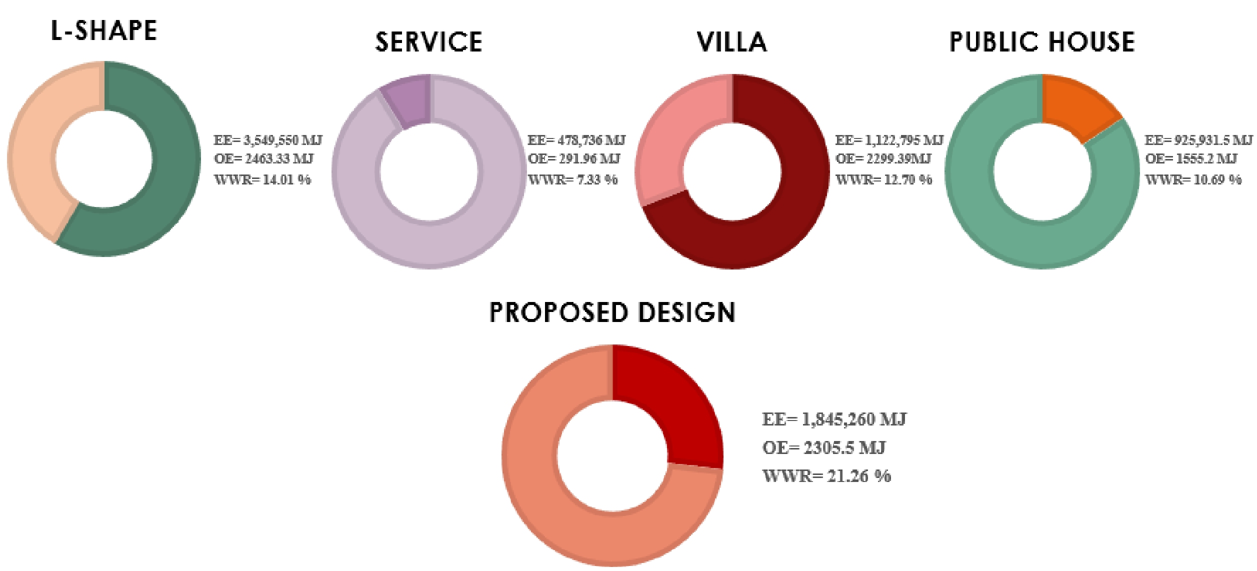

Figure 45: Comparison of Typologies in the Study and Proposed Design

By taking design and recommendation measures that have been specified by the research we can save over 1,704,448 MJ of energy waste over the trending constitution.

Figure 46: Over view of Proposed Design

5.4 Future study

To make energy-efficient residential buildings we completed: a series of more concrete relevant research must be done. For this stand, this research gives a baseline about the influence of construction materials, construction trends, and design influence energy consumption. There are more aspects to see this or to evaluate the design trends that are in the town which need to be evaluated according to environmental capability, according to an indoor thermal concert, and according to daylight, which have an impact on the environment. Besides this research could be an eye-opener for the authorities to provide policies for the residential construction industry as a country.

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APPENDIX

INTERVIEW AND QUESTION FOR CONSTRUCTION STAKEHOLDERS

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY
SCHOOL OF CIVIL ENGINEERING & ARCHITECTURE
DEPARTMENT OF ARCHITECTURE AND URBAN PLANNING & DESIGN

My name is **Bereket Lafraw**, I am an MSc student in Environmental Architecture at Adama Since and Technology University. I am researching the topic " **Assessing Embodied And Operational Energy In Residential Buildings: A Comparative Study In Adama Town For Energy-Efficient Design"** As a part of the research I would like to gather information from you regarding the current trend in material, construction methods, and design consideration in the G+0 residential building construction. I kindly request your valuable insist on the following:

1. Constriction Trends:
    - What are the Emerging technologies and innovations in the construction industry?
    - What are the sustainable and energy-efficiency construction practices?
2. Construction Materials:
    - Commonly used material in G+0 residential construction?
    - Energy-efficient and environmentally-friendly construction materials?
    - Material selection criteria for reducing embodied and operational energy?
3. Constriction Method
    - What are the construction techniques and their energy implication on site?
    - Do you have a knowhow about energy efficiency? What are the innovative methods that have you used on construction sites?
4. Design consideration:
    - What is your aspect on the importance of energy-efficiency design in residential buildings?
    - What are the passive design strategies you implement (eg, orientation, natural ventilation, solar thermal)?
    - The use of integration of renewable energy systems (eg, Solar photovoltaic, solar thermal)?

Building Characters:
Housing Characteristics: G+0 Residential buildings
Location: Adama
Site Location: Dagaga Kebeele
Typology:

- L-Shape - Service - Villa - Public house

House No: ------------------ Building Ownership: Government/ Privet

Energy source:
Primary Energy source:

- Electricity - Solar panel - Biomass like wood & Coal
- Combined Electricity & Coal

Monthly Electric Bill (Avg):_________ETB
Electric utility Customer ID (CA Number): ________________
Other Energy Sources: Solar Panel Usage per hour /Day/week____________

Charcoal: Daily/Monthly________

Household Applications:

Appliance	Availability y (√/x)	Brand/ type (local, modified,)	Energy efficiency Index(if avail)	Quantity	Usage frequency	Remark
Lighting						
Fan/ air ventilator						
Ac						
Dim Lighting						
Electric Mitad						
Electric Stove						
Charcoal Midja						

Oven						
Coffee						
Mixer						
Grinder						
Washing machine						
TV						
Computer						
Audio Device/Speaker						
Refrigerator						
Ironing/ Hair devices						
Any other appliances						

Energy Usage and Saving Awareness:

Did you know about energy efficiency? Yes/No: Did you use energy-efficient appliances? Yes/No How often do you change or buy new appliances?

