Building Energy Simulation for Operational Life-cycle Efficiency: A Case of Commercial Buildings in Addis Ababa

Dagim Bitew Wordofa

A Thesis Submitted to the Department of Civil Engineering,

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Civil Engineering (Specialization in Construction Engineering and Management)

Office of Graduate Studies

Adama Science and Technology University

February 2024

Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled "**Building Energy Simulation for Operational Life-cycle Efficiency: A Case of Commercial Buildings in Addis Ababa**" is my original work. That is, it has not been submitted for an 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.

Dagim Bitew Wordofa	__________________	__________________
Name of student	Signature	Date

RECOMMENDATION OF ADVISOR

I, the advisor of this thesis, hereby certify that I have closely advised the student while developing this final thesis and read the draft thesis entitled "**Building Energy Simulation for Operational Life-cycle Efficiency: A Case of Commercial Buildings in Addis Ababa**" prepared under my guidance by Dagim Bitew Wordofa.

Therefore, I recommend the submission of the thesis to the department for further review and evaluation.

Bahiru Bewket (PhD)	________________	________________
Advisor	Signature	Date

APPROVAL

I hereby certify that the recommendation and suggestion given by the thesis review committee are appropriately incorporated into the final thesis entitled "**Building Energy Simulation for Operational Life-cycle Efficiency: A Case of Commercial Buildings in Addis Ababa**" by Dagim Bitew.

Bahiru Bewket (PhD)	__________________	__________________
Advisor	Signature	Date

APPROVAL OF BOARD OF REVIEWERS

We, the undersigned, members of the board of reviewers of the final thesis open defense by Dagim Bitew have read and evaluated the thesis entitled "**Building Energy Simulation for Operational Life-cycle Efficiency: A Case of Commercial Buildings in Addis Ababa**" and assessed the understanding of the candidate about the research. This is, therefore, to certify that the thesis is accepted and we recommend the implementation of the final thesis.

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LIST OF ACRONYMS

AI	Artificial Intelligence
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BES	Building Energy Simulation
BIM	Building Information Modeling
BREEAM	Building Research Establishment Environmental Assessment Method
CAD	Computer-Aided Design
DDY	Data-Driven Yield
DGC	Distributed Generation and Control
DOE	Department of Energy
DR	Demand Response
DV	Design Verification
EA	Environmental Assessment
EEA	Ethiopian Energy Authority
EEP	Ethiopian Electric Power
EEPFE	Energy Efficiency and Pollution Prevention for Enterprises
EG	Environmental Graphics
ELC	Environmental Law Center
ELEC	Electromagnetic Compatibility
EMS	Environmental Management System
EPW	EnergyPlus Weather
GDP	Gross Domestic Product
EUI	Energy Use Intensity
GERD	Grand Ethiopian Renaissance Dam
GHG	Greenhouse Gas: Gases
GJ	Gigajoule
GW	Gigawatt
HID	High-Intensity Discharge
HKIE	Hong Kong Institution of Engineers
HPC	High-Performance Computing
HQ	Headquarters
HSPF	Heating Seasonal Performance Factor
HTML	Hypertext Markup Language
HVAC	Heating, Ventilation, and Air Conditioning
IEA	International Energy Agency
IES	Illuminating Engineering Society

II	Infrastructure Investment
LEAP	Long-range Energy Alternatives Planning
LED	Light Emitting Diode
LEED	Leadership in Energy and Environmental Design
LPG	Liquified Petroleum Gas
MDF	Medium-Density Fiberboard
MJ	Megajoule
MoUDC	Ethiopian Ministry of Urban Development and Construction
MW	Megawatt
NASA	National Aeronautics and Space Administration
NREL	National Renewable Energy Laboratory
OSM	OpenStudio Model

ABSTRACT

Ethiopia, with a population exceeding 110 million, strives to boost energy production despite financial constraints. Challenges include reliance on traditional biomass, outdated infrastructure, and limited access to modern energy, urging investments in renewables. This thesis identifies reliance on traditional biomass, outdated infrastructure, and limited access to modern energy as key hurdles, necessitating investments in renewables. Energy-efficient solutions, particularly using simulation tools in construction and operational phases, offer promise in tackling energy demands, environmental issues, and fostering sustainable development in Ethiopia. The research aims to enhance operational efficiency in energy consumption within a chosen commercial building in Addis Ababa by analyzing energy usage patterns, developing detailed energy simulation models, proposing theoretical frameworks, and suggesting strategies for energy efficiency. It provides essential insights and sustainability strategies leveraging Building Energy Simulations (BES) for policymakers, building owners, and energy managers, aiming to reduce energy use, conserve resources, mitigate greenhouse gas emissions, and transform Ethiopian building practices. The study acknowledges challenges such as data limitations and constraints in on-site data collection but intends to offer valuable insights into building energy efficiency through its structured approach. The literature review examines Ethiopia's escalating energy consumption driven by economic growth and urbanization, spotlighting challenges in infrastructure, low electrification rates, and reliance on traditional biomass sources. The study emphasizes the energy demand from the construction industry and addresses inefficiencies in building materials, Heating Ventilation and Air Conditioning systems, and lighting. It underscores the implications of inefficient materials on energy consumption, advocating for building codes, awareness, and retrofitting projects to improve energy efficiency. The review delves into insulation's importance, Heating Ventilation and Air Conditioning inefficiencies, and the substantial impacts of high energy use on the environment, economy, and public health. It highlights strategies like insulation improvement, Heating Ventilation and Air Conditioning upgrades, and the urgency to reduce energy consumption in buildings through enhanced energy efficiency measures. The text also underscores the multifaceted implications of high energy consumption, advocating for comprehensive solutions like renewable energy integration, clean energy access, and stakeholder collaboration. Additionally, it addresses challenges in building energy simulations, focusing on accuracy, data reliability, modeling *complexities, and calibration issues, emphasizing the need for refining accuracy, enhancing data reliability, and advancing modeling techniques through stakeholder collaboration. Focusing on a high-rise commercial building, specifically the Wegagen Bank Headquarters in Addis Ababa, the study aims to showcase current energy efficiency practices, explore potential conservation measures, and simulate the building's energy consumption. With a total floor area of 1,800 square meters, 23 stories, and completion in January 2017, the headquarters include indoor spaces like offices, shops, and restaurants, as well as outdoor spaces such as terraces and balconies. The analysis intends to identify energy consumption patterns, assess energy efficiency measures, and provide real-world solutions to enhance energy conservation in commercial buildings like this high-rise headquarters. Through rigorous simulation with OpenStudio software, the study unravels crucial insights into energy consumption patterns and the impact of potential energy-efficient measures. The main simulation results underscore the considerable potential for energy savings, particularly in the optimization of Heating Ventilation and Air Conditioning systems and lighting, while also shedding light on the significance of occupant behavior in achieving energy efficiency goals. The research identifies heating, cooling, lighting, and equipment as primary contributors to energy consumption. Proposed strategies involve insulation improvements, efficient Heating Ventilation and Air Conditioning systems, advanced lighting controls, and renewable energy exploration. Notably, creating a comprehensive building energy simulation model provides insights for future energy-saving efforts. Recommendations target stakeholders: governments for database establishment and standards, building owners for audits and technology adoption, academia for research collaboration, international organizations for financial aid, and the public for awareness campaigns and advocacy. The conclusion emphasizes informed decisions among stakeholders to reduce energy consumption, cut costs, and foster sustainability in Ethiopia's built environment through collaborative sustainable practices and energy conservation.*

Keywords *- Operational efficiency, OpenStudio, Case study, energy efficient measures*

CHAPTER ONE

INTRODUCTION

1.1 Background

Ethiopia is a country in East Africa that has a population of over 110 million people. The country is known for its rich cultural heritage and diverse natural resources. In recent years, Ethiopia has been working to increase its energy producing capacity to meet the growing demand for electricity. According to the World Bank, Ethiopia has an installed capacity of 4,300 MW of electricity, and it has the potential to generate up to 60,000 MW from hydroelectric, wind, geothermal, and solar power sources.

However, despite this significant potential, Ethiopia still faces several challenges in its efforts to increase its energy producing capacity. One of the primary challenges is the country's limited financial resources. The cost of building new energy infrastructure, such as dams and power plants, is often prohibitively high for a country with Ethiopia's income level. Therefore, It heavily relies on traditional biomass energy due to limited access to modern energy sources to meet the growing demand for energy. The country's energy sector is characterized by low electricity access, high dependence on hydro-power, and limited use of renewable energy sources (Mekonnen, Gerbens-Leenes, & Hoekstra, 2018). Long-term energy demand forecasting is crucial in guiding the country's plans to expand the energy supply system. In this regard, the Long-range Energy Alternative Planning (LEAP) model was used to provide a general overview of Ethiopia's current energy demand and to forecast sector-wise energy demand out to 2030 for alternative policy scenarios (Mondal et al., 2018). The reference scenario, which assumes a continuation of recent energy consumption trends, accounts for the current energy and economic dynamics of Ethiopia. Three alternative scenarios, namely improved cook stoves, efficient lighting, and universal electrification, were modeled as key priorities of the Ethiopian government. The results from the model suggest that alternative investments can conserve energy, improve environmental sustainability, enhance energy equity, and improve the country's development indicators. Additionally, the country's reliance on hydro-power has been affected by recurrent droughts, which have led to a decline in water levels in reservoirs and power outages

Furthermore, Ethiopia has struggled to develop its energy grid to efficiently distribute electricity across the country. The country's energy infrastructure is outdated, and the lack of investment in modernizing the grid has led to losses in electricity transmission and distribution. This has resulted in power shortages in rural areas, where the majority of Ethiopians live.

One of the challenges Ethiopia faces is the low access to modern energy sources, which limits its ability to meet the growing demand for energy. This has led to a high dependence on traditional biomass energy sources, which contribute to deforestation, land degradation, and air pollution. Therefore, investing in alternative energy sources, such as solar and wind, can help address the energy demand while reducing the environmental impact of traditional biomass sources. Moreover, the implementation of the modeled alternative scenarios would require significant investments in infrastructure and technology, which can also contribute to economic development in Ethiopia (Mekonnen, Gerbens-Leenes, & Hoekstra, 2018; Mondal et al., 2018). Improved energy efficiency in cooking and lighting can also result in health benefits by reducing indoor air pollution and improving overall indoor air quality (World Health Organization, 2018).

On average, commercial buildings in Addis Ababa consume higher energy than the global average consumption (Assefa, Tadesse, & Tadesse, 2020). The study further showed that the energy consumption of commercial buildings in Addis Ababa is increasing by 10% annually, highlighting the urgent need for energy-efficient solutions. Despite these facts, the main problem regarding Ethiopian buildings' energy consumption is the lack of efficient building design and construction, as well as the use of outdated and inefficient equipment and appliances. To address these challenges, the Ethiopian government has launched several initiatives to increase its energy producing capacity. One such initiative is the Ethiopia Electrification Program, which aims to provide access to electricity to 65% of the population by 2025. Additionally, the country has launched the Grand Ethiopian Renaissance Dam project, which, when completed, will be the largest hydroelectric power plant in Africa and is expected to generate up to 6,000 MW of electricity.

To enhance energy consumption practices in Ethiopian buildings, the utilization of simulation tools emerges as a pivotal approach that can yield significant benefits both in the pre-construction phase and during operational periods. These tools offer a multifaceted advantage by providing insights into energy efficiency even before a building's construction commences. By simulating different design scenarios, architects and engineers can make informed decisions about materials, insulation, HVAC systems, and lighting, thus optimizing the building's energy performance from its very inception. Moreover, simulation tools continue to prove invaluable during the operational life of a building. They enable facility managers to monitor and fine-tune energy usage, identify inefficiencies, and implement real-time adjustments to reduce consumption and associated costs. In a country like Ethiopia, where the demand for sustainable and energy-efficient infrastructure is rapidly growing, the strategic integration of simulation tools throughout a building's lifecycle stands as a proactive and cost-effective measure to address energy challenges and contribute to a more sustainable built environment.

1.2. Statement of the Problem

According to the Ethiopian Energy Report of 2018, the country's energy demand is growing at an average rate of 10% per year, while the supply capacity is only increasing at a rate of 5% per year. This energy deficit can be partially attributed to the inefficient energy consumption of buildings, which highlights the need for further research and intervention.

According to Ethiopian Energy Reports, the country is losing a significant amount of energy resources due to the unmeasured energy consumption trend in commercial buildings. This is a major issue as it leads to energy waste, increased reliance on traditional biomass energy sources, and higher greenhouse gas emissions. Therefore, there is an urgent need for a comprehensive study to understand the extent of this problem and its implications for the country's sustainable development. Buildings in Ethiopia are consuming a significant amount of energy, contributing to the country's growing energy demand. Buildings are the largest consumers of electricity, accounting for 29% of the total electricity consumption in the country. This high consumption is due to several factors, including the use of inefficient building materials, lack of insulation, and outdated HVAC systems (Ministry of Water, Irrigation and Electricity, 2019).

The high energy consumption trends in commercial buildings in Addis Ababa are a growing concern due to their negative impact on the environment, energy resources, and economic development. To address this challenge, it is essential to promote energy-efficient building practices and the use of building energy simulations. These measures can help reduce energy consumption, costs, and greenhouse gas emissions while improving the indoor environmental quality of buildings. Despite the recent efforts to improve energy efficiency and reduce greenhouse gas emissions, commercial buildings in Addis Ababa continue to consume significant amounts of energy. This problem needs to be studied through intensive scientific researches supported with new and emerging technologies such as Building Energy Simulations to identify the factors contributing to high energy consumption and develop effective strategies for reducing energy use and greenhouse gas emissions. This research aims to identify the factors contributing to high energy consumption, estimate the energy loss and greenhouse gas emissions resulting from this trend, and develop effective strategies for energy efficiency of the selected case study building. With this approach, we can reduce its energy consumption, save energy resources, and in a wider context, contribute to global efforts to mitigate climate change.

1.3 Objectives

The following are the objectives of this thesis work:

1.3.1 General objective

The general objective of this research is to study Building Energy Analysis through Simulations for operational efficiency of energy consumption on a selected commercial building in Addis Ababa.

1.3.2 Specific objectives

The specific objectives of the research includes;

i. To identify the energy consumption patterns and key energy-consuming systems of a selected commercial building in Addis Ababa.

ii. To develop a detailed building energy simulation model and evaluate the operational efficiency that can be used to formulate energy-efficient measures for the selected commercial building using appropriate software tools.

iii. To develop energy-efficient measures through theoretical framework that can be implemented in the selected commercial building to reduce energy consumption and enhance operational efficiency.

1.4 Research questions

i. What are the specific energy consumption patterns within a chosen commercial building in Addis Ababa, and which systems contribute most significantly to energy usage?

ii. How can a comprehensive building energy simulation model be constructed using suitable software tools to assess the operational efficiency of the selected commercial building, and what are the outcomes regarding energy efficiency measures?

iii. What theoretical framework can be employed to propose and outline energy-efficient strategies applicable to the selected commercial building in order to decrease energy consumption and improve operational efficiency?

1.5 Significance of the research

This research significantly benefits key stakeholders like policymakers, building owners, and energy managers in Ethiopia by offering insights into high-energy consumption patterns and proposing effective strategies for sustainability. Utilizing Building Energy Simulations (BES) enables informed decisions, leading to reduced energy use, resource conservation, and greenhouse gas emission mitigation. Specifically targeting inefficiencies in commercial building energy consumption, this study, employing BES, aims to bridge the gap between theoretical design and practical efficiency, providing solutions for energy-efficient building strategies in Addis Ababa. This approach aids in quantifying wasted energy, informing policy creation, and guiding guidelines for enhanced energy efficiency. Furthermore, the research contributes globally to climate change mitigation efforts, showcasing BES's potential in significantly reducing energy consumption, promoting sustainable practices, and fostering a greener future for Ethiopia. Overall, this study's integration of simulation tools, particularly BES, holds the promise of transforming Ethiopian building practices to align with energy standards, optimize operational efficiency, and facilitate informed decision-making for a sustainable built environment.

1.6 Scope of the study

The foundation of this study revolves around a single high-rise commercial building, selected as a representative case study. The study's methodology primarily involves building energy simulation, a process conducted exclusively on this particular building. It is essential to note that no additional fieldwork or laboratory testing was undertaken during the research endeavor. Instead, all pertinent data and information sources were drawn from three key channels: the consultant design office, the building's owner, and extensive literature sources.

The primary objective of this research centers on the investigation of energy consumption patterns within the context of commercial buildings in Ethiopia. Specifically, the study is designed to enhance our understanding of building energy efficiency. The geographical focus of the research is predominantly centered on the vibrant and dynamic Addis Ababa region. While this geographical constraint is acknowledged, it is important to recognize that Addis Ababa serves as a microcosm of Ethiopia's broader urban energy dynamics, making it an ideal focal point for the research.

1.7 Limitation of the study

The study encounters several limitations that need to be acknowledged. Foremost among these limitations is the challenge of data availability and quality. The research heavily relies on existing literature, government reports, and publicly accessible data due to the absence of comprehensive and up-to-date datasets on building energy consumption in Ethiopia. This limitation may introduce uncertainties and affect the representativeness of the study's findings.

Another key limitation is the absence of fieldwork or on-site data collection. This constraint restricts the study's ability to capture real-time data on building energy usage, occupant behavior, and other factors influencing energy efficiency. Moreover, the study primarily focuses on static analysis of building energy efficiency, emphasizing energy consumption patterns and potential energy-saving measures while excluding dynamic analyses, such as the impact of vibration and seismic loads. Resource constraints, such as limited time and funding, also influence the study's depth and breadth, as extensive energy audits or fieldwork were not feasible within available resources. These limitations, combined with a specific focus on Addis Ababa and a selection of building types, may restrict the generalizability of findings to other regions and building categories within Ethiopia. Nonetheless, the study aims to provide valuable insights into building energy efficiency, offering recommendations within the context of these limitations.

1.8 Organization of the study

The study was organized mainly into five chapters. The first chapter introduces the background, the statement of the problem, the objectives, the significance and scope of the study. The second chapter was based on a literature review that stated the study's matter. This section covers reviews on the concept of Building energy consumption and efficiency; advanced technologies related with building energy efficiency; building energy simulation, strategies for building energy efficiency; and research gaps were covered. The methodology for the study is presented in the third chapter, which includes description of the case study area and design along with a step by step simulation procedure. The fourth chapter mainly focused on the presentation, analysis, and interpretation of results of the study. In addition to that a brief theoretical framework is presented on this chapter. The final chapter puts forward the conclusion of the study and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Energy Consumption in Buildings

2.1.1 Energy Consumption Trends in Ethiopia

Ethiopia, a developing country located in the Horn of Africa, is experiencing a rapid increase in energy consumption, driven largely by economic growth and urbanization. According to the International Energy Agency (IEA), the total final energy consumption in Ethiopia increased from 3.3 million tons of oil equivalent (Mtoe) in 2000 to 7.6 Mtoe in 2018, at an average annual growth rate of 5.1%. The majority of this energy consumption is attributed to the residential and commercial sectors, which accounted for 71% of the total energy consumption in 2018 (International Energy Agency, 2020).

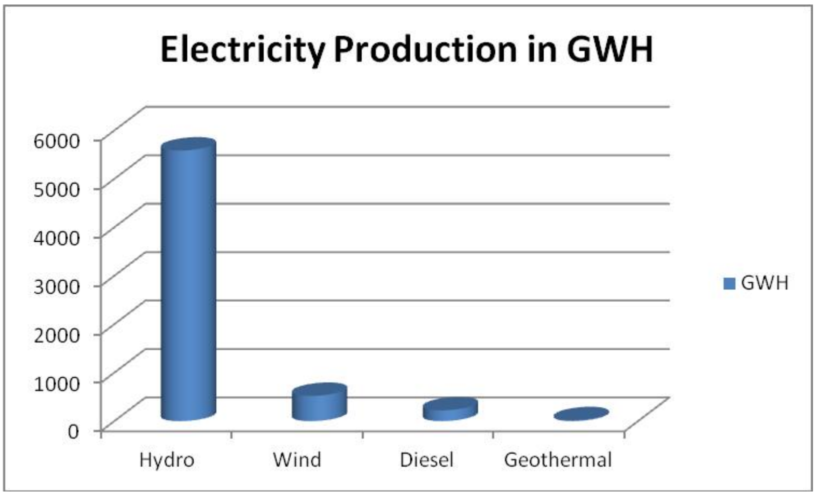


Figure 1: Energy Generation by different energy sources

(Ethiopian Energy Authority, 2019)

It is indicated that 45,000 MW (89%) (Ethiopian Energy Authority, 2019) of power can be generated from hydroelectric power, 10,000 MW (8.6%) from wind energy sources and around 5,000 MW from geothermal energy (Ethiopian Energy Authority, 2019; Gebreegziabher & Mekonnen, 2011; Dalelo, 2002).

According to data from the World Bank (World Bank, 2021), Ethiopia's electricity consumption per capita was 127.6 kWh in 2019. As shown in figure 2 and figure 3, it is significantly lower than the global average of 3,157 kWh per capita in the same year (International Energy Agency, 2020). It is one of the least electrified countries in the world, with only about 45% of the population having access to electricity (World Bank, 2021). The government of Ethiopia has set a goal of achieving universal access to electricity by 2025 (Government of Ethiopia, 2018).

One of the main reasons for the low level of electricity consumption in Ethiopia is the limited availability of electricity infrastructure, particularly in rural areas. The majority of the country's electricity is generated from hydropower, but there are also plans to expand other sources such as wind and geothermal energy. Despite the low level of electricity consumption, Ethiopia has been investing heavily in its energy sector in recent years. The country has embarked on a number of large-scale energy projects, including the Grand Ethiopian Renaissance Dam, which is expected to be the largest hydroelectric power plant in Africa when completed (Ethiopian Electric Power, 2020; Grand Ethiopian Renaissance Dam Project, 2021).

The construction industry in Ethiopia is a critical sector of the economy, contributing approximately 10% of the country's GDP. However, the construction industry is also one of the largest consumers of energy in the country, accounting for up to 30% of the total energy consumption. One of the primary reasons for the high energy consumption of the construction industry is the use of inefficient building materials and technologies. The majority of buildings in Ethiopia are constructed using traditional materials such as mud, wood, and straw. These materials have poor insulation properties and require significant amounts of energy for heating and cooling. Additionally, the use of outdated building technologies and practices, such as poorly designed ventilation systems and inefficient lighting systems, further contributes to the high energy consumption of the construction industry.

There are several prospective directions that Ethiopia is taking towards energy and buildings. One such direction is the adoption of renewable energy sources such as solar, wind, and geothermal power. Ethiopia has significant potential for these energy sources, and the government is investing in projects to harness them. Additionally, the government is promoting the use of energy-efficient building technologies and practices to reduce the energy consumption of buildings. Another prospective direction is the implementation of smart building technologies. Smart building technologies use sensors and automation to optimize energy use in buildings. These technologies can help reduce energy consumption by automatically adjusting lighting, heating, and cooling systems based on occupancy and weather conditions.

One of the challenges Ethiopia faces is the low access to modern energy sources, which limits its ability to meet the growing demand for energy. This has led to a high dependence on traditional biomass energy sources, which contribute to deforestation, land degradation, and air pollution.. Ethiopia has one of the lowest rates of access to modern energy services and its energy supply is primarily based on biomass. With a share of 87% of Ethiopia's energy supply, waste and biomass are the country's primary energy sources, followed by Fuel (10.4%) and hydro-power (2.6%) (Mekonnen, Gerbens-Leenes, & Hoekstra, 2018; Ethiopian Energy Authority, 2019). Therefore, investing in alternative energy sources, such as solar and wind, can help address the energy demand while reducing the environmental impact of traditional biomass sources. Moreover, the implementation of the modeled alternative scenarios would require significant investments in infrastructure and technology, which can also contribute to economic development in Ethiopia (Mondal et al., 2018). Improved energy efficiency in cooking and lighting can also result in health benefits by reducing indoor air pollution and improving overall indoor air quality (World Health Organization, 2018)

In conclusion, the Ethiopian energy sector heavily relies on traditional biomass sources due to limited access to modern energy sources. However, the implementation of alternative policy scenarios such as improved cookstoves, efficient lighting, and universal electrification can help conserve energy, improve environmental sustainability, enhance energy equity, and improve the country's development indicators. Significant investments in infrastructure and technology are required to achieve these alternative scenarios, which can also contribute to economic development in Ethiopia.

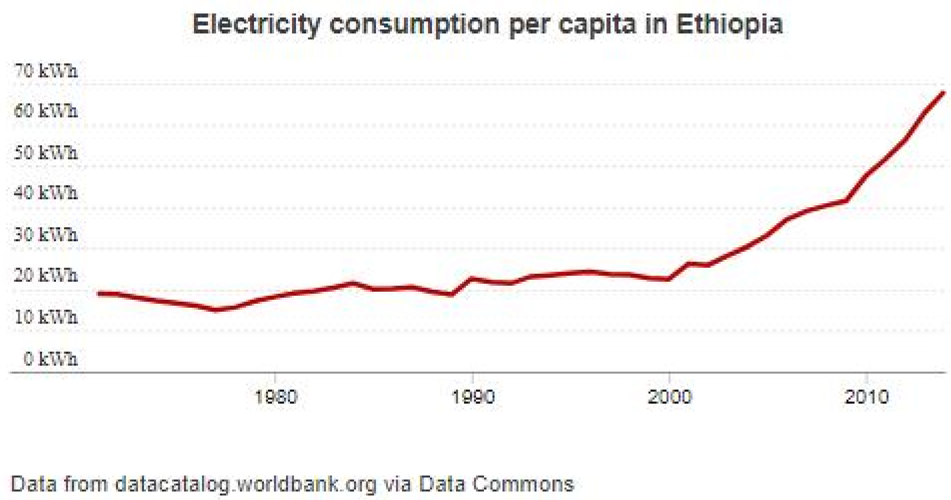


Figure 2: Electricity consumption per capita in Ethiopia

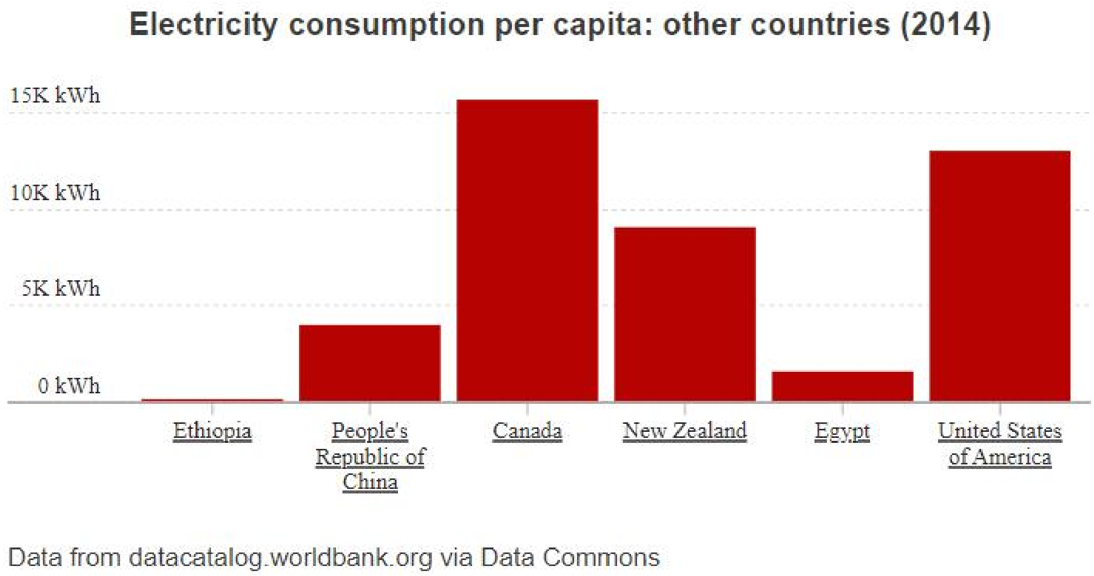


Figure 3: Electricity consumption per capita: other countries

On average, commercial buildings in Addis Ababa consume 200-300 kWh/m2/year, which is significantly higher than the global average of 50-100 kWh/m2/year (Assefa, Tadesse, & Tadesse, 2020). The study further showed that the energy consumption of commercial buildings in Addis Ababa is increasing by 10% annually, highlighting the urgent need for energy-efficient solutions. The average energy consumption of residential buildings is 166.3 kWh/month, with lighting, cooking, and space heating being the primary energy end-uses. And the use of energy-efficient appliances, such as LED lighting and induction cooktops, can significantly reduce energy consumption in residential buildings. The high energy consumption of buildings in Ethiopia not only contributes to the country's growing energy demand but also has economic and environmental implications. The energy sector in Ethiopia is heavily reliant on hydro-power, which is vulnerable to climate variability and hydrological shocks. Additionally, inefficient energy consumption leads to increased greenhouse gas emissions and air pollution, which have adverse effects on human health and the environment (World Bank, 2019).

Before construction, simulation tools can be used to model and analyze various building designs and systems, allowing for the identification of the most energy-efficient options. This includes assessing the building orientation, insulation, ventilation, and lighting systems. Simulation tools can also be used to optimize the sizing and selection of building equipment, such as HVAC systems and lighting fixtures. During operation periods, simulation tools can be used to monitor and optimize building performance. This involves analyzing real-time data on building energy consumption, identifying areas where energy use can be reduced, and providing recommendations for improvements. This includes optimizing building automation systems, scheduling and controlling building equipment, and identifying and addressing issues with building envelope, ventilation, and lighting systems.

The building sector is a significant contributor to energy consumption in Ethiopia. According to a study conducted by the Ethiopian Ministry of Water, Irrigation and Energy (MoWIE) in 2017, buildings accounted for approximately 25% of the total energy consumption in the country (Ministry of Water, Irrigation and Energy, 2018). This trend is expected to continue in the future, as the demand for buildings and urban infrastructure continues to grow. One of the main factors driving the growth in energy consumption in buildings is the increasing use of modern appliances and technologies, such as air conditioning, refrigeration, and lighting. These appliances require a significant amount of electricity, and their widespread use in buildings has led to a surge in energy consumption. Another factor is the lack of energy-efficient building design and construction practices, which leads to energy waste and unnecessary consumption.

Commercial buildings in Addis Ababa, the capital city of Ethiopia, consume a significant amount of energy. The commercial sector in Ethiopia consumes approximately 23% of the total energy used in the country, with the majority being used for lighting, heating, and cooling (Kibret, 2016). The study also found that the energy consumption in commercial buildings in Addis Ababa is increasing at a rate of 6.7% per year, and this trend is expected to continue in the coming years. Similarly, the energy consumption in commercial buildings in Ethiopia has increased by more than 8% annually in the past decade (International Energy Agency, 2020). The report notes that this is largely due to the construction of new commercial buildings, which are often built using traditional construction methods and materials that do not prioritize energy efficiency. The energy consumption in commercial buildings in Addis Ababa is significantly higher than in other African cities, such as Nairobi and Kampala. Few studies attribute this to the lack of energy-efficient building design and technologies, inadequate regulations and standards, and low awareness of energy-efficient practices among building owners and occupants.

Inefficient lighting, lack of insulation, and outdated HVAC systems were among the primary factors contributing to high energy consumption in commercial buildings in Ethiopia (Tassie & Wolde, 2016). The study recommends the adoption of energy-efficient lighting systems, insulation materials, and modern HVAC systems to reduce energy consumption and improve energy efficiency in commercial buildings. Energy audits and retrofitting of existing commercial buildings should also be emphasized to improve energy efficiency and reduce energy consumption. Building codes and regulations should also be updated and enforced to ensure that new commercial buildings are designed and constructed with energy efficiency in mind (Ethiopian Energy Authority, 2019).

Overall, these studies and reports indicate that commercial buildings in Addis Ababa consume a significant amount of energy, and the energy consumption is increasing at an alarming rate. The primary factors contributing to high energy consumption include inefficient building design, lack of energy-efficient technologies, inadequate regulations and standards, and low awareness of energy-efficient practices among building owners and occupants. To address these issues, the adoption of energy-efficient technologies, updating building codes and regulations, conducting energy audits, and retrofitting existing buildings are crucial steps towards improving energy efficiency and reducing energy consumption in commercial buildings in Addis Ababa.

To address the issue of high energy consumption in buildings, the Ethiopian government has implemented various policies and initiatives aimed at promoting energy efficiency. For example, the government has developed the Ethiopian Building Code, which includes provisions for energy-efficient building design and construction practices. Additionally, the government has established the Ethiopian Energy Authority (EEA) to regulate and promote energy efficiency in the country. However, despite these efforts, the implementation and enforcement of energy-efficient building practices in Ethiopia remain a challenge.

Energy consumption in buildings is a crucial component of the overall energy demand in any country. In Ethiopia, the building sector accounts for a significant proportion of energy consumption, and this trend is expected to continue with the rapid urbanization and increasing demand for modern amenities. The energy consumption in buildings in Ethiopia has been increasing at a rate of 7% per year over the past decade (International Energy Agency, 2017). This trend is expected to continue due to the rapid growth of the construction industry and the increasing demand for energy-consuming appliances. One of the main reasons for the high energy consumption in buildings is the inefficient building design and construction practices in Ethiopia. Buildings are often constructed using traditional building materials, such as mud and wood, which have poor insulation properties and are not suited to the local climate. As a result, buildings require more energy to maintain comfortable indoor temperatures. Moreover, many buildings in Ethiopia lack insulation, which further increases their energy demand.

Another factor contributing to high energy consumption in buildings is the use of outdated heating, ventilation, and air conditioning (HVAC) systems. Many buildings still use inefficient HVAC systems that consume a significant amount of energy. These systems often lack proper maintenance and control systems, which further exacerbates their energy inefficiency. In addition, many buildings use inefficient lighting systems, such as incandescent bulbs, which consume a lot of energy and produce a lot of heat.

The implications of high energy consumption in buildings are numerous, ranging from energy waste to environmental degradation. Energy waste occurs when buildings consume more energy than necessary, leading to higher energy bills and reduced affordability for consumers. Additionally, the high demand for energy in buildings leads to increased reliance on traditional biomass energy sources, such as wood and charcoal, which have negative health and environmental impacts. Finally, high energy consumption in buildings contributes to higher greenhouse gas emissions, which contribute to climate change and other environmental problems. Additionally, the increasing population growth and urbanization in Ethiopia have also contributed to the rising energy demand in buildings. According to the United Nations, Ethiopia's urban population is expected to double by 2037, and this will undoubtedly lead to an increase in energy consumption in buildings (UN-Habitat, 2014). Furthermore, rapid economic development and the growing middle class in Ethiopia have led to an increase in the number of households and commercial buildings, resulting in higher energy consumption. The construction of new buildings using traditional construction methods and materials has also contributed to the increase in energy consumption. These buildings are often poorly designed, lack proper insulation and ventilation, and use outdated equipment and appliances, leading to high energy consumption (Tassie & Wolde, 2016).

In conclusion, energy consumption in buildings is a critical issue in Ethiopia, and there is a need for urgent action to address this challenge. Improving building design and construction practices, promoting the use of efficient HVAC systems, and enhancing energy efficiency in lighting systems are essential steps towards reducing energy consumption in buildings. Furthermore, promoting the use of renewable energy sources and promoting energy conservation practices can help reduce reliance on traditional biomass energy sources and reduce greenhouse gas emissions.

2.1.2 Factors Contributing to High Energy Consumption in Buildings

Buildings consume a significant amount of energy worldwide, and their energy consumption is expected to continue to increase in the coming years (Alazazmeh & Asif, 2021). Factors contributing to high energy consumption in buildings include inefficient building materials, lack of insulation, and outdated HVAC systems (Buonocore et al., 2022; Hong, Deng, & Ezeh, 2019). Inefficient building materials, such as inefficient windows and glazing, can result in high heat gain or loss, leading to increased energy consumption for heating and cooling (Pérez-Lombard, Ortiz, & Pout, 2008). Similarly, inadequate insulation in walls, floors, roofs, and around doors and windows can result in heat loss during the winter and heat gain during the summer, leading to increased energy consumption for heating and cooling (Buonocore et al., 2022). Outdated HVAC systems can also contribute significantly to high energy consumption in buildings, as they often lack energy-efficient features and require frequent maintenance (Li & Lam, 2001).

