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ENERGY EFFICIENCY ANALYSIS OF RESIDENTIAL BUILDINGS

Case study in Sanford FL, USA

Bachelor’s thesis
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Degree Program in Construction Engineering		Abstract
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This thesis studies the energy efficiency of a residential building in Sanford, FL, using IDA ICE simulation software. The increasing construction sector significantly impacts global energy consumption and greenhouse gas emissions, with residential buildings playing a crucial role due to their significant energy consumption. Addressing energy efficiency in residential buildings is important in promoting sustainable energy consumption and moderating environmental impacts.

A systematic comparison between simulated and actual energy consumption data from official electricity bills over one year forms the core of this research. The methodology involved validating the simulation results against real-world energy usage patterns to ensure the reliability of the analysis. Acknowledging limitations such as data restraints and modelling assumptions, the study underscores the importance of accurately characterizing buildings for predicting energy consumption.

The findings highlight potential benefits in energy cost reduction and environmental impact mitigation. The study offers valuable insights into enhancing residential building energy efficiency and promoting renewable energy integration. Recommendations for future research emphasize refining simulation models and considering a broader range of construction details to further advance residential building energy efficiency.

Keywords Energy efficiency, residential buildings, IDA ICE simulation, renewable energy

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1 Introduction

The growing construction sector is a major contributor to global energy consumption and greenhouse gas emissions. Especially residential buildings play an important role in this field because they account for a significant share of energy consumption. That is why pursuing energy efficiency in residential buildings has become essential in addressing environmental concerns and achieving sustainable energy consumption patterns. As the need for housing keeps increasing, focusing on making residential buildings more energy-efficient is a key strategy to mitigate the environmental impact associated with increased construction activity. This approach not only aligns with broader sustainability goals but also recognizes the pivotal role of residential buildings in shaping more responsible and eco-friendly energy practices globally. To provide a thorough exploration of these facets, the following elements are considered: background, research objectives, limitations, and importance of the case study. These components are strategically arranged to offer a comprehensive understanding of the context, goals, potential constraints, and the overarching purpose of the study.

1.1 Background

Residential and commercial sectors account for a significant portion of global energy consumption. In the United States, for instance, the residential buildings alone contributed to about 21% of the total energy consumption in 2022 (U.S. Energy Information Administration [EIA], 2023). This statistic, sourced from the authoritative EIA, underscores the importance of prioritizing energy efficiency initiatives in residential buildings. By focusing on energy efficiency in this sector, there is a substantial opportunity to mitigate overall energy consumption and, consequently, reduce associated greenhouse gas emissions.

In the broader context of global energy challenges, the optimization of energy efficiency in residential buildings is seen as an essential approach. By ensuring more efficient energy usage in households, a significant contribution to energy conservation is made, playing a critical role in addressing the impact of climate change.

1.2 Research Objectives

The primary goal of this research is to conduct a wide-ranging analysis of the energy efficiency of the building located at 1634 Silk Tree Circle in Sanford, FL, utilizing the IDA ICE software. The selection of Sanford, FL, USA, for an energy efficiency analysis of residential buildings was influenced by its housing types which is commonly found in both urban and suburban areas. This case study provides insights into energy-efficient practices that can be applied to similar residential buildings, contributing to a broader understanding of residential energy efficiency. This analysis will involve simulating and evaluating the building's energy consumption of the building. The focus is on comparing the simulated energy consumption with the original energy consumption of the building, aiming to identify areas for potential energy savings and improvements.

1.3 Scope and Limitations of the Study

The study exclusively focuses on assessing the energy efficiency of a specific residential building using IDA ICE software. This assessment includes data collection, modeling, simulation, and analysis of the building's energy performance. However, this study does not include other architectural or structural assessments and evaluations. It is important to note that the analysis relies on assumptions and information available at the time of evaluation, as the full HVAC plan and some other necessary detailed information were not available. Any changes made to the building's structure afterward may not be reflected in the results.

1.4 Significance of the Study

The study offers valuable insights for understanding and improving of the energy efficiency in residential buildings. Through a detailed case study using IDA ICE, this study aims to provide a systematic analysis of energy consumption in residential buildings. Rather than focusing on providing sustainable solutions, the primary goal is to offer insights and data that can inform decision-making investors. The findings of this research will be of interest to building owners, energy consultants, and policymakers involved in energy-related decision-making within the residential sector.

This thesis proposal outlines the framework for conducting a preliminary analysis of 1634 Silk Tree Circle, Sanford, FL, and presents a structured approach to investigate its energy efficiency. The subsequent chapters will look into the literature review, methodology, results, and discussion, ultimately culminating in conclusions and recommendations that would have the potential to advance the field of residential building energy efficiency.

2 Literature Review

To broadly study the energy efficiency of residential buildings, two key aspects will be explained in the literature review: energy simulation methodologies and the fundamental role played by IDA ICE software (Section 2.1). A case study example (section 2. 2), Following that, insights into the broader position of energy efficiency in residential buildings will be investigated (Section 2.3).

2.1 Energy Simulation in IDA ICE

IDA ICE, which stands for "IDA Indoor Climate Energy," is a complex but flexible simulation software tool personalized for the field of Indoor Climate and Energy (ICE) within the building industry. It is developed to address the multi-layered challenges of optimizing indoor climate conditions and energy performance. IDA ICE is recognized for its strong capabilities in simulating, analyzing, and optimizing indoor environments, making it an invaluable asset for architects, engineers, building owners, and energy professionals. It claims that "It accurately models the building, its systems, and controllers – ensuring the lowest possible energy consumption and the best possible occupant comfort" EQUA (n.d. -a)

IDA ICE presents a complete suite of features and capabilities made for modeling and analyzing indoor climate and energy performance perfectly. With a focus on dynamic simulation, the software excels in assessing indoor climate and energy performance across different conditions, providing important insights into the interaction among building systems, occupant behavior, and environmental factors. Offering tools for energy consumption analysis, IDA ICE empowers users to model, monitor, and analyse energy usage within buildings, facilitating the identification of inefficiencies and the implementation of energy-saving strategies.

The software enhances its HVAC system simulation capabilities by supporting the improvement of Heating, Ventilation, and Air Conditioning (HVAC) systems, thereby enhancing energy efficiency and occupant comfort. Additionally, IDA ICE facilitates the integration of renewable energy sources such as solar panels and wind turbines. This feature allows users to assess the viability of renewable energy solutions and their impact on building energy performance.

IDA ICE proves to be valueable not only in building design but also in retrofitting efforts. Architects and engineers can influence and control the software during the design phase to evaluate building configurations, energy-efficient technologies, and HVAC systems. This, in turn, enables informed decision-making authorities to adjust energy consumption and indoor climate of residential buildings.

Beyond design and retrofitting, IDA ICE serves as a fundamental tool for energy management, and helps the building owners and facility managers to benefit from the real-time monitoring of energy consumption, enabling the identification of inefficiencies and the implementation of demand-side management strategies to reduce operational costs and environmental impact.

It is also important to mention that using IDA ICE for simulation has its own challenges and considerations. According to Arnaiz Remiro (2017), IDA ICE has shown some limitations in terms of thermal bridges, which accounted for almost 15% of total transmission heat losses. Additionally, although IDA ICE offers significant advantages, including its dynamic modeling capabilities and real-time monitoring, it also presents some significant challenges. For instance the accuracy of simulations depends on input data quality and assumptions, and expertise in building systems and energy modeling is essential for effective utilization. Additionally, the cost of gaining and implementing IDA ICE may be a consideration for smaller organizations.

2.2 Case Study Examples

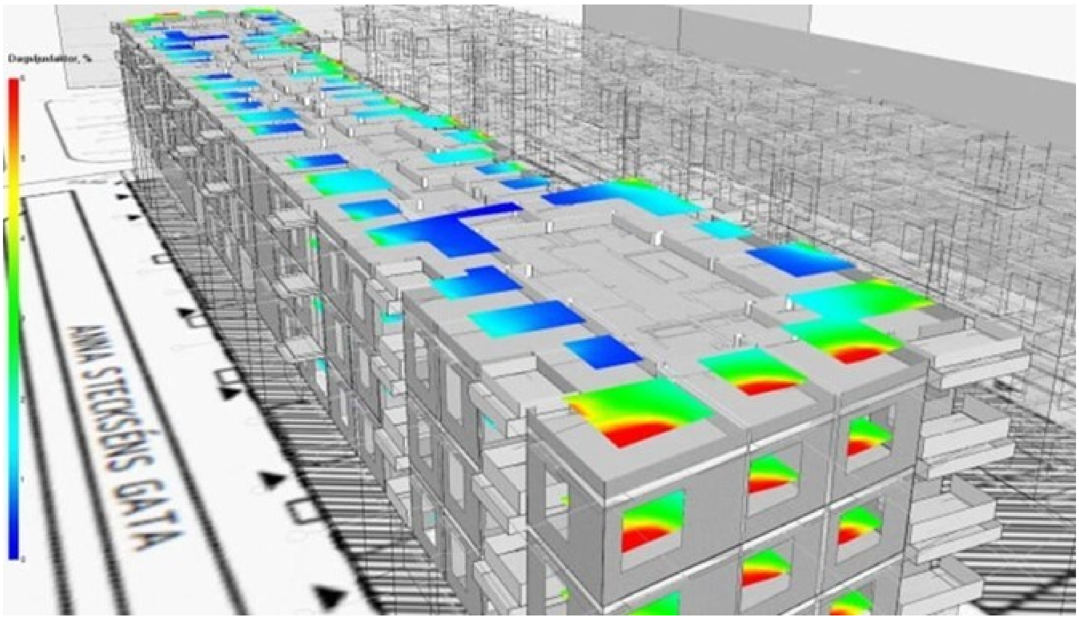
There are several case studies utilizing IDA ICE, operated by many engineers and energy analysts. One notable example is the "Hagastaden Residentials - Miljöbyggnad" project, which involved constructing a sizable multi-storey residential building in Stockholm, Sweden. The project aimed to achieve certification under the Swedish green building system Miljöbyggnad, evaluating various aspects including energy use, heating demand, and thermal comfort (Hagastaden Residential Apartments - Miljöbyggnad, n.d.).

The project faced the challenge of meeting the tough requirements set by Miljöbyggnad, particularly in optimizing glazing sizes and types to enhance energy efficiency. Previous methodologies had involved the use of multiple software tools, leading to a time-consuming process. To address this challenge, a solution was implemented involving the modeling of the entire building at a room-by-room resolution using IDA ICE. The evaluation of six Miljöbyggnad indicators was conducted using the same simulation model. The use of an IDA

ICE extension module played a crucial role in streamlining the process. This extension provided custom-designed simulation setups for the six indicators, automatically adjusting the model and generating reports to align with Miljöbyggnad requirements.

The simulation model generated modifications to both the apartments and building systems. These adjustments were influential in ensuring fulfilment with Miljöbyggnad indicators, thereby guaranteeing the health and comfort of occupants while achieving low energy consumption. The application of IDA ICE, particularly in this case study, exemplifies its efficiency in addressing complex challenges and optimizing building performance in alignment with strict certification standards. In the simulation results presented by EQUA (n.d.), daylight factors are illustrated based on the geometry of the IDA ICE model and the Radiance simulation engine (see Figure 1). Figure 1 portrays modeled building floors and the nearest surrounding building causing shading in the IDA ICE simulation, adapted from EQUA (n.d. -b).

Figure 1. Modeled building floors and nearest surrounding building causing shading - simulation in IDA ICE.



2.3 Energy Efficiency of Residential Buildings

Global energy consumption, experiencing rapid growth in the last half-century, is expected to persist in its upward trajectory for the next 50 years, albeit with notable distinctions. The preceding surge was fueled by relatively inexpensive fossil fuels and heightened industrialization in North America, Europe, and Japan. However, the evolving energy landscape introduces additional complexities, including the escalating energy use in populous countries like China and India, constituting about a third of the global population, the anticipated depletion of oil resources, and the repercussions of human activities on global climate change. According to Goswami and Kreith (2016, p. 4), authors of Global Energy Systems, "On the positive side, the renewable energy (RE) technologies of wind, biofuels, solar thermal, and photovoltaics (PV) are finally showing maturity and the ultimate promise of cost competitiveness".

Statistics from the International Energy Agency (IEA) World Energy Outlook 2004 and 2010 indicate a significant rush in the world's total primary energy demand from 5,536 million tons of oil equivalent (MTOE) in 1971 to 10,345 MTOE in 2002, marking an average annual increase of 2% (IEA, 2010; cited in Kreith & Goswami, 2016).

By 2008, global energy demand had reached 12,271 MTOE, exhibiting an average annual increase of approximately 3%. The accelerated growth is attributed to the increasing energy demand in the Asia Pacific region, particularly in China and India. Subsequently, from 2008 to 2011, the annual increase in energy use moderated to 2.1%, primarily due to a recession in the United States and Europe, leading to a decline in energy consumption.

The latest decade of energy consumption data from BP Corp. reveals a paradox where, despite a decrease in total primary energy use in North America and Europe, the global average increase has risen to 2.8%. This heightened growth is fueled by rapid expansion in Asia Pacific, with an average annual increase of 6.1%, notably in China, where primary energy consumption exceeded by approximately 10% per year from 2002 to 2012. Projections indicate a continuation of this trend in China for at least another decade (IEA, 2013; cited in Kreith & Goswami, 2016).