____

Are you aware of the energy consumption of different appliances in your household?

Have you taken any steps to reduce your energy consumption? If yes, please specify.

Bill of Quantity Of Material Of L-Shaped Residential Building

Item Nº	Description	Unit	Qty	Rate	Amount
	A. SUB STRUCTURE				
	1.0 EXCAVATION & EARTH WORK				
1.01	clear and remove top soil to an average depth of 200mm	M2	105.00	32.00	3,360.00
1.02	300mm depth bulk excavation in ordinary soil to remove soft and fertile soil	M3	70.40	310.00	24,614.00
1.03	700mm width trench excavation in ordinary soil to a depth not exceeding 1000mm from reduced ground level for the construction of masonry foundation	M3	40.30	370.00	18,315.00
1.04	fill under hardcore with selected materials and compact in layer not exceeding 200mm thick	M3	22.10	250.00	5,525.00
1.05	fill around masonry wall with selected materialand compact in layers not exceeding 200mm thick	M3	8.30	250.00	2,075.00
1.06	load and cart away surplus excavated materials to an appropriate tip	M3	17.20	175.00	3,010.00
1.07	250mm thick basaltic stone hardcore well rolled consolidated and blinded with crushed stone	M2	25.40	1,500.00	38,100.00
	TOTAL CARRIED TO SUMMARY.......				**94,919.00**
	2.0 CONCRETE WORK				
2.01	50mm lean concrete quality C-5 with minimum cement content of 150kg/M3 of concrete				
	a) Under beam	M2	27.30	410.00	11,193.00
	b) Under Masonry wall	M2	32.30	410.00	13,243.00
2.02	Reinforced concrete quality C-25, 360kg/m3 filled into formwork and vibrated around rod reinforcement (formwork and reinforcement measured separately)				
	a) in grade beam	M3	12.30	4,900.00	60,270.00
	b) 100mm thick in ground floor	M2	112.90	485.00	54,855.50
2.03	Provide, cut and fix in position sawn structural wood or steel formwork which ever is appropriate				
	a) in grade beams	M2	18.20	410.00	7,462.00
2.04	mild steel reinforcement according to structural drawing. Price includes cutting, bending, placing in position, tying wire and concrete spacers.				

Item Nº	Description	Unit	Qty	Rate	Amount
2.01	Class B 200mm thick HCB with the designed compressive strength bedded in cement mortar (1:3). Price shall include mortar bed.	M2	147.72	410.00	60,565.20
Item Nº	**Description**	**Unit**	**Qty**	**Rate**	**Amount**
	A. SUB STRUCTURE				
	1.0 EXCAVATION & EARTH WORK				
2.13	clear and remove top soil to an average depth of 200mm	M2	68.97	1,985.20	136,366.20
2.17	300mm depth bulk excavation in ordinary soil to remove soft and fertile soil	M3	69.69	2,007.75	139,914.25
2.18	700mm width trench excavation in ordinary	M3	70.41	2,035.30	143,298.97
2.20	fill under hardcore with selected materials and compact in layer not exceeding 200mm thick	M3	71.13	2,062.84	146,726.34
2.22	fill around masonry wall with selected	M3	71.85	2,090.39	150,187.37
2.24	load and cart away surplus excavated materials to an appropriate tip	M3	72.57	2,117.94	153,693.06
2.25	250mm thick basaltic stone hardcore well rolled consolidated and blinded with crushed stone	M2	73.29	2,145.49	157,234.60
2.27	**TOTAL CARRIED TO SUMMARY.......**		74.01	2,173.03	**1,617,618.60**
2.29	**2.0 CONCRETE WORK**		74.73	2,200.58	
2.31	50mm lean concrete quality C-5 with minimum cement content of 150kg/M3 of concrete		75.45	2,228.13	
2.32	a) Under beam	M2	76.17	2,255.68	171,804.86
2.34	b) Under Masonry wall	M2	76.89	2,283.22	175,545.00
2.36	Reinforced concrete quality C-25, 360kg/m3		77.60	2,310.77	
2.38	a) in grade beam	M3	78.32	2,338.32	183,148.23

Item Nº	Description	Unit	Qty	Rate	Amount
	a) Dia 8 mm deformed bar for grade beam stirrup	Kg	192.00	124.60	23,560.00
	b) Dia 12mm deformed bar for grade beam main bars	Kg	91.00	124.60	11,284.00
	TOTAL CARRIED TO SUMMARY.........				**180,970.50**
	3.0 MASONRY WORK				
3.01	500mm thick hard trachytic roughly dressed stone masonry foundation wall below ground level bedded in cement mortar mix ratio(1:3). An average depth of masonry wall 1200mm.	M2	26.20	2,200.00	57,640.00
3.02	Ditto but for exposed part above natural ground level	M2	13.40	2,050.00	27,470.00
3.03	Ditto but for masonry steps	M3	4.50	1415.68	6,370.56
	TOTAL CARRIED TO SUMMARY.......				**91,480.56**
	TOTAL CARRIED TO SUMMERY A				**367,450.06**
	B-SUPER STRUCTURE				
	1.0 CONCRETE WORK				
1.01	Reinforced concrete quality C-25, 360kg of cement(m3) filled into formwork and vibrated around rod reinforcement (formwork and reinforcement measured separately)				
	a) In elevation columns	M3	5.50	4,900.00	26,950.00
	b) In roof beams	M3	8.20	4,900.00	40,180.00
	c) water tank	M3	1.20	4,900.00	5,880.00
	d) In 150mm thick concrete gutter	M3	2.40	4,900.00	11,760.00
1.02	Provide, cut and fix in position sawn structural wood or steel formwork which ever is appropriate				
	a) to elevation columns.	M2	17.50	315.00	5,512.50
	b) to roof beam	M2	35.04	315.00	11,037.60
	c) water tank	M2	2.30	315.00	724.50
	d) to 150mm thick concrete gutter	M2	25.32	315.60	8,035.80
1.03	Mild steel reinforcement according to structural drawings. Price shall include cutting, bending, placing in position, tying wire, concrete spacers and chairs.				
	a) Dia 8 mm deformed bar	Kg	233.00	124.60	28,992.00
	b) Dia 12mm deformed bar	Kg	141.60	124.60	17,558.40
	TOTAL CARRIED TO SUMMARY.......				**156,511.80**
	2.0 BLOCK WORK				