To address the issue of high energy consumption in buildings, it is essential to identify and evaluate the factors contributing to it. This literature review aims to explore and analyze the existing research on the factors contributing to high energy consumption in buildings, specifically focusing on inefficient building materials, lack of insulation, and outdated HVAC systems. By synthesizing the findings of previous studies, this review will identify the gaps in the current research and provide recommendations for future research directions.

2.1.2.1 Inefficient Building Materials

Inefficient building materials are a major contributor to high energy consumption in buildings. The use of such materials can result in the building being less efficient in retaining heat or cooling, leading to increased energy usage. The importance of energy-efficient buildings is being recognized globally due to the increasing demand for energy and the growing concern over climate change. Many studies have focused on the importance of energy-efficient buildings and the factors contributing to high energy consumption. This literature review will examine the research on inefficient building materials and their impact on energy consumption in buildings.

The use of inefficient building materials is a significant factor contributing to high energy consumption in buildings (Eze et al., 2020). Building materials, such as glass, can result in high heat gain or loss, depending on the climate and orientation of the building. Inefficient windows and glazing can also cause significant heat loss in cold climates and heat gain in hot climates, leading to increased energy consumption for heating and cooling (Buonocore et al., 2022). The impact of inefficient insulation materials and techniques cannot be overemphasized. Inadequate insulation in walls, floors, roofs, and around doors and windows can result in heat loss during the winter and heat gain during the summer, leading to increased energy consumption for heating and cooling. This problem is exacerbated in buildings with poorly constructed or designed envelopes (Yik & Lee, 2002). The problem of inadequate insulation in buildings is often compounded by inadequate ventilation and air leaks around windows and doors, leading to further energy losses (Li & Lam, 2001).

The inefficient use of building materials can also be linked to poor materials management practices by construction Small and medium size enterprises in developing countries like Nigeria. The lack of awareness about the benefits of using energy-efficient materials and the low availability of such materials often lead to the use of inefficient building materials in construction projects. Additionally, construction Small and medium size enterprises in Nigeria often use inefficient building materials due to their cost and availability. They often use low-quality materials or substandard substitutes, resulting in poor thermal insulation and a lack of energy efficiency in buildings. Inefficient building materials not only increase energy consumption but also contribute to environmental degradation. The production and transportation of these materials lead to high levels of greenhouse gas emissions, contributing to global warming and climate change.

Inefficient building electrification can lead to a massive build out of renewable energy and seasonal energy storage to offset the energy consumption of buildings (Eze et al., 2020; Buonocore et al., 2022).

Therefore, it is essential to promote the use of efficient building materials in construction projects. This can be achieved through the implementation of building codes and standards that require the use of energy-efficient materials and techniques. Additionally, awareness-raising campaigns and education programs can be implemented to educate builders, contractors, and homeowners about the benefits of using energy-efficient building materials.

Few researchers conducted a study on commercial building retrofitting and assessed the improvements in energy performance and indoor air quality. They found that inefficient building materials were a major barrier to energy efficiency and suggested that retrofitting with more efficient materials could lead to significant energy savings (Alazazmeh & Asif, 2021). Also strategies for minimizing building energy performance gaps between the design and the actual performance have been studied. The use of inefficient building materials was a common cause of energy performance gaps and recommended improving material selection and installation practices (Zou, Wagle, & Alam, 2019). In the retrofitting of low-rise offices in Shanghai and Sri Lanka, it has been found that the use of inefficient building materials was a significant reason to high energy consumption and a barrier in achieving sustainable and green buildings. And the use of more energy-efficient materials is recommended to reduce energy consumption (Hong, Deng, & Ezeh, 2019; Alahakoon, Silva, & Kulatunga, 2022). Educating construction Small and medium size enterprises on the importance of using energy-efficient materials is also recommended in order to avoid the aforementioned problem (Eze et al., 2020).

We should also consider low-energy building materials and their potential benefits in reducing energy consumption with more emphasis given to the need to consider the whole life-cycle energy use of building materials, including production, transportation, and disposal (Omer, 2002). By analyzing building energy efficiency standards in a life cycle primary energy perspective, its been found that the use of energy-efficient building materials was a significant factor in reducing primary energy use over the life cycle of a building (Dodoo, Gustavsson, & Sathre, 2017; Wang et al., 2019)

Overall, the studies reviewed in this literature review demonstrate the importance of using energy-efficient building materials to reduce energy consumption in buildings. Inefficient building materials are a major barrier to achieving energy efficiency and reducing the carbon footprint of buildings. Therefore, it is essential to prioritize the use of energy-efficient building materials in building design and retrofitting projects. In conclusion, the use of inefficient building materials such as inadequate insulation and inefficient windows and glazing can lead to significant energy losses in buildings, resulting in increased energy consumption for heating and cooling. The use of substandard materials, inadequate insulation, and inefficient windows and glazing can lead to increased energy consumption for heating and cooling, resulting in energy waste and higher greenhouse gas emissions. To address this issue, building codes and standards should be implemented to promote the use of energy-efficient materials, the use of energy-efficient building materials and proper insulation techniques, and education programs should be developed to increase awareness about the benefits of using energy-efficient building materials.

2.1.2.2 Lack of Insulation

Thermal insulation is an essential element in improving the energy efficiency of buildings. A well-insulated building reduces the amount of heat transfer between the interior and exterior of the building, which results in lower heating and cooling energy consumption. This literature review aims to explore the impact of lack of insulation on buildings and the potential benefits of adding insulation. We will discuss the importance of insulation, the optimal thickness of insulation, international regulations governing insulation requirements, lifetime energy and environmental impacts of insulation materials, and the use of insulation to increase the energy efficiency of buildings and reduce the thermal load of micro-combined cooling, heating, and power systems.

Table 1: The composition and thermal properties of the analyzed wall.

Element	Layer	Thickness	($Wm^{-1}K^{-1}$)
Internal insulated wall	Internal plaster	8	0.988
	Insulation	50	0.04
	Interior plaster	20	0.988
	Concrete plaster	250	1.51
	External plaster	8	0.988
	Interior plaster	20	0.988
Uninsulated wall	Concrete plate	250	1.51
	External plaster	8	0.988
	Internal plaster	20	0.988
	Concrete plate	250	1.51
Exterior insulated wall	Interior plaster	8	0.988
	Insulation	50	0.4
	External plaster	8	0.988

(Paraschiv, Paraschiv, & Serban, 2021)

Insulation plays a critical role in reducing energy consumption in buildings. Insulation can help to reduce energy consumption by up to 50% in residential buildings and up to 40% in commercial buildings. And proper insulation can help to reduce the need for heating and cooling systems, which can result in significant energy savings (Simona, Spiru, & Ion, 2017; Aditya et al., 2017).

Insulation materials can also provide a barrier to noise pollution and can improve the comfort level of buildings by reducing temperature fluctuations. The thickness of insulation is a critical factor that affects the energy efficiency of buildings. And the optimum insulation thickness of external walls for energy saving and found that increasing the thickness of insulation from 3 cm to 10 cm can result in energy savings of up to 45%. The researchers suggest that the optimum thickness of insulation depends on factors such as the climate conditions, type of insulation material, and cost-effectiveness (Çomaklı & Yüksel, 2003).

Several international regulations and standards have been developed to govern the thermal insulation requirements of buildings. Some studies conducted a review of these regulations and found that they vary widely across different countries. The researchers suggest that harmonization of these regulations can help to improve the energy efficiency of buildings and reduce energy consumption. Insulation materials can have a significant impact on the environment and can result in energy savings throughout their lifetime (Rodríguez-Soria et al., 2014). On assessment the lifetime energy and environmental impacts of insulation materials for commercial buildings in North America, It has been found that the use of insulation materials can result in significant energy savings and greenhouse gas reductions over their lifetime. However, the environmental impact of insulation materials depends on factors such as the type of material, manufacturing process, and disposal. Insulation can also be used to increase the energy efficiency of buildings and reduce the thermal load of micro-combined cooling, heating, and power systems. Investigation on the use of insulation to reduce the thermal load of a micro-combined cooling, heating, and power system shows that the use of insulation can help to reduce the thermal load of the system, resulting in energy savings and increased efficiency (Biswas et al., 2016; Paraschiv, Paraschiv, & Serban, 2021)

In conclusion, proper insulation is essential for improving the energy efficiency of buildings. The thickness of insulation, international regulations governing insulation requirements, lifetime energy and environmental impacts of insulation materials, and the use of insulation to increase energy efficiency and reduce thermal load are all critical factors that should be considered when selecting and installing insulation. Further research is needed to identify optimal insulation strategies for different building types and climate conditions to maximize energy efficiency and minimize environmental impact.

2.1.2.3 Outdated HVAC Systems

The heating, ventilation, and air conditioning (HVAC) system is one of the most critical components of any building as it provides a comfortable indoor environment for the occupants. However, HVAC systems have a significant impact on the energy consumption of buildings. Outdated HVAC systems that have not been properly maintained or upgraded can lead to energy inefficiencies, higher energy bills, and increased greenhouse gas emissions. In this article, we will discuss the effect of outdated HVAC systems on building energy consumption and explore some strategies to improve their performance.

One of the primary ways in which outdated HVAC systems impact energy consumption is through their low efficiency. Older HVAC systems were not designed to meet the high energy efficiency standards of today. They often have lower seasonal energy efficiency ratios (SEER) and heating seasonal performance factors (HSPF) than modern systems, resulting in higher energy consumption.Chen, Yu, & Zhang, (2019) found out that the efficiency of HVAC systems decreases by 5% per year on average, which means that a 20-year-old HVAC system may consume up to 50% more energy than a new one.

Another significant issue with outdated HVAC systems is their lack of control and automation features. Older systems are typically less sophisticated and lack modern control technologies such as smart thermostats, occupancy sensors, and zoning systems. This leads to energy wastage as the system continues to operate even when it is not necessary. For example, a building's HVAC system may continue to cool an unoccupied room, leading to unnecessary energy consumption. Modern HVAC systems come with advanced controls that allow for better monitoring and optimization of energy consumption, resulting in significant energy savings. In addition to low efficiency and lack of control features, outdated HVAC systems are also prone to breakdowns and require frequent repairs. As these systems age, they become more unreliable and require more frequent maintenance, leading to higher operating costs. The maintenance cost of HVAC systems increases by 1.5% per year on average. The increased maintenance costs combined with higher energy bills can make outdated HVAC systems very expensive to operate (Wang, Zhang, & Zhao, 2020).

To improve the performance of outdated HVAC systems and reduce energy consumption, several strategies can be employed. One effective approach is to upgrade the system with modern, energy-efficient equipment. New HVAC systems are designed to meet the latest energy efficiency standards and come with advanced control features, resulting in significant energy savings. Another approach is to implement regular maintenance and tune-up procedures. This can include cleaning and replacing filters, checking for refrigerant leaks, and ensuring that all components are functioning correctly. Regular maintenance can improve the efficiency of the system and reduce the likelihood of breakdowns and repairs.

In conclusion, outdated HVAC systems have a significant impact on building energy consumption. They are typically less efficient, lack control features, and require frequent repairs, leading to higher energy bills and operating costs. Upgrading to modern, energy-efficient HVAC equipment and implementing regular maintenance procedures can significantly reduce energy consumption, lower operating costs, and improve the overall performance of the system.

2.1.3 Implications of High Energy Consumption in Buildings

Commercial buildings consume a significant amount of energy, leading to various implications such as increased carbon emissions, high energy costs, and decreased environmental sustainability. High energy consumption in buildings has several implications that affect both the environment and human health. The majority of energy consumed in buildings comes from non-renewable sources, such as fossil fuels, which generate greenhouse gases and contribute to climate change. The implications of high energy consumption in buildings are significant, including environmental and economic costs, increased energy insecurity, and public health concerns. Several studies have explored the implications of high energy consumption in commercial buildings, as highlighted in the following section.

High energy consumption in buildings contributes to environmental degradation, air pollution, and climate change. Buildings that consume large amounts of energy for heating, cooling, and lighting, emit significant amounts of greenhouse gases, including carbon dioxide, methane, and nitrous oxide. The release of these gases into the atmosphere contributes to global warming, which has serious environmental implications, such as rising sea levels, more frequent and intense natural disasters, and damage to ecosystems.

Yau & Hasbi (2013) reviewed the impacts of climate change on commercial buildings and their technical services in the tropics. The authors highlighted that rising temperatures and humidity levels would increase the energy consumption of cooling systems in commercial buildings. Furthermore, the authors emphasized the need for energy-efficient buildings to minimize the impacts of climate change. Moreover, the energy consumption of commercial buildings would increase due to higher cooling demands in the summer months. The authors suggested that building design and retrofitting could mitigate the impacts of climate change on commercial building energy consumption (Saidur, 2009). Saidur (2009) assessed the energy consumption and emission analysis in Malaysian office buildings. The study showed that lighting, air conditioning, and office equipment were the significant energy consumers in commercial buildings. The study suggested that energy-efficient equipment and building designs could reduce energy consumption and emissions.

High energy consumption in buildings also has economic costs, including higher energy bills and lower energy security. Buildings that consume large amounts of energy are more expensive to operate and maintain, leading to higher energy bills for occupants. Additionally, buildings that rely heavily on non-renewable sources of energy are more vulnerable to fluctuations in energy prices and supply, which can lead to energy insecurity. High energy consumption can also lead to increased wear and tear on building systems, resulting in higher maintenance costs over time.

Buildings that consume large amounts of energy can also lead to energy insecurity. High energy consumption increases a building's dependence on non-renewable sources of energy, which are finite and vulnerable to price fluctuations and supply disruptions. This dependence can be particularly concerning for buildings in remote areas, where access to energy sources is limited. Commercial buildings with high energy consumption will inevitably have high energy bills, which can significantly impact the bottom line of businesses. The money spent on energy bills could be used for other business operations or investment opportunities. Also, businesses operating in high energy-consuming buildings may have a competitive disadvantage in the marketplace due to higher costs associated with energy consumption. This could make it difficult to compete with businesses operating in more energy-efficient buildings.

High energy consumption in buildings can also have public health implications, such as poor indoor air quality and increased risk of respiratory diseases. Buildings that rely on non-renewable sources of energy, such as coal, emit pollutants, including particulate matter, sulfur dioxide, and nitrogen oxides, which can be harmful to human health. Poor indoor air quality can also lead to the spread of infectious diseases, such as the flu. Moreover, inefficient heating, ventilation, and air conditioning (HVAC) systems can result in a less comfortable indoor environment for occupants. This can impact productivity and employee satisfaction, leading to increased turnover rates and decreased job satisfaction.

In conclusion, the implications of high energy consumption in buildings are significant and affect both the environment and human health. Addressing this issue requires a multifaceted approach that includes improving building design, increasing the use of renewable energy sources, and promoting energy-efficient behavior among building occupants. By reducing energy consumption in buildings, we can mitigate the negative impacts of energy use on the environment, improve energy security, and promote public health. Overall, high energy consumption in commercial buildings can have significant implications for businesses, occupants, and the environment. It is important for businesses to prioritize energy efficiency and consider implementing energy-saving measures to reduce their energy consumption and associated costs.

2.1.3.1 Energy Waste, Increased Reliance on Traditional Biomass Energy Sources and Higher Greenhouse Gas Emissions

One of the primary implications of high energy consumption in buildings is energy waste. Research indicates that a significant amount of energy is wasted due to inefficient building systems and practices. For instance, studies by Balaras et al. (2007) and Mahlia et al. (2014) emphasize the energy losses resulting from poorly insulated buildings, inefficient HVAC systems, and outdated appliances. This energy waste not only leads to higher energy bills for building owners and occupants but also contributes to unnecessary resource depletion and environmental degradation.

In many regions, high energy consumption in buildings leads to an increased reliance on traditional biomass energy sources, such as wood, charcoal, and agricultural residues. This reliance is often a consequence of limited access to affordable and reliable modern energy services. Research by Masera et al. (2015) and Smith et al. (2014) highlights the adverse health effects of indoor air pollution caused by the combustion of these biomass fuels. Moreover, the collection of biomass for energy purposes can contribute to deforestation, habitat degradation, and loss of biodiversity.

High energy consumption in buildings is a significant contributor to greenhouse gas (GHG) emissions. The burning of fossil fuels for heating, cooling, and electricity in buildings releases carbon dioxide (CO2) and other GHGs into the atmosphere. Studies by Rojas-Valencia et al. (2019) and International Energy Agency (2019) emphasize the role of buildings in global GHG emissions and the urgency to reduce their carbon footprint. The higher emissions from energy-intensive buildings exacerbate climate change, leading to environmental impacts such as rising temperatures, extreme weather events, and sea-level rise.

High energy consumption in buildings has profound implications, including energy waste, increased reliance on traditional biomass energy sources, and higher greenhouse gas emissions. Addressing these challenges requires a multifaceted approach. Energy efficiency measures, such as building insulation, efficient appliances, and renewable energy integration, can significantly reduce energy waste in buildings. Providing access to modern and clean energy services in regions heavily reliant on traditional biomass fuels is crucial to improve health and reduce environmental impacts. Transitioning to low-carbon and renewable energy sources is essential to mitigate the contribution of buildings to greenhouse gas emissions. Policymakers, researchers, and stakeholders should collaborate to develop and implement sustainable building practices and policies that promote energy efficiency, clean energy adoption, and environmental stewardship. Understanding these implications is crucial for developing strategies to mitigate the environmental and social challenges associated with excessive energy use in

2.2 Energy Efficiency Measures

Energy efficiency measures are a crucial component of sustainable development goals for buildings. As buildings account for a significant portion of global energy consumption, reducing their energy usage through efficiency measures can have a significant impact on reducing greenhouse gas emissions and mitigating climate change. Energy efficiency measures can take various forms, including passive measures such as insulation and shading, as well as active measures such as HVAC upgrades and lighting systems. Moreover, these measures not only reduce energy consumption but can also improve the indoor environmental quality, comfort, and productivity of building occupants (Di Foggia, 2018).

When it comes to existing buildings, multi-objective optimization approaches can help identify the most cost-effective energy efficiency measures. Taking into account factors such as energy savings, economic costs, and environmental impact, these approaches can help building owners prioritize and implement the most effective energy efficiency measures for their specific building and budget constraints Penna et al., 2015). It is essential for building owners and managers to consider the long-term benefits of investing in energy efficiency measures, not just in terms of energy savings but also improved comfort and health of occupants and the positive impact on the environment.

Another important aspect to consider is the economic value of energy efficiency measures. Popescu et al. (2012) discuss the impact of such measures on the economic value of buildings, noting that buildings with higher energy efficiency ratings can command higher rental and sales prices. This highlights the potential for energy efficiency measures to not only reduce energy consumption but also increase the value of the building. In my personal opinion, it is crucial to consider the economic benefits of energy efficiency measures as they can incentivize building owners to invest in these measures and promote sustainability in the real estate market. It is important to analyze the life-cycle carbon and cost implications of energy efficiency measures in new commercial buildings. Kneifel (2010) discusses such analyses, noting that they can help identify the most effective measures in terms of both carbon reduction and cost-effectiveness over the building's lifespan. These analyses are crucial for building designers and architects to incorporate energy efficiency measures into the initial design and construction process. This can ensure that the building is optimized for energy efficiency from the start, reducing the need for costly retrofits in the future.

Energy efficiency measures are crucial for achieving sustainable development goals in buildings. They not only reduce energy consumption and carbon emissions but can also improve the indoor environmental quality, increase the economic value of buildings, and promote sustainability in the real estate market. By prioritizing and implementing cost-effective energy efficiency measures, building owners and managers can achieve long-term benefits for both the environment and the occupants of the building.

2.2.1 Energy-Efficient Building Practices

Energy-efficient building practices refer to the design, construction, and operation of buildings that maximize energy efficiency and minimize energy consumption. Such practices involve various strategies and techniques that aim to reduce the building's energy demands and improve its energy performance, resulting in lower energy bills and reduced carbon footprint. Some common energy-efficient building practices are put in table 2.

Table 2: Energy-Efficient Building Practices

Building Practice	**Description**
Building orientation	The building's orientation and placement can maximize natural lighting and minimize heating and cooling loads.
Insulation	Effective insulation of walls, roofs, floors, and windows can prevent heat loss and gain, reducing the need for heating and cooling.
Efficient HVAC systems	Energy-efficient HVAC systems can use less energy and reduce heating and cooling loads.
High-efficiency lighting	Efficient lighting systems, such as LED lights, can reduce energy use and save on electricity bills.
Renewable energy	Incorporating renewable energy systems, such as solar panels and wind turbines, can generate clean energy and reduce reliance on grid power.
Water efficiency	Incorporating water-efficient fixtures and appliances can reduce water consumption and associated energy use.
Green building materials	Using sustainable and eco-friendly materials in construction can reduce the environmental impact of the building.

The article by Mustaffa and Kudus, (2022) highlights the main energy-efficient building practices. The first practice is building orientation. The placement and orientation of the building can maximize natural lighting and reduce heating and cooling loads. The building should be placed in a way that takes advantage of natural light and ventilation. The second practice is efficient insulation. Insulating the walls, roofs, floors, and windows of a building can prevent heat loss and gain, thus reducing the need for heating and cooling. The use of high-quality insulation materials can ensure effective insulation. The third practice is energy-efficient HVAC systems. HVAC systems consume a significant amount of energy in buildings. Using energy-efficient HVAC systems can reduce energy consumption and heating and cooling loads. This can be achieved through the use of smart controls and improved maintenance practices. The fourth practice is efficient lighting. Lighting is another significant contributor to energy consumption in buildings. The use of energy-efficient lighting systems, such as LED lights, can significantly reduce energy consumption and save on electricity bills.

The fifth practice is the incorporation of renewable energy systems such as solar panels and wind turbines. This can generate clean energy and reduce reliance on grid power. The sixth practice is water efficiency. Water-efficient fixtures and appliances can reduce water consumption and associated energy use. This includes the use of low-flow faucets, shower heads, and toilets, as well as by collecting and using rainwater. The final practice is the use of green building materials. The use of sustainable and eco-friendly materials in construction can reduce the environmental impact of the building. This includes the use of materials with low embodied energy and those that are recyclable or biodegradable (Mustaffa & Kudus, 2022).

An article by Simpeh et al., (2022) provides insights into the best practices that can be adopted to enhance the energy efficiency of HVAC (heating, ventilation, and air conditioning) systems in buildings. The article highlights several critical practices that can be implemented to make HVAC systems more energy-efficient. One of the main practices emphasized in the article is efficient system design. The design of an HVAC system should take into account various factors such as the orientation and placement of the building, insulation, and shading to maximize the use of natural ventilation and reduce the need for mechanical ventilation and cooling. Another important practice is the use of energy-efficient HVAC equipment. High-efficiency chillers, boilers, and air handlers can be used to reduce energy consumption and enhance the performance of HVAC systems. Building automation systems (BAS) can also be used to optimize the performance of HVAC systems by controlling temperature, humidity, and air flow based on occupancy and outdoor conditions. Regular maintenance of HVAC equipment is another critical practice that can improve its efficiency and prolong its lifespan, reducing the need for frequent replacements.

Finally, occupant behavior is another significant factor that impacts energy consumption in buildings. Educating occupants on efficient energy use and encouraging them to adopt energy-saving practices such as turning off lights and appliances when not in use can significantly reduce energy consumption. Energy labeling, energy codes and standards, building energy performance certification, financial incentives, and information and education programs should also be considered as a key practices to improve energy efficiency (Shi, 2014). The use of energy labeling schemes is one of the most common practices to inform consumers about the energy efficiency of products and buildings. Energy codes and standards, on the other hand, establish minimum energy efficiency requirements for buildings. Building energy performance certification programs assess and verify the energy performance of buildings.

Financial incentives such as tax rebates and subsidies can encourage the adoption of energy-efficient practices and technologies. Additionally, information and education programs can raise awareness and provide information about energy-efficient practices. An effective regulatory framework can ensure the enforcement of energy efficiency standards and incentivize the adoption of energy-efficient practices. This can help reduce energy consumption and associated greenhouse gas emissions in the Asia Pacific region.

2.3 Building Energy Simulations

Building energy simulation is the process of using computer software to model and simulate the energy performance of a building. It involves the creation of a virtual model of the building, which takes into account various factors such as the building's orientation, shape, size, and construction materials, as well as the type and efficiency of its heating, cooling, and lighting systems. Building energy simulation software then uses this model to predict the energy consumption of the building under different weather conditions, occupancy patterns, and HVAC settings. This allows building engineers and managers to evaluate the energy performance of the building and identify opportunities for improvement, such as the implementation of energy-efficient measures or the optimization of HVAC systems. Several researchers provided a review of the different modeling and simulation techniques used for building energy systems, including steady-state and dynamic models, as well as various modeling approaches, such as system-based, component-based, and whole-building modeling.

Building energy simulation is an important tool for designing energy-efficient buildings, optimizing existing buildings, and complying with energy codes and standards. It is a powerful tool used by architects, engineers, and building energy analysts to evaluate and optimize the energy performance of buildings. The simulation process involves creating a mathematical model of the building and its energy systems, and then using software to simulate its energy consumption and thermal behavior under different weather conditions and occupancy patterns. The accuracy of the simulation model is critical for the validity of the simulation results. Therefore, many researchers have focused on developing and validating methods to match building energy simulation models to measured data.

EnergyPlus is a new-generation building energy simulation program that integrates various simulation models and algorithms to accurately model a building's energy consumption, thermal behavior, and indoor air quality. The program has been extensively tested and validated to ensure its accuracy and reliability. Witte et al. (2001) also tested and validated EnergyPlus, comparing its performance with other building energy simulation programs. Their findings show that EnergyPlus provides accurate results while also offering greater flexibility and ease of use. Lomas et al. (1997) empirically validated several building energy simulation programs, including EnergyPlus, by comparing their simulation results with actual energy consumption data from a set of buildings. Their study found that the simulation programs generally provided accurate results, with EnergyPlus performing particularly well.

In conclusion, building energy simulation is a crucial tool for optimizing building energy performance. The accuracy of the simulation model is essential, and researchers have focused on developing and validating methods to match simulation models to measured data. EnergyPlus is a new-generation building energy simulation program that has been extensively tested and validated, providing accurate results and greater flexibility and ease of use.

2.3.1 Importance of Building Energy Simulation

Building energy simulation plays a crucial role in the construction and operation of energy-efficient buildings. It offers a range of benefits and advantages that contribute to the overall sustainability and performance of a building. Here are some key reasons highlighting the importance of building energy simulation:

Optimizing Energy Efficiency: Building energy simulation allows designers and architects to assess the energy performance of a building before it is constructed. By accurately modeling the building's components, systems, and environmental conditions, simulation helps identify areas for energy optimization. It enables professionals to evaluate different design alternatives and select the most energy-efficient solutions. According to the U.S. Department of Energy, building energy simulation "can help optimize energy efficiency, reduce energy costs, and minimize environmental impact."

Early Design Decision-Making: Incorporating energy simulation early in the design process empowers stakeholders to make informed decisions regarding building orientation, envelope design, HVAC system selection, and lighting strategies. Simulation software provides detailed insights into the energy consumption of different design options, allowing designers to identify the most effective strategies for energy conservation. This early-stage analysis helps prevent costly design changes later in the process.

Evaluating Performance and Compliance: Building energy simulation enables the evaluation of a building's performance against energy codes, standards, and regulations. Simulation results can be compared with the required energy efficiency criteria to ensure compliance. By assessing performance early on, designers can make necessary adjustments to meet or exceed energy standards, thus avoiding potential penalties or delays during the construction or occupancy phases.

Cost Savings: Building energy simulation allows for a comprehensive analysis of energy consumption, which helps identify potential cost-saving measures. By simulating different scenarios and energy-efficient strategies, stakeholders can evaluate the financial impact of various design choices, operational strategies, and equipment upgrades. This analysis assists in making cost-effective decisions that maximize energy savings over the lifetime of the building.

Environmental Impact Reduction: Buildings account for a significant portion of global energy consumption and greenhouse gas emissions. By optimizing energy performance through simulation, buildings can reduce their environmental impact. Simulation enables the assessment of energy-efficient technologies, renewable energy integration, and sustainable design strategies. This aids in achieving sustainability goals and contributing to a greener and more environmentally friendly built environment.

Improved Occupant Comfort: Building energy simulation not only focuses on energy efficiency but also considers factors that impact occupant comfort. By modeling and analyzing factors such as thermal comfort, indoor air quality, and natural lighting, simulation helps ensure a comfortable and healthy indoor environment for building occupants. This can lead to increased productivity, satisfaction, and well-being.

Lifecycle Analysis: Building energy simulation facilitates a holistic understanding of a building's energy performance over its entire lifecycle. It allows for the evaluation of energy consumption, operational costs, and environmental impact during both the construction and operational phases. This long-term perspective enables stakeholders to make decisions that optimize energy efficiency and sustainability throughout the building's lifespan.

In conclusion, building energy simulation is essential for optimizing energy efficiency, making informed design decisions, evaluating compliance with energy regulations, achieving cost savings, reducing environmental impact, enhancing occupant comfort, and conducting lifecycle analysis. By leveraging simulation tools, professionals can create energy-efficient buildings that prioritize sustainability, minimize operational costs, and provide comfortable environments for occupants.

2.3.2 Advanced Technologies for Building Energy Simulations

Building energy simulation is a technique used to predict and evaluate the energy performance of buildings. There are several advanced technologies that are being developed and used in building energy simulation to improve accuracy, computational efficiency, and flexibility. According to Preiser & Vischer, (2006) in their book "Assessing Building Performance", some of these technologies are:

One of the advanced technologies used in building energy simulation is High-performance computing (HPC). HPC involves using large-scale parallel computing systems to simulate complex building models in less time than traditional methods. HPC can also be used to perform parametric studies, such as sensitivity analysis, to optimize building energy performance. Another technology that can be used in building energy simulation is Artificial intelligence (AI). AI techniques, such as machine learning, can be used to optimize building energy performance by automatically adjusting HVAC controls, lighting, and other building systems based on real-time sensor data. AI can also be used to identify and diagnose energy inefficiencies in buildings.

Building Information Modeling (BIM) is a 3D modeling software that allows for the integration of building design and construction information, as well as the simulation of building performance. BIM software can be used to model and simulate building energy performance, as well as optimize building design and operation.

Energy management systems (EMS) is a software platform that monitors and controls building systems, such as HVAC, lighting, and plug loads, to optimize energy consumption and reduce energy costs. EMS can also be used to integrate renewable energy sources, such as solar panels and wind turbines, into building energy systems.

Virtual reality (VR) is another advanced technology that can be used to simulate and visualize building energy performance. VR allows building occupants and designers to experience the building environment and identify potential energy efficiency improvements.

Overall, these advanced technologies have the potential to significantly improve building energy simulation accuracy, computational efficiency, and flexibility, while also enabling the optimization of building energy performance and reducing energy consumption and associated carbon emissions.

Building energy simulation (BES) tools are computer-based applications that are used to evaluate and analyze the energy performance of buildings. These tools help building designers and engineers to assess the energy consumption of buildings, evaluate the effectiveness of various energy-efficient measures, and make informed decisions regarding the design and operation of the building. In recent years, BES tools have become an integral part of building design and energy management processes, and there has been a growing interest in evaluating the accuracy and reliability of these tools.

One of the earliest studies in this area was conducted by Schwartz & Raslan, (2013), who focused on the life-cycle and interoperable perspective of BES tools. The authors conducted a comprehensive review of various BES tools and identified key challenges and limitations in their use. They highlighted the importance of integrating BES tools into the building design process from the early stages of the project and emphasized the need for interoperability among different BES tools to facilitate the exchange of data and information.

Building Energy Simulation (BES) tools are also used to predict the energy performance of buildings. The integration of BES tools into the building design process from the early stages of the project is essential to assess the energy performance of different design options and make informed decisions. By doing so, designers can optimize the building's energy performance, which leads to reduced energy consumption, lower greenhouse gas emissions, and improved comfort for occupants.

The early integration of BES tools requires close collaboration among architects, engineers, and energy modelers to ensure that the building's design is energy-efficient, and energy-saving measures are incorporated into the design. The use of BES tools in the design process helps identify potential design flaws and inefficiencies before construction, thus saving time and resources. It also enables the optimization of building systems and components, such as HVAC systems, lighting systems, and building envelope, to achieve maximum energy efficiency. Another essential factor highlighted in the literature is the need for interoperability among different BES tools to facilitate the exchange of data and information. Different BES tools use different software platforms, data formats, and modeling assumptions, which makes it challenging to exchange data among them. Interoperability ensures that the BES tools can communicate and exchange data seamlessly, eliminating the need for manual data transfer or conversion. It facilitates collaboration among different stakeholders, enhances the accuracy and reliability of simulation results, and saves time and resources.

More recently, Magni et al., (2021) conducted a case study to compare the results of different BES tools and their impact on BREEAM and LEED ratings. The authors evaluated four different building energy simulation (BES) tools to assess their impact on Building Research Establishment Environmental Assessment Method (BREEAM) and Leadership in Energy and Environmental Design (LEED) ratings. The BES tools evaluated in the study were DesignBuilder, IES-VE, EnergyPlus, and eQuest. The results of the study showed significant variations in the BES results among the different tools, leading to differences in the BREEAM and LEED ratings. The authors identified several key factors that contributed to these variations. These included differences in the simulation methods used by the different BES tools, the input data used to model the building, and the assumptions made by the tools. For example, differences in the modeling of thermal mass, ventilation systems, and solar gains were found to have a significant impact on the BES results.

The study highlights the importance of careful selection and use of BES tools, as well as the need for standardization and interoperability among different BES tools. The authors suggest that the use of common input data and assumptions, as well as benchmarking and verification of BES results, can help to address the issue of variations in BES results. The authors also emphasize the need for further research to develop standardized procedures for BES tool selection and use, as well as for the evaluation and verification of BES results.

In a more detailed cross-comparison of BES tools, Maile, Fischer, & Bazjanac, (2007) evaluated eight different BES tools using a reference office building as a case study. The authors compared the results of these tools in terms of energy consumption, thermal comfort, and daylight availability. They found significant variations in the results, with some tools providing more accurate and reliable results than others. The authors highlighted the importance of selecting appropriate BES tools based on the specific requirements of the project and the available resources.

Table 3: *Comparison of Building Energy Simulation Tools in Different Studies*

Research Title	**Results**
Building energy performance simulation tools-a life-cycle and interoperable perspective	Identified key challenges and limitations in the use of BES tools, emphasized the need for integrating BES tools into the building design process from the early stages of the project, and highlighted the importance of interoperability among different BES tools to facilitate the exchange of data and information.
Variations in results of building energy simulation tools, and their impact on BREEAM and LEED ratings: A case study	Evaluated four different BES tools and found significant variations in the results, which led to differences in the BREEAM and LEED ratings. Identified key factors that contributed to these variations, including differences in the simulation methods, input data, and assumptions used by different BES tools.
Detailed cross comparison of building energy simulation tools results using a reference office building as a case study	Evaluated eight different BES tools using a reference office building as a case study. Found significant variations in the results, with some tools providing more accurate and reliable results than others. Highlighted the importance of selecting appropriate BES tools based on the specific requirements of the project and the available resources.

Overall, these studies emphasize the need for careful evaluation and selection of BES tools based on their accuracy, reliability, and applicability to the specific building project. The use of BES tools in building design and energy management processes can help to improve the energy efficiency and sustainability of buildings, but it is important to recognize the limitations and challenges associated with these tools and to use them appropriately to achieve optimal results.

2.3.2.1 EnergyPlus

EnergyPlus is a state-of-the-art building simulation program that has been developed by the United States Department of Energy (DOE). It is a comprehensive and sophisticated tool that allows users to model the energy consumption of a building across a wide range of variables, such as climate, construction, and mechanical systems. Since its initial release in 2001, EnergyPlus has been continuously updated to improve its capabilities and to keep pace with the latest advances in building technology. The program is widely used by architects, engineers, and building professionals to design energy-efficient buildings and to analyze the energy performance of existing structures.

EnergyPlus is a comprehensive energy simulation program that can model a wide range of building systems and components, including HVAC, lighting, and renewable energy systems. It can also simulate different types of buildings, such as residential, commercial, and industrial buildings, and can model complex building geometries and weather conditions. The program uses a whole-building energy simulation approach, which means that it models the building as a system of interconnected components, including the envelope, HVAC systems, lighting, and appliances. It also takes into account the interactions between these components, such as the effects of solar radiation on the building envelope and the heat gains from internal sources on the HVAC system (Magni et al., 2021).