Even with a conservative estimate of a 2% annual increase, the primary energy demand of 12,271 MTOE in 2008 would double by 2043 and triple by 2063. Acknowledging the impracticality of sustained continuous growth, the IEA (2013) forecasts a global energy use increase at an average annual rate of 1.2% up to 2035. Regarding this with a more optimistic growth rate, the global energy use is projected to rise by 38% by 2035, reaching 16,934 MTOE/year. In 2002, fossil fuels constituted about 80% of the total world primary energy demand, with oil, coal, and natural gas accounting for 36%, 23%, and 21%, respectively. Biomass contributed 11% to global primary energy, primarily traditional biomass used inefficiently for cooking and heating in developing countries.

Despite the continuous rise in oil consumption, its overall share in primary energy decreased from 35% in 2002 to 31% in 2011. Conversely, coal's share in primary energy increased from 23% in 2002 to 29% in 2011, primarily due to rapid power production growth in countries like China, where coal provides over 75% of electrical power (Zhou, 2012). In the United States, while coal's share of electricity generation has declined in recent years due to factors such as increased natural gas use and renewable energy expansion, it still remains a significant contributor to the energy mix. Given the substantial future energy demand in the U.S., particularly for electricity and transportation, a comprehensive evaluation of available resources is crucial (Coal - IEA, n.d.).

While addressing the increasing energy demands for a growing global population, it is essential to consider the ascending population growth's related challenges in energy and food consumption and environmental degradation. As the United Nations forecasts a rise in the global population to around 9 billion by 2050, with an increase of 2.5 billion people predominantly in developing countries, population growth must be factored into the overarching supply and demand considerations to ensure the success of future global energy and pollution strategies (Bartlett, 2002; cited in Kreith & Goswami, 2016).

In the context of the case study, it is important to mention that the efficiency of home and business appliances has significantly improved in the last 30 years. However, there remains an opportunity for further reduction in energy consumption within the buildings. In the U.S., residential and commercial buildings accounted for 39% of the total primary energy and 72% of electricity consumption in 2006, with heating, ventilation, and air-conditioning (HVAC) being the largest energy consumer, followed by lighting.

On the residential side, energy was used in about 80.8 million single-family homes, 24.8 million multifamily housing units, and nearly 6.9 million mobile homes in 2006. On the commercial side, there were around 5 million buildings with 75 billion square feet of floor space in 2006. Despite the long lifespan of buildings and appliances, there have been significant changes in energy use and efficiency over the past 30 years (Kreith & Goswami, 2016).

According to the findings of Ritchie (2021), "A number of countries have decoupled economic growth from energy use, even if we take offshored production into account." This emphasizes the importance of understanding the complexities of energy and economic relationships in today's globalized world. For instance, advancements in technology and shifts toward renewable energy sources may contribute to this decoupling trend, offering opportunities for sustainable development and environmental conservation.

Understanding the potential for improving building energy efficiency requires more detailed data. Unfortunately, much of the available data is based on self-reporting or inferences rather than direct measurement. Growth in the use of various electrical appliances has contributed to the increased energy use in buildings in recent decades.

To summarize, prioritizing energy efficiency in residential buildings is reasonably important about considerations such as the maintenance of resources like energy and personal financial gains. The importance of this aspect can be underscored through the following key points:

- Resource Management: Efficient energy practices contribute to the supervision of valuable natural resources, ensuring a sustainable future.
- Cost Savings: Homeowners benefit from substantial cost savings as energy-efficient measures lead to reduced utility bills and long-term affordability.
- Environmental Impact: Lower energy consumption reduces the environmental footprint, promoting a lifestyle that prioritizes eco-consciousness and long-term sustainability.
- Comfort and Well-being: Energy-efficient homes offer improved living conditions, including consistent temperatures and better indoor air quality, enhancing the overall well-being of residents.
- Sustainable Living: Embracing energy efficiency aligns with broader sustainability goals, promoting responsible living practices for a healthier planet and future.

In consideration of the above-mentioned significance of energy efficiency, the following chapter explores into an inclusive analysis of a real-world case. This case study not only aligns with the discussed importance of energy efficiency but also aims to provide practical insights and solutions within the context of a single-family house.

3 Methodology

The validation process involved a systematic comparison of simulated results with actual energy consumption data obtained from the official electricity bill (see Appendix 4). Key performance metrics, including total energy consumption and individual components (heating, cooling, lighting, and appliances), were inspected against the officially recorded energy usage over the course of the entire year.

3.1 Data Collection

In conducting the analysis of the energy efficiency of the residential property at 1634 Silk Tree Cir, Sanford, FL 32773, it is important to consider various factors that contribute to energy consumption. While detailed information about the construction and design of the property, including insulation levels, window types, and specific HVAC system specifications, was not readily available, a comprehensive approach was still adopted to evaluate other facets of the building's specifications and utility infrastructure. In accordance with energy efficiency guidelines inspections are mandated to ensure compliance with specified standards (Sanford, 2023, p. 36). These inspections cover a range of elements critical to energy efficiency, including assessing the thermal resistance and transmittance (U-value) of envelope insulation. However, it is essential to acknowledge that the exact U-values for doors and other components could not be determined, as the materials and specifications for these elements were not available. Therefore, assumptions and estimations were made in the analysis to address these uncertainties. This inclusive approach seeks to determine the alignment between the actual energy data and the analyzed data from IDA ICE, simultaneously exploring potential options for energy management.

Despite these challenges, the overall efforts in the case study were directed towards aligning with established standards and guidelines, reflecting a careful attempt to follow the energy efficiency norms (Sanford, 2023).

3.2 Building Description

Essential details were extracted from the property records provided by the owner, covering total area in square meters, that includes four bedrooms, two bathrooms, and distinctive features such as the built-in electric fireplace. Construction specifics, including materials (block, stucco) for external walls, foundation (slab), and roof type are carefully noted. The property's Northwest orientation for solar exposure and energy efficiency evaluations was also considered. The building’s central air conditioning system results in the acquisition of insights into heating and cooling systems, exploring their potential impact on thermal comfort and energy consumption of the house. Additionally, energy-contributing appliances, namely the cooktop, dishwasher, electric water heater (replaced in 2021), and microwave, are also acknowledged.

Reviewing the recent updates, specifically the replacement of the water heater in 2021 and the upgrade of the air conditioning unit in 2020, provides better vision into the property's energy-related systems. Verification of the water heater type (electric) and an assessment of its capacity further contribute to a comprehensive understanding of the building's energy infrastructure. Operating seamlessly, the electric water heater connects directly to the city's water supply, facilitating on-demand water heating for domestic utilization and no storage water is used in the building. Considering architectural features that may influence energy efficiency, such as sliding doors, the electric fireplace, and the overall three-dimensional layout, is an important aspect of the analysis.

The estimation extends to the property's geographical location and Northwest orientation in relation to solar exposure, exploring how these factors influence energy efficiency of the whole building. The year of construction (2001) and any other subsequent modifications or renovations that could have affected energy efficiency, was taken into account.

Since the Florida Legislature authorized the implementation of the initial edition of the Florida Building Code in 2000, most modeling assumptions have taken this into consideration. Now in its 7th edition, the code plays a crucial role in guiding the design, construction, modification, and upkeep of public and private structures and facilities across the state. It is strongly recommended to follow to the latest edition of the code for future analyses of energy systems in construction of new residential buildings.

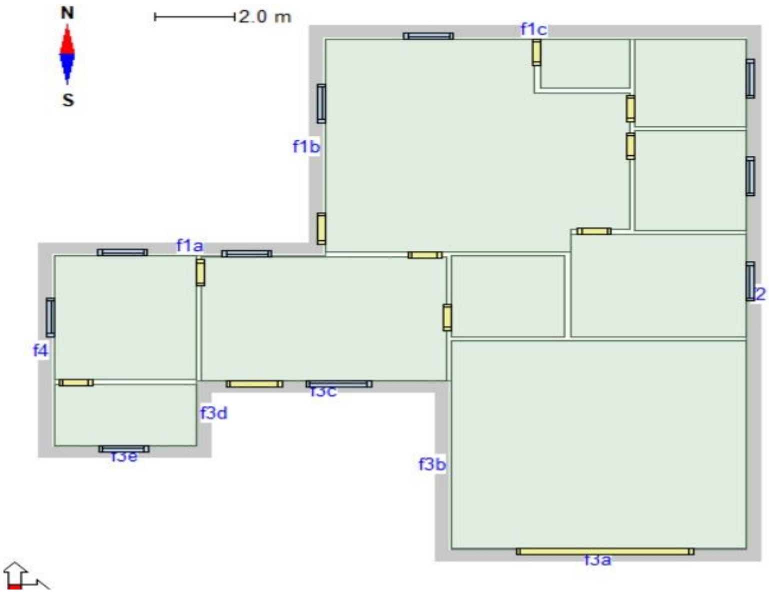
3.3 Modeling the Case Study in IDA ICE

Modeling a building in an energy simulation software involves creating a digital representation of the building and its components within the software to analyze and simulate its energy performance. This process is crucial for evaluating how various design choices, materials, and systems impact energy consumption, thermal comfort, and overall sustainability.

3.3.1 Building Geometry

The Single Family Residence, built in 2001, provides a good dataset for energy modeling. With 180.5 m^2 of living space, four bedrooms, and two bathrooms, the residence features carpet, ceramic tile, and laminate flooring. The central heating and air conditioning systems, including an upgrade in 2020, contribute to year-round comfort. Appliances such as a cooktop, dishwasher, and microwave are integral to the model. The residence is built using block and stucco materials, with a slab foundation supporting the structure. It has a shingle roof. The Northwest orientation, corner lot location, and exterior features like sliding doors are considered for solar exposure simulations. Utilities, zoning, and parcel information further enrich the model, creating a comprehensive representation for accurate energy simulations. Figure 2 shows the floor plan of the building.

Figure 2. Floor plan of the case study building in IDA ICE.



3.3.2 Thermal Bridges

In acknowledging the importance of addressing thermal bridges in building design, it is essential to navigate practical challenges and limitations that may influence their effective implementation. Thermal bridges, which occur due to breaks in the insulation layers, leading to increased heat transfer, can result from differences in material conductivity, structural elements, or changes in geometry. Despite the recognized benefits of minimizing thermal bridges, such as enhanced energy efficiency, improved comfort, and long-term cost savings, practical constraints may necessitate certain assumptions when the actual thermal bridge is not known. According to Jedidi & Benjeddou (2018, p. 42), "Thermal bridges account for 10-40% of losses. They drag on the inner surface of the wall a local temperature drop and create cold areas located in the house". So, it is very crucial to consider it carefully while designing and simulation of the energy consumption of a building.

In building design and construction, addressing thermal bridges is critical to achieving optimal energy efficiency. Thermal bridges, which occur due to breaks in insulation layers, can lead to increased heat transfer and compromise the thermal performance of a building envelope (Florida Building Code, Energy Conservation, Eighth Edition, 2023). The 2023 Florida Building Code mandates that UA calculations consider the thermal bridging effects of framing materials, emphasizing the importance of accounting for these factors in energy performance assessments.

Due to limitations in the existing structure or general regulations applicable during construction, it might be necessary to assume that thermal bridges in a specific single-family house are within acceptable limits in certain circumstances. So, in this case study, all thermal bridges are assumed as 'good,' since it was built after the Florida Building Code was applicable to all newly made buildings, including single-family houses. This assumption acknowledges the historical context of the building's construction. However, it is important to note that thermal bridges, if not addressed, can lead to higher energy consumption, reduced energy efficiency, and potential comfort issues in the house.

In the building construction sector, the presence of thermal bridges represents an unavoidable reality. These thermal bridges manifest in various structural elements such as door and window frames, balcony brackets, and junctions between shell components. Despite efforts to minimize their impact, their existence persists, posing challenges to the thermal efficiency of buildings. Recognizing these factors underscores the complexity involved in controlling heat transfer within buildings, necessitating detailed planning to address these thermal challenges effectively in designing phase of the building (Jedidi & Benjeddou, 2021).

Research and monitoring indicate an increasing recognition of the significance of minimizing thermal bridging in both new constructions and existing buildings. This is crucial for reducing overall energy consumption, preventing condensation on cold surfaces, and enhancing occupant comfort. With growing concerns about sustainability and energy efficiency, addressing thermal bridging has emerged as a key priority in contemporary building design and retrofitting strategies (Building Envelope Thermal Bridging Guide, 2021).

To simplify it, thermal bridge refers to a localized area in a building envelope where the heat transfer is significantly higher than that of the surrounding materials. This can occur when there is a break or interruption in the insulation layer, creating a path for heat to flow more easily. Thermal bridges can occur at joints, corners, or penetrations in the building envelope, and they can have a substantial impact on energy efficiency, potentially leading to heat loss and increased energy consumption.

It is important to mention that knowing the exact and actual thermal bridge is crucial for the analysis of energy consumption in residential buildings, and its absence can affect the accuracy of the calculation process. For the case study, they were assumed to be 'good' since the building was constructed when the relevant regulations were already applicable to all newly made residential buildings (see Figure 3).