Item Nº	Description	Unit	Qty	Rate	Amount
2.39	b) 100mm thick in ground floor	M2	79.04	2,365.87	187,060.03
2.41	Provide, cut and fix in position sawn structural wood or steel formwork which ever is		79.76	2,393.41	
2.43	a) in grade beams	M2	80.48	2,420.96	194,840.01
2.45	mild steel reinforcement according to structural		81.20	2,448.51	
2.46	a) Dia 8 mm deformed bar for grade beam	Kg	81.92	2,476.06	202,847.82
2.48	b) Dia 12mm deformed bar for grade beam	Kg	82.64	2,503.60	206,898.71
2.50	**TOTAL CARRIED TO SUMMARY.......**		83.36	2,531.15	**2,111,130.96**
2.52	**3.0 MASONRY WORK**		84.08	2,558.70	
2.53	500mm thick hard trachytic roughly dressed stone masonry foundation wall below ground level bedded in cement mortar mix ratio(1:3). An average depth of masonry wall 1200mm.	M2	84.80	2,586.25	219,321.31
2.55	Ditto but for exposed part above natural ground level	M2	85.52	2,613.80	223,538.05
2.569	Ditto but for masonry steps	M3	86.24	2641.342675	227,796.03
2.59	**TOTAL CARRIED TO SUMMARY.......**		86.96	2,668.89	**470,636.22**
2.6041	**TOTAL CARRIED TO SUMMERY A**				**3,820,385.78**
2.62	**B-SUPER STRUCTURE**		87.40	2,723.99	
2.64	**1.0 CONCRETE WORK**		88.12	2,751.53	
2.66	Reinforced concrete quality C-25, 360kg of cement(m3) filled into formwork and vibrated around rod reinforcement (formwork and reinforcement measured separately)		89.84	2,779.08	
2.67	a) In elevation columns	M3	90.56	2,806.63	254,171.91
2.69	b) In roof beams	M3	91.28	2,834.18	258,706.09
2.71	c) water tank	M3	92.00	2,861.72	263,281.13

2.72	a) In 150mm thick concrete gutter	M³	93.72	2,889.27	267,483.23
2.74	Provide, cut and fix in position sawn structural wood or steel formwork which ever is appropriate		93.44	2,916.82	
2.76	a) to elevation columns	M²	94.16	2,944.37	277,242.88
2.78	b) to roof beam	M²	94.88	2,971.91	281,975.46
2.80	c) water tank	M²	95.60	2,999.46	286,748.18
2.81	d) to 150mm thick concrete gutter	M²	96.32	3,027.01	291,550.56
2.82	Mild steel reinforcement according to structural drawings. Price shall include cutting, bending, placing in position, tying wire, concrete spacers and chairs.		97.04	3,054.56	
2.85	a) Dia 8 mm deformed bar	Kg	97.76	3,082.10	301,304.83
2.87	b) Dia 12mm deformed bar	Kg	98.48	3,109.65	306,235.66
2.89	**TOTAL CARRIED TO SUMMARY.......**		99.20	3,137.20	**2,789,232.34**
2.90	**2.0 BLOCK WORK**		99.92	3,164.75	
2.92	Class B 200mm thick HCB with the designed compressive strength, bedded in cement mortar (1:3). Price shall include mortar bed.	M²	100.64	3,192.29	321,267.67
Item №	**Description**	**Unit**	**Qty**	**Rate**	**Amount**
	A. SUB STRUCTURE				
	1.0 EXCAVATION & EARTH WORK				
2.94	Clear and remove top soil to an average depth	M²	101.36	3,219.84	326,357.65
2.96	300mm depth bulk excavation in ordinary soil to	M³	102.08	3,247.39	331,487.29
2.97	700mm width trench excavation in ordinary	M³	102.80	3,274.94	336,656.59
2.99	fill under hardcore with selected materials and compact in layer not exceeding 200mm thick	M³	103.52	3,302.48	341,865.55
3.01	fill around masonry wall with selected	M³	104.24	3,330.03	347,114.16
3.03	load and cart away surplus excavated	M³	104.96	3,357.58	352,402.44
3.04	250mm thick basaltic stone hardcore well	M³	105.68	3,385.13	357,730.36
3.06	**TOTAL CARRIED TO SUMMARY.......**		106.40	3,412.67	**2,193,614.05**
	2.0 CONCRETE WORK				
3.08			107.12	3,440.22	
3.10	50mm lean concrete quality C-5 with minimum		107.84	3,467.77	
3.11	a) Under beam	M³	108.56	3,495.32	379,458.65