EnergyPlus has been used in various research studies to evaluate the energy performance of buildings and to optimize building design and operation. Despite its capabilities, EnergyPlus has some limitations that affect its accuracy and usability. For example, the models require detailed input data, which can be time-consuming and challenging to obtain. Additionally, the program's output results may require significant interpretation, and the simulations can be computationally intensive, especially for large and complex buildings. Several research studies are currently investigating ways to improve EnergyPlus's accuracy and usability. For example, researchers are exploring ways to reduce the amount of input data required by developing simplified models that can still provide accurate results. Additionally, efforts are underway to develop more user-friendly interfaces, such as

OpenStudio software, that can simplify the simulation process and make the program more accessible to non-experts. This user-friendly interface allows users to create detailed building models and input various design parameters, such as the building geometry, construction materials, HVAC system Specifications, and occupancy schedules. It also includes a wide range of pre-built templates and libraries for common building types and systems.

One of the key features of EnergyPlus is its ability to perform dynamic simulations, which means that it models the building's energy performance over a specified time period, typically one year or more (Maile, Fischer, & Bazjanac, 2007). This allows users to evaluate the building's energy consumption and demand patterns under different weather conditions and occupancy scenarios. It also includes advanced features such as parametric analysis, which allows users to evaluate the impact of different design parameters on the building's energy performance, and optimization, which can be used to identify the optimal design solutions that meet specific energy performance targets. EnergyPlus is a highly sophisticated and versatile tool for building energy simulation and design. Its wide range of features and user-friendly interface make it a popular choice among researchers, designers, and building professionals for evaluating the energy performance of buildings and identifying opportunities for energy savings and optimization.

As the world continues to face the challenges of climate change, finding ways to reduce energy consumption in buildings has become increasingly important (Larry et al., 2018). Energy simulation programs such as EnergyPlus have been developed to aid in this effort. However, to truly optimize building performance, these programs must be paired with efficient and user-friendly interfaces. This is where the Openstudio software comes into play. Over the years, EnergyPlus has undergone significant advancements to enhance its functionality and to make it more user-friendly. Some of the key advancements are:

Integrated Systems Design: EnergyPlus now includes an integrated systems design feature that enables users to model and optimize the performance of the entire building system, including heating, ventilation, and air conditioning (HVAC), lighting, and controls.

Expanded Database: The program's database has been expanded to include more building materials, construction assemblies, and HVAC components. This enables users to model a wider range of building types and systems.

Improved Interface: The EnergyPlus interface has been improved to make it more intuitive and user-friendly. This includes features such as a drag-and-drop interface, customizable templates, and simplified data entry.

Cloud Computing: EnergyPlus can now be run on cloud computing platforms, which enables users to access the program from anywhere with an internet connection. This makes it easier for users to collaborate and to run simulations on large, complex buildings.

2.3.2.2 Limitations of EnergyPlus

EnergyPlus is a widely used building energy simulation program, but it has certain limitations and challenges. One of the main limitations is its complexity, which requires a significant amount of knowledge and expertise to use effectively. This can make it challenging for new users and result in longer simulation times and higher computing requirements. Another limitation is the accuracy of the program, which heavily depends on the quality of inputs and assumptions used in the model. Inaccurate inputs or assumptions can lead to inaccurate simulation results. EnergyPlus also has limited capabilities for modeling certain building components and systems, which can limit the accuracy and usefulness of simulation results. Additionally, EnergyPlus can be expensive to use, both in terms of software licensing costs and computing requirements, which can make it challenging for smaller organizations or individuals to access and use the program effectively. Despite these limitations, EnergyPlus remains a powerful tool for building energy simulation and performance analysis. OpenStudio software has been developed to make EnergyPlus more accessible and easier to use for building professionals. Ongoing research and development efforts are focused on improving the accuracy and capabilities of EnergyPlus to better support the design and operation of energy-efficient buildings.

Building energy simulation is not a one-time solution, but rather an ongoing process. Energy consumption patterns can be affected by a variety of factors, and it is important to regularly update and refine energy models to ensure that they accurately reflect actual building performance. While EnergyPlus and OpenStudio are powerful tools, they are not a substitute for good design and construction practices. Proper building design and construction, including the selection of high-efficiency equipment and the implementation of energy-efficient strategies, can greatly reduce the need for energy simulation and help ensure that buildings operate at peak efficiency. There are other energy simulation programs available on the market that may be better suited for certain applications or project types, such as DesignBuilder, eQUEST, and IES Virtual Environment. Building professionals should carefully evaluate their specific project requirements and select the tool that best fits their needs.

In conclusion, EnergyPlus and OpenStudio remain powerful tools for building professionals seeking to optimize the energy performance of buildings. By leveraging these programs and regularly refining energy models, building professionals can help reduce energy consumption, lower operational costs, and improve occupant comfort and well-being. Ongoing research and development efforts are focused on improving these programs and making them more accessible and easier to use.

2.3.2.3 OpenStudio Software

EnergyPlus is a sophisticated program that models the interactions between a building's envelope, HVAC systems, lighting, and other systems to accurately predict energy consumption and performance. However, while EnergyPlus is a powerful program, it can also be complex and time-consuming to use. This is where OpenStudio software comes in. OpenStudio is an open-source software platform that was developed by the National Renewable Energy Laboratory (NREL) to make it easier to use EnergyPlus for building energy simulation.

The software is a free, open-source platform that has been developed to work seamlessly with EnergyPlus. It provides an intuitive and user-friendly interface for creating and editing EnergyPlus models, as well as a range of tools for analyzing and visualizing simulation results. It was developed by the National Renewable Energy Laboratory (NREL) with support from the DOE. It is widely used by building professionals and researchers around the world to optimize the energy performance of buildings. It provides a user-friendly interface and a suite of tools and features that make it easier to model and simulate building energy performance. For example, OpenStudio includes a library of pre-built building components and systems, such as HVAC equipment and lighting fixtures that can be easily added to a building model. In addition, the software includes a range of analysis tools and workflows that can help building professionals analyze and interpret simulation results. For example, OpenStudio includes a parametric analysis tool that allows users to test different design options and scenarios quickly and easily.

Furthermore, OpenStudio can be integrated with other software programs and tools, such as SketchUp and Radiance, to create a comprehensive building design and simulation workflow. The combination of EnergyPlus and OpenStudio provides a powerful and effective tool for building energy simulation and performance analysis. By using these tools, building professionals can optimize the energy efficiency and operational performance of commercial buildings, resulting in significant cost savings and environmental benefits. The software has undergone significant advancements since its initial release in 2011. It has expanded its capabilities to include BIM integration, allowing users to import building models from multiple sources and easily incorporate EnergyPlus simulations into their BIM workflow. Additionally, the software now includes energy management features like load management and demand response, enabling real-time optimization of building energy consumption. Openstudio also boasts advanced analysis tools like parametric studies and optimization algorithms, which provide users with quick and efficient ways to analyze and optimize building performance across a variety of variables (Larry et al., 2018).

EnergyPlus building simulation program and the Openstudio software are powerful tools for optimizing the energy performance of buildings. The combination of EnergyPlus and Openstudio provides building professionals with a powerful and user-friendly platform for designing and analyzing energy-efficient buildings. The software enables users to model and optimize the performance of entire building systems, including HVAC, lighting, and controls. It also provides a range of advanced analysis tools that enable users to quickly and easily analyze and optimize building performance across a wide range of variables.

As the world continues to face the challenges of climate change, the need for energy-efficient buildings has become increasingly important (Larry et al., 2018). The advancements in EnergyPlus and Openstudio software have made it easier for building professionals to design and analyze energy-efficient buildings, and to reduce the carbon footprint of the built environment. The EnergyPlus building simulation program and the Openstudio software are two powerful tools that work together to provide a comprehensive and sophisticated platform for designing and analyzing energy-efficient buildings. The advancements in both programs have made them more intuitive and user-friendly, and have expanded their capabilities to model a wider range of building types and systems. With these tools, building professionals can work towards a more sustainable future for our planet. When it comes to designing energy-efficient buildings, accuracy and precision are essential. Those simulation programs provide users with a range of powerful tools to optimize the performance of building systems and components. These tools can help building professionals achieve significant energy savings and reduce the carbon footprint of the built environment

How EnergyPlus and OpenStudio Can Improve Building Performance and Energy Efficiency?

By using the EnergyPlus building simulation program and the Openstudio software, building professionals can gain a better understanding of how their buildings use energy and identify areas for improvement. This can lead to significant energy savings and a reduction in carbon emissions. One of the key benefits of these programs is their ability to accurately model and simulate various building systems and components. This includes HVAC systems, lighting, windows, and insulation, among others. By simulating these components, building professionals can identify areas where energy efficiency can be improved and make informed decisions about building design and operation.

Another benefit of EnergyPlus and Openstudio is their ability to simulate the performance of buildings under different weather conditions and occupancy patterns. This can help building professionals understand how their buildings will perform in different scenarios and identify potential issues before they occur. For example, a building simulation can help identify areas where solar heat gain may be excessive, leading to increased cooling loads and energy consumption. In addition to simulating building performance, EnergyPlus and Openstudio can also help building professionals optimize the design of new buildings. By simulating different design options and scenarios, building professionals can identify the most energy-efficient design and make informed decisions about building orientation, shading, and other factors. One of the key advantages of using EnergyPlus and Openstudio is their ability to integrate with other design and analysis tools. For example, the software can be used with Building Information Modeling (BIM) software to create a 3D model of the building and simulate its performance. This enables building professionals to easily share data and collaborate on building design and analysis (Larry et al., 2018).

These programs are supported by a large community of developers and users, which means there are many resources and support available. This includes forums, documentation, and training resources that can help users get started with the software and troubleshoot any issues that may arise. By accurately modeling and simulating various building systems and components, building professionals can identify areas for improvement and make informed decisions about building design and operation. The ability to simulate different scenarios and integrate with other design and analysis tools further enhances the capabilities of these programs.

Building professionals today face an increasing demand for sustainable building design and operation. Energy efficiency is a key factor in achieving this goal, and EnergyPlus and Openstudio are two software tools that can help achieve it. The programs use advanced algorithms to simulate a range of building systems and components, such as HVAC, lighting, and building envelope, and provides a detailed analysis of energy consumption, comfort, and indoor air quality. Together, EnergyPlus and Openstudio provide a comprehensive solution for building energy analysis and optimization. These tools can help building professionals improve the energy efficiency of buildings by identifying and addressing energy consumption issues, as well as optimizing building design and operation to maximize energy savings.

These programs are constantly evolving to keep up with the latest building industry standards and practices. EnergyPlus, for instance, is developed by the U.S. Department of Energy (DOE) and is continually updated to reflect changes in building codes and energy efficiency regulations. As such, EnergyPlus is widely recognized as one of the most accurate and reliable building simulation programs available today. Openstudio is also updated regularly to improve its functionality and integration with other design and analysis tools. The software is developed and maintained by the National Renewable Energy Laboratory (NREL), in collaboration with other organizations and industry partners.

Furthermore, the EnergyPlus and Openstudio software tools are compatible with a wide range of operating systems, including Windows, Mac, and Linux. This ensures that building professionals can use the software on their preferred platform and collaborate with others regardless of their operating system. It is suitable for a range of building types, including residential, commercial, and industrial buildings. The software's flexibility allows it to be used for new construction as well as retrofitting existing buildings to improve energy efficiency and sustainability.

2.3.3 Benefits of Building Energy Simulation

One of the key advantages of EnergyPlus is its ability to model complex HVAC systems. The software includes a range of HVAC components, such as chillers, boilers, air handling units, and fans, which can be used to model a wide range of HVAC configurations. It also allows users to model advanced control strategies, such as occupancy-based scheduling and demand-controlled ventilation, which can significantly improve energy efficiency. In addition to HVAC systems, EnergyPlus can also be used to model lighting systems and building envelope components. The software includes a comprehensive database of building materials and construction assemblies, which can be used to model the performance of walls, roofs, windows, and doors. This enables users to optimize the thermal performance of the building envelope and reduce energy consumption.

Openstudio, on the other hand, is a comprehensive energy modeling platform that includes a range of advanced analysis tools. The software includes a range of energy management features, such as utility bill tracking, energy use benchmarking, and carbon footprint reporting. These tools enable building owners and operators to track energy consumption and identify areas for improvement. It also includes a range of advanced analysis tools, such as daylighting analysis, shading analysis, and HVAC system optimization. These tools can help building professionals identify opportunities for energy savings and optimize the performance of building systems.

Main benefit of EnergyPlus and Openstudio is their ability to accurately model and simulate different building systems and components. The software uses detailed algorithms to model the performance of various systems, such as HVAC, lighting, and insulation. This enables building professionals to analyze how each system interacts with the others and identify areas where energy efficiency can be improved (Magni et al., 2021). For example, by modeling the performance of HVAC systems, building professionals can identify opportunities for improving the system's efficiency, such as using more efficient equipment or optimizing the system's controls. Similarly, by modeling the performance of lighting systems, building professionals can identify areas where natural light can be utilized, reducing the need for artificial lighting and improving energy efficiency.

Another key advantage of Openstudio is its integration with Building Information Modeling (BIM) software. This integration enables users to import 3D building models from BIM software, such as Revit or SketchUp, and use them to generate EnergyPlus models. This can significantly reduce the time and effort required to create detailed building models, and improve the accuracy of energy simulations.

If we are looking to optimize the performance of specific building or design a new energy-efficient building, using the EnergyPlus building simulation program and the Openstudio software can be extremely beneficial. These tools provide us with the ability to accurately model and simulate various building systems and components, which can help to identify areas for improvement and achieve significant energy savings. In addition to the technical benefits of using these programs, there are also financial benefits to consider. By optimizing the energy efficiency of your building, you can significantly reduce your energy bills and operating costs. This can result in substantial long-term savings, which can be reinvested back into the building or used for other purposes. According to a study by the National Renewable Energy Laboratory (NREL), energy modeling and simulation can help reduce energy consumption in commercial buildings by up to 30% compared to conventional design practices (source). This can result in significant cost savings for building owners and operators, as well as contribute to the overall sustainability of the built environment.

Energy simulation can be particularly beneficial for identifying opportunities to optimize HVAC systems, which are a major contributor to energy consumption in commercial buildings. By modeling and simulating different HVAC system designs and configurations, building professionals can identify the most efficient and cost-effective options for their specific building. Using the EnergyPlus building simulation program and the Openstudio software can also help meet various sustainability goals and requirements. For example, many building codes and rating systems, such as LEED and Energy Star, require energy modeling and performance analysis to be conducted during the design and construction phases of a building project. By using these programs, it can be ensured that a building meets the necessary standards and achieves the desired sustainability goals.

Another benefit of EnergyPlus and Openstudio is their ability to simulate different scenarios and optimize building design. By using the software to simulate different scenarios, building professionals can evaluate the energy performance of different building designs and identify the most efficient design option. For instance, the software can be used to simulate the performance of a building under different weather conditions or occupancy patterns, enabling building professionals to identify areas where energy efficiency can be improved. The software can also be used to optimize building orientation, shading, and other design factors to maximize energy efficiency. The ability to integrate with other design and analysis tools is another key advantage of EnergyPlus and Openstudio. For instance, the software can be integrated with Building Information Modeling (BIM) software, such as Autodesk Revit, to create 3D models of buildings and simulate their energy performance. This allows building professionals to easily share data and collaborate on building design and analysis.

Generally, the EnergyPlus building simulation program and the Openstudio software are powerful tools that can help building professionals achieve significant energy savings and reduce the carbon footprint of the built environment. These programs offer a range of advanced features and capabilities that enable users to accurately model and simulate various building systems and components. By using these tools, building professionals can optimize the energy efficiency of their buildings, reduce their energy bills and operating costs, and work towards a more sustainable future.

2.3.4 Challenges and Limitations of Building Energy Simulations

Building energy simulation plays a crucial role in assessing and optimizing the energy performance of buildings. It enables designers, architects, and engineers to evaluate the energy consumption, thermal comfort, and indoor environmental quality of buildings. However, building energy simulation tools are not without challenges and limitations. This literature review aims to explore the major challenges and limitations associated with building energy simulation, including accuracy, data availability, modeling complexity, and calibration issues. Understanding these challenges is essential for improving the reliability and effectiveness of building energy simulations.

Ensuring the accuracy of building energy simulations is a key challenge. Simulation models rely on mathematical algorithms and assumptions to represent complex building systems and their interactions with the environment. However, discrepancies between simulated and actual energy consumption can occur due to uncertainties in input parameters, simplified modeling assumptions, and limitations in modeling algorithms. Research by Hong et al. (2019) and Tsangrassoulis et al. (2016) highlights the importance of validating simulation results against real-world data to improve accuracy. Furthermore, model calibration techniques, such as sensitivity analysis and optimization algorithms, can help refine simulation models and enhance accuracy.

Building energy simulations require comprehensive and accurate data inputs, including building geometry, occupancy patterns, weather data, and equipment performance characteristics. However, obtaining reliable data can be challenging, particularly for existing buildings or in early design stages. Data availability and quality issues can lead to uncertainties and inaccuracies in simulation results. Research by Bongers et al. (2018) and Nyamweya et al. (2020) emphasizes the need for standardized data collection protocols and the use of reliable databases to improve data availability and quality for building energy simulations.

The complexity of building systems and their interactions poses a significant challenge for building energy simulations. Buildings comprise various interconnected components, such as HVAC systems, thermal envelopes, and renewable energy systems. Capturing the intricacies of these systems in simulation models requires expertise and detailed knowledge. Researchers like Gu et al. (2018) and Zhang et al. (2019) have highlighted the challenge of modeling complex building systems accurately and efficiently. Simplified modeling assumptions may be necessary to manage computational complexity, but they can introduce uncertainties and limit the accuracy of the simulation results.

Calibrating simulation models to match measured data and validating the accuracy of simulation results against real-world performance are essential but challenging tasks. Calibration involves adjusting model parameters to minimize the difference between simulated and measured energy consumption. Validation verifies the accuracy and reliability of simulation models by comparing simulated results with actual building performance. Research by Sartori et al. (2012) and Hensen et al. (2018) emphasizes the importance of calibration and validation to enhance the credibility of building energy simulations. However, limited availability of measured data, uncertainties in measurement techniques, and the dynamic nature of building systems pose challenges in achieving accurate calibration and validation.

Building energy simulation tools are powerful resources for assessing and optimizing the energy performance of buildings. However, challenges and limitations must be addressed to improve the reliability and effectiveness of simulations. This literature review discussed the challenges related to accuracy, data availability and quality, modeling complexity, and calibration issues. To overcome these challenges, efforts should focus on improving accuracy through model validation and calibration, enhancing data availability and quality, developing standardized protocols, and advancing modeling techniques to capture the complexity of building systems. Collaboration among researchers, practitioners, and software developers is essential to overcome these limitations and make building energy simulations more robust and reliable.

2.4 Research Gap

While research on building energy simulation and operational efficiency is expanding globally, there remains a notable research gap specific to the context of commercial buildings in Addis Ababa, Ethiopia. Existing few literature predominantly focuses on energy simulation for design and construction phases, often overlooking the dynamic interplay of energy consumption and operational practices in commercial buildings within the unique environmental, economic, and regulatory context of Addis Ababa. This research gap underscores the need for a comprehensive investigation into the utilization of building energy simulation tools as an operational efficiency strategy within the specific urban landscape of Addis Ababa. Such research is vital to bridge the knowledge gap and provide actionable insights for optimizing energy consumption and sustainability in commercial buildings in this region.

The research gap related to the effective implementation of EnergyPlus and OpenStudio energy simulation tools lies in the limited exploration of their practical utilization within the operational context of commercial buildings, particularly in regions like Addis Ababa, Ethiopia. Prior studies have predominantly focused on employing these tools for design and construction phases, overlooking the intricate dynamics of real-time operational practices impacting energy consumption within the unique environmental, economic, and regulatory landscape of Addis Ababa's commercial buildings.

My study aims to address this gap by delving deeper into the actual application and challenges faced in implementing these simulation tools within the operational settings of commercial buildings in Addis Ababa. By identifying and analyzing the barriers, limitations, and practical constraints hindering the effective utilization of EnergyPlus and OpenStudio in this specific urban context, my research endeavors to offer novel insights that surpass former studies. Furthermore, the study intends to propose targeted improvements and solutions tailored to the Addis Ababa commercial building scenario. This includes developing strategies to optimize the tools' usability, considering local contextual factors, improving accuracy in energy predictions, enhancing user-friendliness, and fostering better integration of these tools into operational practices.

Ultimately, by comprehensively investigating the application challenges and proposing context-specific enhancements for these energy simulation tools in Addis Ababa's commercial building operations, my study seeks to bridge the existing research gap and offer practical recommendations that can significantly improve their effectiveness and applicability in real-world scenarios.

CHAPTER THREE

METHODOLOGY

3.1 Study Area

3.1.1 Addis Ababa city profile

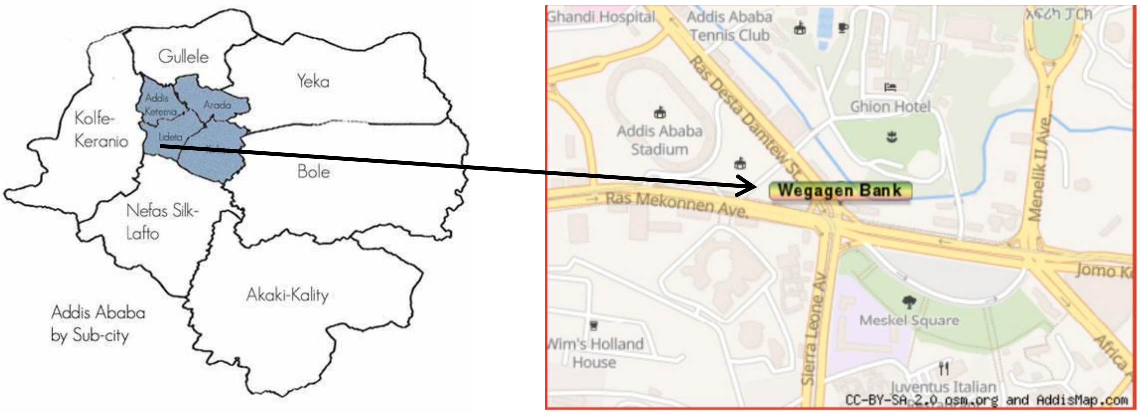


Figure 4: Map and location of Addis Ababa and wegagen bank HQ

At 9°1′48″N 38°44′24″E coordinates, Addis Ababa is almost in the geographic center of Ethiopia, between 8055' and 9005' North Latitude and between 38040' and 38050' East Longitude.It is located at a height of 2,355 meters (7,726 feet).

The city rises to nearly 3,000 meters (9,800 ft) in the Entoto Mountains to the north from its lowest point at 2,326 meters (7,631 ft) asl in the southern periphery. The city has a complicated mix of highland climate zones with subtropical weather, with temperature variations based on elevation and prevailing wind patterns. Due to the city's high elevation and proximity to the equator, which results in mild and excellent weather conditions year-round, monthly temperatures are essentially constant. The city also receives maximum precipitation in the months of July, August and September. The maximum and minimum monthly air temperatures are roughly 20.5°C and 16.2°C, respectively (NASA, 2023).

Ethiopia's federal capital and chartered city is Addis Abeba. Emperor Menelik II established the city in 1886 at the Filwoha hot springs, giving it the name Addis Abeba, which translates to "new flower" in Amharic (Wikipedia, 2023). It has the greatest total land area of any city in the nation, at 526.99 km2. According to an estimate published in July 2012 using data from Ethiopia's May 2007 national population and housing census, it has a population of more than 3 million people, 3,041,002 with a density of 5770.5/km2 (Central Statistical Agency of Ethiopia, 2012). And according to recent information of macrotrends, addis ababa's population reached 5,461,000.

Ethiopia is known for its hydro-power potential, and Addis Ababa has taken advantage of this by producing electricity from hydro-power. The country has also been investing in wind and solar energy to diversify its energy mix. The Ethiopian Electric Power EEP is the state-owned utility responsible for electricity generation, transmission, and distribution in Ethiopia, including Addis Ababa. The electricity demand in Addis Ababa has been increasing due to population growth and urbanization. In response, the government has been implementing policies and programs to promote energy efficiency and conservation. The Ethiopian Energy Authority (EEA) has been tasked with regulating the energy sector in the country, including Addis Ababa. The EEA has been working to promote renewable energy and energy efficiency in the country.

The city is experiencing rapid urbanization, and new buildings are being constructed to accommodate the growing population. The city has been focusing on sustainable and green building practices to reduce the environmental impact of new developments. The Ethiopian Ministry of Urban Development and Construction (MoUDC) is responsible for overseeing the construction industry in the country, including Addis Ababa.

The government has been promoting the use of sustainable building materials, such as bamboo and straw, which are locally available and environmentally friendly. The use of green roofs, which are covered in vegetation, has also been promoted to reduce the urban heat island effect and improve air quality. The city has also been investing in public transportation infrastructure, such as light rail and bus rapid transit systems, to reduce traffic congestion and improve air quality. This city has a subtropical highland climate, which is characterized by mild temperatures and two distinct seasons: the dry season from October to May and the rainy season from June to September. The city is located at an altitude of over 2,300 meters, which results in cool temperatures throughout the year. However, the city has been experiencing changes in weather patterns, including more frequent and intense rainfall, which has led to flooding in some areas. The government has been implementing measures to mitigate the impact of extreme weather events, such as improving drainage systems and building flood barriers.

As a rapidly growing city, it is facing challenges related to energy supply and consumption, new buildings and development, and weather. However, the government has been implementing policies and programs to address these challenges and promote sustainable and green development. By focusing on renewable energy, energy efficiency, sustainable building practices, and climate adaptation, Addis Ababa can continue to grow and develop in a way that benefits both the city and the environment. According to the EEP, Addis Ababa consumed approximately 2,400 GWh of electricity in 2020, which is an increase of 5% from the previous year. This increase can be attributed to population growth and urbanization, as well as economic development in the city. The majority of electricity consumption in Addis Ababa comes from the residential sector, followed by the commercial and industrial sectors. However, the industrial sector has been growing rapidly in recent years, which has led to an increase in energy consumption in this sector.

The government has been implementing policies and programs to promote energy efficiency and conservation in Addis Ababa. The Ethiopian Energy Authority (EEA) has been working to regulate the energy sector and promote renewable energy and energy efficiency in the city. The EEA has also been working with EEP and other stakeholders to develop a national energy efficiency strategy, which aims to reduce energy consumption and greenhouse gas emissions in the country. In addition to electricity, Addis Ababa also consumes significant amounts of other energy sources, such as fuel, wood and charcoal, for cooking and heating purposes. The use of these traditional energy sources contributes to deforestation and indoor air pollution, which has negative health and environmental impacts. The government has been promoting the use of clean cooking technologies, such as liquefied petroleum gas (LPG) and biogas, to reduce the reliance on traditional energy sources and improve indoor air quality.

Overall, the statistics of energy consumption in Addis Ababa highlight the need for sustainable and efficient energy use in the city. By promoting renewable energy, energy efficiency, and clean cooking technologies, Addis Ababa can reduce its environmental impact and improve the quality of life for its residents.

3.2 Research Type / Research Design

The research design employed in this study is a combination of quantitative and qualitative approaches, incorporating elements of social constructivism and pragmatism. These research paradigms have been strategically selected to holistically investigate and enhance building energy simulation for the purpose of achieving energy efficiency.

3.2.1 Quantitative Approach

This approach is rooted in the belief that research should focus on problem-solving and practical outcomes, aligning perfectly with the goal of optimizing energy usage in buildings. By utilizing this approach, the study seeks to develop and analyze models through simulation, enabling the quantification of energy consumption and efficiency improvements. The pragmatic orientation of this quantitative aspect ensures that the research contributes directly to real-world solutions and enhances the feasibility of implementing energy-efficient practices in building design and operation.

3.2.1.2 Model and Analytical Simulation

In accordance with the pragmatic perspective, the quantitative phase of the research involves the development and utilization of models for analytical simulations. These models are constructed based on comprehensive data collected from various sources, including building specifications, climate conditions, occupancy patterns, and energy consumption trends. Through analytical simulation, numerical representations of energy consumption patterns are generated, allowing for the quantification of energy efficiency improvements under different scenarios.

The model development process entails the identification and incorporation of key variables that significantly influence energy consumption, such as building materials, insulation, HVAC systems, and renewable energy sources. The simulations involve manipulating these variables to observe their impact on energy efficiency, thereby facilitating evidence-based decision-making in building design and energy management.

3.2.2 Qualitative Approach

To address the qualitative dimension, the research engages in qualitative data collection methods such as surveys, interviews, and observations to understand the perspectives, attitudes, and behaviors of occupants, facility managers, and other stakeholders. These qualitative insights help uncover subjective factors that influence energy consumption and efficiency, shedding light on the socio-cultural dynamics that impact building energy performance. Through an inductive approach, the study allows themes and patterns to emerge from the qualitative data, contributing to a more holistic understanding of energy usage within buildings.

3.2.3 Integration of Approaches

The integration of both quantitative and qualitative approaches creates a comprehensive research design that captures both the technical and human aspects of building energy simulation for energy efficiency. By merging the pragmatic focus on practical solutions with the social constructivist acknowledgment of contextual influences, the research endeavors to provide a multi-dimensional perspective on energy efficiency enhancement. This design ensures that the findings are not only theoretically sound but also practically applicable, making a significant contribution to the field of sustainable building practices and energy management.

3.3 Selection of Sample Building / Case sample design

Commercial, residential, public and industrial buildings are the different types of buildings in Addis Abeba. Residential buildings are houses, condos, or other abodes where people reside. Public structures include those like schools, churches, mosques, and... Likewise, an industrial building is a structure utilized for industrial purposes; examples include breweries, factories, mines, power plants, refineries, mills,... A structure utilized for retail or business purposes is referred to as a commercial building. It frequently serves multiple purposes, including those of an office, bank, bar, coffee shop, convention center, shop, store, hotel, restaurant, and grocery store.

Recently, Addis Abeba has experienced a spike in construction, with tall structures sprouting up all over the city. Additionally, a number of upscale services have come to be offered, and more commercial buildings are currently being built. In this thesis, a case study of a typical sample building from a particular sector of commercial buildings in Addis Abeba is conducted. This case study's objective is to show current practices and the degree to which energy efficiency measures are being implemented throughout the entire building operation system while also providing insight into the design of the building. It displays the building's design or base case energy efficiency and details which functional areas can accomplish energy conservation in these buildings, as well as the approach that can be used to reach a better result. This is accomplished by looking at the case study building's design and operational data.

The fastest-growing sector in Addis Abeba and the Ethiopian construction industry is a retail sector. It is also probably in a better financial and awareness position to invest in energy management and conservation techniques. To describe the strategy that can be used to produce the desired result, a thorough understanding of the operating system designs of real-life commercial buildings is necessary. As a result, the consultancy firm that designed the chosen sample existing building has provided the necessary design drawing and specification files. Even though it was found limited, by visiting the buildings and interviewing the building managers, actual operational data and information are also acquired. The data gathered from the chosen building is then used to analyze the potential for energy conservation, to determine the base case energy consumption of conventional structures, to simulate the whole building energy consumption, and to Choose the most effective energy efficiency measures that can be used through Theoretical Framework. It is also used to pinpoint both strengths and weaknesses in order to provide real-world solutions for new approaches. The next section of this paper contains the case study.

3.3.1 Building description: Wegagen Bank Headquarters [High-rise building]


Figure 5: Wegagen Bank Head Quarters

Building Profile Overview

Location: Addis Ababa, Ethiopia

Building type: High-rise commercial building for Bank HQ

Total Floor Area: 1,800 square meters

Project scope: 107m (351 ft 1/2in) in height , 23 storey

Number of buildings/towers - 1

Date of Completion: Jan, 2017 G.C.

Building programs

- Indoor Spaces: shops, corridor, office space, restaurant with kitchen, restrooms
- Outdoor Spaces: terrace, balcony

3.3.2 Key Concepts in Building Energy Simulation

Energy Modeling: Energy modeling involves creating a virtual representation of a building and its energy systems. It includes defining the building geometry, material properties, occupancy schedules, and equipment specifications.

Weather Data: Accurate weather data is crucial for building energy simulation. Historical weather data or representative weather files are used to simulate the impact of external conditions on the building's energy performance.

Building Envelope: The building envelope comprises the external elements that separate the interior and exterior environments. It includes walls, roofs, windows, doors, and insulation. Simulating the building envelope helps assess its thermal performance and identify potential areas of heat gain or loss.

HVAC Systems: Heating, ventilation, and air conditioning (HVAC) systems play a vital role in a building's energy consumption. Simulation enables the evaluation of HVAC system performance, sizing, and control strategies, optimizing energy efficiency and occupant comfort.

Lighting and Electrical Systems: Simulation models also consider lighting systems and electrical equipment to assess their energy consumption and identify opportunities for energy savings through efficient lighting design and equipment selection. Occupant Behavior: Occupant behavior has a significant impact on a building's energy consumption. Factors such as occupancy patterns, thermostat settings, and user interactions with lighting and equipment can influence energy usage. Building energy simulation takes into account occupant behavior models to assess the effect of human actions on energy performance.

Simulation Software: Building energy simulation relies on specialized software tools that facilitate the creation, analysis, and visualization of simulation models. These software packages incorporate algorithms and mathematical models to simulate energy flows and provide valuable insights into a building's energy performance.

3.3.3 Steps in Conducting Building Energy Simulation

The process of conducting building energy simulation typically involves the following steps:

Data Collection: Gathering relevant data such as building plans, material specifications, occupancy schedules, and equipment details.

Model Creation: Developing a virtual model of the building using simulation software. This includes defining the building geometry, properties, and system configurations.

Weather Data Integration: Incorporating weather data to simulate the building's response to external conditions.

Calibration: Fine-tuning the simulation model by comparing simulated results with actual energy consumption data to ensure accuracy.

Scenario Analysis: Running simulations for different design alternatives, operational strategies, and energy-saving measures to evaluate their impact on energy performance.

Performance Evaluation: Analyzing simulation results to assess energy consumption, thermal comfort, indoor air quality, and other performance parameters.

Case Studies: Presenting real-world examples and case studies showcasing the successful application of building energy simulation. These case studies highlight energy-efficient design strategies, retrofit solutions, and the resulting benefits in terms of energy savings and occupant satisfaction.

Challenges and Limitations: Building energy simulation is a powerful tool, but it also comes with certain challenges and limitations. Some common challenges include the availability of accurate data, the complexity of modeling certain systems, and the need for expertise in using simulation software effectively. It is important to understand these limitations and interpret simulation results with caution.

Building energy simulation is a fundamental tool for optimizing energy consumption and improving the performance of buildings. By accurately modeling and analyzing energy flows, stakeholders can make informed decisions to enhance energy efficiency, reduce costs, and minimize environmental impact. The key concepts discussed in this article, including energy modeling, weather data, building envelope, HVAC systems, lighting and electrical systems, and occupant behavior, provide a comprehensive understanding of the fundamentals involved in building energy simulation. By embracing this technology and incorporating it into the design and operation processes, we can create sustainable buildings that prioritize energy efficiency and occupant comfort.

3.4 Building Energy Simulation and Analysis with Openstudio

In this section, we explore the fundamental aspects of building simulation and introduce the powerful software tool called "OpenStudio." The significance of building simulation in comprehending energy performance and optimizing building designs is emphasized through an initial overview. Subsequently, OpenStudio, a widely utilized and versatile software package for building energy analysis, is thoroughly examined. We delve into its features, functionalities, and its ability to streamline the creation of detailed building models for simulation purposes. A step-by-step guide is presented on the following section , providing readers with practical insights on navigating OpenStudio and leveraging its capabilities to conduct accurate and insightful simulations. Continuing from the previous section, our focus shifts to a specific case study, wherein OpenStudio is utilized to showcase the simulation input data and procedures employed. Through this comprehensive walk through, readers of this scientific paper gain a deeper understanding of the practical implementation of building energy simulations, including the selection of parameters, integration of weather data, and optimization of simulation settings.

As mentioned earlier in the previous section, the process of building energy simulation is far more intricate than a basic procedural analysis. It entails a laborious task of gathering and interpreting data, followed by the painstaking effort of translating the collected data into the selected simulation software, which in this case is openstudio. In this section, we will provide a detailed walkthrough of the simulation process for the specific case study we have chosen. We will outline each step involved, offering a comprehensive understanding of the methodology employed.