Figure 3. Thermal bridges of the envelope area

Envelope area definition

● Internal ○ Overall internal ○ External ○ External incl. floor slab ○ Preserve wall volume

Thermal bridges

	Value	Unit
External wall / internal slab	0.01	W/K/(m joint)*
External wall / internal wall	0.01	W/K/(m joint)*
External wall / external wall	0.06	W/K/(m joint)
External windows perimeter	0.02	W/K/(m perim)
External doors perimeter	0.02	W/K/(m perim)
Roof / external walls	0.07	W/K/(m joint)
External slab / external walls	0.07	W/K/(m joint)
Balcony floor / external walls	0	W/K/(m joint)
External slab / Internal walls	0	W/K/(m joint)*
Roof / Internal walls	0.01	W/K/(m joint)*
External walls, inner corner	-0.15	W/K/(m joint)
External slab / external walls, inner corner	-0.07	W/K/(m joint)
Roof / external walls, inner corner	-0.12	W/K/(m joint)

3.3.3 HVAC System and AHU

HVAC, which stands for Heating, Ventilation, and Air Conditioning, includes the technology designed to regulate indoor air and automative environmental conditions. In residential buildings, HVAC systems are important to sustaining a pleasant and healthy indoor air (Howell, 2017). The system contains three key functions:

- Heating (H): This component ensures warmth in living spaces during cold weather, utilizing systems such as heaters, boilers, and heat pumps.
- Ventilation (V): Ventilation involves the continuous exchange of indoor and outdoor air to guarantee a fresh air supply. Effective ventilation helps in eliminating indoor pollutants and managing moisture levels, often employing mechanical systems like fans and air exchangers.
- Air Conditioning (AC or C): It is responsible for cooling indoor spaces during hot weather, air conditioning can be achieved through central systems or individual units like window or split systems.

In the case study, the building uses a centralized HVAC system. In a centralized HVAC system, all the heating, ventilation, and air conditioning functions are handled by a single, joined system. While for a centralized HVAC system for a residential building, the Air Handling Unit (AHU) is a critical component responsible for processing and distributing conditioned air. The AHU is typically located in a central mechanical room or utility area. It takes in air from various sources, including return air from inside the building and fresh air from the outside (Puccio, 2021).

Assuming a standard AHU in a centralized HVAC system is a common practice. The HVAC system integrates a compressor mechanism for cooling purposes, complemented by electric heating elements. This amalgamation of cooling and heating functionalities enhances operational versatility and energy efficiency, aligning with contemporary sustainability standards. A standard AHU, or Air Handling Unit, is a crucial component in HVAC systems designed for buildings and industrial facilities. Its primary function is to manage and circulate air to maintain optimal environmental conditions. The AHU achieves this by incorporating various components, including a fan that facilitates air movement, heating and/or cooling coils to adjust temperature, filters for air purification, and dampers to regulate airflow.

For the case study, the electrical heating coil is used for energy simulation purpose (see Figure 4). The purpose of the AHU (Air Handling Unit) heating coil is to heat the air passing through the HVAC system. It is a key component in the process of providing warm air to a building or space, particularly during colder periods or in climates where heating is necessary.

The AHU heating coil consists of a series of tubes or pipes arranged in a coil shape, often made of materials such as copper or steel. These coils are typically connected to a heat source, such as a boiler or a heat pump, which circulates hot water, steam, or other heating fluids through the coils. When the HVAC system operates in heating mode, it pulls cold air from the surrounding environment into the Air Handling Unit (AHU). As this air flows over the heating coil, the heat from hot water or steam circulating within the coil is transferred to the air. Consequently, the air's temperature increases, effectively heating it before it is circulated throughout the building via ductwork (VR Cooler, 2023).

The heating coil within the AHU plays a fundamental role in ensuring a comfortable indoor environment by providing the necessary heat during colder seasons. It allows for precise temperature control and ensures that the air delivered to different areas of the building meets the desired temperature requirements (What is the purpose of the AHU heating coil? 2023). The heating coil is often integrated with other components within the AHU, such as filters, fans, and dampers, to facilitate efficient and effective heat transfer. By properly sizing and designing the heating coil, HVAC systems can achieve optimal energy efficiency, occupant comfort, and overall system performance.

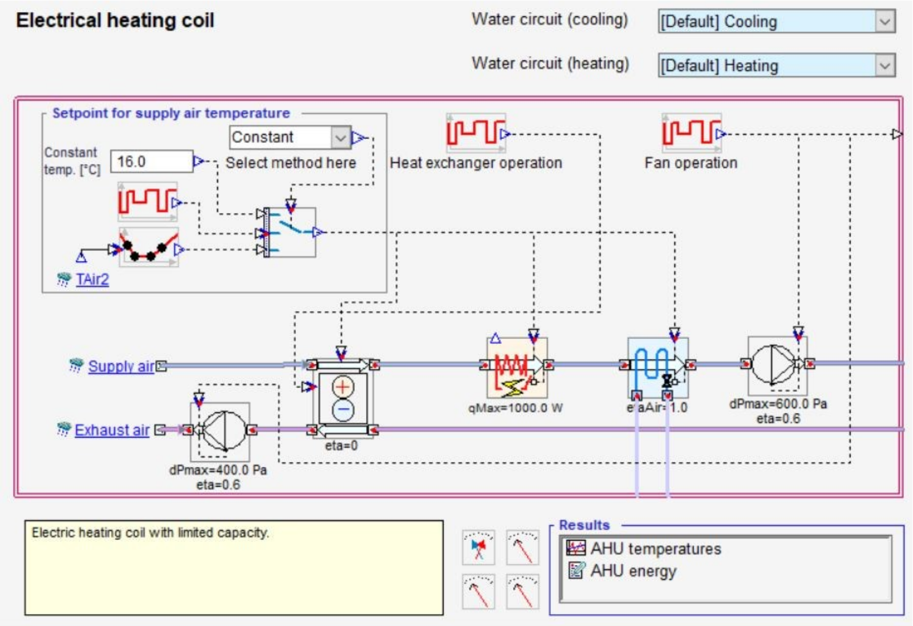
The fresh air is taken from outside, the air then passes through filters, which remove impurities and particles, enhancing indoor air quality. Depending on the system's requirements, the AHU may include heating coils to raise the air temperature or cooling coils to lower it. This allows the AHU to control both the temperature and humidity levels within the selected space (Morris, 2023).

Dampers within the unit help manage the airflow by adjusting the volume of incoming air. By modulating the dampers, the AHU can balance the distribution of conditioned air throughout the building, ensuring consistent comfort levels. The AHU is selected based on the specific requirements of the building, considering factors such as the size of the space, the number of occupants, and the desired level of comfort. Standardization simplifies the design, installation, and maintenance processes, making it more cost-effective. Basically, all air handling units (AHUs) contain fans, which generate airflow within the occupied space and circulate air over heating and cooling components (Puccio, 2021).

The centralized HVAC system with a standard AHU offers benefits such as energy efficiency, consistent performance, and easier maintenance. The AHU becomes a central hub for air processing, contributing to the overall effectiveness of the HVAC system in providing a comfortable and healthy indoor environment.

In energy use calculations, the supply air temperature typically ranges from 12°C to 20°C. However, some systems struggle with lower supply air temperatures, which can affect their efficiency and ability to maintain indoor comfort levels effectively (Johansson, n.d.). Thus, since the exact air supply temperature was not known for the case study, the average number 16 was used for the energy simulation purpose. This highlights the importance of selecting equipment and system configurations that can handle the specified temperature range for optimal performance and energy efficiency.

Figure 4. Electrical heating coil used for the case study in IDA ICE


Electrical heating coil

Water circuit (cooling) [Default] Cooling

Water circuit (heating) [Default] Heating

Constant temp. [°C] 16.0

Electric heating coil with limited capacity.

3.3.4 Global Data

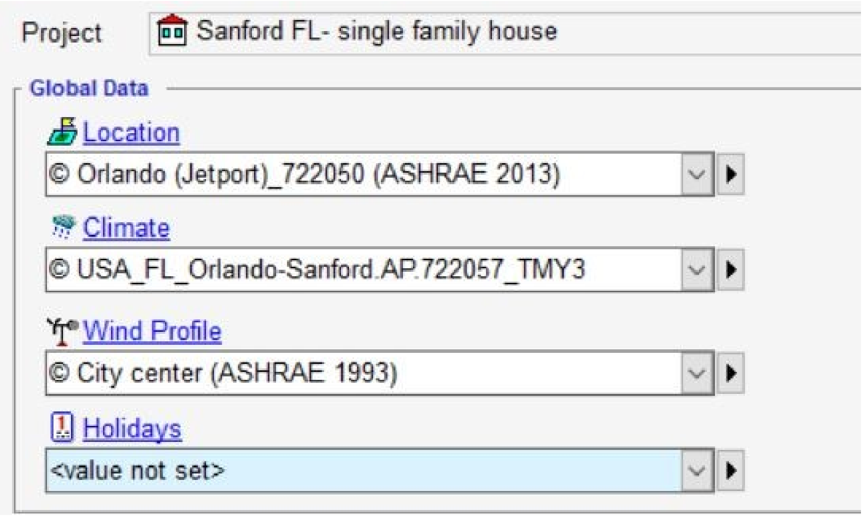
Global data, including location, climate, wind profile, and holidays, is another important parameter to be considered when simulating energy consumption in IDA ICE. The location file was selected from the software database, but due to some limitations, it was not possible to sync the climate data directly. Therefore, for the case study, the climate data was manually inputted, with the nearest data station point to the building—Orlando – Sanford Airport/Jetport—being selected. This choice was made to ensure the utilization of accurate climate data, as it significantly contributes to precise analyses. The climate data file used was obtained from EnergyPlus's weather data website.

Climate data plays a fundamental role in the energy simulation conducted in IDA ICE, influencing the accuracy of simulations through several critical factors. In weather-dependent simulations, IDA ICE assesses the energy performance of buildings under varying weather conditions (Equa Simulation AB, n.d.).

Important meteorological parameters, including temperature, humidity, solar radiation, and wind speed, are incorporated into the simulations. These factors have a significant impact on the building's heating, cooling, and lighting requirements. Moreover, climate data enables site-specific analysis by considering the geographical position and local weather patterns. Many climatic conditions in different regions necessitate accurate climate data to ensure that simulations accurately reflect the environmental conditions of the building site. Climate data also plays a key role in solar gain and daylighting analysis. It helps in evaluating the impact of solar radiation on the building's energy consumption, facilitating the simulation of solar gains, shading effects, and daylight availability. This information is crucial for optimizing the building's design and orientation to achieve both energy efficiency and occupant comfort (IDA ICE Getting Started, 2016).

In summary, the selection of the Orlando – Sanford Airport/Jetport data station, coupled with the use of accurate climate data, ensures a robust foundation for the energy simulations conducted within IDA ICE. This approach considers various meteorological factors, site-specific conditions, and solar-related parameters, contributing to a comprehensive analysis of the building's energy performance (see Figure 5).

Figure 5. Climate data



Project: Sanford FL- single family house

Global Data

Location: © Orlando (Jetport)_722050 (ASHRAE 2013)

Climate: © USA_FL_Orlando-Sanford.AP.722057_TMY3

Wind Profile: © City center (ASHRAE 1993)

Holidays: <value not set>

The wind profile chosen for the analysis is based on the city center, selected for its proximity to the building's actual location. Additionally, holidays were omitted from inspection in the simulation, considering the residential nature of the house and the negligible impact of holidays on its performance.

3.3.5 U-Values: Insights into Thermal Efficiency

The U-value, or thermal transmittance, is a measure in the world of building physics and insulation. It shows how good a material is at letting heat through. This measure is expressed in watts per square meter-kelvin (W/(m²·K)), which explains how much heat can pass through one square meter of a material with a one-degree temperature difference (tec-science, 2020). It is obtained by:

Formula (1). Formula of U-value

$$U = \frac{1}{R_{si} + \sum_{i=1}^{n} R_i + R_{se}}$$

Where:

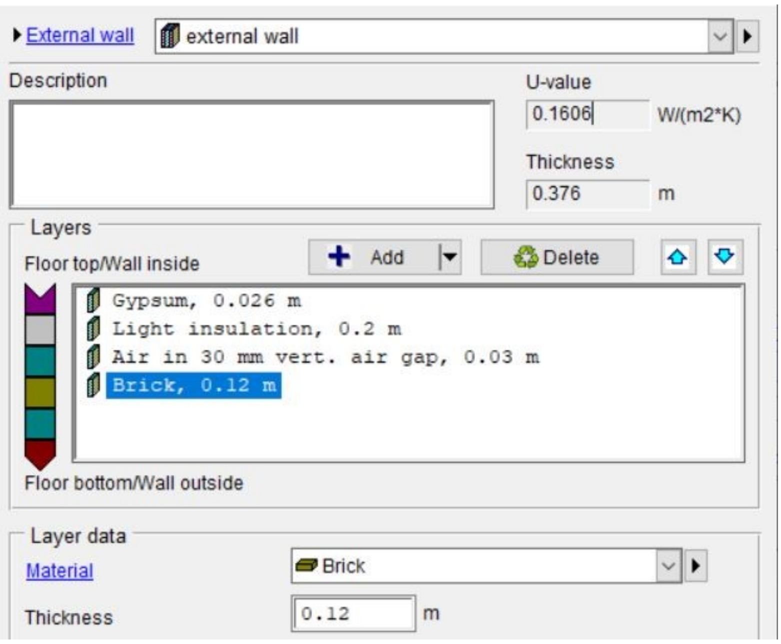
$R_i = =$ all layers resistance $[\mathrm{w/m^2K}]$

$R_{si} = =$ indoor's surface resistance $[\mathrm{w/m^2K}]$

$R_{se} = =$ outdoor's surface resistance $[\mathrm{w/m^2K}]$

When selecting materials for building components in IDA ICE, all materials were chosen thoughtfully to closely align with the specified U-values for key building components, including external walls, roofs, and floors. For instance, the calculated U-value of the external wall was 0.1725 [W/(m²·K)], while the closest value obtained by IDA ICE was 0.1606 [W/(m²·K)], and this consideration was applied to all building elements during the design process in the software (see Figures 6, 7 and 8).