3.46	a) In elevation columns	M³	122.95	4,045.27	497,407.80
3.48	b) In roof beams	M³	123.67	4,073.82	503,817.26
3.50	c) water tank	M³	124.39	4,101.36	510,176.28
3.52	d) In 150mm thick concrete gutter	M³	125.11	4,128.91	516,574.96
3.53	Provide, cut and fix in position as structural		125.83	4,156.46	
3.55	a) to elevation columns	M²	126.55	4,184.01	529,491.29
3.57	b) to roof beam	M²	127.27	4,211.55	536,008.95
3.59	c) water tank	M²	127.99	4,239.10	542,565.23
3.60	d) to 150mm thick concrete gutter	M²	128.71	4,266.65	549,168.22
3.62	Mild steel reinforcement according to structural drawings. Price shall include		129.43	4,294.20	
3.64	a) Dia 8 mm deformed bar	Kg	130.15	4,321.74	562,456.19
3.66	b) Dia 12mm deformed bar	Kg	130.87	4,349.29	569,192.07
3.68	**TOTAL CARRIED TO SUMMARY.......**		131.59	4,376.84	**5,216,964.22**
3.69	**2.0 BLOCK WORK**		132.31	4,404.39	
3.71	Class B 200mm thick HCB with the designed compressive strength, bedded in cement mortar (1:3). Price shall include mortar bed.	M²	133.03	4,431.93	589,577.83
	a) Dia 50 mm	ml	24	276.00	6,624.00
	b) Dia 110 mm	ml	18	524.00	9,432.00
9.3.5	Construct rectangular ditch around the building to convey the run off from down pipe to local collector ditch as shown on drawing provided price include all assistance and related works there to	ml	14	560.00	7,840.00
9.4	ROOF RUNOFF DRAINAGE SYSTEM				
9.4.1	Supply and install PVC down pipe complete with bends of 45 and 90 degree as per the drawing				
	a) Dia 110 mm	ml	28	524.00	14,672.00
9.4.2	Supply and install galvanized steel pipe (GSP) as per roof lay out distribute water from water tank to sanitary rooms, unit price shall include all necessary fittings.				
	a) Dia 15mm	ml	15	490.00	7,350.00

3.33	b) Under Masonry wall	m²	109.20	2,523.88	264,993.87
3.35	Reinforced concrete quality C-25, 360kg/m3 filled into formwork and vibrated around rod		110.00	2,550.43	
3.37	a) in grade beam	m³	110.72	2,577.98	290,138.28
3.38	b) 100mm thick for ground floor	m³	111.44	2,605.53	402,785.47
3.20	Provide, cut and fix in position sawn structural wood or steel formwork which ever is appropriate		112.16	2,633.08	
3.22	a) in grade beams	m²	112.88	2,660.60	472,188.82
3.24	Mild steel reinforcement according to structural drawing. Price includes cutting, bending, placing in position, tying wire and concrete spacers		113.59	2,688.15	
3.25	a) Dia 8 mm deformed bar for grade beam	Kg	114.31	2,715.70	424,718.79
3.27	b) Dia 12mm deformed bar for grade beam [illegible]	Kg	115.03	2,743.24	428,428.27
3.29	**TOTAL CARRIED TO SUMMARY.......**		115.75	2,770.79	**2,824,877.17**
3.31	**3.0 MASONRY WORK**		116.47	2,798.34	
3.32	300mm thick hard trachytic roughly dressed stone masonry foundation wall below ground level bedded in cement mortar mix ratio(1:3) An average depth of masonry wall 300mm	m³	117.19	2,825.89	442,170.69
3.34	Ditto but for exposed part above natural ground level	m³	117.91	2,853.44	434,572.72
3.318	Ditto but for masonry steps	m³	118.63	[illegible]	462,411.37
3.38	**TOTAL CARRIED TO SUMMARY.......**		119.35	2,908.53	**1,562,577.89**
3.3942	**TOTAL CARRIED TO SUMMARY A**				**6,587,445.38**
3.41	**B.SUPER STRUCTURE**		120.79	2,963.63	
3.43	**2.0 CONCRETE WORK**		121.51	2,991.17	
3.45	Reinforced concrete quality C-25, 360kg of cement/m3 filled into formwork and vibrated around rod reinforcement (formwork and reinforcement measured separately)		122.23	4,018.72	