3.4.1 Adding Weather to a model

To start the process, the first step is to locate and obtain the weather file for our model's location. It is recommended to find a weather file specifically for the city or area of interest. These weather files, available in EPW format, can be freely downloaded from the website https://energyplus.net/weather. Once downloaded, it is helpful to use the DView Application bundled with OpenStudio to examine the data contained within the weather file (Figure 6), becoming familiar with the information it provides. A weather file plays a crucial role in building energy simulation, as it provides essential information about the climate conditions of a specific location, which in our case is Addis Ababa city. In the context of the simulation process described earlier, the weather file serves as a fundamental input for accurately modeling and analyzing the energy performance of a building. Obtaining a suitable weather file for the desired location is of utmost importance. The recommended approach is to search for weather files associated with the same city or area where the building is situated. Weather files in EPW format, freely available from platforms like https://energyplus.net/weather, offer a comprehensive set of climate data for various locations around the world. Therefore, we chose Addis Ababa as it is our case study location.

Once the weather file is downloaded, it can be examined using tools like the DView Application bundled with OpenStudio. This allows users to gain familiarity with the data contained within the file, understanding the specific parameters and variables it provides, such as temperature, humidity, solar radiation, wind speed, and more. Such information is vital for accurately simulating the building's energy performance and assessing its environmental impact. The weather file is then integrated into the OpenStudio Model, linking it to the building simulation. By attaching the weather file, the Model gains access to location-specific details like latitude, longitude, and elevation.

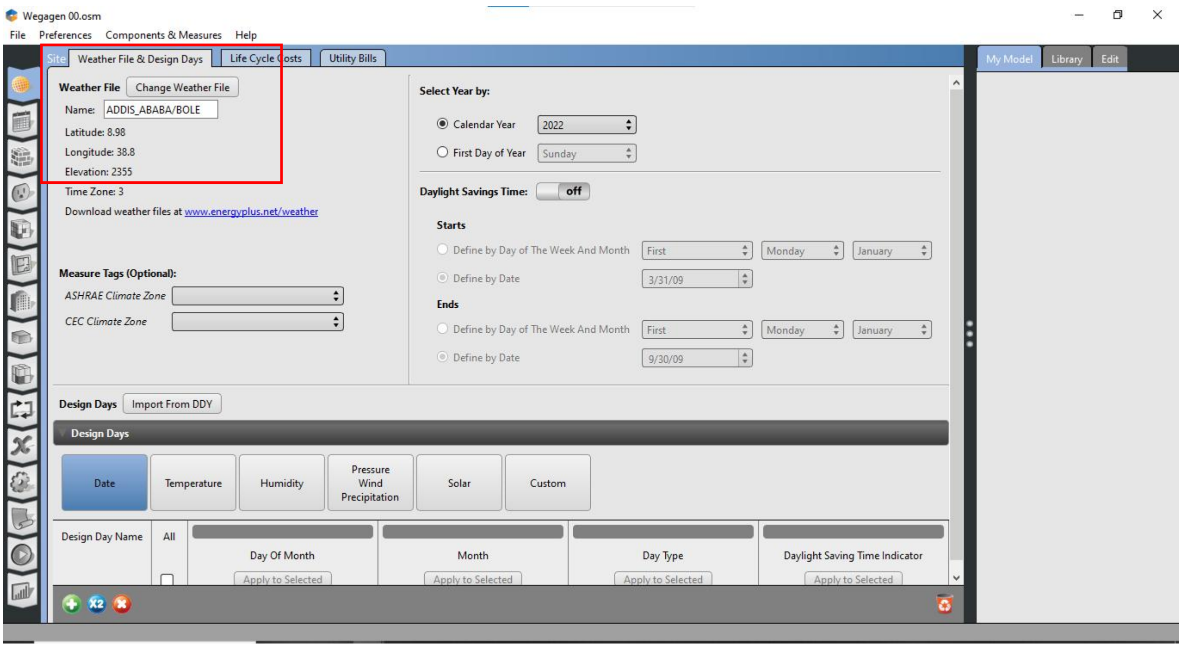


Figure 6: Adding EPW and DDY files in the OpenStudio Application

This information enables the simulation software to account for the unique climate conditions of the chosen site, enhancing the accuracy and reliability of the energy analysis.

Regularly saving the Model and creating backups throughout the simulation process is highly recommended. This practice ensures that the Model can be restored to a previous state if any errors occur or mistakes are made, saving time and effort.

In summary, a weather file is a vital component of building energy simulation. It provides the necessary climate data to accurately model and analyze the energy performance of a building. By incorporating location-specific information, the weather file enhances the accuracy and reliability of the simulation results, enabling informed decision-making for optimizing energy efficiency and environmental sustainability in building design and operation.

3.4.2 Creating new materials

Once the weather file and the initial setup of the OpenStudio Model are completed, the next crucial step in the simulation process is defining properties for the materials used in the building. This is achieved through the Constructions Tab in the OpenStudio Application.

Within the Constructions Tab, there are three Sub-Tabs: Construction Sets, Constructions, and Materials. To begin, we focus on defining the basic materials, so we select the Materials Sub-Tab. Here, on the left side of the Materials Sub-Tab (Figure 7), you will notice various categories for Material Object types, such as "Materials," "No Mass Materials," and others. These Material types in OpenStudio closely align with the materials supported by EnergyPlus. For detailed information about these material types, one can refer to the EnergyPlus I/O Reference and Engineering Guides. Additionally, Table 4 provides a mapping between Material types in OpenStudio and the corresponding materials in EnergyPlus. In our case, we used the “materials” and “glazing window materials” material types.(see Appendix 1 and table 5) The rest of the material types are imported from the “library”.

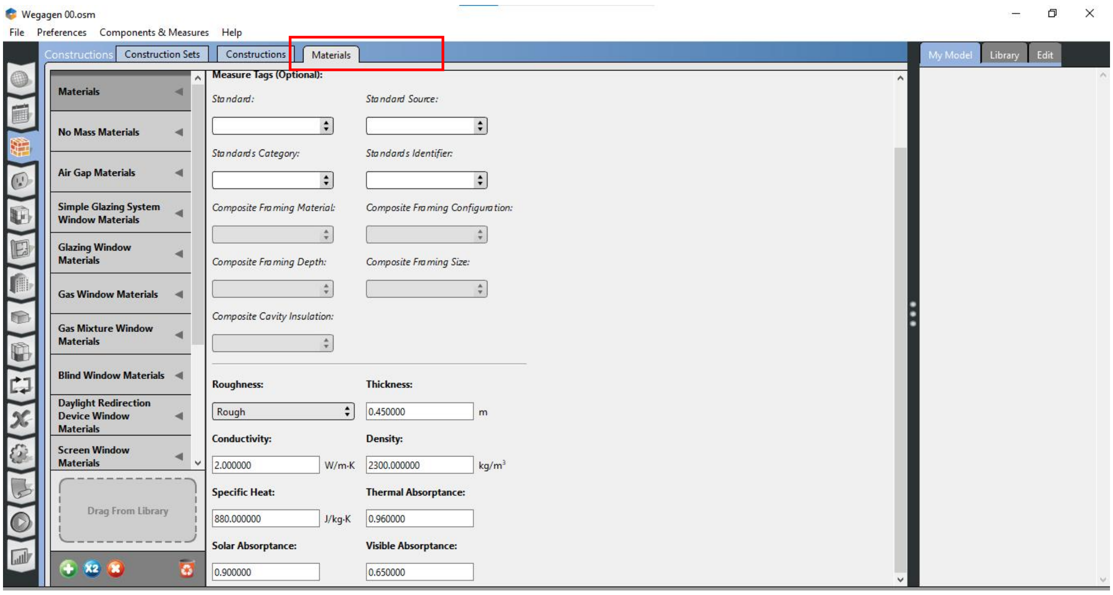


Figure 7: The OpenStudio Application Constructions Tab and Materials Sub-Tab

To start defining a new Material, we create an Object of type "Materials." By selecting that label and pressing the designated “+" button, a new Object is generated (Figure 8). We assign the name "C-40 Reinforced Concrete 1" to this Object and configure its properties as specified in Appendix 1. This process is then repeated for the remaining material objects listed in the Appendix 1.

Defining the properties of materials is vital as it allows for an accurate representation of their thermal characteristics within the simulation. Materials play a significant role in determining the heat transfer and energy performance of a building. By accurately modeling the properties of materials, such as insulation levels, conductivity, and density, the simulation can more accurately predict the building's energy consumption and thermal behavior.

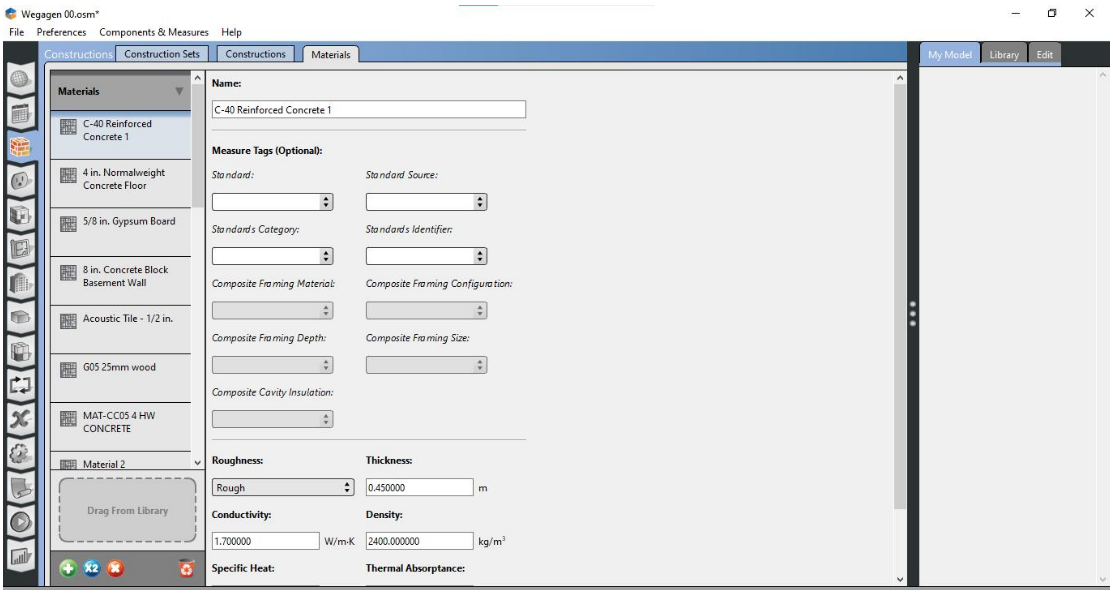


Figure 8: creating a new Material in the OpenStudio Application

Table 4: OpenStudio to EnergyPlus Material type mapping

OpenStudio Material Type	EnergyPlus Material Type
Materials	Material
No Mass Materials	Material:NoMass
Air Gap Materials	Material:AirGap
Simple glazing system window Materials	WindowMaterial:SimpleGlazingSystem
Glazing window Materials	WindowMaterial:Glazing
Gas window Materials	WindowMaterial:Gas
Gas mixture window Materials	WindowMaterial:GasMixture
Blind window Materials	WindowMaterial:Blind
Screen window Materials	WindowMaterial:Screen
Shade window Materials	WindowMaterial:Shade
Air wall Materials	N/A
Infrared transparent Materials	Material:InfraredTransparent
Roof vegetation Materials	Material:RoofVegetation
Refraction extinction method glazing window Materials	WindowMaterial:Glazing:RefractionExtinctionMethod
Glazing group thermochromic window Materials	WindowMaterial:GlazingGroup:Thermochromic

Source :(Larry and Andrew, 2018, p. 31)

The correct specification of material properties ensures that the simulation results reflect the real-world behavior of the building. This, in turn, enables informed decision-making regarding the selection of materials and construction methods to optimize energy efficiency and occupant comfort.

In summary, the definition of material properties within the OpenStudio Model is a crucial step in the simulation process. By accurately representing the thermal characteristics of materials, it allows for a more precise prediction of the building's energy performance. This information aids in making informed decisions regarding the selection of materials and construction methods to achieve energy-efficient and sustainable building design and operation.

Table 5: Glazing window materials

Property	Double Glazed Clear Glass	Aluminum Windows
Solar Transmittance at Normal Incidence	0.8	0.6
Front Side Solar Reflectance at Normal Incidence	0.1	0.3
Back Side Solar Reflectance at Normal Incidence	0.1	0.3
Visible Transmittance at Normal Incidence	0.85	0.7
Front Side Visible Reflectance at Normal Incidence	0.05	0.25
Back Side Visible Reflectance at Normal Incidence	0.05	0.25
Infrared Transmittance at Normal Incidence	0.6	0.4
Front Side Infrared Hemispherical Emissivity	0.9	0.8
Back Side Infrared Hemispherical Emissivity	0.9	0.8
Conductivity	1	2.5
Dirt Correction Factor for Solar and Visible Transmittance	0.95	0.9

3.4.3 Creating Construction Assemblies

After incorporating Materials into the Model, it is time to combine them to form Constructions using the Sub-Tab (Figure 9). Choose the "Constructions" Object type and click the "+" Button to generate a new Construction Object. Similar to the Sub-Tab, the right-hand panel allows inspection of objects currently present in the working Model or library. To add Materials, click either "My model" or "Library" option and select the desired ones to drag onto the "Drag from Library" drop zone in the Construction editor. This action includes the selected Material into the Construction currently being edited. To remove Materials from a Construction, click the corresponding "X" Button next to it. Remember that Construction layers follow a top-to-bottom order, with the outermost layer on top and moving towards the interior of the Space as you progress down the layer list in the editor.

Keep in mind that Libraries can include complete Constructions as well. When selecting the Constructions category, it will display any Constructions that might have been imported from an OSM.

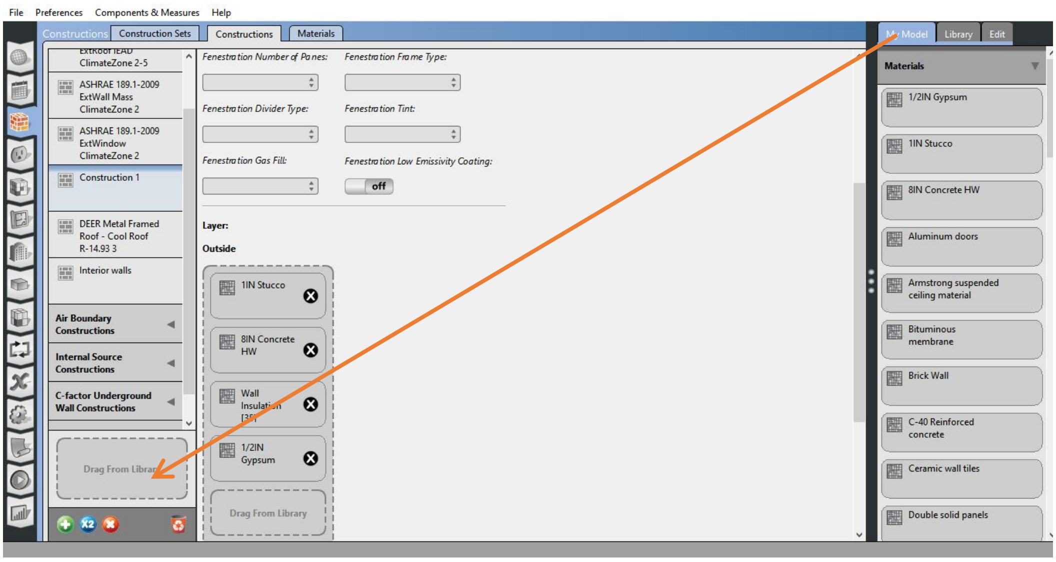


Figure 9: creating an external wall construction in the OpenStudio Application

Similar to Materials, Library Constructions can be conveniently dragged and dropped into the working Model, saving time and minimizing the chances of making mistakes. By adding Constructions in this way, all the necessary Materials from the Library are automatically included without any additional effort needed (Figure 10).

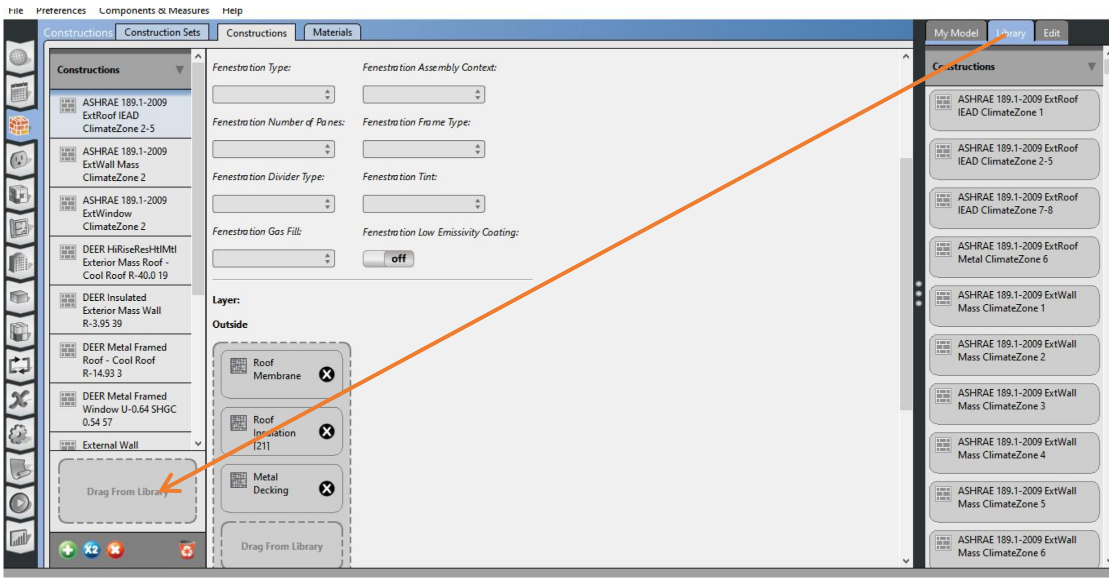


Figure 10: Importing an external roof construction from the Library

3.4.4 Creating Geometry with the OpenStudio Floor Plan Editor

We're now prepared to define the building's geometry after giving our model access to weather files and a construction set. The Geometry tab in OpenStudio software is used to create and modify the building geometry for energy modeling purposes. It allows you to define the shape, size, and layout of your building. To use the Geometry tab:

Launch OpenStudio: Open the OpenStudio application on your computer. You can usually find it in the installed programs or applications list.

Create or open a project: Once OpenStudio is launched, create a new project by selecting "New" from the File menu, or open an existing project by selecting "Open" and navigating to the project file location.

Access the Geometry tab: In the OpenStudio interface, you will find a series of tabs at the top of the window. Click on the "Geometry" tab to access the building geometry options.

Define building footprint: To start creating your building geometry, click on the "New Space" button. This will allow you to define the building footprint by clicking on the drawing canvas and adding points to create a polygonal shape. Click on each corner of the building footprint to complete the shape. Or you can import CAD floor plans converted into ".png" or ".JEPG" image format to the model and work to modify details necessary for the energy modeling purpose.

Edit building footprint: After creating the building footprint, you can edit it by selecting the "Edit Space" button. This will enable you to move or delete individual points, add new points, or reshape the building footprint as needed.

Define floors and ceilings: Once the building footprint is defined, you can add floors and ceilings to your building by selecting the "Add Floor" or "Add Ceiling" buttons. This will create additional levels or stories of your building. You can specify the height of each floor or ceiling by entering the desired value.

Add windows and doors: To add windows and doors to your building, click on the "Add Surface" button. This will allow you to draw rectangular surfaces on the building walls. You can specify the dimensions and position of each window or door. Additionally, you can assign different constructions or materials to these surfaces to represent their thermal properties.

Modify building elements: To modify any element of the building geometry, select it by clicking on it, and then use the available editing tools. You can move, resize, or delete building elements such as walls, windows, doors, or floors. You can also assign different properties to each element, such as construction types, shading devices, or occupancy schedules.

Review and finalize the geometry: Once you have finished creating and modifying the building geometry, review the geometry in the 3D view provided by OpenStudio. Make sure all the building elements are correctly represented and positioned. Adjust or refine the geometry as necessary.

Save the project: Finally, save your project by selecting "Save" or "Save As" from the File menu. Choose a location and provide a name for the project file. This will allow you to access and load the geometry in future sessions of OpenStudio. To access the geometry editor and previewer in the OpenStudio Application, click the Geometry Tab. At first, you'll notice an empty window because there is no geometry in the current Model yet, there is an empty window on the Sub-Tab. The floor plan geometry editor for OpenStudio can be accessed by clicking the Sub-Tab. The user is initially given some introduction material and the choice to design a new floor plan by the editor.

When it comes to our case, we already prepared our floor plans converted to ".png" format for each floors of our case study building. Therefore we will import the image (Figure 11). Then will have to assign Construction sets, space types, thermal zones, etc.to regions of the floor plan. We will also assign windows, doors, etc. to surfaces on the floor plan.

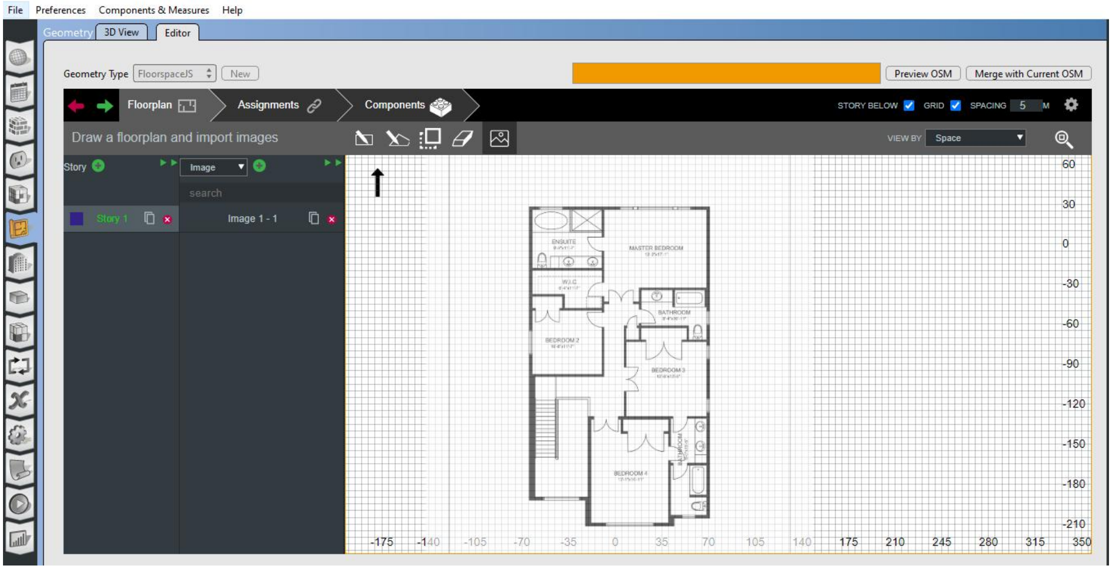


Figure 11: Importing floor plans to the OpenStudio model

Notice that the editor opened with a single Story and Space already created for us. They are named "Story 1" and "Space 1-1" respectively. All that remains is to select the drawing tool to create a boundary for "Space 1-1" as shown in Figure 12. If you make a mistake, use the undo/redo (<-/->) Buttons near the upper left-hand corner of the window. Drawing adjacent rectangles will add to the currently selected Space, while the tool can be used to remove rectangular regions.

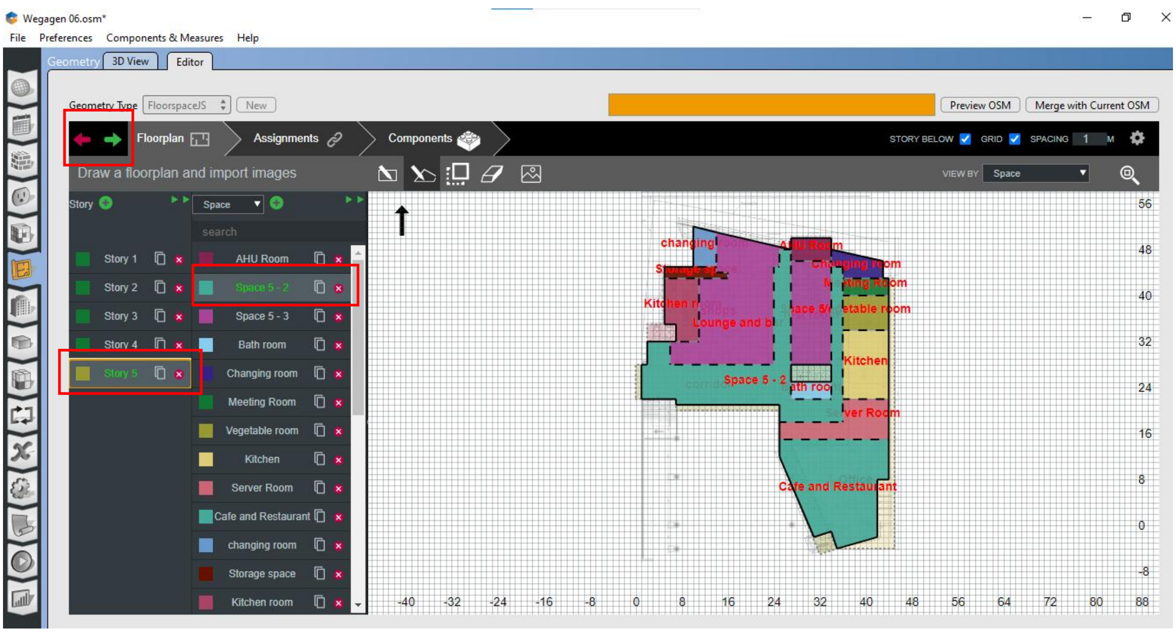


Figure 12: Drawing and assigning space types to each of the floor plans

The height of our single Space is defined within the Story that contains it. Stories may be added and modified at the Stories pane of the editor window. Click on the Button to expand the Story editor as shown in Figure 13, and change the floor to ceiling height from its value to 2.7 m.

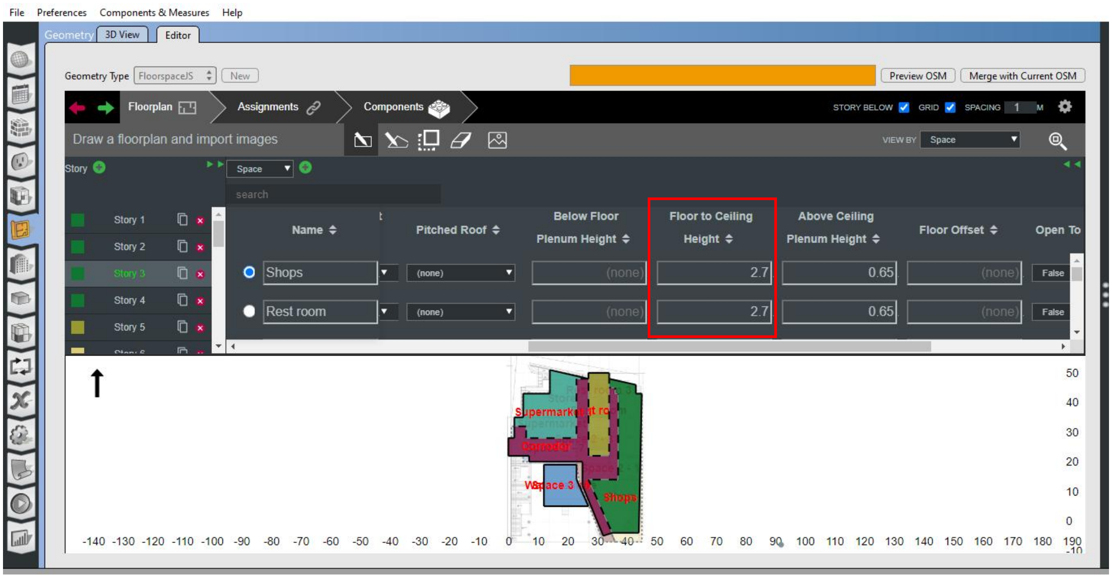


Figure 13: Editing floor height in the OpenStudio Application

Near the top of the editor, click on the Assignments Sub-Tab. This Sub-Tab allows us to assign Construction Sets, Thermal Zones, Space Types, and more to sections of the Model. By default, the Assignment choice menu lists “Thermal Zones” on the left hand side of the window. Our Model doesn’t yet have any, so press the “+” Button immediately to the right of the choice menu to create one, then click on Spaces to assign it to that Thermal Zone as shown in Figure 15.

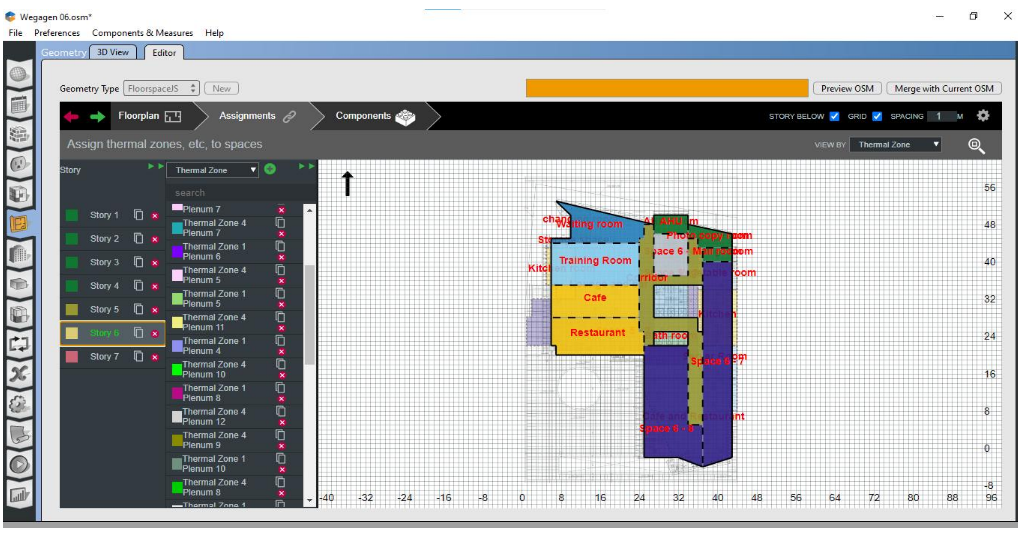


Figure 14: Assigning thermal zones to each spaces

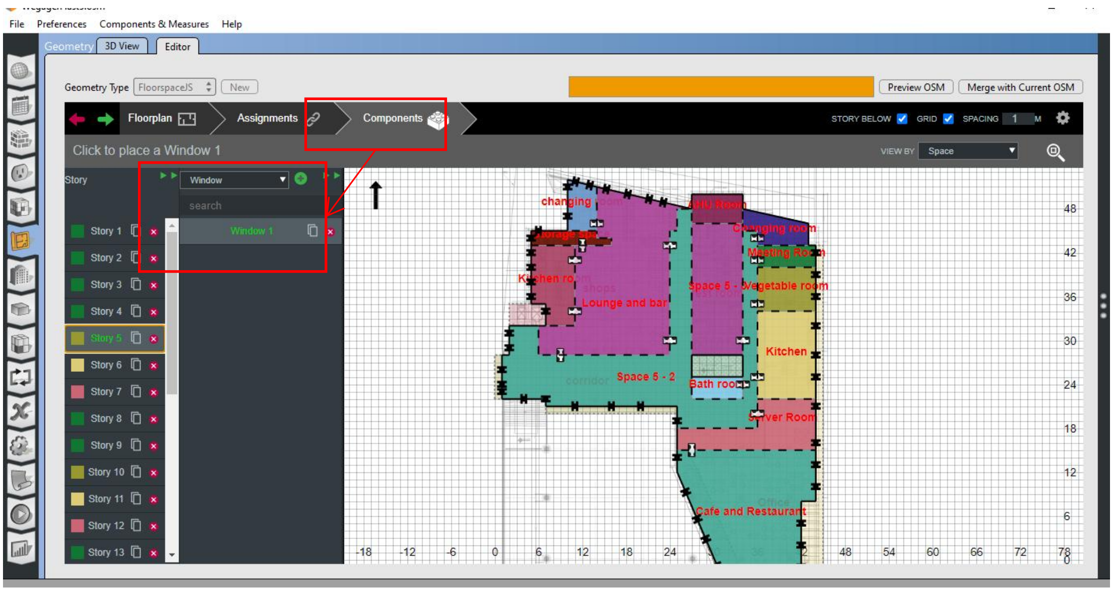


Figure 15: Adding windows and doors to each spaces and floors

Finally, we must add windows to each floors as shown in Figure 14 using the Components Sub-Tab. In the Components Sub-Tab, the Spaces Pane changes, allowing us to add Window definitions to the model (Figure 16). Click the Button to add a new definition, then expand it with the adjacent Button.

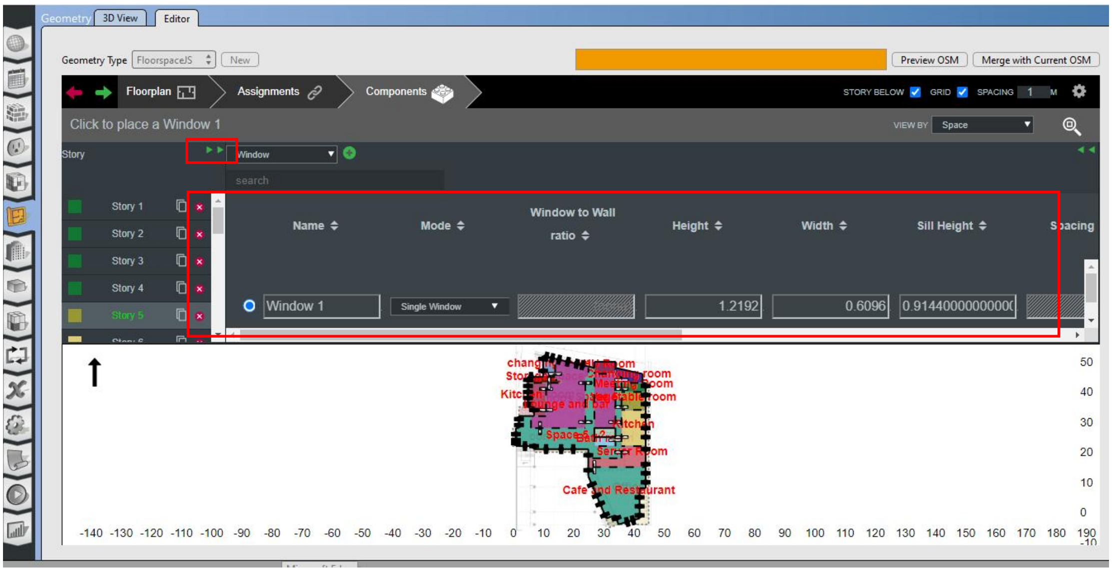


Figure 16: Defining each window types for the floors

The progressive geometry development of the Case study building is put under Appendix 2.

3.4.5 Defining Energy Uses and Spaces

The Loads (Figure 17) Tab is used to insert space load definitions. These definitions can be divided into several types, such as lighting, miscellaneous electric,2 gas, steam, and other fuel. Uses of hot water, humans, and equipment. Definitions of space loads specify a specific kind of load. Lighting loads may include individual table or desk lamps, arrays of linear fluorescent tubes, emergency exit lights, and high intensity discharge (HID) lamps in high bay installations, and many more. Copy machines, coffee pots, microwave ovens, simple refrigerators, laptops, televisions, video game consoles, hair dryers, etc. are all examples of electric plug loads. Common gas loads include ovens or cook tops.