Figure 6. Designed exterior wall in IDA ICE



External wall: external wall

Description

U-value 0.1606 W/(m2*K)

Thickness 0.376 m

Layers

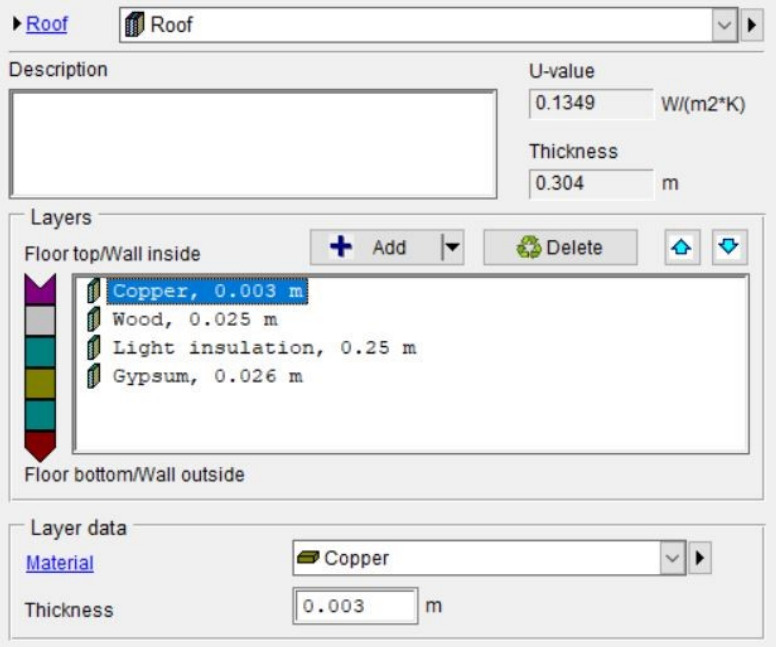
```
Gypsum, 0.026 m
Light insulation, 0.2 m
Air in 30 mm vert. air gap, 0.03 m
Brick, 0.12 m
```

Layer data

Material: Brick

Thickness 0.12 m

Figure 7. Designed roof layers in IDA ICE



Roof: Roof

Description

U-value 0.1349 W/(m2*K)

Thickness 0.304 m

Layers

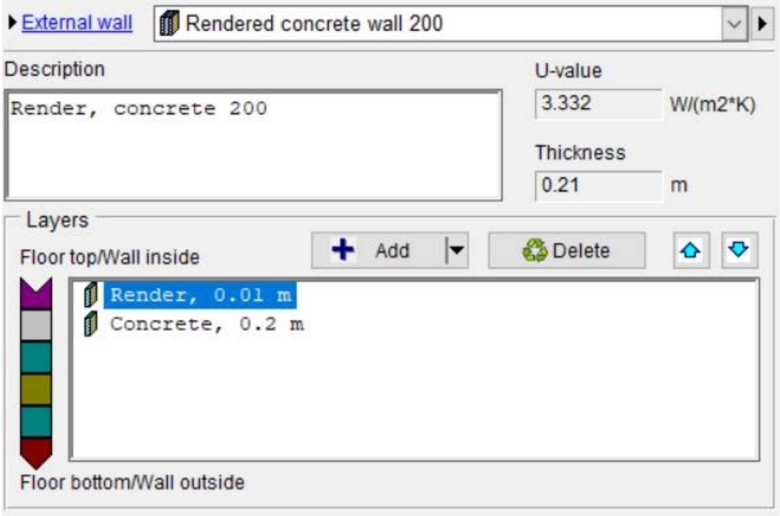
```
Copper, 0.003 m
Wood, 0.025 m
Light insulation, 0.25 m
Gypsum, 0.026 m
```

Layer data

Material: Copper

Thickness 0.003 m

Figure 8. Designed basement wall towards ground


External wall: Rendered concrete wall 200

Description: Render, concrete 200

U-value: 3.332 W/(m2*K)

Thickness: 0.21 m

Layers:
Render, 0.01 m
Concrete, 0.2 m

While designing the structural elements in IDA ICE, similar or close U-values were considered for all building elements rather than similar building materials due to some limitations in the software. A lower U-value means the material is better at controlling heat flow more effectively (A Quick and Easy Guide to U-values, 2023). A lower U-value signifies that a material exhibits better thermal insulation characteristics, offering increased resistance to heat transfer. Consequently, such materials are more useful at minimizing heat loss or gain, contributing to greater energy efficiency in buildings. It includes both conductive and convective heat transfer circumstances, meaning how heat moves through a material directly (conduction) and how it moves through fluids like air or water convectively (Garcia, 2024).

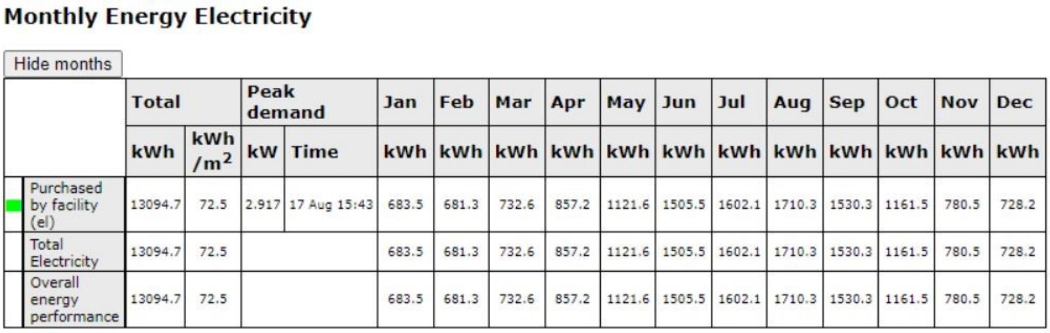
Considering that different materials have different U-values, all building parts were taken into account accordingly. The calculated U-value in the delivered energy report is 0.2431 W/(m²·K) (see Appendix 1), which falls below the recommended threshold of 0.30 for Florida homes, where effective heat management is crucial (A1 Windows & Doors, n.d.). This value indicates low energy consumption, aligning with the requirements for buildings constructed in the early 2000s. It is important to mention that U-values are crucial in construction building codes and energy efficiency guidelines and standards, as these guidelines set specific U-value standards for different parts of buildings, such as walls, doors and windows, to optimize indoor thermal comfort. In short, the U-value describes how well a material can keep heat in or out, and a lower U-value for building materials used makes them more energy-efficient and comfortable.

3.3.6 Analysis and Evaluation of Simulation Results

The delivered energy report covers the most important aspects of the energy analysis, which includes building comfort reference, delivered energy overview, monthly purchased/sold energy (see Figure 9) and grand total.

- Building comfort reference: The Building Comfort Reference section offers insights into the thermal conditions experienced by occupants. It provides the percentage of time when the operative temperature surpasses 27°C in both the worst and average zones. Additionally, it measures overall occupant satisfaction by presenting the percentage of total occupant hours with thermal dissatisfaction, which is 22 % (see appendix 1).
- Delivered energy overview: This section details the energy consumption and peak demand associated with key components. Specifically, it breaks down the usage of HVAC auxiliary systems, cooling, and heating systems. The total facility electric consumption is also summarized, covering all electrically powered systems. Since there is no additional electricity source, such as solar energy, for the building's use, the consumed energy and purchased energy would be the same.

Figure 9. Delivered energy overview



Monthly Energy Electricity

		Total		Peak demand		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		kWh	kWh /m^2	kW	Time	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh
🟩	Purchased by facility (el)	13094.7	72.5	2.917	17 Aug 15:43	683.5	681.3	732.6	857.2	1121.6	1505.5	1602.1	1710.3	1530.3	1161.5	780.5	728.2
	Total Electricity	13094.7	72.5			683.5	681.3	732.6	857.2	1121.6	1505.5	1602.1	1710.3	1530.3	1161.5	780.5	728.2
	Overall energy performance	13094.7	72.5			683.5	681.3	732.6	857.2	1121.6	1505.5	1602.1	1710.3	1530.3	1161.5	780.5	728.2

- Monthly purchased/sold energy: A more detailed monthly breakdown follows, outlining energy consumption for various categories, including HVAC auxiliary, cooling and heating, lighting (tenant), and equipment (tenant). This provides a rough view of how energy is utilized across different aspects of the building on a monthly basis (see Appendix 1).
- Grand Total: Concluding the report, the Grand Total section consolidates the information, summarizing the total tenant electric usage and providing an overall figure for the building's total energy consumption. This holistic perspective aids in

understanding the comprehensive energy performance of the building (see Appendix 1).

In summary, the delivered energy report efficiently integrates insights into thermal comfort conditions with a detailed analysis of energy consumption patterns, offering a detailed overview of the building's performance in these key areas.

4 Results and Discussion

This section presents an in-depth exploration of the results obtained from the analysis, followed by a comprehensive discussion of the findings. Through careful examination, key insights are revealed, shedding light on the factors influencing building energy performance. Various parameters and trends are studied, offering valuable perspectives that contribute to a deeper understanding of energy utilization dynamics within the built environment.

4.1 Building Energy Performance Analysis

In this section results of the building energy performance analysis for a single-family house using the IDA ICE simulation software is covered. The objective was to compare simulated energy consumption against actual measured data for the purpose of assessing the simulation model's accuracy.

4.1.1 Validation and Reliability

During this research, considerable emphasis was placed on the accurate findings. The methodology employed included measures aimed at addressing variations and uncertainties, underscoring the reliability and constancy of the analysis. In summary, the study, utilizing IDA ICE for the energy efficiency analysis of residential buildings, provides valuable insights. The carefully designed methodology ensures reliability; nevertheless, it is essential to acknowledge some limitations. Factors such as data restraints, modelling assumptions, and external variables may influence the interpretation of results. While the findings significantly contribute to the field. It is important to be cautious when generalizing them to all scenarios. This recognition of limitations emphasizes the author’s commitment to transparent and responsible research, urging further investigation for a more comprehensive understanding of energy efficiency in residential buildings.

4.1.2 Simulation Input Parameters

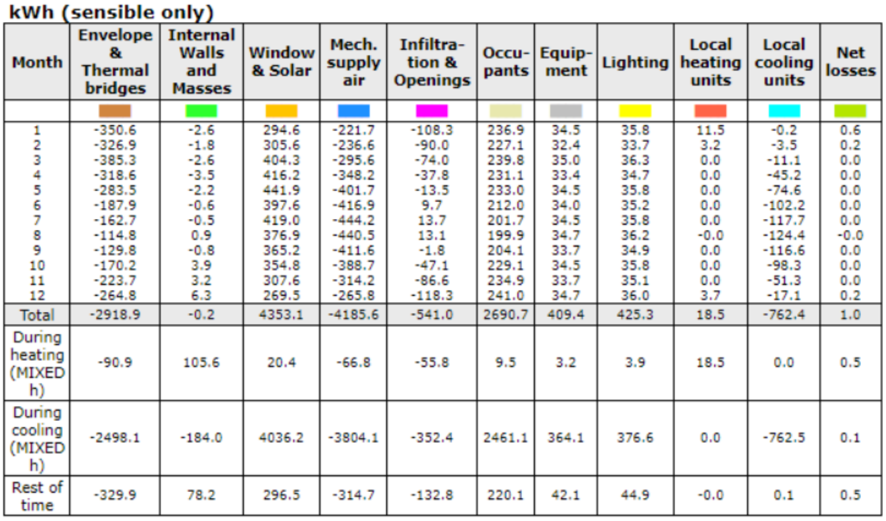
Detailed input parameters encompassing building geometry, materials, HVAC systems, and occupant behavior were employed. It is important to note that certain assumptions were made for the data that were not entirely available during the building modeling process in IDA ICE.

A calibration process was utilized to enhance the accuracy of the simulation model. This involved adjusting selected parameters to align simulated results with actual energy consumption patterns. As a result, there was an improved correlation between simulated and actual data, particularly during peak load periods.

4.1.3 Energy Balance (Sensible Only)

The analysis of the building's energy performance included a detailed examination of the energy balance, with a focus on sensible heat exchanges (see Figure 10). The energy balance (sensible only) provides an account of the heat transfer that causes changes in temperature without a change in phase, encompassing heating and cooling processes within the building (see Appendix 2).