	b) Dia 20mm	ml	41	763.00	[illegible]
9.4.3	Supply and install gate valve (Italy made) or equivalent standard complete with union and other necessary fittings and accessories				
	a) Dia 15mm	ml	1	420.00	420.00
	b) Dia 20mm	ml	2	910.00	1,820.00
9.4.4	Supply and mount water tank of roto type vertical type with inlet outlet and over flow of size				
	a) size 2000 liter	No	1	11,300.00	11,300.00
9.5	[illegible]				
9.5.1	Supply and lay Galvanized steel pipe or equivalent standard, for water system from municipality water meter to the roof mounted water tank. Complete with all fittings and as per the drawing				
	a) Dia 25 mm	ml	25	850.00	21,250.00
9.5.2	Supply and install gate valve (Italy made) or equivalent standard complete with union and other necessary fittings and accessories				
	a) Dia 25 mm	pcs	4	1,110.00	4,440.00
9.5.3	Supply and lay UPVC SEWAGE WASTER drainage pipes or equivalent standards for sewer lines conveying soil and waste water from the building up to the septic tank				
	a) Dia 110 mm	ml	16	482.00	[illegible]
	TOTAL CARRIED TO SUMMARY				**[illegible]**
10	**10 ELECTRICAL INSTALLATION**				
10.1	Power / auxiliary installation (provisional quantity)				
10.1.1	Manhole				
10.1.2	PVC PIPES				
	a) 16 mm diameter	ml	75	[illegible]	[illegible]
	b) 20 mm diameter	ml	185	55.00	10,175.00
10.2	LOW VOLTAGE SYSTEM EARTHING				
10.2.1	Drive the earthing rod with copper clad steel length 3m	No	1	1,770.00	1,770.00
10.2.2	1 x 16sqmm. Bare copper earth conductor from MDP earth terminal to the earth rod	ml	7.5	396.00	2,970.00
10.3	DISTRIBUTION BOARDS				
10.3.1	Flush mounted distribution board, MDP, with lockable door and including bus bar of [illegible] phase, all necessary fixing and connecting accessories, complete and [illegible]				
	a) 1pos 25A, MCB, 1phase				
	b) 1pos 25A, MCB, 1phase				
	c) 2pos 25A, MCB, 1 phase	No	1	4,200.00	4,200.00
10.3.2	Flush mounted distribution board, UPP - BB, with lockable door and including bus bar of [illegible] phase, all necessary fixing and connecting accessory, complete and [illegible]				
	a) 2pos 16A, MCB, 1phase				
	b) 1pos 16A, MCB, 1phase				
	c) 1pos 25A, MCB, 1 phase	No	1	3,300.00	3,300.00
10.4	FEEDER POWER CABLES AND WIRE				
10.4.1	Multi - core power cable copper conductor, PVC/PVC, color coded, in PVC conduits connected and tested, all specified and as shown on drawings.				
	a) 4 x 2.5 mm sq cable	ml	105	400.00	42,000.00
	b) 4 x 6 mm sq wire	ml	6	420.00	-
	c) 2 x 2.5 mm sq wire	ml	150	300.00	45,000.00
	d) 3 x 2.5 mm sq wire	ml	150	[illegible]	[illegible]
10.5	10.5.1 LIGHT POINTS				
10.5.1	Flush mounted light point fed through PVC insulated conductors of 2 x 2.5 mm sq in rigid PVC conduits of 20mm diameter, including junction boxes with screw and insulating screw cap connectors, complete.				
	a) Single fluorescent of [illegible]	pcs	4	575.00	-

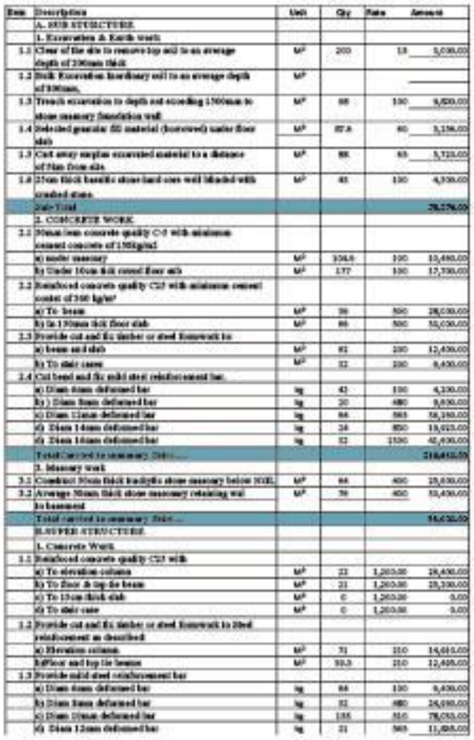
Bill of Quantity of Material Of Service Residential Building

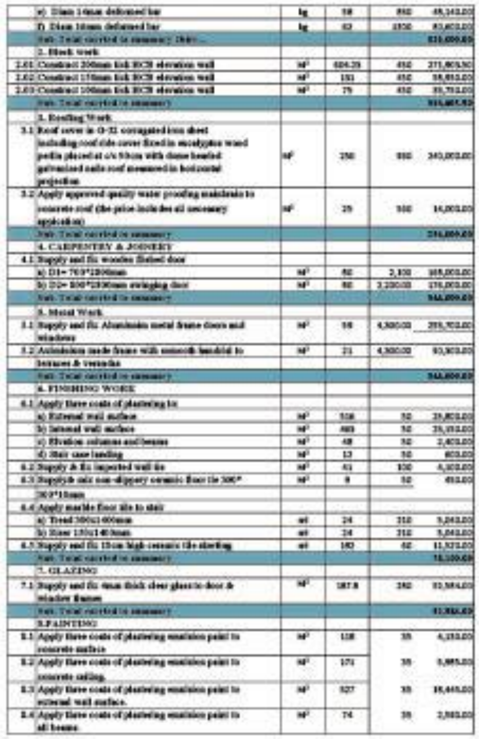
Item No	Description	Unit	Qty	Rate	Amount
	A. SUB STRUCTURE				
	1. Excavation & Earth work				
1.1	Clear of the site to remove top soil to an average depth of 20cm thick	M^2	200	6	1200
1.2	Excavation for trench foundation to a depth of 90cm starting from reduced level	M^3	37.71	36	1357.56
1.3	Selected material back fill	M^3	44.61	172.5	7695.225
1.4	Cart away surplus excavated	M^3	34.8	18	626.4
1.5	25cm thick basaltic or equivalent stone hard core well rolled consolidated and blinded with crushed stone	M^2	114.8	127	14579.6
	Sub- Total				25458.785
	2. Concrete Work				
2.0	Use concrete class C-20,320kgs of cement /M2 filled in to form work and vibrated around rod reinforcement steel & from work measured separately.				
2.1	In 10cm thick mass concrete to floor slab evenly spread and leveled	M^3	11.62	1950	22659.0
2.2	In R.C grade beam	M^3	3.12	2250	7020
2.3	From working provide cut & fix in position sawn zigba wood form work of R.C grade beam	M^2	19.2	22	422.4
2.4	Steel reinfocement according to structural drawing price includes cutting, placing in position & tying wires.				
	a) 12mm def bar	kg	326.5	45	14692.5
	b) 6mm plain bars	kg	122.93	30	3687.9
	Sub - Total				45481.8
	3. Masonry work				
1.1	Masonry wall below ground level	M^3	25.87	902.88	23357.508
1.2	Masonry wall above ground level	M^3	45.75	902.88	41306.76
	Sub - Total				64664.268