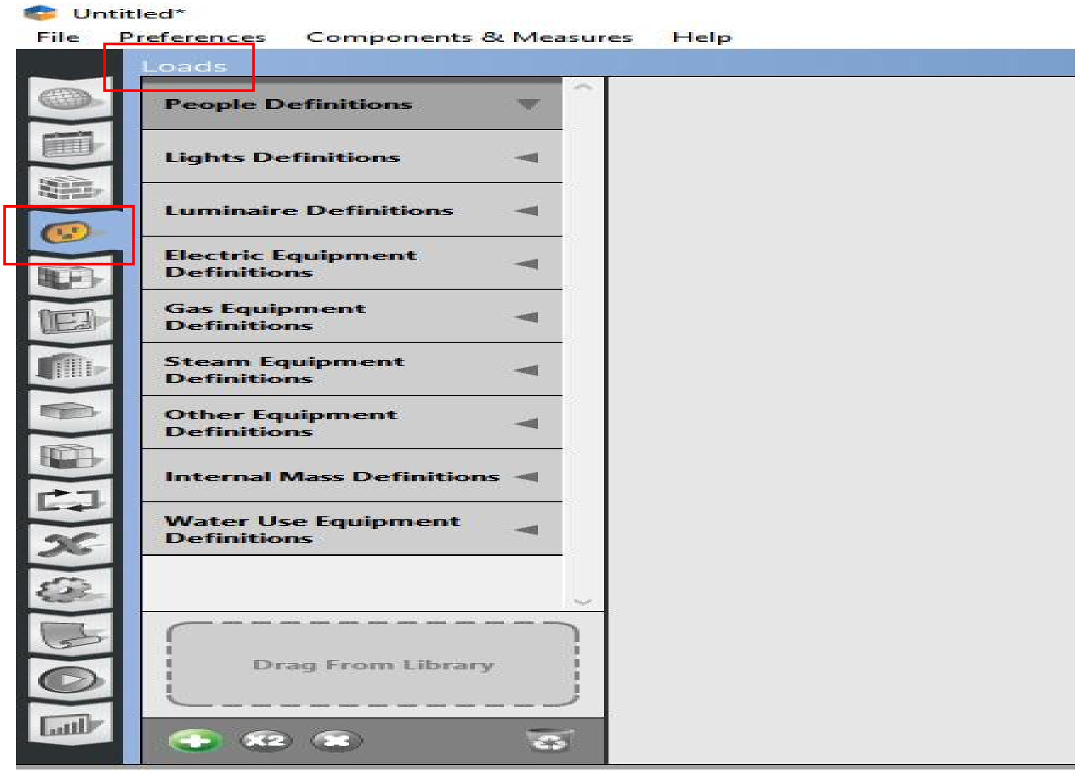


Figure 17: Loads tab

In the "Space Types" tab and "Loads" sub tab, the window changes to a breakdown of loads within each space type as shown in Figure 18 when the Loads Button at the top of the window is clicked. Additional Load Instances can be added by dragging Load Definitions from the right hand into the "Definition" column. Infiltration will appear immediately. The Schedule Set determines how schedules are automatically assigned, but this can be changed if necessary. The modeller can alter the Space Type and Load Names to suit their preferences. Finally, for objects that were defined using unique rated power values, load multipliers may be given (for example, a multiplier of 10 may be applied to the number of computers in a space).

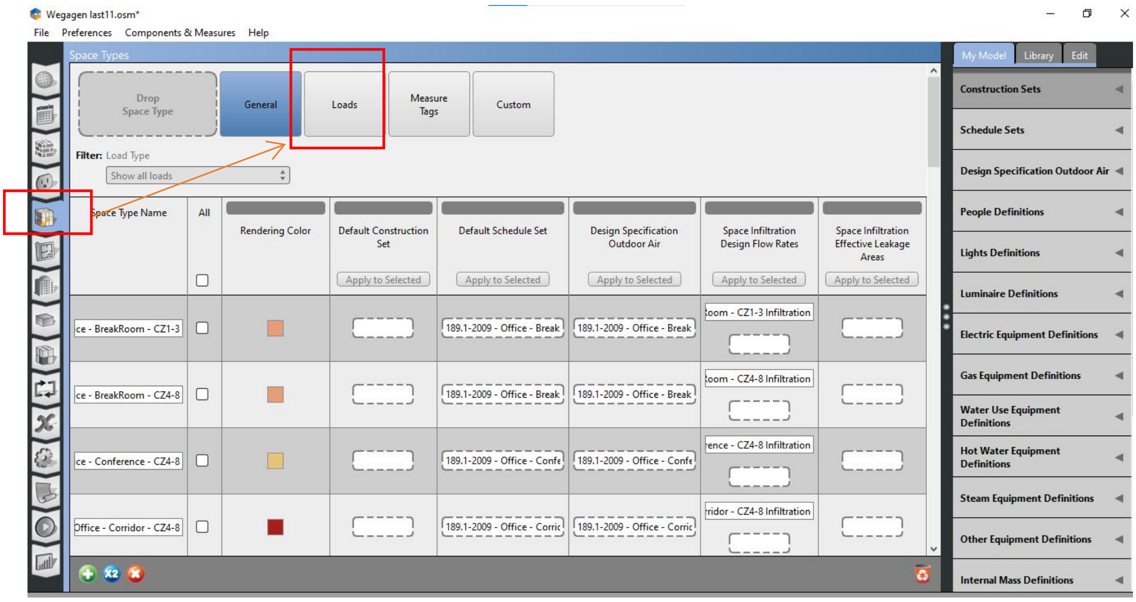


Figure 18: Adding loads to define four office Space Types

The assignment of Space Types can also be done using the Spaces ( ) Tab as in Figure 19. This Tab may appear unnecessary at first glance considering that the floor plan editor offers comparable capability in addition to the convenience of being able to see the locations of the Spaces within the floor plan. However, the Spaces Sub-Tabs give us more functionality and a higher degree of flexibility when setting Space contents, allowing us to edit numerous Spaces on each Floor at once.

The Sub-Tab is shown in Figure 20 being used to inspect the Loads inside each Space. The loads recommended by each Space Type were accurately applied, as shown by a brief comparison with the original definitions in Figure 18. The font colour is one small difference between these two views. While the text in the real Spaces is green, the text in the Space Type descriptions is black. This is a visual indicator provided by Open Studio that data is being inherited and used across the Application. This specific Sub-Tab enables the user to drag in extra loads that will appear in black text and may be exclusive to a certain Space that is otherwise well specified by a Space Type. By the same token, check boxes next to inherited rows may be used to select individual Loads for deletion with the Button. Like Construction Sets, Space Types allow the user to quickly assign activities and loads from manually assembled definitions or Libraries, but they are not restrictive, and Spaces may be customized when necessary

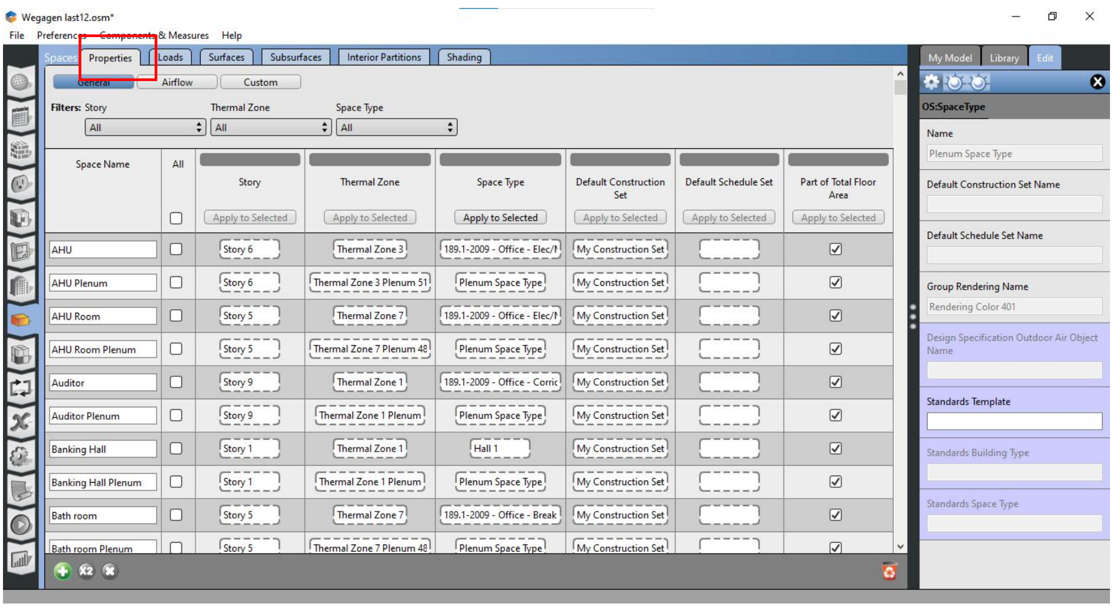


Figure 19: Space assignment Sub-Tab

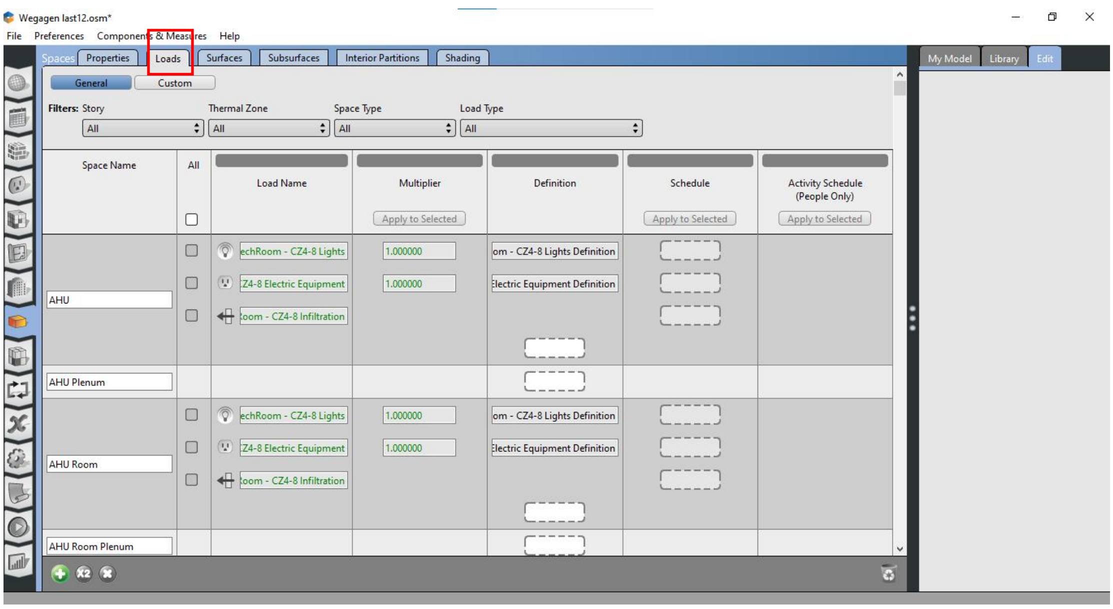


Figure 20: Space load assignments defaulted from Space Type definition

Both the “surfaces” and the “sub-surfaces” The tabs in Figures 21 and 22 similarly use Construction Sets to demonstrate the idea of data inheritance. According to the Surface Type in this instance, the relevant Constructions have been applied to each Surface and Sub-Surface. When necessary, distinct Constructions may be brought in to replace inherited Constructions.

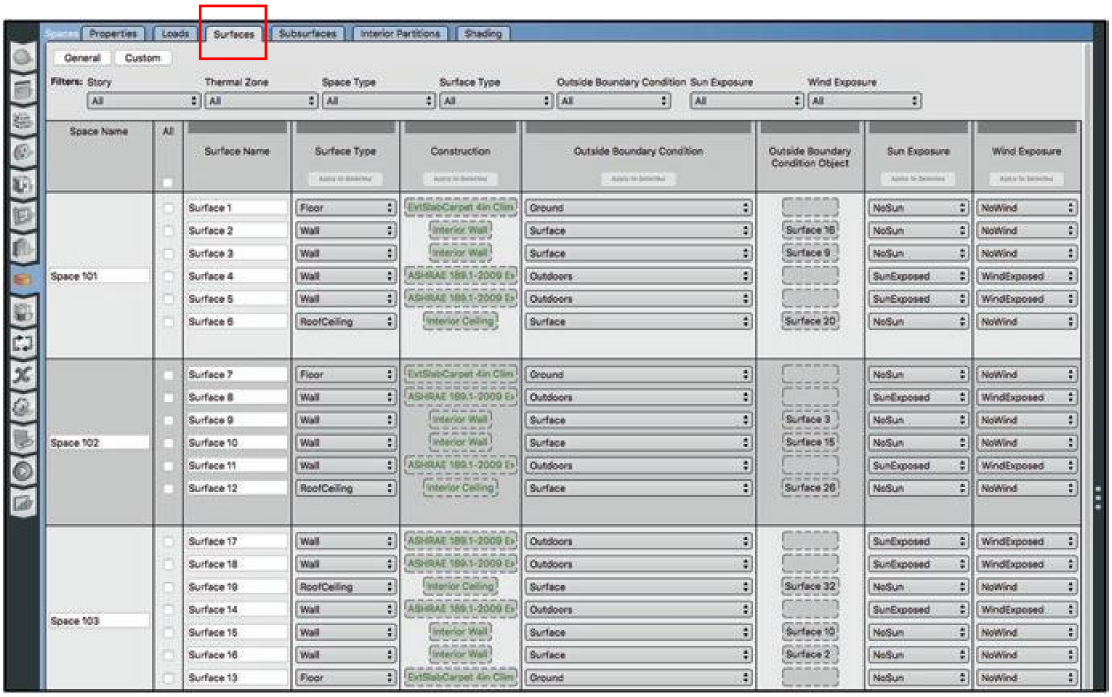


Figure 21: Space Surfaces Sub-Tab with defaulted Construction Set

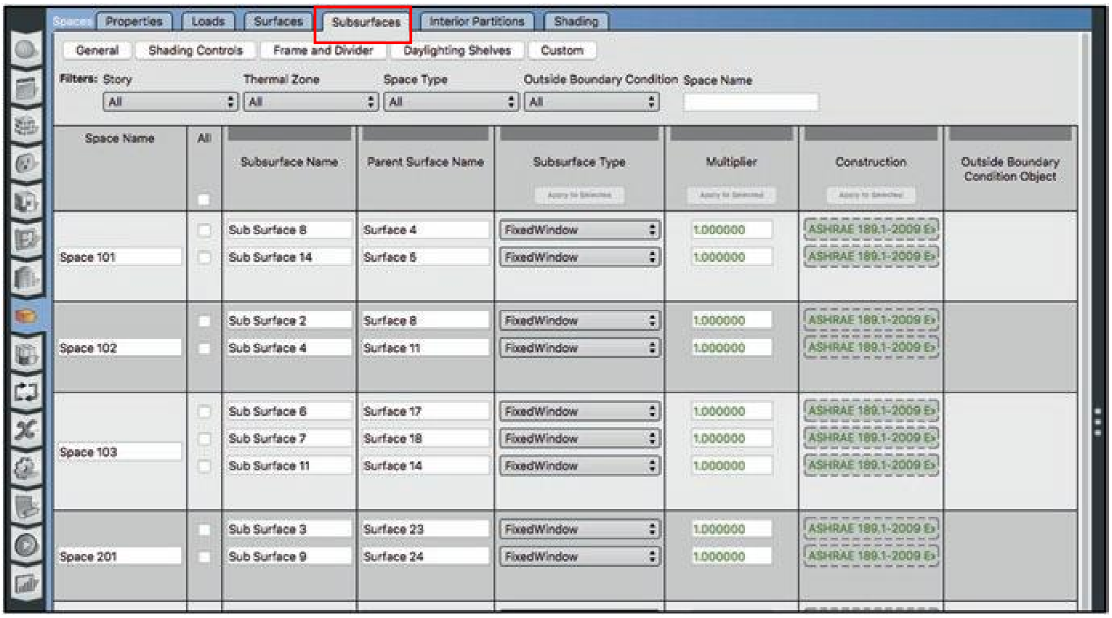


Figure 22: Space Sub-Surfaces Sub-Tab

3.4.5.1 Ideal Air Load Simulation

Creating a Schedule Set

It's time to make changes to the Schedules themselves. Note that the user can specify summer and winter design day profiles as well as a Default Run Period Profile for each Schedule Object by choosing one of them. Select the 'Default Run Period' Profile for each schedule, which has a light blue band next to it, and disregard the design day profile selections. As seen in Figure 23, this enables a graphical tool for editing our Schedules. Notice that the light blue color band next to Default matches the color of each day on the calendar to the right of the window. This indicates that the Default schedule will be used 365 days of the year.

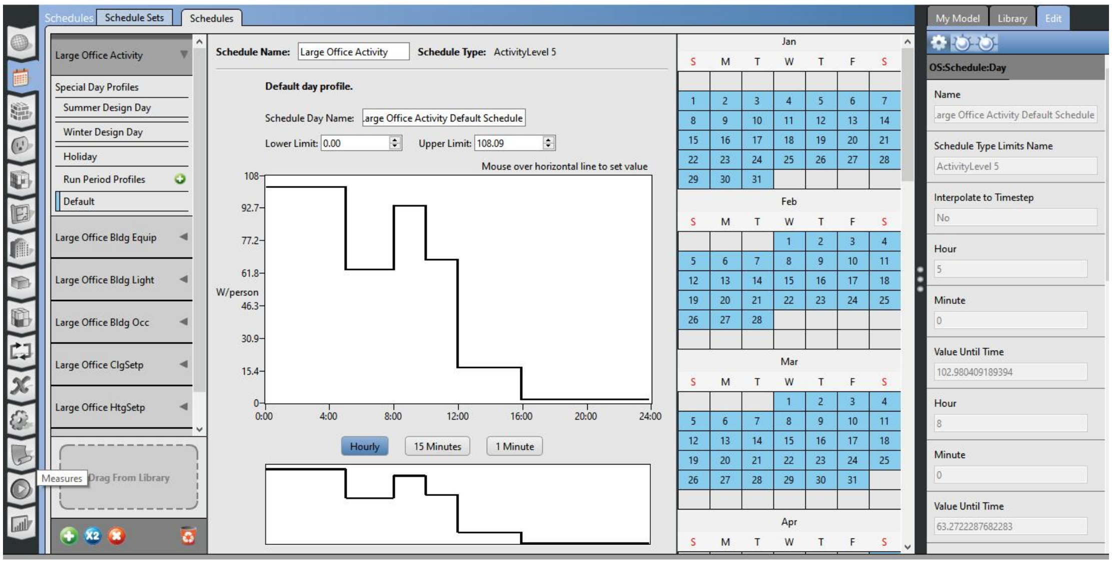


Figure 23: Default activity schedule for the model

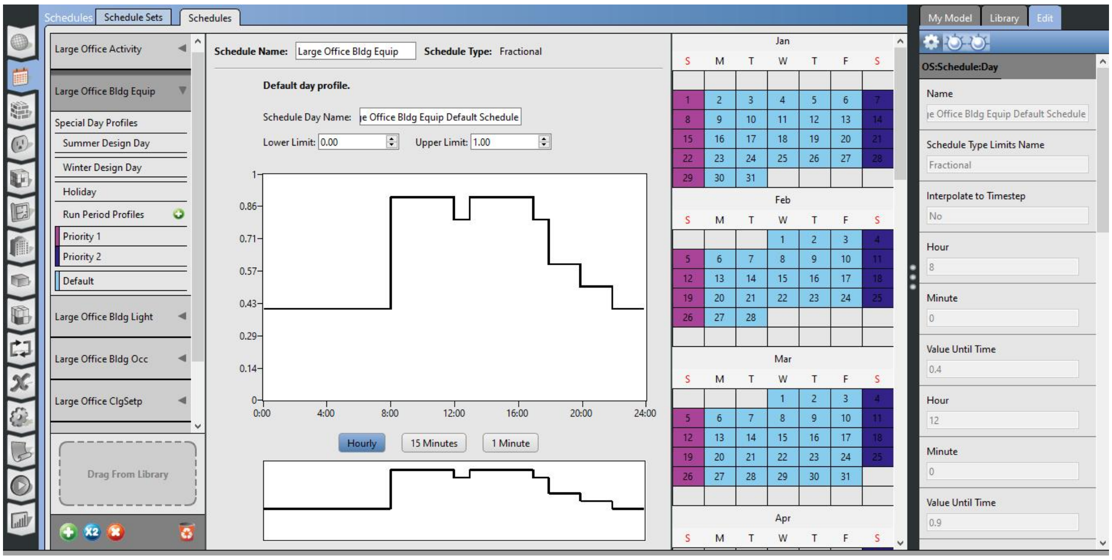


Figure 24: Equipment rule-set schedule for the model

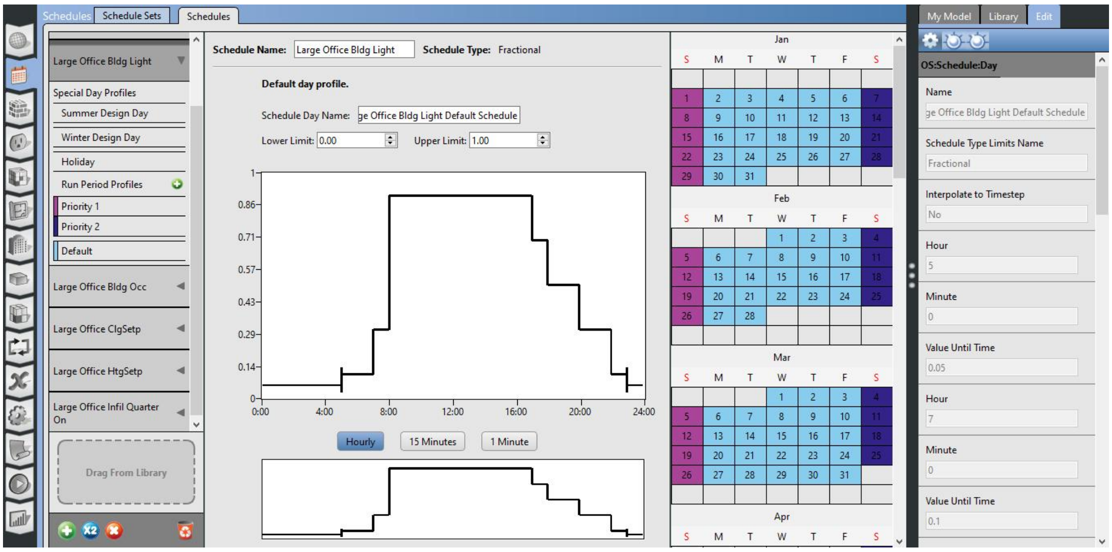


Figure 25:Light rule-set schedule for the model

Having completed the process of editing our rule-set schedule, it is worth observing the presence of diverse schedules tailored to specific aspects of our case, including the People activity schedule, equipment schedule, and light schedule, among others. These schedules serve the purpose of delineating the energy consumption patterns of the building based on the daily estimated values projected throughout the simulated year. Undertaking this endeavor holds significant importance due to its ability to optimize energy management and enhance overall operational efficiency. By carefully designing and implementing these schedules, we can align energy consumption with the anticipated demand, thereby minimizing wastage and maximizing cost-effectiveness. Furthermore, this meticulous approach enables us to maintain a comfortable and productive environment for building occupants while reducing our carbon footprint. Consequently, the undertaking of refining and utilizing these schedules contributes not only to resource conservation but also to the promotion of sustainable practices in line with our organizational goals and societal responsibilities.

3.4.5.2 Defining our Loads

To proceed, let's access the Loads () tab to establish the load definitions for our specific Space Type. In our case study building, we primarily focused on three key loads: People load (Figure 26), Lights load (Figure 27), and Equipment loads (Figure 28). However, it is important to note that due to limitations in the available input data, we recommend considering only these specified load definitions for the sake of accuracy and reliability in our analysis and simulation.

While it would be ideal to incorporate a more comprehensive range of loads that directly impact the energy consumption of the building, such as Luminaire definitions, Gas equipment definitions, Steam equipment definitions, Internal mass definitions, and Water use equipment definitions, the lack of precise data or insufficient information regarding these additional loads may compromise the integrity and validity of our analysis.

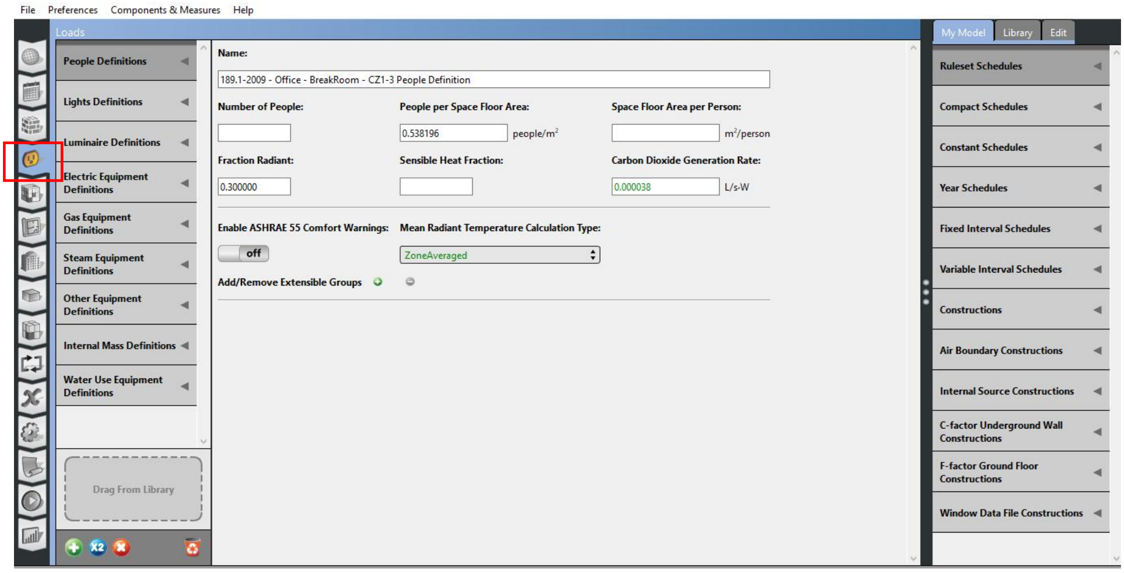


Figure 26: Defining People load for the model

By concentrating on the designated loads that we have reliable and sufficient data for, we can still achieve meaningful insights and conduct a thorough analysis of the building's energy consumption. This approach ensures that our simulation results are based on accurate and verified information, enabling us to make informed decisions and recommendations regarding energy efficiency measures and optimization strategies.

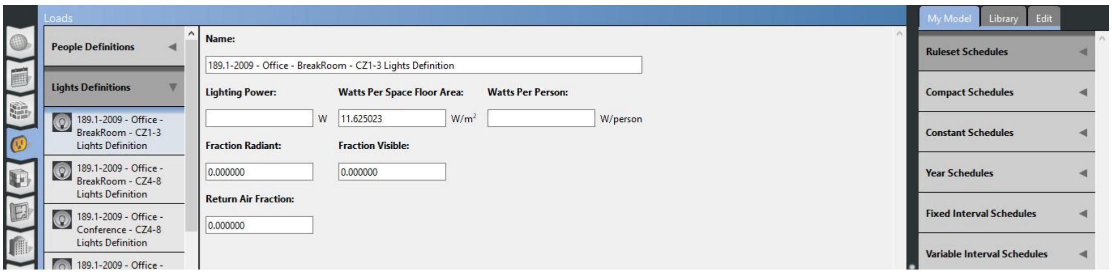


Figure 27: Defining Light load for the model

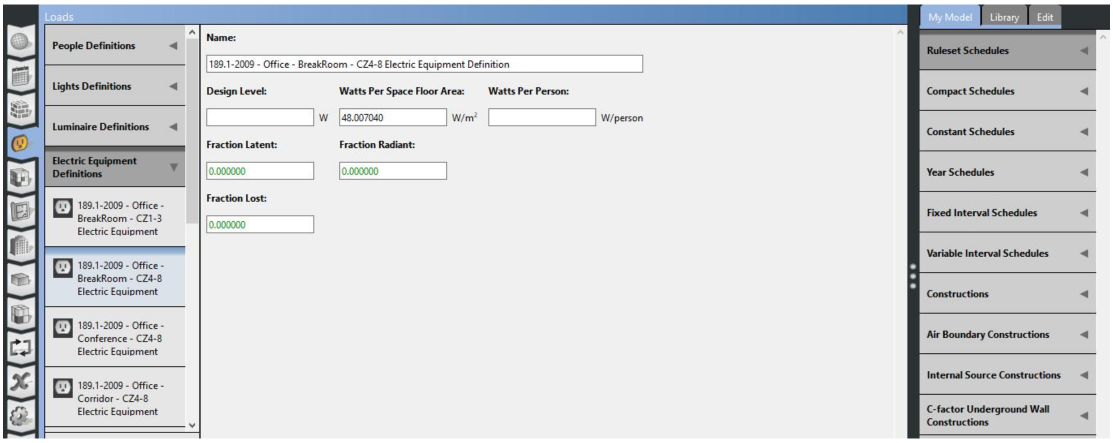


Figure 28: Defining Electric Equipment load for the model

3.4.6 Running the Simulation

The final simulation running on OpenStudio software represents the culmination of a comprehensive and meticulously crafted building performance analysis. Now we can run the model we have created so far. The run simulation tab (Figure 29) will open a window which allows the button to run the simulation. Press on run button (Figure 30) and the simulation result will start to be produced.

Error codes encountered during a simulation run can provide critical information about issues within the simulation process. These codes serve as diagnostic tools to pinpoint errors, allowing users to identify and resolve problems effectively. Whether it's a syntax error in the input file, a convergence issue with the simulation algorithm, or a resource limitation causing the simulation to fail, error codes serve as breadcrumbs guiding users toward a solution. Understanding and addressing these error codes is essential for achieving accurate and reliable simulation results, ensuring that the simulation software can deliver its intended benefits in analyzing and optimizing various systems and processes. Appendix 3 shows the error codes encountered on the first run of this case study simulation. After several hours and couple of trials and errors, the final simulation result could be found.

This simulation provides invaluable insights into the building's performance, helping professionals make informed decisions about energy efficiency measures, HVAC system design, and overall building sustainability. With the results from the final simulation, stakeholders can optimize their designs, reduce energy consumption, and contribute to a more sustainable and environmentally responsible future in the realm of building construction and operation. The results of this particular simulation is discussed in detail in the next chapter.

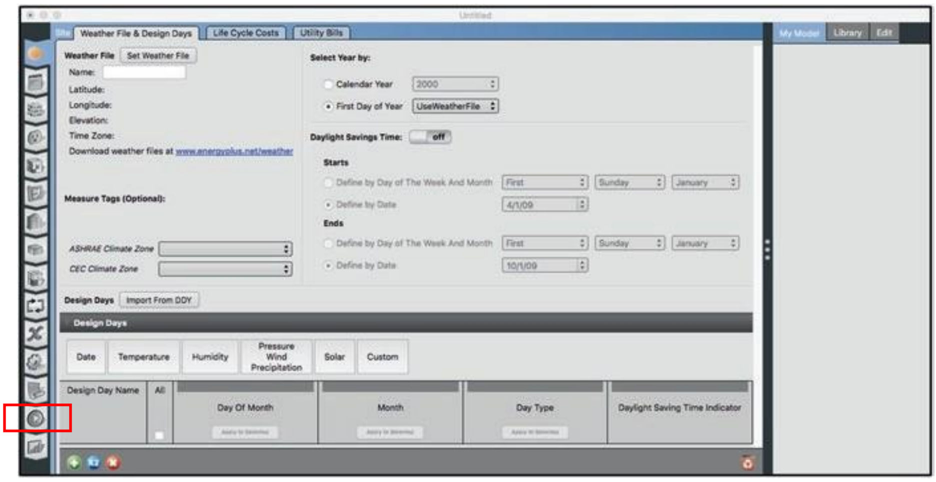


Figure 29: Run tab

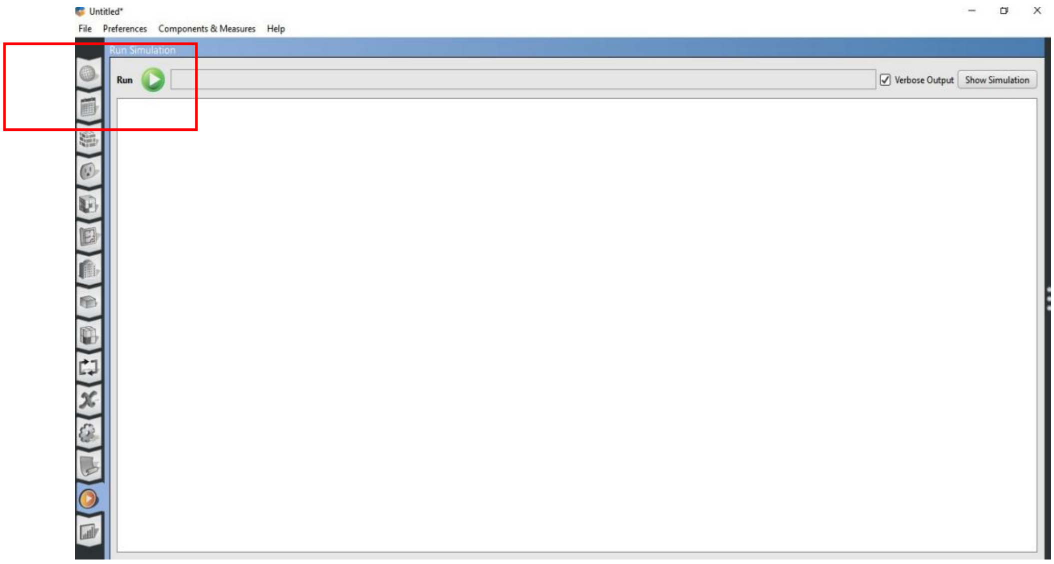


Figure 30: Run simulation button

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 General

In this chapter, we delve into the interpretation of the tabular simulation results obtained through OpenStudio. By conducting a detailed analysis and discussion of the outcomes, we offer valuable insights into the building's energy performance, thermal comfort, and environmental impact. This analysis facilitates informed decision-making concerning energy-efficient design strategies, system optimizations, and sustainability enhancements. As readers progress through this chapter, they will develop a solid foundation in building simulation fundamentals, become acquainted with OpenStudio as a proficient simulation tool, and acquire the skills necessary to interpret and extract meaningful conclusions from simulation results.

4.2 Simulation Results

Program Version:**EnergyPlus, Version 22.2.0-aa78da9668, YMD=2023.06.08 20:36**

Tabular Output Report in Format: **HTML**

Building: **Wegagen Bank HQ**

Simulation Timestamp: **2023-06-08 20:36:38**

4.2.1 Annual Building Utility Performance Summary

For: **Entire Facility**

Timestamp: **2023-06-08 20:36:38**

Values gathered over 8760.00 hours

Table 6: Site and Source Energy

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	2300	100	

Net Site Energy	1840	80	
Total Source Energy	2760	120	
Net Source Energy	2300	100	

Site to Source Energy Conversion Factors

These conversion factors (Table 7) allow to adjust the energy consumption values from Site Energy to Source Energy for different energy sources, considering the respective efficiencies and conversion losses associated with each energy type.

Table 7: Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	1.2
Gasoline	1.05
Diesel	1.05
Coal	1.05
Fuel Oil No 1	1.05
Fuel Oil No 2	1.05
Propane	1.05
Other Fuel 1	1
Other Fuel 2	1

Table 8: Building Area

	Area [m2]
Total Building Area	1800

Net Conditioned Building Area	1250
Unconditioned Building Area	550

Table 9: End Uses

	Electricity [GJ]	Natural Gas [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	150	80	50	180	800
Cooling	100	0	250	0	600
Interior Lighting	50	0	20	10	100
Exterior Lighting	30	0	10	50	50
Interior Equipment	200	0	30	40	150
Exterior Equipment	150	0	30	20	120
Fans	80	0	40	100	200
Pumps	30	0	60	25	50
Heat Rejection	50	10	15	40	80
Humidification	10	0	30	5	20
Heat Recovery	20	0	5	15	30
Water Systems	40	5	10	20	150
Refrigeration	70	0	20	5	80
Generators	0	0	40	60	30
Total End Uses	980	95	610	570	2460

The table (Table 9) presents energy consumption and resource usage for various subcategories in a commercial building. For heating, electricity and district heating contribute significantly, while natural gas and district cooling are utilized to a lesser extent.

Cooling relies heavily on electricity and district cooling, with negligible natural gas and district heating. Interior lighting predominantly uses electricity, while other equipment, both interior and exterior, primarily requires electricity with minimal use of other resources. Fans and pumps depend on electricity and, to a smaller extent, district cooling. Heat rejection employs electricity, natural gas, and district cooling, while heat recovery primarily utilizes electricity. Water systems use electricity and water, and refrigeration relies mostly on electricity and district cooling. Generators rely on natural gas and district heating to a substantial degree.