Figure 10. Energy balance (sensible only)



kWh (sensible only)

Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltration & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units	Net losses
	🟫	🟩	🟧	🟦	🟪	🟨	⬜	🟨	🟥	🟦	🟩
1	-350.6	-2.6	294.6	-221.7	-108.3	236.9	34.5	35.8	11.5	-0.2	0.6
2	-326.9	-1.8	305.6	-236.6	-90.0	227.1	32.4	33.7	3.2	-3.5	0.2
3	-385.3	-2.6	404.3	-295.6	-74.0	239.8	35.0	36.3	0.0	-11.1	0.0
4	-318.6	-3.5	416.2	-348.2	-37.8	231.1	33.4	34.7	0.0	-45.2	0.0
5	-283.5	-2.2	441.9	-401.7	-13.5	233.0	34.5	35.8	0.0	-74.6	0.0
6	-187.9	-0.6	397.6	-416.9	9.7	212.0	34.0	35.2	0.0	-102.2	0.0
7	-162.7	-0.5	419.0	-444.2	13.7	201.7	34.5	35.8	0.0	-117.7	0.0
8	-114.8	0.9	376.9	-440.5	13.1	199.9	34.7	36.2	-0.0	-124.4	-0.0
9	-129.8	-0.8	365.2	-411.6	-1.8	204.1	33.7	34.9	0.0	-116.6	0.0
10	-170.2	3.9	354.8	-388.7	-47.1	229.1	34.5	35.8	0.0	-98.3	0.0
11	-223.7	3.2	307.6	-314.2	-86.6	234.9	33.7	35.1	0.0	-51.3	0.0
12	-264.8	6.3	269.5	-265.8	-118.3	241.0	34.7	36.0	3.7	-17.1	0.2
Total	-2918.9	-0.2	4353.1	-4185.6	-541.0	2690.7	409.4	425.3	18.5	-762.4	1.0
During heating (MIXED h)	-90.9	105.6	20.4	-66.8	-55.8	9.5	3.2	3.9	18.5	0.0	0.5
During cooling (MIXED h)	-2498.1	-184.0	4036.2	-3804.1	-352.4	2461.1	364.1	376.6	0.0	-762.5	0.1
Rest of time	-329.9	78.2	296.5	-314.7	-132.8	220.1	42.1	44.9	-0.0	0.1	0.5

This analysis is allowable for a comprehensive understanding of how sensible heat exchanges contribute to the overall energy utilization of the single-family house. The focus on sensible heat is particularly relevant for assessing the impact of heating and cooling systems on energy consumption.

The outcomes of the energy balance analysis (sensible only) revealed insights into the distribution of sensible heat within the building and its contribution to the observed difference between simulated and actual energy consumption.

4.1.4 Seasonal Variations

The simulation was evaluated for its ability to capture seasonal variations in energy consumption. While the model demonstrated good settlement with actual data during moderate climate conditions, slight deviations were observed during extreme temperature periods like peak summertime. Further study is warranted to enhance the model's robustness across a wider range of climatic conditions.

4.2 Comparison with Actual Energy Consumption Data

The validation process for simulated energy consumption in a single-family house involved several crucial steps to ensure alignment with actual data. Monthly and annual energy bills were compared to total energy consumption from the simulation, revealing notable variations that were systematically analyzed. The accuracy of the simulation was quantified by calculating the percentage difference across an entire year, allowing for a comprehensive evaluation of the model's performance. Instances of significant deviation prompted an investigation into potential causes, such as changes in occupancy or equipment efficiency.

To verify the alignment of the simulation model's behavior with actual data variations identified during analysis, a thorough review was conducted. Simulation documentation was reevaluated to ensure precision in representing the physical characteristics of the house and occupants' behavior regarding energy consumption. Differences were addressed through the refinement of the simulation model, involving adjustments to parameters or input data based on insights gained from the comparative analysis.

4.2.1 Quantifying Deviation

The variation between simulated and actual energy consumption was quantified by calculating the percentage difference using the following formula:

$$\text{Difference Error (\%)} = \left|\frac{\text{Simulated Value} - \text{Actual Value}}{\text{Actual Value}}\right| \times 100$$

$$\text{Difference Error (\%)} = \left|\frac{13094.7 - 13653}{13653}\right| \times 100 = 4.08\%$$

This formula provides a clear measure of the percentage by which the simulated value deviates from the actual value. In the analysis phase, a percentage difference close to zero indicates a close match between simulated and actual values. An affirmative percentage suggests an overestimation by the simulation, while a negative percentage implies an underestimation. According to Arnaiz Remiro (2017), values that are approximately within a 5% range of the actual value are considered valid.

Following the quantification of accuracy through percentage differences, the analysis inspects these values across diverse time intervals, including monthly and annual periods. Patterns were identified to distinguish specific months or conditions where the simulation consistently overestimated or underestimated energy consumption. In the energy analysis's adjustment stage, if necessary, it is crucial to carefully assess and potentially modify simulation parameters or input data to improve accuracy, particularly when dealing with consistently high percentage differences. Thus, the case study model underwent repetitive refinement based on insights derived from the analysis.

Given the natural uncertainties in real-world factors, some degree of variation is normal between the simulated results and actual data. The primary aim is to attain a reasonable level of accuracy, considering the complexity of the simulation and the available data. The calculation and analysis of percentage differences provide a quantitative measure of the alignment between the simulation and actual data, guiding the refinement of the model for improved accuracy.

In the context of energy simulation using IDA ICE, it is essential to acknowledge that the software does not incorporate ventilation for apartments, presuming consistent closure of windows. This omission significantly impacts calculations for both space heating and cooling systems. As a result, the energy consumption attributed to space heating closely approximates the actual values, resulting in an error margin of approximately 5%. With this 5% error considered acceptable, the model is deemed valid. It is important to mention that in the design of energy simulations for single-family houses, achieving an error percentage of 5% or lower is considered acceptable when detailed building information is available. However, when faced with limitations or incomplete data, it becomes significant to consider additional factors. In such cases, a tolerance of ±2% to the 5% is acceptable, allowing for minor deviations due to constraints or unforeseen circumstances. For instance, this includes the software's assumption of consistently closed windows, which may not align with real-world scenarios.

4.3 Indoor Thermal Comfort: Simulation and Estimation Strategies

This section explores indoor thermal comfort and analyses the complexities of building performance. It concentrates on indoor temperature and comfort metrics, introducing innovative estimation strategies within the framework of IDA ICE. When precise mean indoor temperature data is unavailable, the author suggests a practical approach based on established comfort ranges to guide estimation methods.

4.3.1 Building Comfort

Building thermal comfort covers the study and optimization of indoor environmental conditions to ensure the well-being, satisfaction, and productivity of occupants. Achieving thermal comfort is essential in architectural and environmental design, requiring an understanding of occupant expectations, climate considerations, and the integration of effective heating, ventilation, and air conditioning (HVAC) systems. This multidimensional concept considers factors such as air temperature, humidity, air quality, air velocity, and radiant temperature to create an environment that meets the preferences and needs of building occupants (Stouhi, 2019). The factors influencing thermal comfort extend beyond temperature alone and encompass a holistic approach to indoor environmental quality.

4.3.2 Indoor Temperature and Comfort Metrics

In building design and environmental engineering, "Indoor Temperature and Comfort Metrics" focuses on understanding human experiences with temperature indoors. This field involves examining various measures to assess and quantify the comfort levels of occupants (Monash University, 2019).

Considerations includes aspects like the temperature of the air, humidity levels, air movement, and the perceived warmth of surrounding surfaces. These elements collectively contribute to evaluating whether the indoor environment aligns with the comfort needs of individuals or not. It is not solely about numerical values; the approach takes into account a broader perspective to figure out what contributes to human comfort beyond the immediate temperature.

Optimizing indoor temperature and associated comfort metrics is vital in creating spaces that cater to the well-being and productivity of occupants. Researchers and designers employ specific measures and standards to objectively evaluate and enhance the indoor thermal environment. This methodology aids in capturing a comprehensive understanding of the indoor climate, acknowledging factors that influence human comfort beyond numerical parameters.

4.3.3 Estimation Methods for Mean Indoor Temperature

In situations where the exact mean indoor temperature is not available, it becomes necessary to estimate reasonable limits and boundaries for the minimum and maximum temperatures to ensure a comprehensive evaluation of thermal conditions within the simulated model environment. While precise mean indoor temperatures are ideal, the absence of such data requires a pragmatic approach guided by established comfort guidelines.

Considering commonly accepted comfort ranges for indoor environments, a conservative estimate is adopted for both the minimum and maximum temperatures. The widely recognized comfort range is typically between 68-72°F (20-22°C). Therefore, for the purpose of this study, the following estimates are used:

- Minimum Temperature: The lower limit for the indoor temperature is set at 20°C (68°F). This value represents the lower boundary of the comfort range, ensuring that even under cooler conditions, the indoor temperature remains within a generally accepted zone of thermal comfort.
- Maximum Temperature: Conversely, the upper limit for the indoor temperature is conservatively estimated at 22°C (72°F). This upper boundary provides a barrier against higher temperatures that may be less conducive to occupant comfort. It aligns with the upper end of the commonly cited comfort range.

While these estimations serve as a practical workaround when precise mean indoor temperatures are unavailable, it is acknowledged that specific comfort preferences can vary among occupants. Moreover, the purpose of the space and external factors may influence the acceptable temperature range. Future research may explore methodologies for more accurate estimation or measurement of mean indoor temperatures in diverse building contexts.

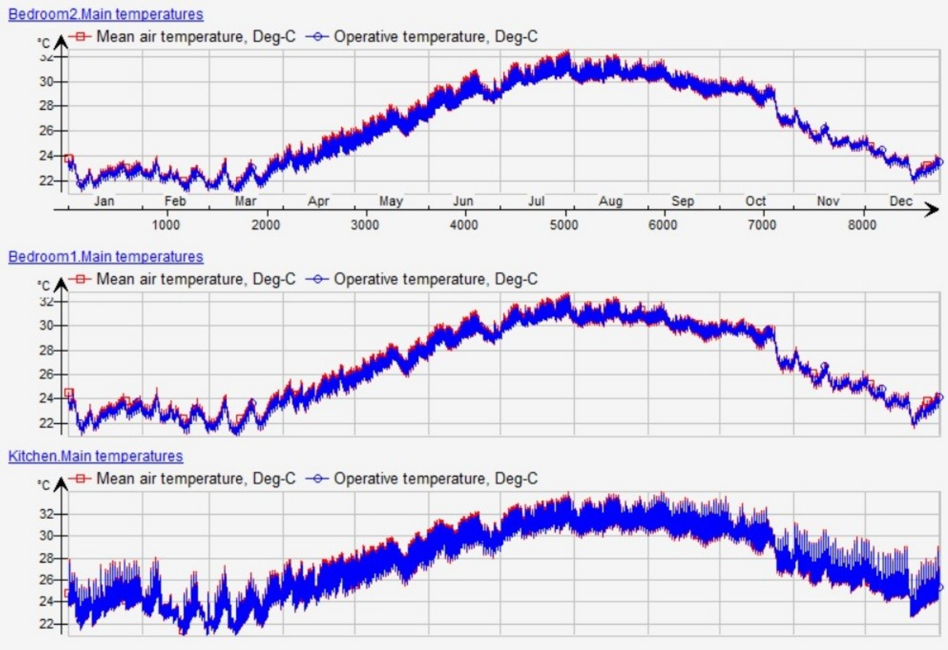
These temperature estimations are crucial for evaluating the thermal conditions within the simulated environment and contribute to a more general analysis of building performance, particularly in the absence of precise mean indoor temperature data.

4.3.4 Simulation Results and Analysis of Mean Temperature and Operative Temperature

The earlier discussion explained how simulated temperatures match real-world conditions, especially in heating seasons, but it also pointed out differences, especially during peak summertimes. This part looks closely at simulated data to uncover details behind seasonal variations. The analysis examines factors affecting indoor temperatures of the building.

A key point to note is the indirect yet significant impact on results arises from IDA ICE's in-built assumption of closed windows throughout the entire simulation. This complexity sets the stage for a comprehensive analysis that excels a mere examination of temperatures. It shifts the focus towards evaluating the reliability of simulated indoor climate to real-world conditions, thereby contributing meaningfully to the broader field of indoor temperature modelling. Taking this analytical approach yields deep insights into the complexities of building performance simulation (see Figure 11).

Figure 11. Main temperature overview of 2 bedroms and kitchen of the case study building



- Heating Season: The simulated results align reasonably well with real-world temperatures when the control set point is at 21 °C during the heating season. This suggests that the model is accurate and valid during these periods.
- Summer Period: However, during the summer period, there is a notable discrepancy between simulated and real-world temperatures. The simulation tends to show higher temperatures (reaching 29 °C) compared to the actual maximum of around 26 °C. This difference is attributed to occupants opening windows for fresh air when feeling discomfort, a behavior not fully captured in the simulation.
- Mean Indoor Temperature: The mean indoor temperature in reality is found to be higher than the set point of 21 °C in summer. This difference is attributed to the likelihood that the actual energy used for space heating is higher than simulated. The suggestion is made to potentially increase the temperature set point in the simulation tool (IDA ICE) to better align with real-world conditions.
- Operative Temperature: Operative temperature, which reflects how people perceive the thermal climate, is discussed. The analysis indicates a range from a minimum of 21 °C to a maximum of 31 °C across all apartments.

In summary, the simulation model performs well during the heating season but exhibits discrepancies during the summer period, likely due to occupant’s behaviour not fully considered in the model. The real-world mean indoor temperature is higher, possibly indicating a need for adjustment in the simulation tool to better reflect actual energy use. The operative temperature analysis provides insights into the range of temperatures experienced by occupants.

4.4 Discussion of Results and Limitations

After analysing the simulated model, key insights have highlighted areas that could benefit from optimization to enhance energy efficiency. Notably, deviations between simulated and actual energy consumption, especially during extreme temperature periods, suggest the need for an inclusive approach to the building's energy systems. Utmost considerations, such as optimizing the heating, ventilation, and air conditioning (HVAC) system, encompass strategies like adjusting temperature setpoints, improving insulation, and contemplating equipment upgrades for more energy-efficient alternatives to achieve the minimum deviation.