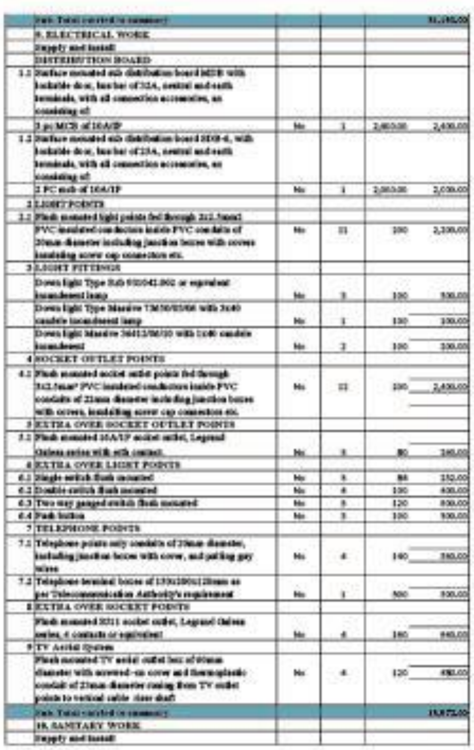
Item No	Description	Unit	Qty	Rate	Amount
	B. SUPPER STRUCTURE				
	1.Concrete Work				
1.1	Reinforced concrete as before described C-20 cement 320m3				
	a) In RC elevation columns.	M^3	3.6	2500	9000
	b) In RC top tie beam	M^3	4.49	2600	11674
	c) In RC lintels	M^3	1.72	1800	3096
1.2	Form work as before described				
	a) To column	M^2	47.24	35	1653.4
	b) To top tie beam	M^2	48.12	23	1106.76
	c) To RC lintels	M^2	8.34	22	183.48
1.3	Steel reinfocement as before described				
	a) 12mm def bar	Kg	306.23	45	13780.35
	b) 6mm plain bars	kg	98.53	30	2955.9
	Sub- Total				43443.9
	2. Wall work				
2.1	20 cm thick hollow block concrete wall bedded in cement 1:3 both sides left for plaster	M^2	263.52	360	94867.2
	Sub- Total				94867.2
	3. Carpentry & Joiner				
3.1	8-10cm vertical and diagonal member	Ml	143	22	3146
3.2	10-12cm eucalyptus upper & lower member	Ml	122	25	3050
3.3	Ditto but purline placed at c/c 90 cm 7cms	Ml	164	26	4264
3.4	Supply and fix size wood facia board 25x5cm	Ml	88	60	5280
3.5	wooden door	Ml	8.87	85	753.95
	Sub- Total				16493.95
	4. Roofing				
4.1	CIS Roof covering including roof ride cover fixed in eucalyptus wood perlin placed at c/c 90cm with dome headed galvanized nails roof measured in horizontal projection	M^2	72	385	26280
4.2	Decorative Roof Covering	M^2	53	172	9116
	Sub- Total				35396

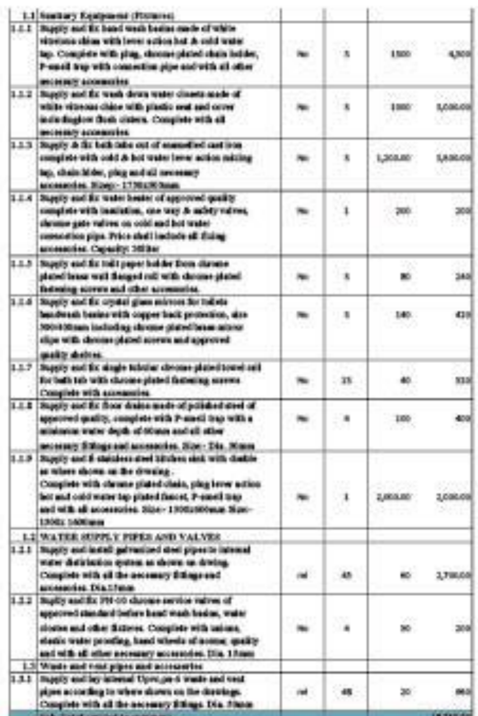
Item No	Description	Unit	Qty	Rate	Amount
	5. Metal work				
	All metal doors and windows shall be fabricated from locally manufactured galvanized kasi profile will all necessary iron mongory and glazed price includes moutach to opening side and all accessories on coat of primer and two coast of synthetic enameled paints and price shoudl be clued security grill (as per the drawing)				
5.1	Metal Window	M^2	8.63	1150	9924.5
5.2	Metal Door	M^2	32.32	1200	38784
	Sub- Total				48708.5
	6. Plastering & other finishing				
6.1	Three coats of smooth plaster up to fine finish	M^2	423.1	86.17	36460.26
6.2	Cement floor finish	M^2	128	104.00	13312.00
6.3	Gypsem ceiling	M^2	128.47	228.00	28582.22
6.4	Rendering to External wall	M^2	168	110.00	18480.00
	Sub- Total				95834.47
	7. Glazing				
7.1	4mm thick clear glass glazes to metal beads & putty	M^2	38.15	520.00	19838.00
	Sub- Total				19838.00
	8. Painting				
8.1	Three coats of plastic paint to internal wall	M^2	268.22	53.57	14368.56
8.2	Three coats of plastic paint to External wall	M^2	264.33	55.00	14538.15
8.3	Ditto to ceiling	M^2	126.47	53.57	6775.00
	Sub - Total				35681.69
	9. Electric Installation				
9.1	Light point with all acces	Pcs	20.00	140.00	2800.00
9.2	Soket & Switch	Pcs	26.00	85.00	2210.00
	Sub- Total				5010.00