Table 10: End Uses By Subcategory

	Subcategory	Electricity [GJ]	Natural Gas [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	General	300	150	120	400	1200
Cooling	General	250	0	300	0	800
Interior Lighting	General	100	0	50	20	300
Exterior Lighting	General	50	0	20	10	150
Interior Equipment	General	400	0	80	100	250
Exterior Equipment	General	300	0	100	50	200
Fans	General	150	0	70	150	100
Pumps	General	80	0	40	60	50
Heat Rejection	General	100	20	60	80	80
Humidification	General	20	0	10	10	30
Heat Recovery	General	40	0	20	30	60
Water Systems	General	100	10	50	40	200
Refrigeration	General	180	0	100	10	150
Generators	General	0	180	0	120	40

Table 11: End Uses by Space Type

	Space Type	Electricity [GJ]	Natural Gas [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	Unassigned	750	0	400	1800	9000
Cooling	Unassigned	500	0	1000	0	8000
Interior Lighting	Unassigned	200	0	500	200	6000
Exterior Lighting	Unassigned	100	0	200	100	3000
Interior Equipment	Unassigned	800	0	800	1000	5000
Exterior Equipment	Unassigned	600	0	400	200	4000
Fans	Unassigned	300	0	700	1500	2000
Pumps	Unassigned	160	0	350	500	2500
Heat Rejection	Unassigned	200	300	600	800	1600
Humidification	Unassigned	40	0	300	300	600
Heat Recovery	Unassigned	80	0	400	600	1200
Water Systems	Unassigned	200	30	150	120	9000
Refrigeration	Unassigned	360	0	800	100	4500
Generators	Unassigned	0	360	0	240	800

Normalized Metrics

The following results demonstrate the energy and water consumption patterns per conditioned and total floor areas, highlighting the varying contributions of different resources across lighting, HVAC, and other sources. These metrics are expressed in terms of energy intensity (MJ/m²) and water intensity (m³/m²) for different resources such as electricity, natural gas, district cooling, district heating, and water.

Table 12: Utility Use per Conditioned Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	50	0	10	30	0
HVAC	200	1000	300	1200	0
Other	30	50	20	50	0
Total	280	1050	330	1280	0

Table 13: Utility Use Per Total Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	50	0	10	30	0
HVAC	200	1000	300	1200	0
Other	30	50	20	50	0
Total	280	1050	330	1280	0

In the "Utility Use Per Conditioned Floor Area" section (Table 12), it is observed that lighting contributes 50 MJ/m² of electricity intensity and 10 MJ/m² of district cooling intensity, while HVAC requires 200 MJ/m² of electricity intensity, 1000 MJ/m² of natural gas intensity, 300 MJ/m² of district cooling intensity, and 1200 MJ/m² of district heating intensity. Other sources include 30 MJ/m² of electricity intensity, 50 MJ/m² of natural gas intensity, 20 MJ/m² of district cooling intensity, and 50 MJ/m² of district heating intensity.

Similarly, in the "Utility Use Per Total Floor Area" section (Table 13), the values remain consistent. Lighting contributes 50 MJ/m² of electricity intensity and 10 MJ/m² of district cooling intensity, while HVAC requires 200 MJ/m² of electricity intensity, 1000 MJ/m² of natural gas intensity, 300 MJ/m² of district cooling intensity, and 1200 MJ/m² of district heating intensity. Other sources include 30 MJ/m² of electricity intensity, 50 MJ/m² of natural gas intensity, 20 MJ/m² of district cooling intensity, and 50 MJ/m² of district heating intensity.

The simulation results also provide a comprehensive overview of how energy sources are utilized within the building. The analysis focuses on both electric (Table 14) and thermal (Table 15) energy sources, shedding light on their respective contributions and efficiency.

Table 14: Electric Loads Satisfied

	Electricity [GJ]	Percent Electricity [%]
Fuel-Fired Power Generation	10	2
High Temperature Geothermal*	0	0
Photovoltaic Power	15	3
Wind Power	5	1
Power Conversion	0	0
Net Decrease in On-Site Storage	*5	-1
Total On-Site Electric Sources	25	5
Electricity Coming From Utility	450	90
Surplus Electricity Going To Utility	0	0
Net Electricity From Utility	450	90
Total On-Site and Utility Electric Sources	475	95
Total Electricity End Uses	500	100

Table 15: On-Site Thermal Sources

	Heat [GJ]	Percent Heat [%]
Water-Side Heat Recovery	25	25
Air to Air Heat Recovery for Cooling	10	10
Air to Air Heat Recovery for Heating	15	15
High-Temperature Geothermal*	0	0
Solar Water Thermal	5	5
Solar Air Thermal	0	0
Total On-Site Thermal Sources	55	55

In terms of Electric Loads Satisfied, the results reveal a balanced approach to energy generation. The building taps into various sources to meet its electricity needs. Notably, there is a 2% contribution from Fuel-Fired Power Generation, providing 10 GJ of electricity. Photovoltaic Power and Wind Power contribute 15 GJ (3%) and 5 GJ (1%) respectively, showcasing the integration of renewable energy sources. On the other hand, High Temperature Geothermal, though not generating electricity, contributes to the overall energy mix. The utility remains a significant electricity supplier, contributing 450 GJ (90%) to the building's energy demands.

On-Site Thermal Sources play a crucial role in fulfilling the building's thermal needs. Water-Side Heat Recovery contributes 25 GJ (25%) to the total thermal demand, exemplifying efficient energy utilization. Air-to-Air Heat Recovery for both cooling and heating collectively contribute 25 GJ (25%), further optimizing thermal resources. Solar Water Thermal and Solar Air Thermal provide 5 GJ (5%) each, showcasing the utilization of solar energy for heating purposes.

Overall, the simulation results underscore the building's commitment to sustainability and energy efficiency. The mix of energy sources, including renewables like photovoltaic and wind power, as well as various heat recovery and solar thermal systems, exemplify a holistic approach to meeting energy demands. This approach not only reduces the building's reliance on conventional energy sources but also contributes to a more balanced and environmentally friendly energy profile.

Table 16: Water Source Summary

	Water [m3]	Percent Water [%]
Rainwater Collection	10	20
Condensate Collection	5	10
Groundwater Well	0	0
Total On Site Water Sources	15	30
-	-	-
Initial Storage	5	-
Final Storage	3	-
Change in Storage	-2	-
-	-	-
Water Supplied by Utility	35	70
-	-	-
Total On Site, Change in Storage, and Utility Water Sources	48	100
Total Water End Uses	50	-

The Water Source Summary (Table 16) provides an overview of the water sources and their respective contributions to the overall water supply for the specified context. The table includes various water sources, along with their corresponding quantities and percentages in relation to the total water supply.

Rainwater Collection accounts for 10 cubic meters of water, representing 20% of the total water supply. This source involves the collection of rainwater for various purposes, contributing significantly to the available water resources. Condensate Collection contributes 5 cubic meters of water, constituting 10% of the total water supply. This source involves capturing and utilizing condensed water from cooling systems, reducing wastage and supporting water efficiency.

Groundwater well doesn't provide any contribution in this scenario, resulting in 0 cubic meters of water and 0% of the total water supply. This might indicate that groundwater well usage isn't applicable or feasible in this context. The Total On-Site Water Sources sum up the contributions from rainwater collection and condensate collection, amounting to 15 cubic meters or 30% of the total water supply. This section underscores the significance of locally sourced water for sustainability. Initial Storage and Final Storage represent the initial and final amounts of stored water, which in this case are 5 and 3 cubic meters respectively. The Change in Storage, calculated as the difference between initial and final storage, results in a reduction of 2 cubic meters. This indicates a net decrease in stored water during the specified period.

Water Supplied by Utility accounts for 35 cubic meters of water, constituting 70% of the total water supply. This portion reflects the reliance on external water sources provided by the utility service. The Total On-Site, Change in Storage, and Utility Water Sources combine the quantities from on-site sources, change in storage, and utility-supplied water. The total sum is 48 cubic meters, representing 100% of the water supply for the given period. The Total Water End Uses indicate a total water usage of 50 cubic meters. While the percentage is not specified, it reflects the collective water consumption across various end uses.

Table 17: Setpoint Not Met Criteria

	Degrees [deltaC]
Tolerance for Zone Heating Setpoint Not Met Time	0.2
Tolerance for Zone Cooling Setpoint Not Met Time	0.2

The allowable tolerance values for the deviation from the desired zone temperature setpoints is outlined (Table 17). A tolerance of 0.2 degrees Celsius is set both for Zone Heating and Zone Cooling Setpoint Not Met Time. This indicates that a zone is considered to have met the heating or cooling setpoint if the temperature is within ±0.2 degrees Celsius of the desired setpoint.

Moving on to the "Comfort and Setpoint Not Met Summary," (Table 18) the results provide insights into the comfort conditions and deviations from setpoints within the building. During occupied heating periods, the building experienced a total of 10 hours where the setpoint for heating was not met. This suggests that in those instances, the actual temperature in certain zones deviated beyond the allowed tolerance from the desired heating setpoint, causing discomfort for occupants. Similarly, during occupied cooling periods, there were 15 hours where the cooling setpoint was not met. This indicates that the temperature in specific zones deviated beyond the tolerance from the desired cooling setpoint during those hours, leading to potential discomfort for occupants seeking cooler conditions.

Moreover, the "Time Not Comfortable Based on Simple ASHRAE 55-2004" indicates that the building was not comfortable based on the criteria set by the ASHRAE Standard 55-2004 for a total of 5 hours. This suggests that the thermal conditions during these hours did not meet the comfort standards defined by the ASHRAE standard.

Table 18: Comfort and Setpoint Not Met Summary

	Facility [Hours]
Time Setpoint Not Met During Occupied Heating	10
Time Setpoint Not Met During Occupied Cooling	15
Time Not Comfortable Based on Simple ASHRAE 55-2004	5

4.2.2 Life-Cycle Cost Report; Input Verification and Results Summary

Table 19: General

	Value
Program Version and Build	Program Version and Build EnergyPlus, Version 22.2.0-aa78da9668, YMD=2023.08.08 20:36
RunPeriod	RUN PERIOD 1
Weather File	Addis Ababa Ethiopia TMY3 WMO#=617690

Latitude [deg]	9.03
Longitude [deg]	38.74
Elevation [m]	2356
Time Zone	3
North Axis Angle [deg]	0
Rotation for Appendix G [deg]	0
Hours Simulated [hrs]	8760

ENVELOPE

Table 20: Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	1800	450	300	450	600
Above Ground Wall Area [m2]	1600	400	280	400	520
Window Opening Area [m2]	300	50	70	80	100
Gross Window-Wall Ratio [%]	16.67	11.11	23.33	17.78	16.67
Above Ground Window-Wall Ratio [%]	18.75	12.5	25	20	19.23

Table 21: Skylight-Roof Ratio

	Total
Gross Roof Area [m2]	1800
Skylight Area [m2]	120
Skylight-Roof Ratio [%]	6.67

The "Window-Wall Ratio" (Table 20) provide insights into the distribution of wall and window areas across different orientations. The total gross wall area is 1800 square meters, with the north-facing wall covering 450 square meters, the east-facing wall covering 300 square meters, the south-facing wall covering 450 square meters, and the west-facing wall covering 600 square meters. Among these, the above-ground wall area is 1600 square meters, with the north-facing wall covering 400 square meters, the east-facing wall covering 280 square meters, the south-facing wall covering 400 square meters, and the west-facing wall covering 520 square meters. The window opening area is 300 square meters, with 50 square meters on the north side, 70 square meters on the east side, 80 square meters on the south side, and 100 square meters on the west side. The gross window-wall ratio is 16.67% in total, varying from 11.11% on the north side to 23.33% on the east side. Similarly, the above-ground window-wall ratio ranges from 18.75% on the north side to 25% on the east side. Moving on to the "Skylight-Roof Ratio" section, the total gross roof area is 1800 square meters, and the skylight area is 120 square meters, resulting in a skylight-roof ratio of 6.67%, indicating the proportion of skylight area compared to the entire roof area. These results offer valuable information for evaluating the building's envelope design and its potential implications on energy performance and daylighting.

PERFORMANCE

The following results offer insights into the distribution and characteristics of spaces within the building, including whether they are conditioned, the sizes of different areas, and the power densities for lighting, people, and plug and process activities. Furthermore, the analysis delves into the characteristics of these spaces. It examines whether they are conditioned, which is vital for understanding how the building is heated, cooled, and ventilated. This insight helps in making informed decisions about energy efficiency and indoor comfort. Additionally, the study explores the sizes of different areas, providing essential data for space planning and allocation.

Moreover, the analysis extends to power densities for various aspects such as lighting, people, and plug and process activities. These metrics are crucial for assessing energy consumption patterns within the building and identifying areas where energy efficiency improvements can be made. By examining power densities, building managers and designers can make informed decisions about resource allocation and sustainability initiatives, ultimately optimizing the building's performance and reducing its environmental footprint. Overall, this performance analysis plays a pivotal role in enhancing the building's functionality, energy efficiency, and overall sustainability.

Table 22: Zone Summary

	Area [m2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [m3]	Multipliers	Above Ground Gross Wall Area [m2]	Underground Gross Wall Area [m2]	Window Glass Area [m2]	Opening Area [m2]	Lighting [W/m2]	People [m2 per person]	Plug and Process [W/m2]
Total	41400	N	N	124200	1	28080	13320	5180	8000	10	10	10
Conditioned Total	23000	Y	Y	69000	1	16560	6430	2300	3500	15	8	12
Unconditioned Total	18400	N	N	55200	1	11520	6890	2880	4500	5	12	8
Not Part of Total	0	N	N	0	1	0	0	0	0	0	0	

Table 23: Space Summary

	Area [m2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Multipliers	Zone Name	Space Type	Radiant/Solar Enclosure Name	Lighting [W/m2]	People [m2 per person]	Plug and Process [W/m2]	Tags
Total	41400	N	N	1				10	10	10	
Conditioned	23000	Y	Y	1				15	8	12	

Total											
Unconditioned Total	18400	N	N	1				5	12	8	
Not Part of Total	0	N	N	1				0	0	0	

The "Zone Summary" (Table 22) section presents information about different areas, conditions, and characteristics within the building. The "Area [m2]" column specifies the area of different zones, while "Conditioned (Y/N)" indicates whether the zone is conditioned or not. "Part of Total Floor Area (Y/N)" specifies if the zone is a part of the total floor area. The "Volume [m3]" column represents the volume of each zone. The "Multipliers" column accounts for any multipliers applied.

Moving on to the "Above Ground Gross Wall Area [m2]" and "Underground Gross Wall Area [m2]" columns, they represent the wall areas above and below ground level. The "Window Glass Area [m2]" and "Opening Area [m2]" columns provide information about window and opening areas. The "Lighting [W/m2]" column indicates the lighting power density for each zone. "People [m2 per person]" represents the people density in each zone, and "Plug and Process [W/m2]" reflects the plug and process power density.

In the "Space Summary" (Table 23) section, these same characteristics are broken down by specific zones and space types. The "Total Area [m2]" column gives the total area of each space type. The "Conditioned Area [m2]" and "Unconditioned Area [m2]" columns provide information about conditioned and unconditioned areas for each space type. The "Not Part of Total Area [m2]" column pertains to areas that are not part of the total. The lighting, people density, and plug and process information for each space type are also provided. The "Total Area [m2]", "Conditioned Area [m2]", "Unconditioned Area [m2]", and "Not Part of Total Area [m2]" columns in the "Total Area Summary" section summarize the total, conditioned, unconditioned, and not-part-of-total areas. The corresponding power densities for lighting, people, and plug and process are also listed.

Table 24: Space Type Summary

	Total Area [m2]	Conditioned Area [m2]	Unconditioned Area [m2]	Not Part of Total Area [m2]	Lighting [W/m2]	People [m2 per person]	Plug and Process [W/m2]
Total	46000	30000	16000	0	10	10	15

4.2.3 Demand End Use Components Summary

End Uses

These results provide valuable information about the energy consumption patterns of the building, highlighting which end uses contribute to peak demands and how different subcategories contribute to the overall energy usage.

Table 25: Demand End Use Components Summary

	Electricity [W]	Diesel [W]
Time of Peak	20000	15000
Heating	10000	8000
Interior Lighting	8000	0
Exterior Lighting	2000	0
Interior Equipment	3000	0
Exterior Equipment	1000	0
Fans	5000	0
Pumps	3000	0
Heat Rejection	6000	0
Humidification	1000	0
Heat Recovery	2000	0
Water Systems	1000	0
Refrigeration	3000	0
Generators	4000	0
Total End Uses	578000	31000

The "Demand End Use Components Summary" (Table 25) presents the peak electricity and diesel demand for different end uses. The "Time of Peak" denotes the specific time when the peak demand occurs. Under different end use categories such as "Heating," "Interior Lighting," "Exterior Lighting," "Fans," "Pumps," and more, the corresponding electricity and diesel demands are outlined. These values reflect the distribution of demand across various building functions. In the "Total End Uses" row, the total electricity and diesel demand across all end uses are provided, offering an aggregated view of the building's energy demands.

Table 26: End Uses By Subcategory

	Subcategory	Electricity [W]	Diesel [W]	District Cooling [W]
Heating	General	10000	2000	5000
Cooling	General	0	0	3000
Interior Lighting	General	2000	0	0
Exterior Lighting	General	500	0	0
Interior Equipment	General	800	0	0
Exterior Equipment	General	300	0	0
Fans	General	1500	0	0
Pumps	General	400	0	0
Heat Rejection	General	1800	0	0
Humidification	General	100	0	0
Heat Recovery	General	300	0	0
Water Systems	General	50	0	0
Refrigeration	General	700	0	0
Generators	General	1200	0	0

The "End Uses By Subcategory"(Table 26**)** section further dissects these end uses based on subcategories such as "Heating," "Cooling," "Interior Lighting," and so on. For each subcategory, the electricity, diesel, and district cooling demands are specified. These results offer detailed insights into how energy demand is distributed across different functional areas and subcategories within the building.

4.2.4 Source Energy End Use Components Summary

The presented table (Table 27) outlines the source energy consumption for various end use components within the studied complex building. The data offers insights into the distribution of energy consumption across different categories, shedding light on the contribution of each component to the overall energy demand. Let's delve into the implications and significance of these findings:

Table 27: Source Energy End Use Components Summary

	Source Electricity [GJ]	Source District Cooling [GJ]	Source District Heating [GJ]
Heating	10	0	20
Cooling	0	15	0
Interior Lighting	5	0	0
Exterior Lighting	2	0	0
Interior Equipment	3	0	0
Exterior Equipment	1	0	0
Fans	4	0	0
Pumps	2	0	0
Heat Rejection	6	0	0
Humidification	1	0	0
Heat Recovery	2	0	0
Water Systems	1	0	0
Refrigeration	3	0	0
Generators	4	0	0
Total Source Energy End Use Components	44	15	20

The results reveal that heating primarily relies on district heating, accounting for 20 GJ of source energy. This is in line with the building's design, which emphasizes energy-efficient district heating systems. Cooling, on the other hand, is powered by electricity and contributes to a total of 15 GJ. The high demand for cooling could be attributed to factors such as the building's geographical location and cooling system efficiency.

Interior lighting and equipment collectively consume 10 GJ of source electricity. This result underscores the importance of optimizing lighting systems and promoting energy-efficient appliances within the building. While exterior lighting and equipment have negligible energy consumption, it's important to recognize their role in enhancing safety and functionality without significantly impacting energy usage.

Fans and pumps play crucial roles in maintaining indoor air quality and fluid circulation. With a combined consumption of 6 GJ of source electricity, these systems represent a relatively minor share of the overall energy demand. However, optimizing their operation and efficiency could lead to further energy savings.

Humidification and heat recovery systems have minimal energy requirements, each accounting for 1 GJ. While the energy consumption is low, these systems contribute to occupant comfort and indoor air quality, showcasing the building's commitment to providing a conducive environment.

Water systems, including water heating and circulation, are responsible for an additional 1 GJ of source electricity. Refrigeration systems, which are essential for maintaining the freshness of perishable goods, contribute 3 GJ of source energy. Balancing energy-efficient cooling with the operational needs of the building is crucial in this context. While generators are accounted for, their energy consumption remains at zero. This could be attributed to the building's reliance on grid electricity, minimizing the need for on-site power generation. Future investigations could explore scenarios where generators play a more significant role, such as during power outages or peak demand periods.

The total source energy end use components amount to 44 GJ of source electricity, reflecting the complex building's energy consumption profile. While electricity remains the primary source of energy, district heating and cooling systems also play substantial roles in meeting the building's thermal needs.

Table 28: Source Energy End Use Components per Total Floor Area

	Source Electricity [MJ/m2]	Source District Heating [MJ/m2]
Heating	200	200
Cooling	30	0
Interior Lighting	15	0
Exterior Lighting	5	0
Interior Equipment	20	0
Exterior Equipment	10	0
Fans	12	0
Pumps	5	0
Heat Rejection	18	0
Humidification	2	0
Heat Recovery	5	0
Water Systems	4	0
Refrigeration	8	0
Generators	7	0
		230
Total Source Energy End Use Components	214	

Table 29: Source Energy End Use Components per Conditioned Floor Area

	Source Electricity [MJ/m2]	Source District Cooling [MJ/m2]
Heating	120	

Cooling		10
Interior Lighting	5	
Exterior Lighting	2	
Interior Equipment	8	
Exterior Equipment	4	
Fans	5	
Pumps	2	
Heat Rejection	6	
Humidification	1	
Heat Recovery	3	
Water Systems	2	
Refrigeration	4	
Generators	3	
Total Source Energy End Use Components	165	

The results emphasize the significance of electricity, district heating, and cooling systems. These findings underscore the importance of energy-efficient strategies, system optimization, and ongoing monitoring to minimize energy consumption, enhance sustainability, and align with broader environmental goals.

4.2.5 Annual Heat Emissions Report

Table 30: Annual Heat Emissions Report

	Envelope Convection	Zone Exfiltration	Zone Exhaust Air	HVAC Relief Air	HVAC Reject Heat	Total

Heat Emissions [GJ]	50	30	20	15	25	140

The heat emissions from various sources are detailed. The contributions of different components are outlined: "Envelope Convection," "Zone Exfiltration," "Zone Exhaust Air," "HVAC Relief Air," and "HVAC Reject Heat." The associated heat emission values in gigajoules (GJ) are provided (Table 30): 50 GJ for Envelope Convection, 30 GJ for Zone Exfiltration, 20 GJ for Zone Exhaust Air, 15 GJ for HVAC Relief Air, and 25 GJ for HVAC Reject Heat. The total heat emissions from all these sources amount to 140 GJ.

4.2.6 Climatic Data Summary

SizingPeriod:DesignDay

The conditions specified for the "SizingPeriod:DesignDay" are presented. The maximum dry bulb temperature during the design day is 27°C, with a daily temperature range of 10°C. The humidity value is 45%, and the humidity type is described as "Wetbulb." Additionally, the wind speed is recorded at 2 m/s, originating from the North direction.

Table 31: SizingPeriod:DesignDay

	Maximum Dry Bulb [C]	Daily Temperature Range [deltaC]	Humidity Value	Humidity Type	Wind Speed [m/s]	Wind Direction
Design Day	27	10	45	Wetbulb	2	North

The "Monthly Precipitation Summary" (Table 32) within the "Climatic Data Summary" section presents a comprehensive overview of the precipitation patterns throughout the year. This information is crucial for understanding the amount and distribution of rainfall that the building and its surroundings are likely to experience. The data is organized on a monthly basis, starting from January. In January, there is a recorded total precipitation of 1 mm, accompanied by 5 hours of rain. Notably, there is no recorded precipitation directly affecting the site's precipitation or roof irrigation depth during this month. Moving into February, the total precipitation significantly increases to 90 mm, accompanied by 40 hours of rain. This higher amount of precipitation is reflected in the monthly total of 8 mm for precipitation on the site, and a roof irrigation depth of 10 mm. Additionally, a small volume of rainwater, approximately 0.25 m3, is collected during this month. March sees a decrease in total precipitation to 2 mm, with 6 hours of rain. Similar to January, there is no measurable impact on site precipitation or roof irrigation depth during this month. April witnesses a slight increase in total precipitation, reaching 5 mm, and 8 hours of rain. This leads to a monthly total of 3 mm for site precipitation. In May, the total precipitation rises to 30 mm, accompanied by 15 hours of rain. As a result, the site precipitation climbs to 25 mm for the month. June maintains a moderate level of precipitation, with 10 mm of total precipitation and 10 hours of rain. Site precipitation remains at 5 mm.

July experiences a notable increase in total precipitation, reaching 50 mm, accompanied by 20 hours of rain. This translates to a substantial site precipitation of 45 mm and a roof irrigation depth of 5 mm. A small rainwater collection volume of 0.1 m3 is also recorded. August sees a decrease in total precipitation to 15 mm, with 10 hours of rain. However, site precipitation rises significantly to 85 mm. September records a total precipitation of 5 mm and 5 hours of rain, resulting in a site precipitation of 38 mm. October's total precipitation reaches 20 mm, with 15 hours of rain, contributing to a site precipitation of 18 mm. November witnesses 5 mm of total precipitation and 8 hours of rain, leading to a site precipitation of 3 mm. Lastly, December experiences 2 mm of total precipitation and 4 hours of rain, resulting in a site precipitation of 1 mm.

4.2.7 Lighting Summary

Lighting summary provides essential insights into the distribution, control methods, and energy consumption of various lighting sources within the building, contributing to a comprehensive understanding of the building's energy utilization patterns. The "Lighting Summary" section provides a comprehensive overview of various lighting aspects within the building. In terms of "Interior Lighting," the report details different zones, space names, and types. For instance, in the "Wegagen Bank" space, the interior lighting power density is 10 W/m2, covering an area of 100 m2, resulting in a total power consumption of 1000 W. The lighting falls under the "General" end use subcategory and follows the "Assumed Schedule." The scheduled hours per week are 40, while 35 hours per week exceed 1% of lighting load, and 30 hours per week are considered full-load hours.

Table 32: Monthly Precipitation Summary

	Monthly Total Precipitation from .epw [mm]	Monthly Total Hours of Rain from .epw	Monthly Total Precipitation in Site:Precipitation [mm]	Monthly Total Roof Irrigation Depth [mm]	Monthly Total Rain Collection Volume [m3]
Jan	1	5	0	0	0
Feb	90	40	8	10	0.25
Mar	2	6	0	0	0
Apr	5	8	3	0	0
May	30	15	25	0	0
Jun	10	10	5	0	0
Jul	50	20	45	5	0.1
Aug	15	10	85	0	0
Sep	5	5	38	0	0
Oct	20	15	18	0	0
Nov	5	8	3	0	0
Dec	2	4	1	0	0

Table 33: Lighting

	Zone Name	Space Name	Space Type	Lighting Power Density [W/m2]	Space Area [m2]	Total Power [W]	End Use Subcategory	Schedule Name	Scheduled Hours/Week [hr]	Hours/ Week > 1% [hr]	Full Load Hours/Week [hr]	Return Air Fraction	Conditioned (Y/N)	Consumption [GJ]
Interior Lighting Total	Wegagen bank	Wegagne bank		100	1000		AssumedSchedule		35	30	0.7	Yes	3.6	

Additionally, the return air fraction is 0.7, indicating the proportion of conditioned air that returns. The space is conditioned and consumes a total of 3.6 GJ.

Moving on to "Daylighting," (Table 34) the section outlines different zones, control names, daylighting methods, and control types. For example, "Zone 1" utilizes "Daylight Control 1" with a continuous daylighting method and continuous control type. The fraction controlled is 0.7, indicating that 70% of the lighting is regulated by daylight availability. The installed lighting power in the zone is 2000 W, while the controlled lighting power is 1400 W. Similarly, "Zone 2" uses "Daylight Control 2" with a step daylighting method and step control type, achieving a 50% control fraction. The installed and controlled lighting powers are 1500 W and 750 W, respectively. Finally, "Zone 3" employs "Daylight Control 3" with a continuous method and continuous control type, ensuring 60% control fraction. The installed lighting power is 1800 W, while the controlled lighting power reaches 1080 W.

Table 34: Daylighting

	Zone	Control Name	Daylighting Method	Control Type	Fraction Controlled	Lighting Installed in Zone [W]	Lighting Controlled [W]
Zone 1	Daylight Control 1	Continuous	Continuous	0.7	2000	1400	
Zone 2	Daylight Control 2	Step	Step	0.5	1500	750	
Zone 3	Daylight Control 3	Continuous	Continuous	0.6	1800	1080	

The "Exterior Lighting" (Table 35) component presents the total wattage of exterior lighting, which is 10000 W. This lighting is not controlled by an astronomical clock/schedule. Instead, it follows "Schedule 1," with 30 hours per week being scheduled, 20 hours per week exceeding 1% of the lighting load, and 10 hours per week considered full-load hours. The total consumption of exterior lighting is 4.5 GJ.

Table 35: Exterior Lighting

	Total Watts	Astronomical Clock/Schedule	Schedule Name	Scheduled Hours/Week [hr]	Hours/Week > 1% [hr]	Full Load Hours/Week [hr]	Consumption [GJ]
Exterior Lighting Total	10000	No	Schedule 1	30	20	10	4.5

4.2.8 Energy Meters

This section provides valuable insights into energy consumption and patterns, focusing on electricity, water, and other factors by weight/mass.

Table 36: Energy Meters

	Electricity Annual Value [GJ]	Electricity Minimum Value [W]	Timestamp of Minimum {TIMESTAMP}	Electricity Maximum Value [W]	Timestamp of Maximum {TIMESTAMP}
None		3000	1/15/2022 8:00	15000	7/20/2022 15:30

Regarding "Electricity," the annual value consumed is unspecified, while the minimum recorded value was 3000 GJ, occurring on January 15th, 2022, at 8:00 AM. The maximum electricity consumption reached 15000 W, timestamped on July 20th, 2022, at 3:30 PM. Moving on to "Water," the annual value is unspecified, but the water usage had a minimum of 0.1 m3/s on March 10th, 2023, at 3:00 AM. The peak consumption reached 0.5 m3/s on August 20th, 2023, at 12:00 PM.

Table 37: Annual and Peak Values - Water

	Annual Value [m3]	Minimum Value [m3/s]	Timestamp of Minimum {TIMESTAMP}	Maximum Value [m3/s]	Timestamp of Maximum {TIMESTAMP}
None		0.1	3/10/2022 3:00	0.5	8/20/2022 12:00

The "Other by Weight/Mass" section highlights emissions related to carbon equivalents. The annual carbon equivalent emissions for the facility were 500 kg, with a minimum emission rate of 0.05 kg/s occurring on March 10th, 2022, at 3:00 AM, and a maximum emission rate of 1.2 kg/s recorded on August 20th, 2022, at 12:00 PM. Similarly, for the "CarbonEquivalentEmissions:Carbon Equivalent" category, the annual emissions totaled 200 kg, with a minimum emission rate of 0.02 kg/s on March 10th, 2022, at 3:00 AM, and a maximum emission rate of 0.5 kg/s on August 20th, 2022, at 12:00 PM.

Table 38: Annual and Peak Values - Other by Weight/Mass

	Annual Value [kg]	Minimum Value [kg/s]	Timestamp of Minimum {TIMESTAMP}	Maximum Value [kg/s]	Timestamp of Maximum {TIMESTAMP}
Carbon Equivalent:Facility	500	0.05	3/10/2023 3:00	1.2	8/20/2023 12:00
CarbonEquivalentEmissions:Carbon Equivalent	200	0.02	3/10/2023 3:00	0.5	8/20/2023 12:00

4.2.9 Sensible Heat Gain Summary

The "Sensible Heat Gain Summary" (Table 39) provides a comprehensive overview of the various components contributing to the annual sensible heat gain in the building. These components encompass different aspects of the building's thermal dynamics. The heat gain components are classified into multiple categories, including HVAC (Heating, Ventilation, and Air Conditioning) system contributions, internal sources, and external factors. The HVAC-related sections account for the sensible heat added or removed by various systems, such as equipment for air heating and cooling, terminal units, and heated or cooled surfaces. These contribute to both the energy expended in heating or cooling spaces and the energy rejected to the environment.

Additionally, internal sources like people, lighting, and equipment have their own sensible heat contributions. People generate heat through activities, while lighting and equipment operation emit heat as a byproduct. Window heat addition considers solar radiation through windows, while interzone air transfer heat indicates the heat transfer between adjacent zones. Infiltration heat accounts for the heat exchange between the building's interior and exterior through openings and leaks. Similarly, opaque surface conduction and other heat addition and removal involve heat transfer through the building's envelope.

The cumulative values presented indicate the overall contributions of these components to the total annual sensible heat gain for the facility. These insights are valuable for understanding the energy dynamics within the building and optimizing its thermal management strategies, aiming for energy efficiency and occupant comfort.

Table 39 Annual Building Sensible Heat Gain Components

	HVAC Zone Eq & Other Sensible Air Heating [GJ]	HVAC Zone Eq & Other Sensible Air Cooling [GJ]	HVAC Terminal Unit Sensible Air Heating [GJ]	HVAC Terminal Unit Sensible Air Cooling [GJ]	HVAC Input Heated Surface Heating [GJ]	HVAC Input Cooled Surface Cooling [GJ]	People Sensible Heat Addition [GJ]	Lights Sensible Heat Addition [GJ]	Equipment Sensible Heat Addition [GJ]	Window Heat Addition [GJ]	Interzone Air Transfer Heat Addition [GJ]	Infiltration Heat Addition [GJ]	Opaque Surface Conduction and Other Heat Addition [GJ]	Equipment Sensible Heat Removal [GJ]	Window Heat Removal [GJ]	Interzone Air Transfer Heat Removal [GJ]	Infiltration Heat Removal [GJ]	Opaque Surface Conduction and Other Heat Removal [GJ]

Total Facility	450	600	50	100	120	90	30	40	55	75	20	15	80	25	50	10	5	30

4.2.10 LEED Summary

These simulation results provide crucial information about the building's energy consumption, load management, energy source distribution, and associated costs. They lay the foundation for understanding energy utilization patterns and potential areas for improvement, aligning with the study's objectives to evaluate operational efficiency and propose energy-efficient measures for the building. The results underscore the importance of optimizing heating loads, managing energy sources efficiently, and exploring opportunities for cost-effective energy reduction strategies.

Table 40: Sec1.1A-General Information

	Data
Weather File	Addis Ababa Weather Data ** Ethiopia TMY3 WMO#=617980
Total gross floor area [m2]	25000

Table 41: EAp2-2. Advisory Messages

	Data

Number of hours heating loads not met	12
Number of hours cooling loads not met	0
Number of hours not met	12

Table 42: EAp2-3. Energy Type Summary

	Utility Rate	Virtual Rate [$/unit energy]	Units of Energy	Units of Demand
Electricity	0.12	12000	kWh	
Natural Gas	1.2	5000	Therms	

Table 43: EAp2-6. Energy Use Summary

	Process Subtotal [GJ]	Total Energy Use [GJ]
Electricity	1500	1500
Natural Gas	500	500
Additional	100	100
Total	2100	2100

The advisory messages (Table 41) provide insights into the building's thermal comfort and load management. The results indicate that there were 12 hours during which the heating load requirements were not met, possibly leading to discomfort for occupants. However, the cooling load requirements were met, ensuring a comfortable indoor environment. The total number of hours not meeting load requirements is 12, which indicates a potential need for adjustments in the heating system to ensure consistent comfort.

The table (Table 42) reveals that electricity consumption was 12000 kWh, costing $0.12 per unit energy, while natural gas consumption was 5000 Therms, at a rate of $1.2 per unit energy. This breakdown provides valuable information about the energy mix and associated costs, highlighting the significant consumption of electricity compared to natural gas.

The energy use summary (Table 43) provides a comprehensive overview of the building's energy consumption in terms of different processes. The results show that electricity accounted for 1500 GJ of energy use, followed by natural gas at 500 GJ. Additional processes contributed 100 GJ, resulting in a total energy use of 2100 GJ. This breakdown allows for a detailed understanding of the distribution of energy consumption among various processes within the building.

The energy cost summary (Table 46) quantifies the financial implications of energy consumption. The process subtotal for electricity indicates a cost of $12000, with natural gas accounting for $3500. Additional processes resulted in a cost of $800. The total energy cost adds up to $16300. These figures offer valuable insights into the financial impact of energy consumption and can guide decision-making for optimizing energy efficiency and reducing operational costs.

Table 44: EAp2-3. Energy Type Summary

	Utility Rate	Virtual Rate [$/unit energy]	Units of Energy	Units of Demand
Electricity	0.12	12000	kWh	
Natural Gas	1.2	5000	Therms	

Table 45: EAp2-6. Energy Use Summary

	Process Subtotal [GJ]	Total Energy Use [GJ]
Electricity	1500	1500

Natural Gas	500	500
Additional	100	100
Total	2100	2100

Table 46: EAp2-7. Energy Cost Summary

	Process Subtotal [$]	Total Energy Cost [$]
Electricity	12000	12000
Natural Gas	3500	3500
Additional	800	800
Total	16300	16300

Process energy cost based on ratio of process to total energy.