The impact of occupant behaviour on energy consumption is considerable. Strategies to address this involve enhancing energy-efficient habits through potential awareness programs or integrating smart technologies to promote responsible energy use among occupants.

A rough estimation has been conducted for the suggested renewable energy system. This provides an initial assessment to prompt consideration of the potential feasibility and impact of the proposed system. The topic has been discussed briefly in a separate section following this one.

Simultaneously, enhancements to the building envelope, such as improved insulation or advanced window technologies, provide additional avenues for amending the impact of external temperature fluctuations on energy consumption. Collectively, these strategic interpolations establish a comprehensive approach for identifying and addressing opportunities to conserve energy within the simulated model.

While an almost 5% difference between the simulated and actual energy consumption data has been identified, considering the natural uncertainties and real-world constraints, this level of accuracy falls within the acceptable range commonly acknowledged in the construction field estimations. Therefore, the need for refining the simulation model may be reconsidered, considering the practical limitations and the balance between accuracy and real-world complexities.

4.5 Suggested Energy Efficiency Strategies

In the case study, a solar energy system was chosen as the primary strategy to improve energy efficiency for several reasons. The location of the building is crucial in this decision. Situated in an area with high solar exposure, the building can harness enough sunlight throughout the year. This optimal condition ensures that solar panels (PV) can generate a significant amount of clean electricity efficiently.

Another reason for selecting a solar energy system is the potential for long-term cost savings. While there's an initial investment in solar panels and installation, the system pays for itself through reduced electricity bills over time. Many regions also offer incentives, rebates, and tax credits for renewable energy installations, making solar energy financially attractive (U.S. Department of Energy, 2022). Additionally, PV systems have low maintenance needs and a long lifespan of 25 years or more, which adds to their cost-effectiveness (De Luca et al., 2024).

Furthermore, integrating a solar energy system supports broader sustainability goals. By decreasing reliance on fossil fuels and reducing greenhouse gas emissions, solar energy promotes environmental conservation. In this case study, adopting solar energy not only demonstrates a commitment to sustainability but also positions the building as a role model for green energy practices.

4.5.1 Solar Energy System

A solar energy system, commonly referred to as a solar power system or photovoltaic (PV) system, utilizes sunlight for the generation of electricity. Photovoltaic (PV) cells, commonly known as solar cells, constitute devices capable of generating electricity through exposure to sunlight (Roderick, 2021). Their suitability for this application stems from their reliability, minimal maintenance requirements (attributed to the absence of moving parts), and reliance solely on sunlight—an abundant and perpetually available resource in space. In the current era, solar cells emerge as an increasingly appealing energy source, particularly in response to challenges associated with greenhouse gas emissions and the diminishing reserves of fossil fuel energy (Marsh, 2023) .

The key components of a solar energy system encompass solar panels, an inverter, a mounting structure, and optionally, a battery, charge controller, monitoring system, grid connection, and a power meter. Solar panels are equipped with photovoltaic cells, typically composed of silicon, adept at converting sunlight into direct current (DC) electricity. The inverter performs an important role in transforming direct current (DC) electricity into alternating current (AC), the standard electricity used in homes and businesses. The mounting structure ensures secure placement of the solar panels, optimizing their exposure to sunlight and withstanding various weather conditions (Stapleton and Neill, 2012).

In solar energy systems incorporating a battery, surplus energy generated during periods of plenty sunlight is stored and subsequently utilized during cloudy days or at night, ensuring a continuous power supply. A charge controller, within systems featuring batteries, regulates charging and discharging processes to prevent overcharging and enhance battery longevity. Monitoring systems, frequently integrated into solar energy setups, track the performance and energy production of the solar panels, offering valuable insights for issue identification and overall system optimization.

For grid-tied systems, a connection to the local electricity grid is established. Extra electricity generated by the solar panels can be redirected back into the grid, with system owners potentially receiving credits or compensation for surplus energy. A bi-directional power meter is installed to measure the electricity flow between the solar energy system and the grid, recording both the electricity consumed from the grid and the excess electricity fed back into it (Bruce, 2022).

In summary, a solar energy system adeptly converts sunlight into electricity using solar panels and incorporates various components like inverters, batteries, and monitoring systems to enhance efficiency and reliability. Grid-tied systems contribute to the reduction of electricity bills and carbon footprints, while off-grid systems provide a self-sufficient power source, this is particularly considerable in remote areas.

4.5.2 Solar Energy System Modeling in IDA ICE

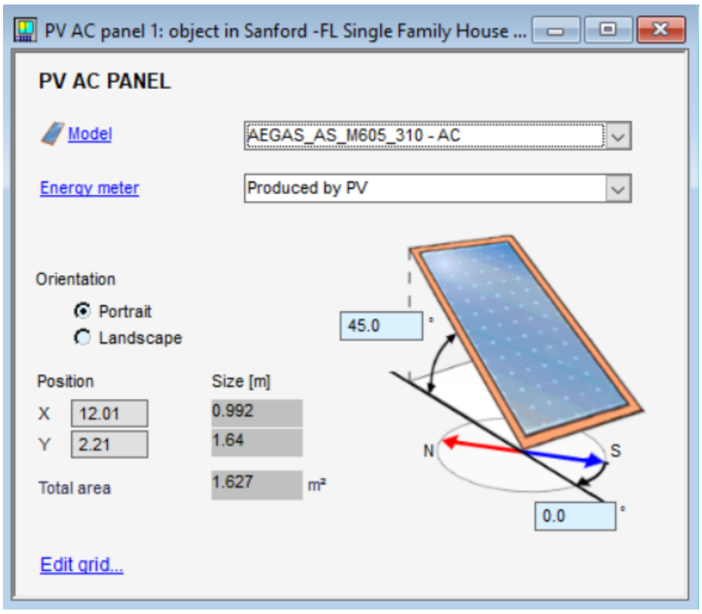
To model a solar energy system in IDA ICE, climate data files are essential for site-specific calculations. These files provide hourly average weather data, including solar radiation, air temperature, humidity, wind speed, and wind direction. Understanding how the PV system operates within IDA ICE involves leveraging this data to accurately predict energy production and assess system performance (EQUA Simulation AB, 2020).

Calculating the amount of sunlight that reaches a building's surface begins by defining the building's shape and nearby objects. This helps determine how much sunlight (irradiation) hits specific surfaces. Basic shading tools in IDA-ICE software create simple shade objects. For more complex shapes, such as intricate shading structures, CAD software is used to design these objects, which are then incorporated into the building model. For photovoltaic (PV) modules arranged in a row, calculations focus on each solar cell's exposure to sunlight. This involves weather data, location details (latitude, longitude), time of day, and the precise orientation (azimuth) and tilt angle of each cell. The process also considers shading from nearby objects, using a polygon clipping shade algorithm to assess how shadows affect each cell's sunlight exposure over time (EQUA Simulation AB, 2020).

AC PV modules, also referred to as AC solar modules, integrate an inverter directly within the solar panel structure. Unlike traditional PV modules, which generate direct current (DC) electricity that requires external conversion to alternating current (AC), AC PV modules convert DC to AC electricity right at the module level. This integration simplifies the installation process by reducing the need for separate inverters and associated wiring, which can streamline system setup and improve overall efficiency (Enphase Energy, 2022).

To enhance system performance and reliability, AC PV modules convert electricity to AC at the source, ensuring consistent power output suitable for residential and commercial applications alike. In this study, a rectangular array of AC PV modules was created using the 'create grid' function to perform the simulation (see Figures 12 and 13).

Figure 12. AC PV panel



PV AC panel 1: object in Sanford -FL Single Family House ...

PV AC PANEL

Model: AEGAS_AS_M605_310 - AC

Energy meter: Produced by PV

Orientation

● Portrait
○ Landscape

Position
X 12.01
Y 2.21

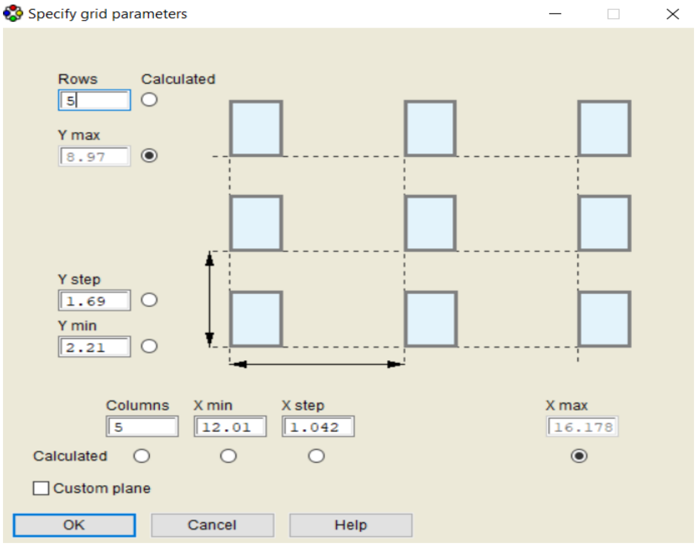
Size [m]
0.992
1.64

Total area 1.627 m²

45.0 °

0.0 °

Figure 13. Grid parameters



Specify grid parameters

Rows: 5 ○ Calculated
Y max: 8.97 ● Calculated
Y step: 1.69 ○
Y min: 2.21 ○
Columns: 5 ○ Calculated
X min: 12.01 ○
X step: 1.042 ○
X max: 16.178 ●
☐ Custom plane

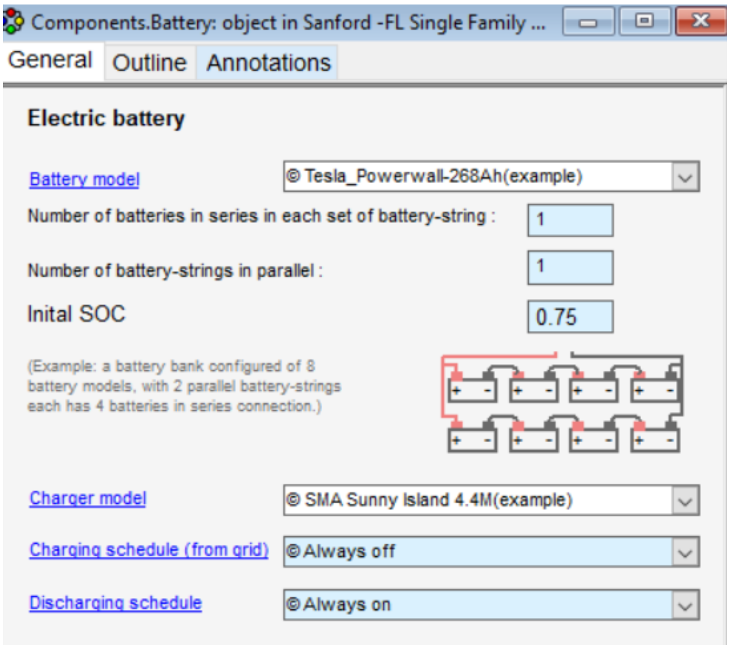
To store surplus solar energy for use during periods of low solar production, a battery should be added to a PV system, ensuring a reliable and cost-effective power supply while enhancing energy independence and sustainability (E. ON Next, n.d.).

Integrating a battery into a PV (photovoltaic) system significantly enhances the system's benefits and efficiency. Adding a battery to a PV system enables the storage of surplus electricity generated during peak sunlight hours. This stored energy can be used during evenings or cloudy days when solar energy production is low, ensuring a consistent and reliable power supply (Vega-Garita, Harsarapama, Ramirez-Elizondo, & Bauer, 2016). This capability provides a level of energy independence, allowing the PV system to operate independently from the grid, enhancing resilience, and providing backup power during grid outages or emergencies.

Furthermore, batteries enable users to optimize their energy consumption patterns. By storing excess energy, homeowners or businesses can use this stored energy during peak electricity rate periods, reducing overall electricity costs and making the initial investment in battery storage more attractive. Integrating batteries with PV systems also aligns with broader renewable energy goals by maximizing self-consumption of solar energy and reducing reliance on fossil fuels for electricity generation, thus supporting environmental conservation efforts (Chen et al., 2024).

The Tesla_Powerwall-268Ah battery was used as generic battery for the case study’s model in IDA ICE (see Figure 14).

Figure 14. Electric battery used for the case study in IDA ICE



Components.Battery: object in Sanford -FL Single Family ...

Electric battery

Battery model: © Tesla_Powerwall-268Ah(example)
Number of batteries in series in each set of battery-string : 1
Number of battery-strings in parallel : 1
Inital SOC: 0.75

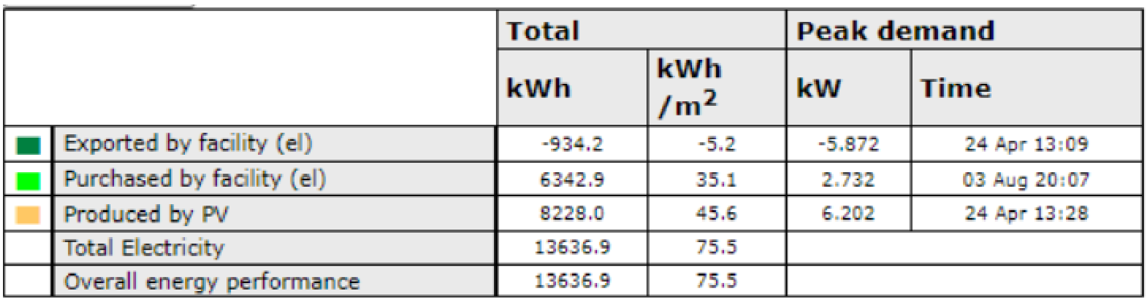
(Example: a battery bank configured of 8 battery models, with 2 parallel battery-strings each has 4 batteries in series connection.)