Bill of Quantity of Material of Villa Residential Building









Bill of Quantity of Material of Public House Residential Building

Description	Unit	Qty	Rate	Amount
A. SUB STRUCTURE				
1. Excavation & Earth work				
Clear of the site to remove top soil to an average depth of 20cm thick	M^2	200	6	1200
Excavation for trench foundation to a depth of 80cm starting from reduced level	M^3	37.71	36	1357.56
Selected material back fill	M^3	44.61	172.5	7695.225
Cart away surplus excavated	M^3	34.8	18	626.4
25cm thick basaltic or equivalent stone hard core well rolled consolidated and blinded with crushed stone	M^2	114.8	127	14579.6
Sub-Total				25458.785
2. Concrete Work				
Use concrete class C-20,320kgs of cement /M2 filled in to form work and vibrated around rod reinforcement steel & from work measured separately.				
In 10cm thick mass concrete to floor slab evenly spread and leveled	M^3	11.62	1950	22659.0
In R.C grade beam	M^3	3.12	2250	7020
From working provide cut & fix in position sawn zigba wood form work of R.C grade beam	M^2	19.2	22	422.4
Steel reinfocement according to structural drawing price includes cutting, placing in postion & tying wires.				
a) 12mm def bar	kg	326.5	45	14692.5
b) 6mm plain bars	kg	122.93	30	3687.9
Sub - Total				48481.8
3. Masonry work				
Masonry wall below ground level	M^3	25.87	902.88	23357.5056
Masonry wall above ground level	M^3	45.75	902.88	41306.76
Sub - Totla				64664.2856
5. Metal work				
All metal doors and windows shall be fabricated from locally manufactured galvanized kasi profile will all necessary iron mongory and glazed price includes moutach to opening side and all accessories on coat of primer and two coast of synthetic enameled paints and price shoudl be clued security grill (as per the drawing)				
Metal Window	M^2	8.63	1150	9924.5
Metal Door	M^2	32.32	1200	38784
Sub- Total				48708.5
6. Plastering & other finishing				
Three coats of smooth plaster up to fine finish	M^2	423.1	86.17	36460.25
Cement floor finish	M^2	128	104.00	13312.00
Gypsem ceiling	M^2	126.47	226.00	28582.22
Rendering to External wall	M^2	168	110.00	18480.00
Sub- Total				96834.47
7. Glazing				
4mm thick clear glass glazes to metal beads & putty	M^2	38.15	520.00	19838.00
Sub- Total				19838.00
8. Painting				
Three coats of plastic paint to internal wall	M^2	268.22	53.57	14368.55
Three coats of plastic paint to External wall	M^2	264.33	55.00	14538.15
Ditto to ceiling	M^2	126.47	53.57	6775.00
Sub - Total				35681.69
9. Electric Installation				
Light point with all acces	Pcs	20.00	140.00	2800.00
Soket & Switch	Pcs	26.00	85.00	2210.00
Surface mounted sub distribution board MDB with lockable door, bus bar of 32A, neutral and earth terminals, with all connection accessories, an consisting of:				
3 pc MCB of 10A/IP	No	1	2,400.00	2,400.00
Surface mounted sub distribution board SDB-6, with lockable door, bus bar of 25A, neutral and earth terminals, with all connection accessories, an consisting of:				
2 PC mcb of 10A/1P	No	1	2,000.00	2,000.00
LIGHT POINTS				
Flush mounted light points fed through 2x2.5mm2 PVC insulated conductors inside PVC conduits of 20mm diameter including junction boxes with covers insulating screw cap connectors etc.	No	11	200	2,200.00
LIGHT FITTINGS				
Down light Type Rzb 931042.002 or equivalent incandescent lamp	No	3	100	300.00
Down light Type Massive 73650/03/06 with 3x40 candle incandescent lamp	No	1	100	100.00
Down light Massive 36412/06/10 with 1x40 candle incandescent	No	2	100	200.00
SOCKET OUTLET POINTS				
Flush mounted socket outlet points fed through 3x2.5mm² PVC insulated conductors inside PVC conduits of 22mm diameter including junction boxes with covers, insulating screw cap connectors etc.	No	12	200	2,400.00
EXTRA OVER SOCKET OUTLET POINTS				
Flush mounted 16A/1P socket outlet, Legrand Galea series with erth contact.	No	3	80	240.00
EXTRA OVER LIGHT POINTS				
Single switch flush mounted	No	3	84	252.00
Double switch flush mounted	No	4	100	400.00
Two way ganged switch flush mounted	No	5	120	600.00
Push button	No	3	100	300.00
TELEPHONE POINTS				
Telephone points only conduits of 20mm diameter, including junction boxes with cover, and pulling g wires	No	4	140	560.00
Telephone terminal boxes of 150x200x120mm as per Telecommunication Authority's requirement	No	1	500	500.00
EXTRA OVER SOCKET POINTS				
Flush mounted RJ11 socket outlet, Legrand Galea series, 4 contacts or equivalent	No	4	160	640.00
TV Aerial System				
Flush mounted TV aerial outlet box of 60mm diameter with screwed -on cover and thermoplasti conduit of 23mm diameter runing from TV outlet points to vertical cable riser shaft	No	4	120	480.00
Sub- Total				1317501.23
B. SUPPER STRUCTURE				
1.Concrete Work				
Reinforced concrete as before described C-20 cement 320m3				
a) In RC elevation columns.	M^3	10.6	2500	26500
b) In RC top tie beam	M^3	8	2600	20800
c) In RC lintels	M^3	6	1800	10800
Form work as before described				
a) To column	M^2	95	35	3325
b) To top tie beam	M^2	120	23	2760
c) To RC lintels	M^2	50	22	1100
Steel reinfocement as before described				
a) 12mm def bar	Kg	500	45	22500
b) 6mm plain bars	kg	2500	30	75000.0
Sub- Total				162785.0
2. Wall work				
20 cm thick hollow block concrete wall bedded in cement 1:3 both sides left for plaster	M^2	263.52	360	94867.2
Sub- Total				94867.2
3. Carpentry & Joiner				
8-10cm vertical and diagonal member	Ml	143	22	3146
10-12cm eucalyptus upper & lower member	Ml	122	25	3050
Ditto but purline placed at c/c 90 cm 7cms	Ml	164	26	4264
Supply and fix size wood facila board 25x5cm	Ml	88	60	5280
wooden door	Ml	8.87	85	753.95
Sub- Total				16493.95
4. Roofing				
CIS Roof covering including roof ride cover fixed in eucalyptus wood perlin placed at c/c 90cm with dome headed galvanized nails roof measured in horizontal projection	M^2	72	365	26280
Decorative Roof Covering	M^2	53	172	9116
Sub- Total				35396