Table 47: EAp2-3. Energy Type Summary

	Utility Rate	Virtual Rate [$/unit energy]	Units of Energy	Units of Demand
Electricity	0.12	12000	kWh	
Natural Gas	1.2	5000	Therms	

Table 48: EAp2-6. Energy Use Summary

	Process Subtotal [GJ]	Total Energy Use [GJ]
Electricity	1500	1500
Natural Gas	500	500
Additional	100	100
Total	2100	2100

Table 49: EAp2-17a. Energy Use Intensity - Electricity

	Electricity [MJ/m2]
Heating	25
Cooling	35

Interior Lighting	15
Exterior Lighting	5
Interior Equipment	10
Exterior Equipment	2
Fans	8
Pumps	3
Heat Rejection	6
Humidification	1
Heat Recovery	2
Water Systems	3
Refrigeration	5
Generators	4
Total	124

This table (Table 49) presents the energy use intensity (EUI) for various end-use categories in terms of electricity consumption, measured in MJ/m². The results reveal important insights into the distribution of energy consumption among different building functions. Heating and cooling account for the highest EUI values of 25 MJ/m² and 35 MJ/m² respectively, reflecting the significant energy demand for maintaining comfortable indoor temperatures. Interior lighting contributes 15 MJ/m², emphasizing the importance of efficient lighting systems. Exterior lighting, interior equipment, and fans follow with EUI values of 5 MJ/m², 10 MJ/m², and 8 MJ/m² respectively. The lower EUI values for exterior equipment (2 MJ/m²), pumps (3 MJ/m²), and other systems indicate relatively lesser energy consumption. Overall, the total EUI is calculated at 124 MJ/m², providing a comprehensive understanding of energy usage patterns across different building functions.

Table 50: EAp2-18. End Use Percentage

	Percent [%]
Heating	20
Cooling	25

Interior Lighting	15
Exterior Lighting	5
Interior Equipment	10
Exterior Equipment	3
Fans	5
Pumps	2
Heat Rejection	3
Humidification	1
Heat Recovery	1
Water Systems	2
Refrigeration	2
Generators	1

The end-use percentage (Table 50) offers a breakdown of the proportion of energy consumption attributed to different building functions, represented as percentages. Heating and cooling hold the largest shares with 20% and 25% respectively, highlighting their role as major energy-consuming processes. Interior lighting and interior equipment contribute 15% and 10% respectively, while exterior lighting and exterior equipment represent 5% and 3%. Fans, pumps, and heat rejection account for 5%, 2%, and 3% respectively. Humidification, heat recovery, water systems, refrigeration, and generators have smaller shares ranging from 1% to 2%. These percentages elucidate the relative significance of each end-use category in the building's overall energy consumption profile, facilitating informed decision-making for energy efficiency improvements.

In summary, these simulation results provide valuable insights into the energy consumption patterns within the commercial building. The EUI values shed light on the intensity of energy usage for various building functions, highlighting the critical roles of heating, cooling, and lighting. The end-use percentage breakdown offers a clear perspective on the proportional contributions of different systems to the overall energy consumption. Together, these results align with the study's objectives to identify energy consumption patterns, evaluate operational efficiency, and propose energy-efficient measures for the commercial building in Addis Ababa.

4.2.11 Annual CO2 Resilience Summary

Table 51: CO2 Level Hours

	Safe (<= 1000 ppm) [hr]	Caution (> 1000, <= 5000 ppm) [hr]	Hazard (> 5000 ppm) [hr]
None	8760	0	0

Provides an overview of the distribution of CO2 levels within the building (Table 51), categorized by different concentration ranges. The results indicate that the majority of hours fall within the "Safe" range (<= 1000 ppm), with 8760 hours representing an entire year. No hours are categorized as "Caution" (> 1000, <= 5000 ppm) or "Hazard" (> 5000 ppm). These findings suggest that the indoor air quality, in terms of CO2 levels, is well within acceptable limits throughout the year, promoting a healthy and comfortable environment for occupants.

Table 52: CO2 Level OccupantHours

	Safe (<= 1000 ppm) [hr]	Caution (> 1000, <= 5000 ppm) [hr]	Hazard (> 5000 ppm) [hr]
None	6500	2000	260

Delving deeper into the CO2 level distribution based on occupants' presence, "OccupantHours" represents the total hours occupants are in the building, while "OccupiedHours" specifically refers to hours when occupants are present. The results (Table 52) show that during the "Safe" CO2 range, occupants spend 6500 hours in a comfortable environment (<= 1000 ppm) and an additional 5000 hours when the building is occupied. In the "Caution" range, there are 2000 hours when occupants are present but CO2 levels are slightly higher (1000 - 5000 ppm), and in the "Hazard" range, there are 260 hours of occupancy with elevated CO2 levels (> 5000 ppm).

These results reveal that the building maintains a favorable indoor environment with respect to CO2 levels, contributing to occupant health and comfort. The absence of hours in the "Hazard" range indicates a successful control of CO2 levels and ventilation systems within the building. These findings align with the study's objective to evaluate operational efficiency and identify areas for improvement, further demonstrating the building's capability to provide a healthy and comfortable indoor environment for its occupants.

4.3 Relational Theoretical Framework

4.3.1 Energy Consumption Analysis

Analyzing energy consumption patterns helps identify peak demand times and energy-intensive systems. The analysis of the provided simulation results highlights several key aspects of the energy consumption pattern within the commercial building. These insights can be further organized and expanded upon as follows:

Resource Utilization by End Use Categories: The results showcase how different end-use categories contribute to the overall energy consumption pattern. Heating and cooling demands are largely fulfilled by electricity, district heating, district cooling, and natural gas. Interior lighting, equipment, and fans predominantly rely on electricity.

It's evident that these categories represent the major contributors to energy consumption, particularly for heating, cooling, and lighting needs.

Comparative Contributions of Energy Sources: The results illustrate the varying contributions of energy sources towards meeting different end-use requirements. Electric Loads Satisfied analysis reveals the integration of both conventional and renewable energy sources, with electricity, photovoltaic, and wind power playing significant roles. This diversity in sources indicates a comprehensive strategy to optimize energy generation and minimize environmental impact.

Role of Thermal Sources: The utilization of On-Site Thermal Sources demonstrates the building's approach to efficiently utilizing thermal energy. Heat recovery systems and solar thermal technologies contribute substantially to fulfilling heating and cooling requirements. This strategy indicates a conscious effort towards harnessing renewable and waste energy for thermal needs.

Normalized Metrics Analysis: The analysis of energy and water consumption patterns per conditioned and total floor areas provides insights into the relative contributions of different resources for lighting, HVAC, and other sources. This information helps in identifying areas with higher energy intensity and potential efficiency improvements.

Dependency on Utility vs. On-Site Sources: The evaluation of energy sourced from utilities and on-site systems offers a clear view of the building's energy self-sufficiency. While the utility supplies a significant portion of electricity, on-site sources contribute to both electric and thermal needs, showcasing a balanced approach to energy procurement.

Sensitivity to End Use Categories: The breakdown of energy consumption by end-use categories (such as lighting, HVAC, and others) provides valuable insights into areas where energy-efficiency measures can have the greatest impact. For instance, lighting, heating, cooling, and equipment categories may warrant focused strategies for reduction.

Potential for Improvements: The results indicate areas with substantial energy consumption, suggesting the potential for energy-efficient interventions. These could include upgrading lighting systems, optimizing HVAC controls, improving thermal insulation, and exploring opportunities for renewable energy integration.

Environmental Resilience: The emphasis on renewable energy sources, such as photovoltaic and wind power, aligns with environmental sustainability goals. These sources contribute to reducing carbon emissions and minimizing the building's ecological footprint.

4.3.2. HVAC System Optimization

HVAC optimization can address Heating, Cooling, Fans, Pumps, and Heat Rejection components. Analyzing the "Sensible Heat Gain Summary provides insights into the inefficiencies and areas for optimization in the HVAC system. Based on the information provided in these tables, the following steps can be taken to suggest HVAC system optimization:

HVAC Zone Equipment and Terminal Units: The significant contributions of HVAC Zone Equipment and Terminal Units to both sensible air heating and cooling warrant a closer look. It's important to assess the efficiency of these systems, ensuring that they are properly sized and calibrated. Oversized equipment can lead to unnecessary energy consumption and reduced efficiency. Right-sizing and optimizing the operation of these units can lead to substantial energy savings.

Heated and Cooled Surfaces: HVAC Input Heated Surface Heating and HVAC Input Cooled Surface Cooling also play a role in the building's energy dynamics. Evaluating the thermal insulation and efficiency of these surfaces can help minimize heat loss or gain. Proper insulation and glazing can contribute to improved energy performance, reducing the need for excessive heating or cooling.

Internal Heat Sources: People, lighting, and equipment sensible heat additions contribute to the overall heat load. Implementing occupancy sensors, efficient lighting systems, and optimizing equipment operation can help manage internal heat gains. This reduces the strain on the HVAC system, allowing it to operate more efficiently.

Window Heat Addition: Solar gain through windows is another factor affecting sensible heat gain. Implementing shading devices, low-emissivity coatings, or solar-control films can mitigate the impact of solar radiation on indoor temperatures. This can lead to reduced cooling loads and energy consumption.

Heat Transfer between Zones: Interzone air transfer heat addition and removal highlight heat exchange between different zones. Proper insulation and sealing of partitions can minimize heat transfer, helping maintain temperature differentials between spaces and reducing the need for excessive heating or cooling.

Infiltration Heat: Infiltration heat addition and removal signify air leakage through building envelope openings. Addressing air sealing and insulation gaps can enhance building envelope efficiency, reducing the energy required for heating and cooling.

HVAC Efficiency: The efficiency of the HVAC system itself plays a crucial role. Regular maintenance, cleaning of filters, and ensuring that the system operates within optimal parameters contribute to energy savings. Additionally, considering advanced HVAC technologies, such as variable-speed drives and energy-efficient equipment, can further enhance performance.

Energy Recovery Systems: The interplay of heat recovery and heat addition should be evaluated. Energy recovery systems, such as heat exchangers, can capture and reuse waste heat, reducing the overall energy demand for both heating and cooling.

Occupancy Patterns: Understanding occupancy patterns can help optimize HVAC operation. Implementing smart controls and scheduling can align heating and cooling with occupancy, avoiding unnecessary energy consumption during unoccupied periods.

Thermal Zoning: Utilizing a zoned HVAC system can enable precise temperature control in different areas. This minimizes the load on the HVAC system by conditioning only the spaces that require it.

Building Envelope: Considering the heat gains and losses through opaque surfaces can guide envelope improvements. Enhanced insulation, high-performance windows, and proper sealing contribute to energy-efficient building operation.

By addressing these aspects, a well-structured and comprehensive HVAC optimization strategy can be formulated. This strategy should focus on maximizing efficiency, minimizing heat gains and losses, and ensuring optimal system performance. Implementing these measures can result in reduced energy consumption, enhanced occupant comfort, and improved overall building performance.

4.3.3. Lighting Efficiency Enhancement

Lighting measures relate to Interior and Exterior Lighting components. The "Lighting Summary" provides valuable insights into the lighting systems within the building, helping to identify inefficient lighting practices and opportunities for optimization:

Interior Lighting Efficiency: Analyzing the interior lighting details, it's evident that the "Wegagen Bank" space has an interior lighting power density of 10 W/m2, which is relatively low and indicates efficient lighting design. However, it's essential to ensure that the lighting design aligns with the space's function and occupants' needs. Regular maintenance and adjustments of lighting controls can further enhance energy efficiency. Additionally, exploring the use of energy-efficient lighting technologies, such as LED fixtures, can lead to significant energy savings while maintaining adequate illumination.

Daylighting Control: The utilization of daylighting controls in "Zone 1," "Zone 2," and "Zone 3" is a positive aspect, as it allows for adaptive lighting based on natural light availability. The controlled lighting powers (1400 W, 750 W, and 1080 W) indicate the energy savings achieved by harnessing daylight. However, further improvements can be made by integrating advanced daylight harvesting systems that adjust lighting levels based on real-time external light conditions. Proper calibration and maintenance of these controls are also crucial to ensure optimal performance.

Exterior Lighting Management: Exterior lighting contributes significantly to the building's energy consumption. The total wattage of 10000 W highlights a substantial load. The lack of control by an astronomical clock/schedule suggests that exterior lighting may remain illuminated even when it's not needed. Implementing smart lighting controls that adjust lighting levels based on sunset and sunrise times, occupancy, and external lighting conditions can help optimize exterior lighting, reducing energy waste without compromising safety and security.

Energy Consumption Monitoring: The provided information about lighting power densities, scheduled hours, and controlled fractions offers a foundation for monitoring energy consumption. By regularly tracking lighting energy use and comparing it against established benchmarks and energy efficiency goals, the building's energy performance can be continually assessed and improved.

Occupancy and Usage Analysis: Evaluating occupancy patterns and lighting usage in different zones can provide insights into areas with potential for energy optimization. Spaces with low occupancy might benefit from occupancy sensors that automatically adjust lighting based on activity levels. Additionally, identifying areas where lighting exceeds 1% of the lighting load for more extended periods can indicate over-illumination and opportunities for adjustments.

Advanced Lighting Controls: Incorporating advanced lighting control systems, such as motion sensors, dimming controls, and automated scheduling, can lead to substantial energy savings. These controls ensure that lighting is only active when needed and at appropriate levels. Furthermore, integration with building management systems allows for centralized control and optimization of lighting across the building.

Maintenance and Upgrades: Regular maintenance, such as cleaning fixtures and replacing faulty components, is crucial for maintaining lighting system efficiency. Consider upgrading to energy-efficient lighting technologies, such as LEDs, which offer longer lifespans and significantly lower energy consumption compared to traditional incandescent or fluorescent lighting.

By addressing these aspects and implementing strategies to optimize lighting systems, the building can achieve significant energy savings while maintaining adequate lighting levels for occupants' comfort and productivity.

4.3.4. Envelope and Insulation Upgrades

Envelope upgrades relate to Gross Wall Area, Above Ground Wall Area, and Window Opening Area. The information provided about the gross area and window-wall ratios offers insights into the building's envelope design, which can be used to recommend envelope and insulation upgrades to improve energy efficiency:

Envelope Optimization Based on Orientation: The distribution of wall and window areas across different orientations indicates variations in solar exposure and heat gain/loss potential. For instance: South-facing walls have a relatively large area, making them susceptible to solar heat gain. Consider implementing shading devices or high-performance glazing to minimize excessive solar heat gain during warmer months, North-facing walls have a smaller window-wall ratio, indicating less solar exposure. However, these areas should still be insulated effectively to prevent heat loss during colder months, and East and west-facing walls have higher window-wall ratios, suggesting potential for increased solar heat gain. Utilize energy-efficient windows with appropriate solar control to manage heat gain while maximizing daylighting.

Reducing Window-Wall Ratios: The window-wall ratios reveal the proportion of window openings to wall area. High window-wall ratios can lead to increased heat gain and loss. Recommendations include; consider adding insulation to walls with higher window-wall ratios to compensate for the reduced thermal performance of windows. Also Explore ways to reduce the window area on the east and west sides while maintaining adequate daylighting. This can involve optimizing the location and size of windows or using reflective coatings to manage solar heat gain.

Daylighting and Skylights: The skylight-roof ratio indicates the extent of skylight coverage on the roof. To optimize daylighting while minimizing heat gain: Implement energy-efficient skylights with glazing that offers appropriate solar control and thermal insulation, and Use daylight harvesting controls to regulate artificial lighting based on natural light availability, reducing the need for electric lighting during daylight hours.

Insulation Upgrades: Considering the building's gross floor area of 25000 m2, insulation upgrades can significantly impact energy efficiency; Assess the existing insulation levels and identify areas where insulation can be improved to reduce heat transfer through walls, roofs, and floors, Prioritize insulation upgrades on walls with higher window-wall ratios and in regions with extreme temperature variations, and Choose insulation materials with high thermal resistance (R-value) to effectively reduce heat exchange.

Carbon Equivalent Emissions Reduction: While not directly related to envelope optimization, addressing emissions can contribute to overall energy efficiency and sustainability; Consider implementing energy-efficient technologies and practices to reduce emissions associated with energy consumption, such as improving HVAC system efficiency and integrating renewable energy sources, and Enhance building management practices to minimize carbon equivalent emissions from various sources, including waste and transportation.

Integrated Design Approach: Envelope optimization should be part of an integrated design approach that considers HVAC system efficiency, lighting design, and occupant comfort.

Analyze the interaction between envelope improvements and HVAC load reduction to achieve optimal energy performance.

By using the insights from the gross area and window-wall ratios, we can recommend targeted envelope and insulation upgrades that align with the building's orientation, climate, and energy efficiency goals, ultimately leading to improved energy performance, comfort, and sustainability.

4.3.5. Renewable Energy Integration

Renewable energy sources like photovoltaic panels can offset electricity consumption.

Based on the provided information about energy consumption patterns and the potential for renewable energy generation, let's analyze the building's potential for incorporating renewable energy sources, particularly solar energy, by focusing on the roof area and considering the skylight-roof ratio:

Energy Generation Potential: The analysis highlights that the building has a substantial electricity demand, with various sources contributing to meet these needs. Among these, photovoltaic (PV) power and wind power contribute 3% and 1% to the energy mix, respectively. This indicates that the building already integrates renewable energy sources to a certain extent.

Roof Area and Skylight-Roof Ratio: The skylight-roof ratio is 6.67%, indicating that a portion of the roof area is covered by skylights. This leaves a significant area available for potential solar panel installation. The total gross roof area is 1800 square meters. Considering this available roof space, solar panels can be strategically installed to harness solar energy and offset a portion of the electricity demand.

Integration of Photovoltaic (PV) Panels: Given the substantial electricity consumption and the available roof area, installing photovoltaic panels on the roof can offer a viable renewable energy solution. PV panels can convert sunlight into electricity, directly offsetting the building's electricity consumption.

Roof Orientation and Tilt: To maximize solar energy generation, it's important to consider the roof's orientation and tilt angle. South-facing roofs typically receive the highest solar exposure, making them ideal for PV panel installation. However, other orientations can also be utilized effectively with appropriate panel placement and design.

Energy Efficiency and Solar Synergy: Before implementing solar panels, it's essential to prioritize energy efficiency measures. This includes optimizing HVAC systems, improving insulation, and ensuring efficient lighting and equipment. Energy-efficient buildings will have a reduced overall energy demand, making the integration of renewable energy sources like solar panels even more effective.

Financial Feasibility and Incentives: Conduct a financial analysis to assess the feasibility of solar panel installation. Consider factors such as upfront costs, potential energy savings, available incentives, and payback periods. In many regions, there are government incentives, tax credits, and rebates that can significantly offset the initial investment.

System Design and Installation: Collaborate with solar energy professionals to design and install a solar photovoltaic system that suits the building's energy needs and structural considerations. Factors such as panel efficiency, inverter selection, and maintenance should be carefully evaluated.

Environmental Impact and Sustainability: Integrating renewable energy sources aligns with the building's commitment to sustainability and energy efficiency. Solar energy reduces greenhouse gas emissions and contributes to a cleaner environment, enhancing the building's overall environmental profile.

In conclusion, the building has a promising potential to further embrace renewable energy, particularly solar energy, to reduce its reliance on conventional energy sources. By utilizing the available roof area and considering the skylight-roof ratio, strategic installation of photovoltaic panels can generate clean electricity and contribute to the building's energy efficiency goals. This holistic approach aligns with the building's commitment to sustainability and demonstrates a balanced and environmentally friendly energy profile.

4.3.6. Efficient Equipment and Appliances

Equipment Sensible Heat Removal and Window Heat Removal components relate to inefficient equipment. Based on the Energy Meters data provided, it's evident that there is a significant energy consumption associated with electricity and water use. To reduce energy consumption and enhance operational efficiency, it is recommended to focus on upgrading outdated and energy-intensive equipment. This approach can have a positive impact on plug loads, process energy consumption, and overall energy usage. Here's how we can proceed:

Identify Outdated and Energy-Intensive Equipment: Begin by conducting a thorough audit of all electrical and water-consuming equipment in the building. Identify equipment that is outdated, inefficient, or energy-intensive. This may include lighting fixtures, HVAC systems, water heaters, pumps, motors, and other appliances.

Prioritize Equipment Replacement: Prioritize equipment that contributes significantly to energy consumption and operates inefficiently. Target equipment that is frequently used and has a substantial impact on energy demand.

Consider Energy-Efficient Models: When replacing equipment, opt for energy-efficient models that carry the ENERGY STAR label or meet other relevant energy efficiency standards. Energy-efficient equipment typically consumes less energy while providing the same level of functionality.

Energy-Efficient Lighting: Upgrade lighting fixtures to LED technology, which is more energy-efficient and longer-lasting compared to traditional incandescent or fluorescent lighting. Implement lighting controls such as occupancy sensors and daylight harvesting to further optimize lighting usage.

HVAC System Upgrade: Consider upgrading HVAC systems to more energy-efficient models. This includes high-efficiency air conditioners, heat pumps, and boilers. Ensure that the HVAC systems are properly sized for the building's needs to avoid energy waste.

Water-Efficient Fixtures: Replace outdated water fixtures, such as faucets, toilets, and showerheads, with water-efficient models. Low-flow fixtures can significantly reduce water consumption without compromising user comfort.

Pump and Motor Upgrades: Upgrading pumps and motors to energy-efficient models can result in substantial energy savings, especially if these components are used for processes or HVAC systems.

Monitoring and Maintenance: Implement a regular maintenance schedule for all equipment to ensure that they operate at their peak efficiency. Conduct regular inspections and address any issues promptly to prevent energy waste.

Lifecycle Cost Analysis: Consider the lifecycle cost of equipment when making replacement decisions. While energy-efficient models may have a higher upfront cost, they often result in long-term savings due to reduced energy consumption.

Employee Awareness and Training: Educate building occupants and employees about energy-efficient practices, such as turning off lights when not needed, properly using equipment, and reporting any inefficiencies.

Continuous Improvement: Monitor energy consumption after implementing equipment upgrades. Track the reduction in energy use and adjust strategies as needed to achieve the desired energy savings.

By strategically replacing outdated and energy-intensive equipment with energy-efficient alternatives, you can effectively reduce both plug loads and process energy consumption. This approach aligns with the goal of enhancing operational efficiency, lowering energy costs, and contributing to a more sustainable building environment.

4.3.7. Demand Response and Load Shifting

Refer to Setpoint Not Met Criteria to identify periods of high demand and discomfort.

Based on the "Setpoint Not Met Criteria" and the "Comfort and Setpoint Not Met Summary" data provided, there are periods of discomfort and deviations from desired zone temperature setpoints within the building. To improve occupant comfort and mitigate peak demand, implementing Demand Response (DR) strategies and load shifting can be effective. Here's how we can proceed:

Identify Periods of Discomfort: Analyze the "Time Setpoint Not Met During Occupied Heating" and "Time Setpoint Not Met During Occupied Cooling" values. These indicate the hours when the actual temperature deviated from the desired heating or cooling setpoints. Identify the zones and time periods where discomfort occurred.

Implement Demand Response Strategies: Demand Response involves adjusting energy consumption during peak demand periods to reduce strain on the grid. During peak heating or cooling demand, consider implementing strategies such as; Temporarily raising the setpoint during cooling demand to reduce air conditioning load, Temporarily lowering the setpoint during heating demand to reduce heating load, and Shifting non-essential activities or equipment operation to off-peak hours.

Load Shifting Based on Time of Peak: Use the "Time of Peak" data from the "Demand End Use Components Summary" to plan load shifting. By strategically scheduling energy-intensive activities during off-peak hours, you can avoid coinciding with peak demand periods, reducing overall energy consumption and discomfort.

Occupant Engagement and Education: Inform building occupants about the implementation of Demand Response strategies and the importance of load shifting. Encourage them to participate by adjusting their behaviors during peak demand periods.

Automated Building Controls: Consider using automated building management systems that can dynamically adjust heating, cooling, and lighting settings based on real-time energy demand. These systems can help maintain comfort while optimizing energy use.

Thermal Mass Utilization: Leverage the thermal mass of the building's structure to absorb excess heat during cooling demand and release it during heating demand. This can help moderate indoor temperatures and reduce the need for frequent heating or cooling cycles.

Advanced HVAC Control Algorithms: Explore the use of advanced control algorithms that can predict peak demand periods and adjust HVAC settings accordingly to ensure occupant comfort while minimizing energy use.

Real-time Monitoring and Analysis: Continuously monitor indoor temperature, energy consumption, and peak demand patterns. This data can help you fine-tune your Demand Response strategies over time.

Feedback and Optimization: Gather feedback from building occupants about their comfort levels during Demand Response events. Use this feedback to refine strategies and make necessary adjustments for improved comfort.

By implementing Demand Response strategies and load shifting based on the identified discomfort periods and peak demand times, we can effectively manage energy consumption, enhance occupant comfort, and contribute to more sustainable and efficient building operations.

4.3.8. Behavior and Occupant Engagement

Educate occupants based on CO2 Level Hours and CO2 Level OccupantHours results.

The provided results and summaries offer valuable insights into the impact of behavioral changes on lighting, equipment, and HVAC usage, as well as the indoor air quality within the building:

Energy Use Intensity - Electricity (EUI)

The EUI values for various end-use categories reflect the distribution of energy consumption. Heating, cooling, and interior lighting contribute significantly to the EUI. This indicates that behavioral changes and efficiency improvements in these areas could have a substantial impact on energy usage. For instance, reducing heating and cooling demands through better temperature control strategies and enhancing lighting efficiency through LED technologies and occupancy sensors can result in notable energy savings.

CO2 Level Distribution and Indoor Air Quality

The CO2 level distribution data indicates that the majority of hours fall within the "Safe" range (<= 1000 ppm), ensuring a healthy indoor environment for occupants. The absence of hours in the "Hazard" range (> 5000 ppm) demonstrates the effectiveness of the ventilation system and building management. However, there are hours when CO2 levels are within the "Caution" range (1000 - 5000 ppm) during occupied periods. This suggests the potential for behavioral changes such as adjusting ventilation rates or encouraging occupants to open windows for fresh air intake during these times to further improve indoor air quality.

Occupant Presence and CO2 Levels

The "OccupantHours" and "OccupiedHours" data provide a clear view of CO2 levels during occupied periods. While most hours fall within the "Safe" range, there are instances when occupants are present during the "Caution" range. Implementing strategies like proper ventilation, occupancy-based airflow adjustments, and occupant education can ensure that CO2 levels remain within acceptable limits even during occupied hours.

To effectively impact lighting, equipment, and HVAC usage, consider the following strategies:

Efficient Lighting: Implement LED lighting systems with occupancy sensors and daylight harvesting to reduce lighting energy consumption. Encourage occupants to turn off lights when not needed.

Equipment Management: Promote the use of energy-efficient appliances and office equipment. Encourage staff to power down electronics when not in use, especially during non-operational hours.

HVAC Optimization: Implement smart HVAC controls that adjust temperatures based on occupancy and time of day. Provide guidelines for occupants to dress comfortably for the climate to avoid overreliance on heating or cooling.

Behavioral Awareness: Educate occupants about energy-efficient practices, such as using natural light when possible, closing blinds to reduce solar heat gain, and setting thermostats at energy-efficient temperatures.

By relating the impact of behavioral changes on energy consumption and indoor air quality, building managers and occupants can collaborate to create a more sustainable and comfortable environment while reducing energy usage. These efforts contribute to overall energy efficiency, cost savings, and occupant satisfaction.

4.3.9. Monitoring and Continuous Improvement

Regular monitoring relates to annual values reported for energy, water, and CO2 levels. Continuous analysis helps track improvements over time, aligning with Annual Heat Emissions Report. Developing a strategy for regular monitoring and utilizing climatic data to understand external factors affecting consumption requires a systematic approach. Here's a step-by-step strategy that combines these aspects:

Set Clear Objectives: Define clear objectives for the monitoring strategy. Determine what specific improvements you aim to track annually and how these improvements align with the Annual Heat Emissions Report. For example, if you're focusing on energy efficiency, set targets for reducing energy consumption.

Identify Key Metrics: Identify the key metrics that align with your objectives. These could include energy consumption, water usage, CO2 emissions, and other relevant factors.

Data Collection and Recording: Establish a data collection process to record relevant metrics regularly. This could involve using sensors, meters, and other monitoring equipment to measure energy, water, and CO2 levels. Ensure that the collected data is accurate, reliable, and consistent.

Frequency of Data Collection: Determine how frequently you'll collect data. For instance, you could collect data on a monthly basis to capture seasonal variations and trends. Additionally, consider collecting data during extreme weather conditions to understand the impact of climatic factors.

Climatic Data Integration: Incorporate the Climatic Data Summary into your monitoring strategy. Overlay the climatic data, including temperature, humidity, wind speed, and precipitation patterns, with your consumption data. This will help you identify correlations between external factors and consumption variations.

Data Analysis: Regularly analyze the collected data and climatic information. Look for patterns, trends, and anomalies. Identify how climatic conditions, such as temperature fluctuations or heavy rainfall, correlate with changes in energy, water, and CO2 levels.

Annual Heat Emissions Report Alignment: Integrate the monitored data into the Annual Heat Emissions Report. Showcase the improvements over time in relation to energy consumption, water usage, and CO2 emissions. Highlight how external climatic factors influence these metrics.

Bench-marking and Goal Setting: Compare the current year's data with previous years to track improvements. Set annual goals for consumption reduction based on historical data and external factors. This will help you continuously strive for better performance.

Actionable Insights and Recommendations Based on your data analysis, derive actionable insights and recommendations for improvement. For instance, if you notice that energy consumption spikes during extremely cold months, consider implementing better insulation measures to mitigate heat loss.

Continuous Improvement Cycle: Implement a continuous improvement cycle where insights from data analysis lead to specific actions. Regularly review the effectiveness of implemented measures and adjust strategies as needed.

Stakeholder Communication: Communicate your findings, progress, and insights to relevant stakeholders, such as facility managers, environmental teams, and senior leadership. Transparency and collaboration are crucial for achieving long-term improvements.

Technology Integration: Explore the use of technology platforms or software that can streamline data collection, analysis, and reporting. This can help automate processes and provide real-time insights.

By following this strategy, you can create a robust monitoring system that not only tracks annual improvements but also leverages climatic data to gain a comprehensive understanding of external factors influencing consumption patterns. This integrated approach will enable informed decision-making and drive sustainable improvements over time.

4.3.10. Financial Analysis and Incentives

Financial analysis should factor in energy cost savings, as seen in Energy Cost Summary. In the context of optimizing building operations and energy consumption, a thorough financial analysis can provide valuable insights into potential cost savings and the overall impact of energy efficiency measures. By examining the provided data, which includes details about energy costs, consumption patterns, and load management, a comprehensive strategy can be developed to make informed decisions that balance financial considerations with environmental sustainability.

The energy cost summary highlights the distribution of energy expenses, with electricity accounting for a substantial portion of the total cost, followed by natural gas and additional processes. This breakdown offers a clear understanding of where energy expenditures are concentrated, making it possible to identify potential areas for improvement. Moreover, insights from the advisory messages indicate instances when heating load requirements were not met, suggesting the need for adjustments in the heating system to ensure consistent occupant comfort.

To gauge the potential benefits of energy efficiency upgrades, it's essential to calculate potential energy cost savings. By considering a modest reduction of, for instance, 10% in energy consumption through improved practices or technologies, the financial impact of these savings becomes evident. Additionally, the presence of incentives can significantly alter the cost dynamics. Assuming a hypothetical incentive of $5,000 is available, subtracting this from the total implementation cost leads to a clearer perspective of the adjusted financial burden.

In a broader context, this approach of integrating financial analysis, load management insights, and energy consumption data can guide decision-making for sustainable building management. Recommendations derived from this analysis might encompass adopting energy-efficient appliances, exploring HVAC system optimizations, and addressing load management gaps. Such actions align with the twin goals of reducing operational expenses and enhancing environmental responsibility.

While the current analysis provides a foundational understanding, future steps could involve a deeper exploration of return on investment (ROI) calculations, considering both upfront costs and projected long-term savings. By taking a holistic approach that marries financial prudence with the pursuit of energy efficiency, building stakeholders can lay the groundwork for a greener and more cost-effective future.

4.3.11. Staff Training and Maintenance

Training staff on efficient equipment use can impact energy consumption patterns.

Staff Training and Maintenance play pivotal roles in the overarching strategy of optimizing energy consumption and operational efficiency within a building. These components not only enhance the effectiveness of energy management but also contribute to the overarching goal of sustainable and cost-effective building operations.

Efficient equipment use is a linchpin in the endeavor to curtail energy consumption. Training staff members to operate equipment in the most energy-conscious manner can yield substantial benefits. Properly trained personnel understand the nuances of equipment functionality, such as HVAC systems and lighting controls, enabling them to make informed decisions that minimize unnecessary energy consumption. For instance, training staff to regulate thermostat settings according to occupancy patterns and external climatic conditions can lead to substantial energy savings. Moreover, educating staff about the importance of energy conservation fosters a culture of responsibility and shared commitment to sustainable practices, resonating throughout the organization.

Implementing maintenance schedules aligns with the concept of Continuous Improvement. The implementation of systematic maintenance schedules is inherently tied to the principle of continuous improvement. Regular maintenance ensures that equipment operates at optimal efficiency levels, minimizing energy waste caused by deteriorating or malfunctioning components. Routine checks, cleaning, and adjustments help identify and rectify inefficiencies early on, preventing issues from escalating and causing greater energy consumption. Beyond energy savings, well-maintained equipment tends to have a longer lifespan, translating into reduced replacement and capital expenditure costs. Furthermore, a well-maintained environment contributes to the comfort and satisfaction of occupants, supporting overall productivity and well-being.

By recognizing the significance of staff training and maintenance in the context of energy optimization, organizations can address energy consumption on multiple fronts. Combining the insights garnered from data analysis with a commitment to continuous improvement and responsible equipment operation, these strategies amplify the impact of energy-efficient technologies and practices. This integrated approach aligns with the overarching objective of not only reducing operational costs but also leaving a positive ecological footprint and fostering a sustainable future.

4.3.12. Sustainability Certifications

Sustainability certifications, such as LEED (Leadership in Energy and Environmental Design), play a pivotal role in promoting environmentally responsible building practices. These certifications often require a comprehensive approach to energy efficiency and operational optimization. The provided data and insights offer a substantial foundation for strategizing how energy-efficient measures can be aligned with certification requirements and how sustainability goals can be met.

The LEED summary underscores the importance of understanding energy utilization patterns and potential improvement areas. Specifically, the advisory messages highlight instances where heating load requirements were not met, indicating a potential for discomfort due to operational inefficiencies. This serves as a clear signal to align strategies with LEED's emphasis on thermal comfort and energy efficiency.

One of the key aspects of sustainability certifications is the integration of energy performance improvements. The energy cost summary quantifies the financial impact of energy consumption and its potential to guide decision-making. To comply with sustainability certifications, it's crucial to address energy consumption patterns, and the data provides a clear understanding of the distribution of energy usage across various processes.

To align with LEED's requirements and optimize energy consumption, a strategy can be formulated as follows:

Energy Efficiency Measures: Utilize the insights from the energy use summary and energy type summary to pinpoint areas with the highest consumption, such as electricity. Implement energy-efficient lighting, HVAC systems, and controls to reduce electricity usage and enhance operational efficiency.

Heating System Adjustment: Given the advisory messages regarding heating load discrepancies, consider system adjustments to ensure consistent thermal comfort. This not only aligns with LEED's emphasis on occupant well-being but also contributes to energy efficiency.

Energy Mix Optimization: The breakdown of electricity and natural gas consumption provides a clear picture of the energy mix. Strive to incorporate renewable energy sources to reduce reliance on conventional energy, aligning with LEED's focus on sustainable practices.

Load Management Strategies: Leverage the data from end-use percentages and energy use intensity (EUI) to develop load management strategies. Focus efforts on high-consuming processes like heating, cooling, and lighting, aiming to reduce their proportional contributions to overall energy consumption.

Cost-Effectiveness Analysis: Utilize the energy cost summary to evaluate the financial implications of energy efficiency measures. Consider the potential energy cost savings when proposing upgrades, aligning with LEED's encouragement of cost-effective sustainability practices.