Charger model: © SMA Sunny Island 4.4M(example)
Charging schedule (from grid): ©Always off
Discharging schedule: ©Always on

The charging schedule "Always off" prevents the battery from charging via the grid. Instead, it relies on local renewable sources such as PV, windmills, or CHP when their production exceeds the building's electricity consumption. A daily discharge schedule is recommended to supply power to the building's loads (EQUA Simulation AB, 2020).

Figure 15 presents the delivered energy report incorporating a solar energy system, illustrating the simulation results. This report provides detailed insights into the energy output and performance of the integrated solar system, highlighting its potential impact on the building's energy consumption and sustainability goals.

Figure 15. Delivered energy report integrating a solar energy system.



		Total		Peak demand	
		kWh	kWh/m^2	kW	Time
🟩	Exported by facility (el)	-934.2	-5.2	-5.872	24 Apr 13:09
🟩	Purchased by facility (el)	6342.9	35.1	2.732	03 Aug 20:07
🟧	Produced by PV	8228.0	45.6	6.202	24 Apr 13:28
	Total Electricity	13636.9	75.5		
	Overall energy performance	13636.9	75.5		

The facility's energy performance metrics are essential for understanding its operational efficiency and sustainability efforts. Key data points include the amount of energy exported and purchased, energy generated by solar panels, and the overall electricity consumption and generation, as detailed below:

- Exported by Facility: This shows the amount of energy exported by the facility, totaling -934.2 kWh, with a peak demand of -5.872 kWh. A negative value indicates energy exported back to the grid or another facility.

- Purchased by Facility: This indicates the energy purchased by the facility, totaling 6342.9 kWh, with a peak demand of 2.732 kW.

- Produced by PV: This refers to the energy generated by the facility's photovoltaic (solar) panels, amounting to 8228.0 kWh, with a peak generation of 6.202 kW.

- Overall Performance: The total electricity consumption and generation for the facility amount to 13636.9 kWh over the monitored period. This data is crucial for assessing the facility's energy efficiency and sustainability, providing insights into its operational energy balance and the impact of renewable energy sources like solar panels.

This information is fundamental for evaluating the efficiency of the building's energy management and highlighting the benefits of integrating a solar energy system to supplement its electricity needs.

The variation between simulated and actual energy consumption was quantified once again by calculating the percentage difference using the following formula:

$$\text{Difference Error (\%)} = \left|\frac{\text{Simulated Value} - \text{Actual Value}}{\text{Actual Value}}\right| \times 100$$

$$\text{Difference Error (\%)} = \left|\frac{13636.9 - 13653}{13653}\right| \times 100 = 0.12\ \%$$

In this comparison, which involved integrating a solar energy system into the IDA ICE model and comparing it with actual energy consumption, the difference error was almost zero (see the calculation results) and it was determined that approximately 60% of the building's energy demand could be met through solar energy (see Figure 15). This finding underscores the potential of renewable energy sources, such as solar power, to significantly contribute to the building's energy needs.

4.5.3 Energy Savings Estimation and Solar System Recommendations

Taking into account multiple factors such as the building's geographical location, typical climate patterns, and other relevant considerations, it has been concluded that, for the scope of this case study, recommending the adoption of a solar energy system is reasonable, as demonstrated by simulating the case in IDA ICE with the integration of a solar energy system.

In the pursuit of sustainable energy solutions, accurately estimating potential energy savings and recommending efficient solar energy systems is critical. This research explores the utility of EnergySage, a leading platform known for its proficiency in estimating energy savings and suggesting optimal solar configurations.

The methodology involves inputting specific parameters, including current energy consumption, location, roof characteristics, and other relevant data, into the platform’s application. The platform then utilizes this information to estimate potential energy savings and proposes solar energy system configurations and recommendations.

Based on the estimates of energy savings, personalized solar energy systems are suggested. For regions with full sunlight, configurations involving high-capacity solar panels and efficient inverters are recommended. The economic and environmental benefits associated with these configurations are also explored.

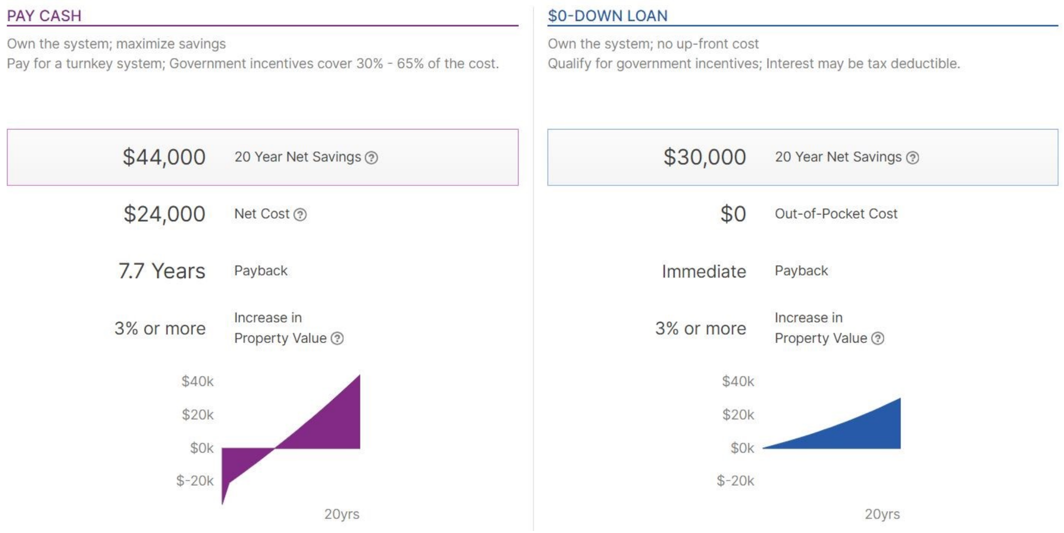
A comparison between the platform's estimates and industry standards reveals alignment in many instances, confirming its reliability. Notably, the platform consistently provides accurate predictions that closely match established benchmarks within the energy sector. This alignment underscores the platform's solid algorithms and their ability to generate dependable estimations. Additionally, positive feedback and endorsements from users further bolster the platform's credibility, affirming its reputation as a trustworthy resource for energy savings estimation and solar system recommendations.

For this case, the following solar energy systems are recommended, considering all aspects to ensure that the owner benefits from using solar energy, including a detailed purchase option. Two financing options for the installation of the solar energy system were examined, yielding the following results (see Figure 16).

Option A: Cash Payment: The Net Cost is $24,000. This is the total cost of the solar panel system after accounting for government incentives and other discounts. It mentions a $44,000 20 Year Net Savings. This is the estimated amount of money you would save over 20 years by paying cash for the solar panel system. It takes into account the cost of the system, the amount of energy it produces, and the cost of electricity in your area. Payback time is indicated as 7.7 Years. This is the amount of time it would take for the savings from the solar panel system to equal the initial cost of the system. There is an increase of 3% or more in property value. This means that installing a solar panel system can increase the value of your property by 3% or more. A purple triangle graph shows the estimated savings over 20 years. The graph shows that the savings from the solar panel system increase over time and eventually exceed the initial cost of the system.

Option B: $0-Down Loan: The out-of-pocket cost is indicated as $0, allowing for the installation of a solar panel system without any upfront payment. A $30,000 for 20 Year Net Savings is specified, representing the projected amount accrued over two decades by opting for a $0-down loan for the solar panel system. Considerations encompass the system cost, energy production, and local electricity expenses. Immediate payback is underscored, denoting the commencement of savings from the solar panel system immediately, covering the monthly loan payments. An increase of 3% or more in property value is also demonstrated, signifying the potential appreciation in property value resulting from the installation of a solar panel system. The estimated savings over 20 years are visually presented through a blue triangle graph, depicting an escalating trajectory wherein savings progressively surpass the total cost of the loan.

Figure 16. Suggested solar energy system, costs, and estimated savings



PAY CASH

Own the system; maximize savings
Pay for a turnkey system; Government incentives cover 30% - 65% of the cost.

$44,000	20 Year Net Savings
$24,000	Net Cost
7.7 Years	Payback
3% or more	Increase in Property Value

$0-DOWN LOAN

Own the system; no up-front cost
Qualify for government incentives; Interest may be tax deductible.

$30,000	20 Year Net Savings
$0	Out-of-Pocket Cost
Immediate	Payback
3% or more	Increase in Property Value

After analyzing the financial aspects of both Option A (Cash Payment) and Option B ($0-Down Loan), it becomes obvious that each option offers different advantages. Option A provides immediate ownership with a shorter payback time, while Option B allows for the installation of the solar panel system without any upfront payment. The decision between these options depends on factors such as liquidity, payback time tolerance, and the desire for immediate savings. Figure 10 visually represents the comparative analysis of these financing options, assisting in making an informed decision based on the unique circumstances at hand.

5 Conclusion

This thesis examined the energy efficiency of a residential building in Sanford, FL, using the IDA ICE simulation software. The study highlights the critical importance of accurately characterizing buildings and setting appropriate parameters to consistently predict energy consumption. The methodology's reliability is supported by comparing simulated energy use with actual consumption data. Additionally, the solar energy simulation conducted through IDA ICE demonstrates its value for the case study, emphasizing the potential of solar energy integration.

While this study offers valuable insights into residential building energy efficiency, it is crucial to acknowledge its limitations, particularly the incomplete details of the HVAC system. The findings still have significant implications for enhancing building energy efficiency and promoting the integration of renewable energy sources, such as solar panels. These recommendations align with sustainability goals and offer potential reductions in energy costs and environmental impacts for homeowners.

The comprehensive analysis of other influencing factors, such as thermal bridges and various building components, provides a nuanced understanding of residential building energy efficiency.

In future research, refining simulation models to offer a more precise depiction of building usage patterns and exploring a broader scope of construction details would be beneficial. This thesis contributes to the existing body of knowledge on residential building energy efficiency and paves the way for further studies.

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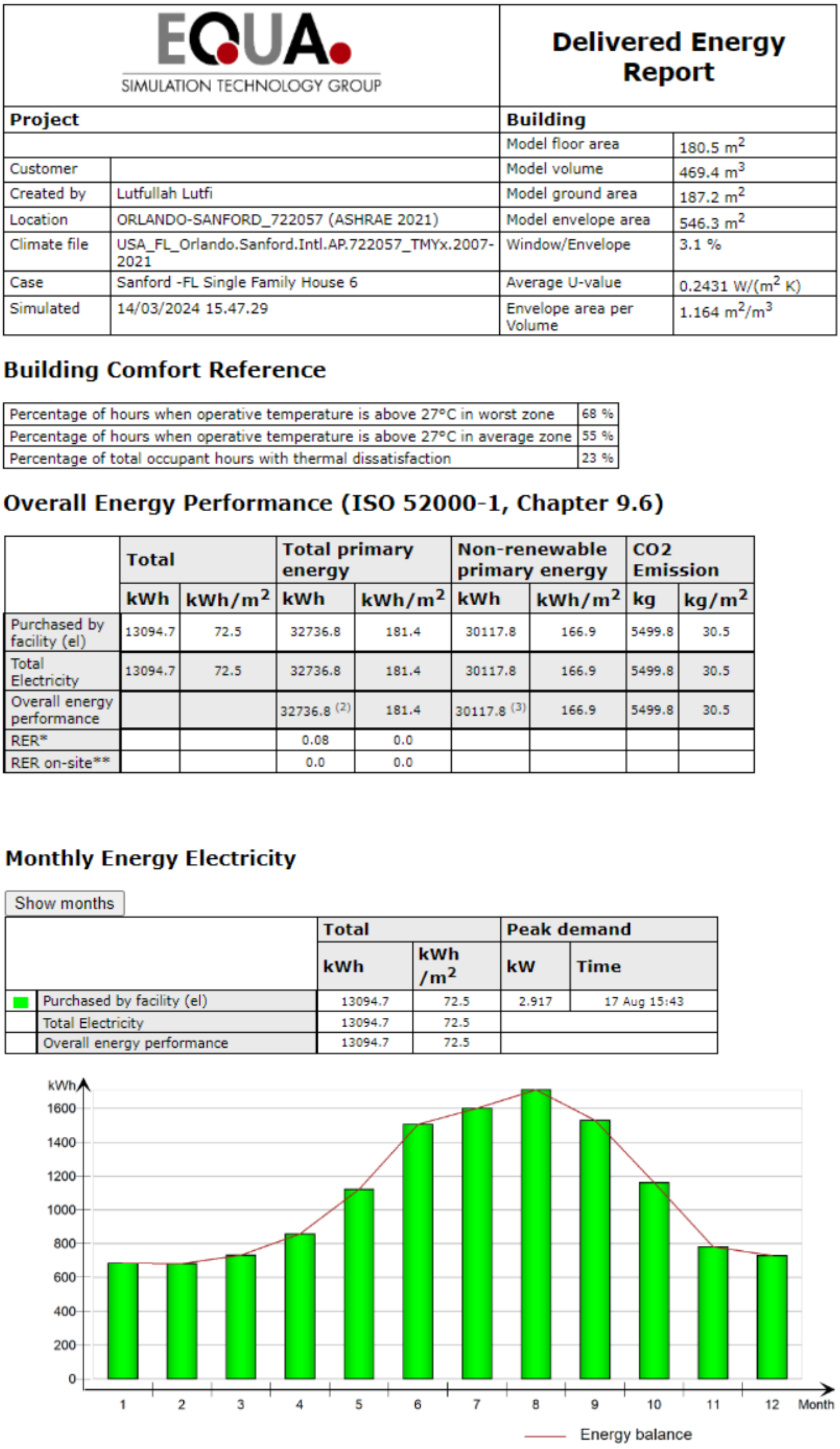
Appendix 1. Delivered Energy Report