Customer Electricity Consumption

Energy Bill month	Customer ID							
	90182	101508	18405	90190	101512	67052	101520	90125
	Energy (kWh)							
Jan/22	625	613	673	667	989.92	551	615	598
Feb/22	615.6	621	634	646	1002	562	622	675
Mar/22	695	610	660	650.31	982	589	618	803
Apr/22	870	606	676.16	652	866	577	619	610
May/22	640	642	724	684	767	600	622	619.38
Jun/22	610	667	684	655	605	838	609	750
Jul/22	612	637	665	650	886	584	618	569
Aug/22	697	620	840	576	601	583	638	655
Sep/22	685	612	1005	634	865	554	601	675
Oct/22	860	650	673.55	615.6	1007	588	615	684.86
Nov/22	710	638	1085	567	880	593	622	614
Dec/22	620	640	1020	646	750	551	618	774

Energy Bill month	Customer ID							
	70182	60412	G-1688	70208	60450	G-1690	70190	60460
	Energy (kWh)							
Jan/22	42.73	69.08	59.27	56.54	81.11	88.16	102.13	52.15
Feb/22	47.9	112.92	119.13	84.79	87.36	65.91	110.21	67.18
Mar/22	40.72	101.69	81.59	66.66	82.42	92.77	116.62	58.84
Apr/22	46.1	68.29	38.95	76.06	87.91	77.88	119.29	56.98
May/22	63.55	72.4	71.75	108.2	119.29	86.75	86.52	67.17
Jun/22	46.07	99.28	67.6	58.59	109.45	92.21	185.6	58.95
Jul/22	63.49	90.75	80.6	87.32	111.27	104.06	46.5	59.95
Aug/22	55.95	91.49	62.64	121.67	104.28	85.13	48.81	59.72
Sep/22	58.88	87.82	70.33	58.95	81.11	98.31	105.19	53.29
Oct/22	130.65	77.2	59.27	83.76	87.36	79.98	102.13	71.26
Nov/22	111.31	87.82	119.13	56.54	82.42	88.16	110.21	52.07
Dec/22	85.55	69.08	81.59	84.79	87.91	65.91	116.62	54.65

Energy Bill month	Customer ID / Customer account							
	18360	18362	18181	60318	84614	60320	84613	18350
	Energy (kWh)							
Jan/22	578.57	482.14	464.29	461.61	579.46	524	578	536.21
Feb/22	480	462.14	580	562.5	441.07	479	579	4162.3
Mar/22	569.64	551.79	469.64	473.21	437.5	573	437	620.34
Apr/22	559.29	476.79	578.57	464.29	446.43	482	446	551.11

May/22	564.29	580.36	580.36	563.21	440.36	576	440	649.17
Jun/22	479.46	481.25	463.39	580	424.64	478	562	540.02
Jul/22	476.79	464.29	455.36	579.46	428.57	446	564	436.21
Aug/22	465.18	474.11	579.46	573.71	405.36	580	482	562.3
Sep/22	567.5	539.29	557.14	575	574	552	570	420.34
Oct/22	542.86	460.71	578.57	564.29	507.14	4157	475	651.11
Nov/22	463.21	481.07	5180	563.21	542.86	441	554	449.17
Dec/22	496.43	460.71	479.46	478.57	478.57	475	580	440.02
Energy Bill month	Customer ID							
	301	632	325	310	305	628	640	302
	Energy (kWh)							
Jan/22	359.82	460	339	414.81	451.05	310.97	420.47	427.91
Feb/22	408.93	462	452	383.69	401.42	434	435.5	406.03
Mar/22	401.79	320	348	410.75	3130.5	417.28	430.62	442.73
Apr/22	446.43	464	329	329.81	450.15	421	431.81	431.83
May/22	340.36	340	358	302.49	460.98	400.97	434.09	435.24
Jun/22	424.64	445	345	464	323.67	404.84	413	447.1
Jul/22	328.57	329	439	323.34	443.82	404.98	424.67	458.5
Aug/22	405.36	348	352	443.65	432.29	432.38	419.63	444.39
Sep/22	351.79	370	448	432.26	457.52	412.16	446.07	499.76
Oct/22	439.29	439	334	421.19	440.95	415.68	459.27	408.49
Nov/22	351.79	354	348	411.53	317.08	400.03	429.91	422.4
Dec/22	348.21	339	408.93	423.65	327.01	427.17	420.47	425.39