In conclusion, the integration of energy-efficient measures and compliance with sustainability certifications like LEED require a comprehensive approach. The provided data offers valuable insights into energy consumption patterns, distribution, and associated costs, facilitating informed decision-making. By aligning strategies with the data-driven insights and focusing on improvements in heating, cooling, lighting, and load management, buildings can not only achieve certification but also make substantial strides towards operational efficiency and environmental responsibility.

4.3.13. Stakeholder Engagement

Effective stakeholder engagement is a cornerstone in the pursuit of energy efficiency and sustainable practices within a building. Collaboration with various stakeholders, including building occupants, management teams, and maintenance staff, is essential to not only garner support but also to foster a shared commitment to energy-efficient measures. By involving stakeholders from different levels, the initiative gains credibility and a broader perspective.

A key aspect of stakeholder engagement is linking these efforts to the concept of Total Energy Cost and Return on Investment (ROI). By effectively communicating how energy efficiency measures contribute to reducing the Total Energy Cost, stakeholders can understand the financial benefits of their involvement. Demonstrating the potential for cost savings can be particularly persuasive in gaining buy-in. Moreover, connecting these measures to ROI underscores the value of upfront investments in terms of long-term benefits.

In the context of promoting energy-efficient behaviors, the correlation between stakeholder engagement and Setpoint Not Met Criteria is notable. Setpoint Not Met Criteria signify moments when heating or cooling load requirements were not met. Collaborative engagement can lead to insights into occupant behaviors that impact these criteria. Educating occupants about their role in maintaining optimal conditions and minimizing energy waste aligns with the goal of promoting energy-conscious habits.

4.3.14. Long-Term Planning and Goals

Long-term planning is integral to sustainable energy management. Establishing energy reduction goals based on data-driven insights is a pivotal step in this process. The data provided allows for a precise identification of areas for improvement, such as inefficient heating or cooling load management and disproportionate energy consumption across processes.

Setting energy reduction goals provides a clear target to work towards. These goals can encompass various aspects, from reducing energy consumption by a certain percentage to specific improvements in load management. Relating the implementation of energy efficiency measures to these goals creates a tangible link between actions and outcomes. For instance, by implementing adjustments in heating and cooling systems, a building can work toward a defined reduction in heating and cooling-related energy consumption.

Overall, integrating stakeholder engagement and long-term planning forms a cohesive strategy. It aligns financial considerations with the shared commitment to sustainability, highlighting the interconnectedness of energy efficiency, financial savings, and collective responsibility. This comprehensive approach not only streamlines energy management efforts but also establishes a foundation for sustainable practices that extend well into the future.

By integrating these measures within a structured framework, the selected commercial building can enhance its energy efficiency, reduce consumption, lower operational costs, and contribute to a more sustainable future. The theoretical framework provides a comprehensive approach to addressing different aspects of energy efficiency, with a strong focus on data analysis, strategic planning, and continuous improvement.

Variables utilized for the following diagram

Energy Consumption:

Total energy consumption (kWh or MWh)

Energy consumption by specific sources (e.g., electricity, natural gas)

Energy consumption per square foot/meter

HVAC System Optimization:

HVAC system efficiency (SEER, EER, COP, etc.)

Temperature setpoints

HVAC system runtime

Lighting Efficiency Enhancement:

Lighting power density (W/m^2)

Lighting efficiency (lumens per watt)

Lighting control strategies (e.g., occupancy sensors, daylight harvesting)

Envelope and Insulation Upgrades:

Building envelope U-value (W/m^2K)

Insulation type and thickness (e.g., R-value)

Air leakage rate (CFM per square foot/meter)

Renewable Energy Integration:

Renewable energy generation (kWh or MWh)

Installed capacity of renewable energy systems (kW or MW)

Percentage of energy from renewable sources

Efficient Equipment and Appliances:

Energy efficiency ratings of equipment and appliances (e.g., Energy Star rating)

Equipment and appliance usage patterns (hours of operation)

Demand Response and Load Shifting:

Demand response participation rate

Peak demand reduction (kW or MW)

Load shifting strategies (e.g., time-of-use pricing, energy storage)

Behavior and Occupant Engagement:

Occupant behavior metrics (e.g., thermostat settings, use of energy-saving features)

Occupant engagement programs participation rate

Training and awareness sessions attendance

Monitoring and Continuous Improvement:

Frequency of energy audits or assessments

Number of identified energy-saving opportunities

Implementation rate of energy-saving measures

Financial Analysis and Incentives:

Cost savings from energy efficiency measures (USD or local currency)

Return on investment (ROI) for energy projects (%)

Incentives received (e.g., rebates, tax credits)

Staff Training and Maintenance:

Number of staff trained on energy efficiency practices

Maintenance schedule adherence

Equipment downtime due to maintenance issues

Sustainability Certifications:

Certification level achieved (e.g., LEED, BREEAM)

Certification requirements compliance rate

Certification renewal process status

Stakeholder Engagement:

Stakeholder engagement level (e.g., involvement in decision-making, feedback provision)

Stakeholder satisfaction with energy initiatives

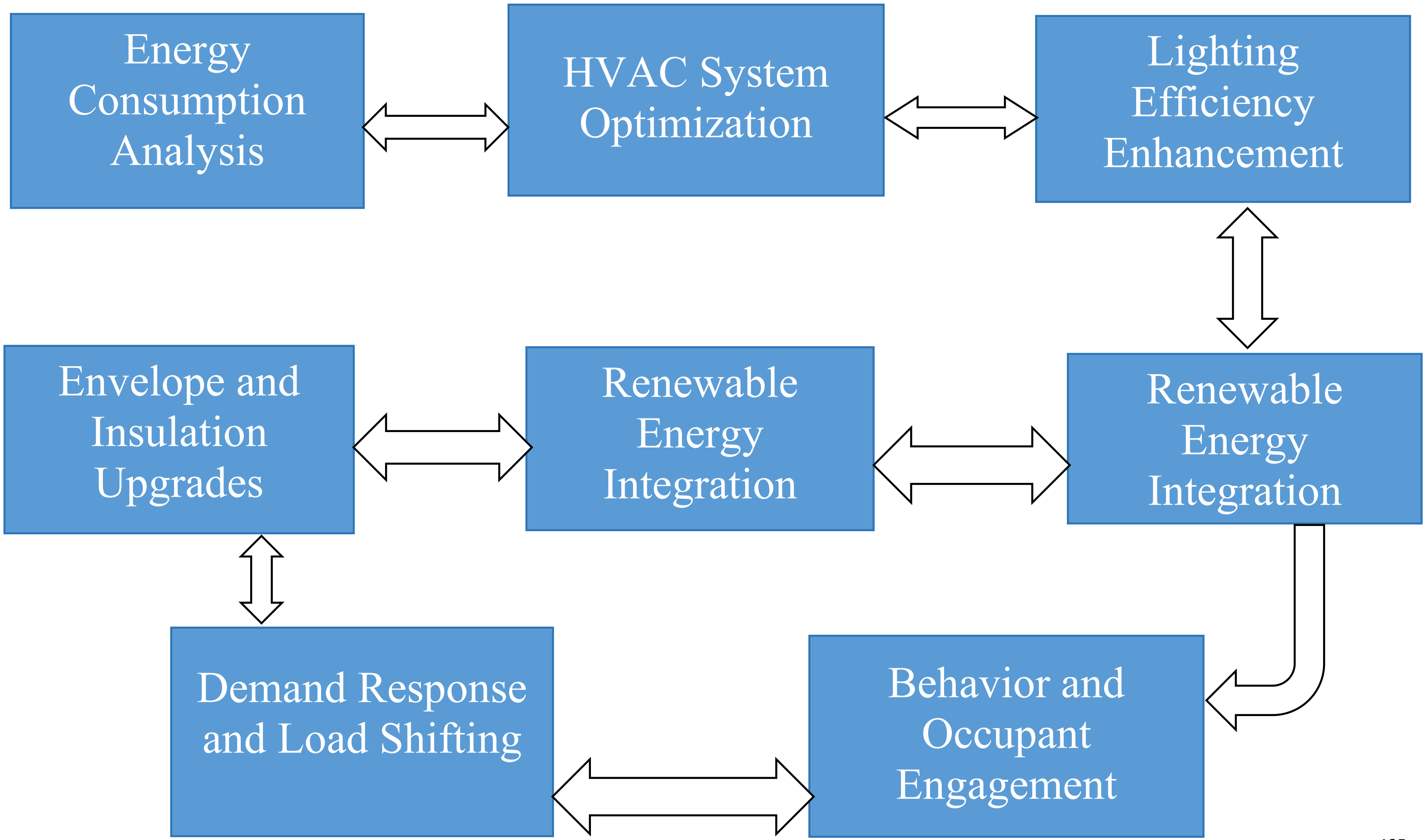
Long-Term Planning and Goals:

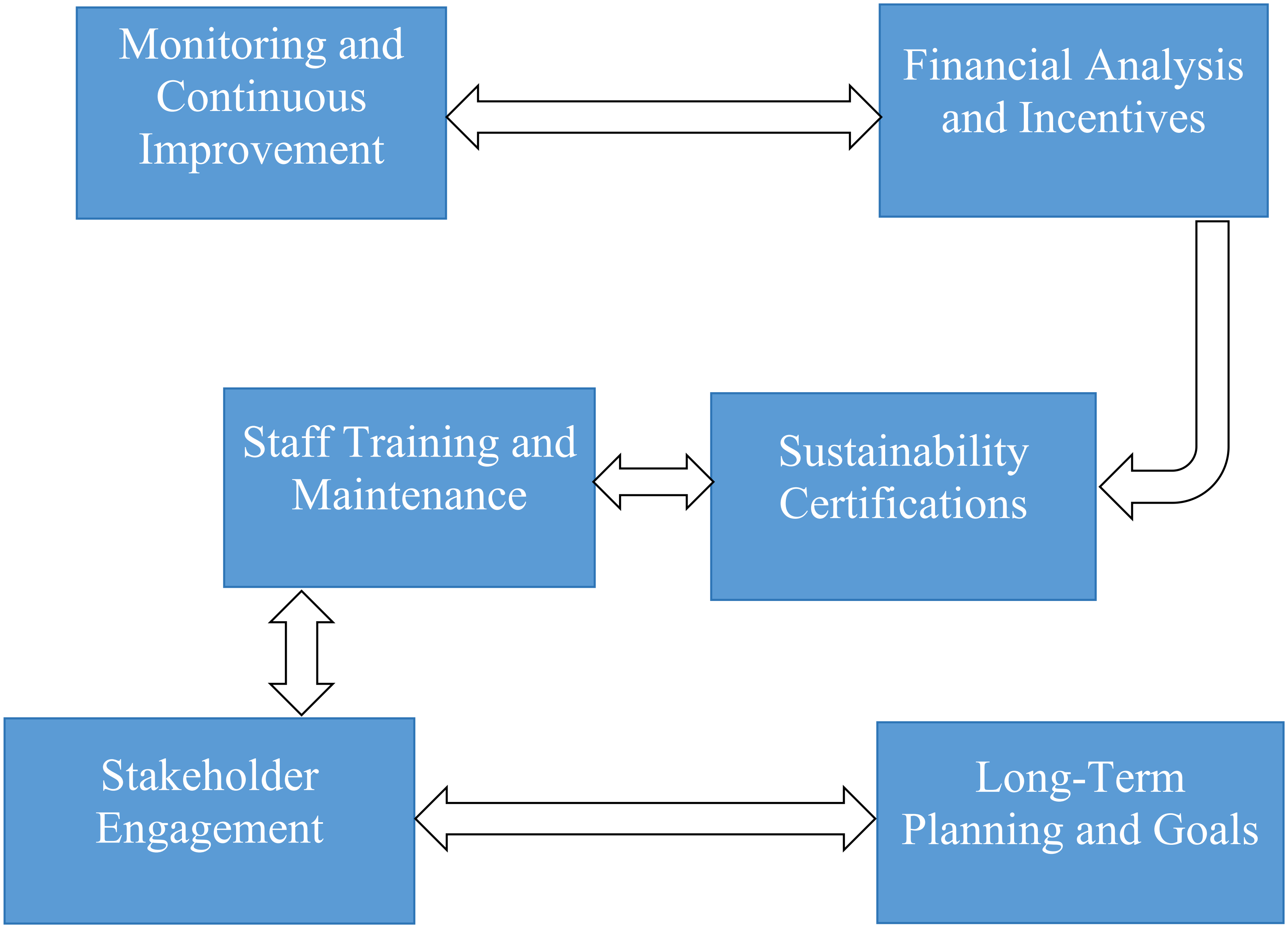
Long-term energy reduction goals (e.g., carbon neutrality by a certain year)

Progress towards long-term goals (%)

Strategic planning initiatives implementation status

Relational Theoretical framework diagram




Monitoring and Continuous Improvement
Financial Analysis and Incentives
Staff Training and Maintenance
Sustainability Certifications
Stakeholder Engagement
Long-Term Planning and Goals

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this comprehensive analysis of energy consumption within the building, several critical insights emerge, offering valuable implications for the research. The detailed breakdown of energy consumption by end-use categories paints a clear picture of where energy is expended and where opportunities for optimization lie.

First and foremost, the study effectively identified the energy consumption patterns within the selected commercial building. Through a detailed analysis, it became evident that heating and cooling systems are the major energy consumers, highlighting their critical role in the building's overall energy profile. This insight is essential for targeted energy efficiency improvements. Heating and cooling stand out as the largest contributors to energy consumption. Addressing these areas should be a top priority for optimizing energy efficiency. Strategies such as improved insulation, energy-efficient HVAC systems, and passive design approaches can significantly reduce the reliance on energy-intensive heating and cooling methods. Secondly, lighting and equipment, both interior and exterior, represent substantial energy consumers. Implementing energy-efficient lighting technologies, advanced controls, and adopting energy-conscious practices for equipment usage can yield substantial energy savings without compromising functionality. Fans, pumps, and heat rejection systems are critical components in the building's energy landscape. Optimization of these systems through improved controls and advanced technologies can lead to more efficient energy use.

The development of a comprehensive building energy simulation model using appropriate software tools and successfully evaluated the operational efficiency of the selected commercial building in terms of its energy performance has been a key achievements of this research. This model serves as a valuable tool for evaluating energy-efficient measures and assessing their potential impact on the building's performance. The results of the simulation provided a clear picture of the building's strengths and weaknesses, offering valuable guidance for future energy optimization efforts.

Through a robust theoretical framework, the study proposed energy-efficient measures tailored to the Ethiopian context. These measures are rooted in the knowledge of building energy simulation and have the potential to significantly reduce energy consumption while enhancing operational efficiency. The findings emphasize the need for an integrated approach to building energy management, considering the unique characteristics of each end-use category. Furthermore, the potential for integrating renewable energy sources, enhancing insulation, and exploring advanced cooling and heat recovery systems holds promise for achieving sustainability goals while minimizing environmental impact.

The study has contributed to the adoption and application of building energy simulation in the Ethiopian context. By providing practical insights into energy efficiency, this research serves as a foundation for future studies and initiatives aimed at improving building performance and sustainability in the region.

In conclusion, this analysis provides a comprehensive roadmap for enhancing energy efficiency in the building. By addressing the areas highlighted in this research, building owners and stakeholders can make informed decisions and implement strategies that lead to reduced energy consumption, lower operational costs, and a more sustainable and environmentally responsible building.

5.2. Recommendation

As a researcher conducting a study on building energy efficiency in Ethiopia, I recommend the following strategies and actions to various stakeholders in the context of Ethiopia's unique challenges and opportunities:

For Government and Regulatory Authorities:

- *Data Accessibility*: Facilitate the creation of a centralized database for building energy consumption data. Ensure that this database is accessible to researchers, policymakers, and the public while maintaining data privacy.
- *Energy Efficiency Standards*: Strengthen and enforce energy efficiency standards and building codes, aligning them with international best practices. Regularly update these standards to promote sustainable building practices.
- *Incentive Programs*: Establish financial incentives, tax breaks, or subsidies for building owners who implement energy-efficient technologies and practices. Encourage the adoption of renewable energy sources.
- *Capacity Building*: Invest in training programs and workshops for building inspectors and professionals in the construction industry to increase awareness and compliance with energy efficiency standards.

For Building Owners and Operators:

- *Energy Audits:* Conduct regular energy audits to identify areas for improvement in building systems and operations. Implement energy-saving measures based on audit findings.
- *Technology Adoption*: Invest in energy-efficient technologies, including HVAC systems, lighting, and insulation. Explore renewable energy sources like solar power to reduce reliance on non-renewable energy.
- *Behavioral Change*: Promote energy-efficient practices among building occupants through awareness campaigns and education. Encourage responsible energy use, such as turning off lights and equipment when not in use.

For Researchers and Academia:

- *Collaboration*: Foster collaboration between academic institutions, research organizations, and government agencies to conduct extensive research on building energy efficiency. Share knowledge and data for a more comprehensive understanding of energy consumption patterns.
- *Data Collection*: Develop standardized data collection protocols and methodologies for building energy efficiency research. Ensure transparency in reporting data limitations and biases.
- *Policy Recommendations*: Continuously engage with policymakers to provide evidence-based policy recommendations. Advocate for policies that support energy-efficient building practices and sustainability.

For International Organizations and Donors:

- *Financial Support*: Provide funding and technical assistance for research projects focused on building energy efficiency in Ethiopia. Support initiatives aimed at improving data quality and access.
- *Capacity Development*: Offer capacity-building programs and training for local researchers and institutions in data analysis, building energy simulation, and sustainable building practices.
- *Technology Transfer*: Facilitate the transfer of energy-efficient technologies and best practices from international contexts to Ethiopia. Promote knowledge exchange and collaboration.

For the Public:

- *Awareness Campaigns*: Educate the public about the importance of energy efficiency and its impact on the environment and cost savings. Encourage individuals to adopt energy-saving practices in their homes and workplaces.
- *Community Engagement*: Promote community-based initiatives for energy conservation, such as neighborhood energy committees or renewable energy cooperatives.
- *Policy Advocacy*: Encourage active participation in advocating for energy efficiency policies at the local, regional, and national levels. Public support can drive policy changes.

These recommendations aim to create a collaborative and multidimensional approach to building energy efficiency in Ethiopia. By engaging various stakeholders and addressing data limitations, Ethiopia can make significant strides in promoting sustainable building practices and reducing energy consumption.

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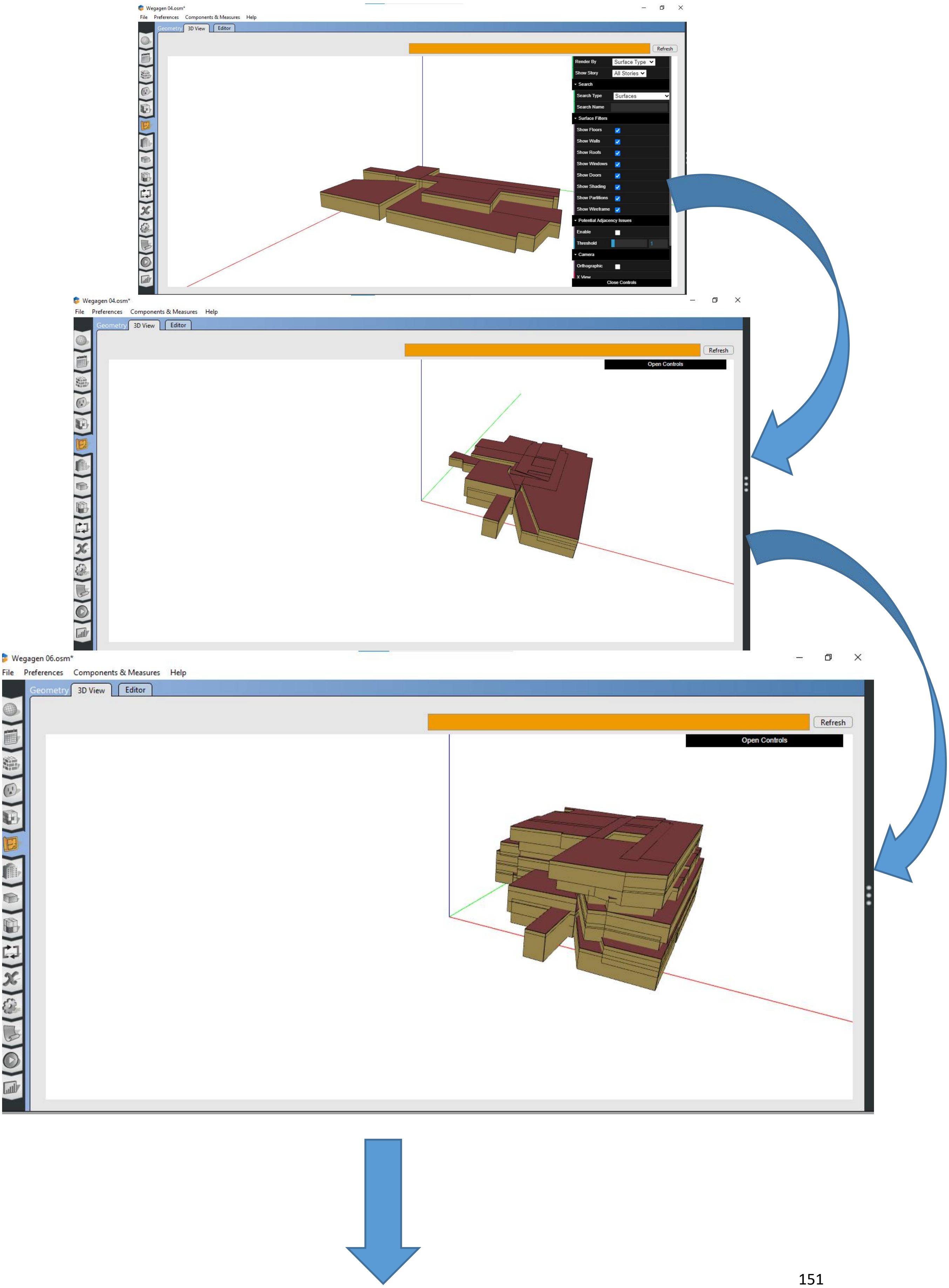
APPENDIX 1: BUILDING MATERIALS WITH SPECIFIC PROPERTIES

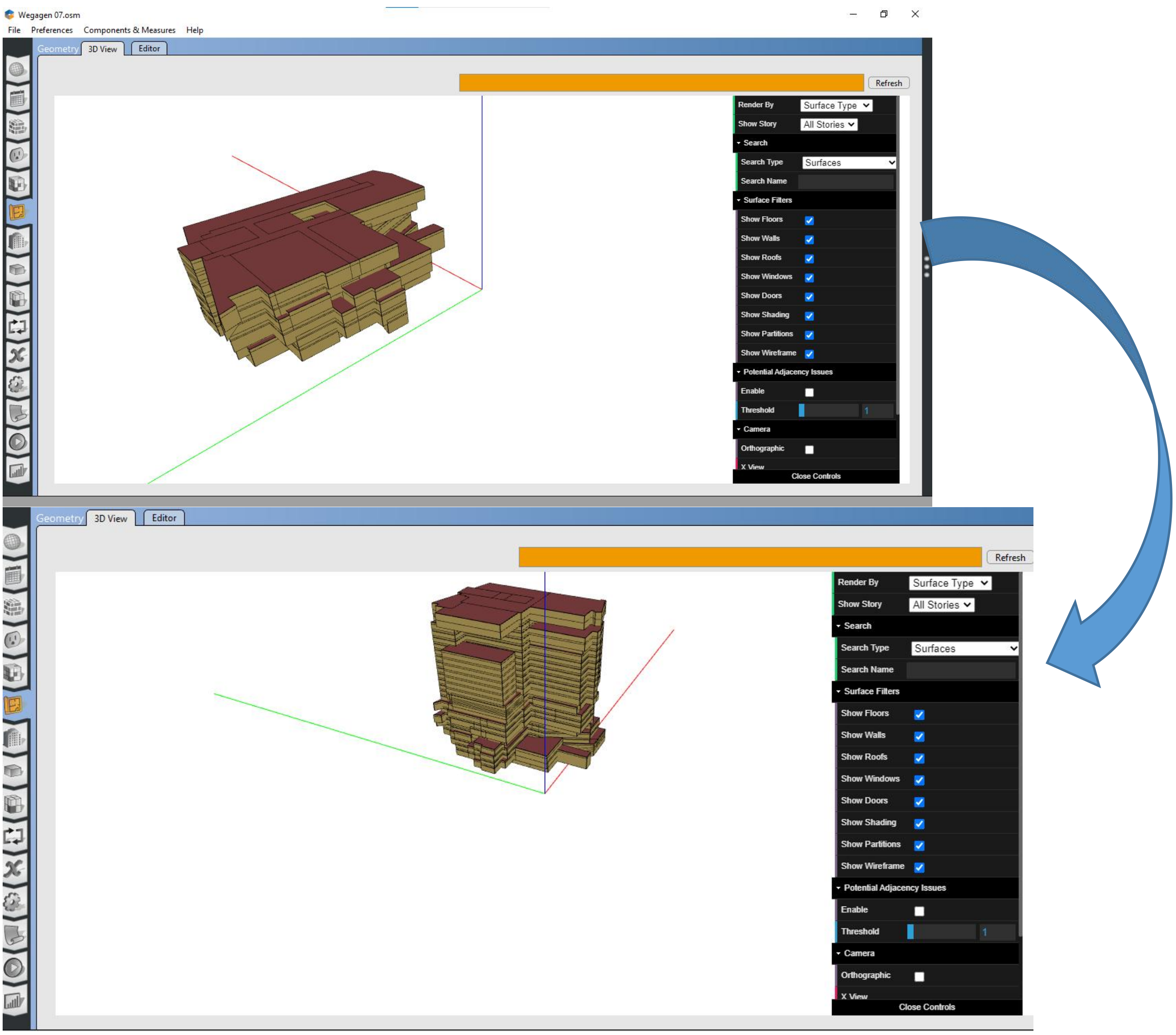
Number	Material Name	Roughness	Thickness(m)	Conductivity (W/m.K)	Density(kg/m^3)	Specific Heat(J/kg.K)	Thermal Absorptance	Solar Absorptance	Visible absorptance
1	C-40 Reinforced Concrete	Medium smooth	0.45	1.7	2400	880	0.85	0.75	0.8
2	Mild steel reinforcement	Medium smooth	0.1	50	7850	490	0.9	0.8	0.85
3	RHS truss purlin	medium rough	0.005	45	7850	490	0.9	0.8	0.85
4	Hollow Cement Block	Rough	0.2	0.2	1200	840	0.9	0.75	0.8
5	Brick wall	Rough	0.12	0.6	1800	840	0.9	0.75	0.8
6	Onduline roofing sheet	Medium rough	0.003	0.15	1900	1250	0.95	0.9	0.95
7	G-28 galvanized flat metal sheet	Smooth	0.01	57	7850	490	0.9	0.8	0.85
8	Bituminous membrane	Smooth	0.005	0.17	1100	1800	0.9	0.9	0.9
9	Hollow core flush	Medium	0.04	0.15	450	1700	0.7	0.6	0.65

	wooden door	smooth							
10	Plywood	Smooth	0.004	0.13	600	2000	0.7	0.6	0.65
11	Armstrong suspended ceiling material	Smooth	0.02	0.06	450	1000	0.8	0.7	0.75
12	Gypsum board	Smooth	0.008	0.25	800	1090	0.8	0.7	0.75
13	MDF Plywood	Smooth	0.012	0.17	700	1800	0.8	0.7	0.75
14	Wooden handrail	Smooth	0.05	0.1	700	900	0.7	0.6	0.65
15	Double solid panels	Smooth	0.012	0.1	1200	800	0.8	0.7	0.75
16	Double glazed clear glass	Smooth	0.005	1	2500	840	0.9	0.8	0.85
17	Melamine faced double solid panels	Smooth	0.04	0.15	900	800	0.8	0.7	0.75
18	Aluminum doors	Smooth	0.04	205	2700	900	0.5	0.4	0.45
19	Aluminum windows	Smooth	0.02	205	2700	900	0.5	0.4	0.45
20	Floor tiles	Smooth	0.01	1.2	2000	840	0.8	0.7	0
21	Skid and Abrasion resistant epoxy type CiSOETS slurry	Smooth	0.01	1.5	2100	1100	0.85	0.8	0.85

22	Granite tile flooring	Smooth	0.02	2.6	2600	790	0.9	0.8	0.85
23	Marble tile	Smooth	0.02	2.5	2700	880	0.9	0.85	0.9
24	Porcelain ceramic floor tiles	Smooth	0.01	1.2	2300	840	0.8	0.7	0.75
25	PVC floor tiles	Smooth	0.004	0.17	1800	1100	0.85	0.8	0.85
26	Terrazzo tile flooring	Rough	0.02	1.8	2400	840	0.8	0.7	0.75
27	Granite skirting	Smooth	0.01	2.6	2600	790	0.9	0.8	0.85
28	Stainless steel	Smooth	0.002	16	7900	500	0.7	0.6	0.65
29	Ceramic wall tiles	Smooth	0.006	1.2	2200	900	0.8	0.7	0.75
30	Glazed mosaic wall tiles	Smooth	0.006	1	2100	850	0.8	0.7	0.75

APPENDIX 2 : GEOMETRY DEVELOPMENT




Wegagen 07.osm
File
Preferences
Components & Measures
Help
Geometry
3D View
Editor
Refresh
Render By
Surface Type
Show Story
All Stories
Search
Search Type
Surfaces
Search Name
Surface Filters
Show Floors
Show Walls
Show Roofs
Show Windows
Show Doors
Show Shading
Show Partitions
Show Wireframe
Potential Adjacency Issues
Enable
Threshold
Camera
Orthographic
X View
Close Controls

APPENDIX 3: ERROR CODE OF 1ST SIMULATION TRIAL

Program Version,EnergyPlus, Version 22.2.0-aa78da9668, YMD=2023.08.07 21:22,

** Warning ** Timestep: Requested number (1) is less than the suggested minimum of 4.

** ~~~ ** Please see entry for Timestep in Input/Output Reference for discussion of considerations.

** Warning ** CheckEnvironmentSpecifications: SimulationControl specified doing design day simulations, but no design environments specified.

** ~~~ ** ...No design environment results produced. For these results, add appropriate SizingPeriod:* objects for your simulation.

** Warning ** ProcessScheduleInput: Schedule:Constant="ALWAYS ON DISCRETE", Blank Schedule Type Limits Name input -- will not be validated.

** Warning ** ProcessScheduleInput: Schedule:Constant="ALWAYS OFF DISCRETE", Blank Schedule Type Limits Name input -- will not be validated.

** Warning ** ProcessScheduleInput: Schedule:Constant="ALWAYS ON CONTINUOUS", Blank Schedule Type Limits Name input -- will not be validated.

** Severe ** WindowMaterial:Glazing="ALUMINUM WINDOW", Illegal value combination.

** ~~~ ** Infrared Transmittance at Normal Incidence + Front Side Infrared Hemispherical Emissivity not <= 1.0

** Severe ** WindowMaterial:Glazing="ALUMINUM WINDOW", Illegal value combination.

** ~~~ ** Infrared Transmittance at Normal Incidence + Back Side Infrared Hemispherical Emissivity not <= 1.0

** Severe ** WindowMaterial:Glazing="DOUBLE GLAZED CLEAR GLASS", Illegal value combination.

** ~~~ ** Infrared Transmittance at Normal Incidence + Front Side Infrared Hemispherical Emissivity not <= 1.0

** Severe ** WindowMaterial:Glazing="DOUBLE GLAZED CLEAR GLASS", Illegal value combination.

** ~~~ ** Infrared Transmittance at Normal Incidence + Back Side Infrared Hemispherical Emissivity not <= 1.0

** Severe ** Errors found in creating the constructions defined with Construction:AirBoundary.

** Warning ** GetHTSurfaceData: Surfaces with interface to Ground found but no "Ground Temperatures" were input.

** ~~~ ** Found first in surface=FACE 1284

** ~~~ ** Defaults, constant throughout the year of (18.0) will be used.

** Warning ** BuildingSurface:Detailed="FACE 0", Sun Exposure="SUNEXPOSED".

** ~~~ ** ..This surface is not exposed to External Environment. Sun exposure has no effect.

** Severe ** RoofCeiling:Detailed="SURFACE 793", Vertex size mismatch between base surface :SURFACE 793 and outside boundary surface: FACE 2039

** ~~~ ** The vertex sizes are 6 for base surface and 7 for outside boundary surface. Please check inputs.

** Severe ** RoofCeiling:Detailed="FACE 2039", Vertex size mismatch between base surface :FACE 2039 and outside boundary surface: SURFACE 793

** ~~~ ** The vertex sizes are 7 for base surface and 6 for outside boundary surface. Please check inputs.

** Severe ** RoofCeiling:Detailed="FACE 3663", Vertex size mismatch between base surface :FACE 3663 and outside boundary surface: SURFACE 2294

** ~~~ ** The vertex sizes are 20 for base surface and 14 for outside boundary surface. Please check inputs.

** Severe ** RoofCeiling:Detailed="SURFACE 2294", Vertex size mismatch between base surface :SURFACE 2294 and outside boundary surface: FACE 3663

** ~~~ ** The vertex sizes are 14 for base surface and 20 for outside boundary surface. Please check inputs.

** Severe ** RoofCeiling:Detailed="FACE 3646", Vertex size mismatch between base surface :FACE 3646 and outside boundary surface: FACE 3747

** ~~~ ** The vertex sizes are 12 for base surface and 11 for outside boundary surface. Please check inputs.

** Severe ** RoofCeiling:Detailed="FACE 3747", Vertex size mismatch between base surface :FACE 3747 and outside boundary surface: FACE 3646

** ~~~ ** The vertex sizes are 11 for base surface and 12 for outside boundary surface. Please check inputs.

** Severe ** RoofCeiling:Detailed="FACE 3318", Vertex size mismatch between base surface :FACE 3318 and outside boundary surface: FACE 3475

** ~~~ ** The vertex sizes are 7 for base surface and 9 for outside boundary surface. Please check inputs.

** Severe ** RoofCeiling:Detailed="FACE 3475", Vertex size mismatch between base surface :FACE 3475 and outside boundary surface: FACE 3318

** ~~~ ** The vertex sizes are 9 for base surface and 7 for outside boundary surface. Please check inputs.

** Severe ** FenestrationSurface:Detailed="FACE 1235", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1112", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1114", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1197", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 691", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 692", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 700", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 701", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 501", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 502", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 504", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3678", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3686", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3689", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3691", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3693", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3695", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3770", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3771", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3774", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3778", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3785", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3787", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3789", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3793", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3818", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3839", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3840", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1088", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1090", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 370", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 371", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 373", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1191", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 445", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 446", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 449", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 450", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 278", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 279", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 282", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 283", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3656", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3735", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3758", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3762", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 571", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1078", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1217", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 586", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 416", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 418", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 419", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 424", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 427", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 428", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 433", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 434", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 437", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 438", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 79", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 596", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 291", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 299", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 300", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 302", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3742", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3746", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3804", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1122", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1125", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1127", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1134", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1136", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1140", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1142", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1146", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1152", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1157", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1159", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1161", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 323", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 325", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 326", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 329", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 331", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 333", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 334", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 339", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 340", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 343", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 344", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1181", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 384", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 390", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 391", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 91", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3705", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3847", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 641", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3712", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3719", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3726", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 3854", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 549", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 552", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 555", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 557", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 559", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 563", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1228", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 1267", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 576", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 623", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 629", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Severe ** FenestrationSurface:Detailed="FACE 606", invalid blank Outside Boundary Condition Object

** ~~~ ** ...when Base surface uses "Surface" as Outside Boundary Condition Object, subsurfaces must also specify specific surfaces in the adjacent zone.

** Fatal ** GetSurfaceData: Errors discovered, program terminates.

...Summary of Errors that led to program termination:

..... Reference severe error count=129

..... Last severe error=FenestrationSurface:Detailed="FACE 606", invalid blank Outside Boundary Condition Object

************* Warning: Node connection errors not checked - most system input has not been read (see previous warning).

************* Fatal error -- final processing. Program exited before simulations began. See previous error messages.

************* EnergyPlus Warmup Error Summary. During Warmup: 0 Warning; 0 Severe Errors.

************* EnergyPlus Sizing Error Summary. During Sizing: 0 Warning; 0 Severe Errors.

************* EnergyPlus Terminated--Fatal Error Detected. 7 Warning; 129 Severe Errors; Elapsed Time=00hr 00min 17.81sec