EQUA SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		**Building**	
		Model floor area	180.5 m^2
Customer		Model volume	469.4 m^3
Created by	Lutfullah Lutfi	Model ground area	187.2 m^2
Location	ORLANDO-SANFORD_722057 (ASHRAE 2021)	Model envelope area	546.3 m^2
Climate file	USA_FL_Orlando.Sanford.Intl.AP.722057_TMYx.2007-2021	Window/Envelope	3.1 %
Case	Sanford -FL Single Family House 6	Average U-value	0.2431 W/(m^2 K)
Simulated	14/03/2024 15.47.29	Envelope area per Volume	1.164 m^2/m^3

Building Comfort Reference

Percentage of hours when operative temperature is above 27°C in worst zone	68 %
Percentage of hours when operative temperature is above 27°C in average zone	55 %
Percentage of total occupant hours with thermal dissatisfaction	23 %

Overall Energy Performance (ISO 52000-1, Chapter 9.6)

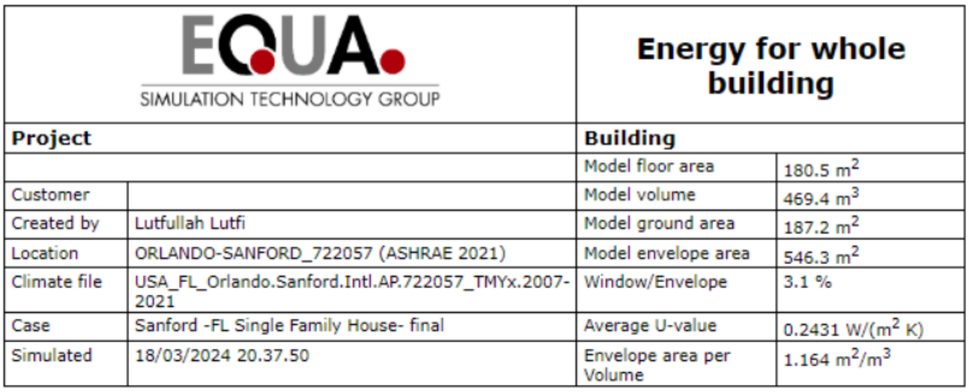
	Total		**Total primary energy**		**Non-renewable primary energy**		**CO2 Emission**	
	kWh	**kWh/m^2**	**kWh**	**kWh/m^2**	**kWh**	**kWh/m^2**	**kg**	**kg/m^2**
Purchased by facility (el)	13094.7	72.5	32736.8	181.4	30117.8	166.9	5499.8	30.5
Total Electricity	13094.7	72.5	32736.8	181.4	30117.8	166.9	5499.8	30.5
Overall energy performance			32736.8 (2)	181.4	30117.8 (3)	166.9	5499.8	30.5
RER*			0.08	0.0				
RER on-site**			0.0	0.0				

Monthly Energy Electricity

Show months

		Total		**Peak demand**	
		kWh	**kWh/m^2**	**kW**	**Time**
🟩	Purchased by facility (el)	13094.7	72.5	2.917	17 Aug 15:43
	Total Electricity	13094.7	72.5		
	Overall energy performance	13094.7	72.5		

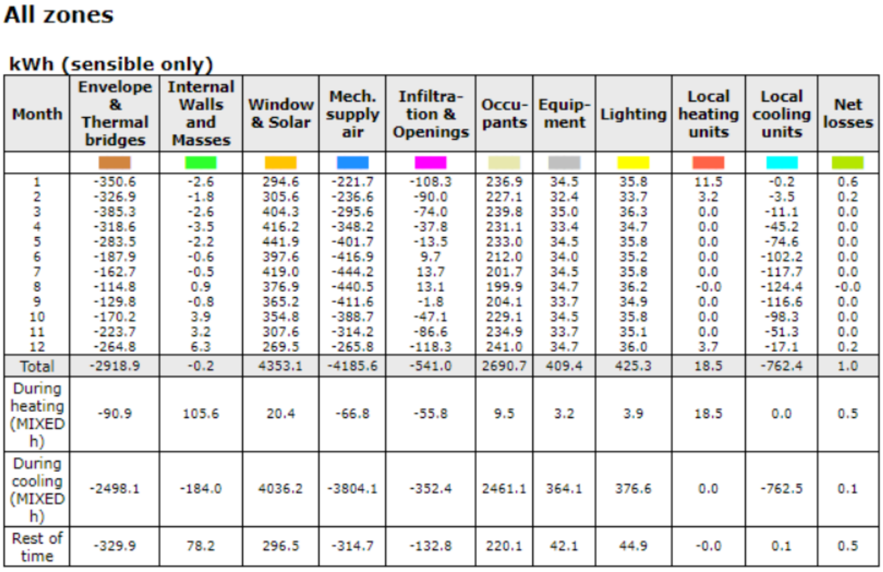
Appendix 2. Energy for Whole Building (Sensible Only)



EQUA SIMULATION TECHNOLOGY GROUP

Energy for whole building

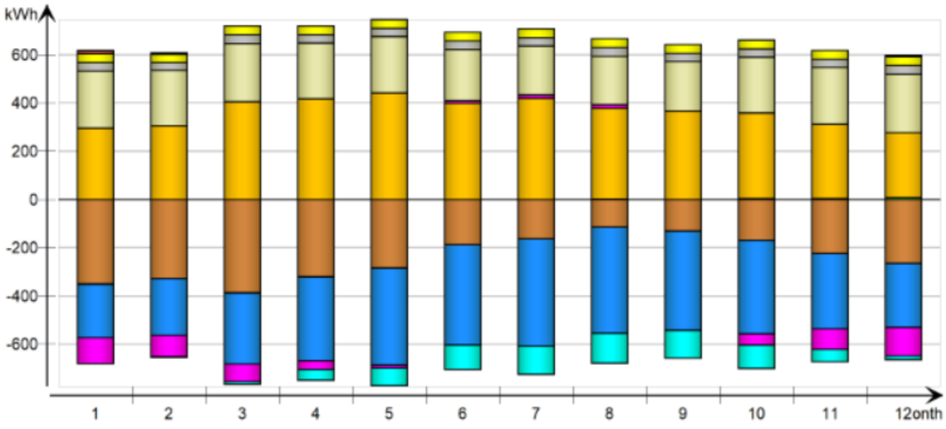
Project		Building	
		Model floor area	180.5 m^2
Customer		Model volume	469.4 m^3
Created by	Lutfullah Lutfi	Model ground area	187.2 m^2
Location	ORLANDO-SANFORD_722057 (ASHRAE 2021)	Model envelope area	546.3 m^2
Climate file	USA_FL_Orlando.Sanford.Intl.AP.722057_TMYx.2007-2021	Window/Envelope	3.1 %
Case	Sanford -FL Single Family House- final	Average U-value	0.2431 W/(m^2 K)
Simulated	18/03/2024 20.37.50	Envelope area per Volume	1.164 m^2/m^3



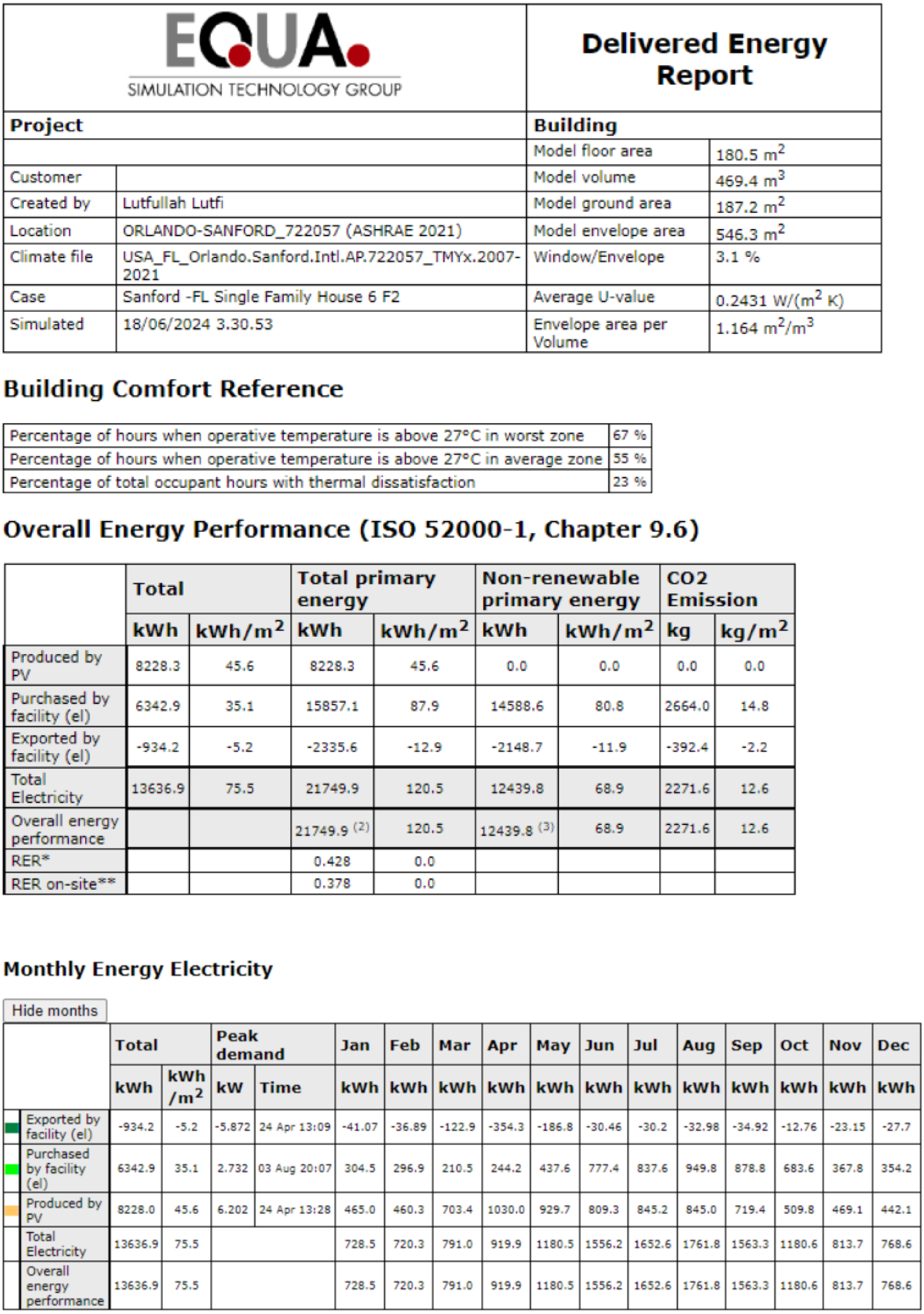
All zones

kWh (sensible only)

Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltration & Openings	Occupants	Equipment	Lighting	Local heating units	Local cooling units	Net losses
	🟫	🟩	🟧	🟦	🟪	⬜	⬜	🟨	🟥	🟦	🟩
1	-350.6	-2.6	294.6	-221.7	-108.3	236.9	34.5	35.8	11.5	-0.2	0.6
2	-326.9	-1.8	305.6	-236.6	-90.0	227.1	32.4	33.7	3.2	-3.5	0.2
3	-385.3	-2.6	404.3	-295.6	-74.0	239.8	35.0	36.3	0.0	-11.1	0.0
4	-318.6	-3.5	416.2	-348.2	-37.8	231.1	33.4	34.7	0.0	-45.2	0.0
5	-283.5	-2.2	441.9	-401.7	-13.5	233.0	34.5	35.8	0.0	-74.6	0.0
6	-187.9	-0.6	397.6	-416.9	9.7	212.0	34.0	35.2	0.0	-102.2	0.0
7	-162.7	-0.5	419.0	-444.2	13.7	201.7	34.5	35.8	0.0	-117.7	0.0
8	-114.8	0.9	376.9	-440.5	13.1	199.9	34.7	36.2	-0.0	-124.4	-0.0
9	-129.8	-0.8	365.2	-411.6	-1.8	204.1	33.7	34.9	0.0	-116.6	0.0
10	-170.2	3.9	354.8	-388.7	-47.1	229.1	34.5	35.8	0.0	-98.3	0.0
11	-223.7	3.2	307.6	-314.2	-86.6	234.9	33.7	35.1	0.0	-51.3	0.0
12	-264.8	6.3	269.5	-265.8	-118.3	241.0	34.7	36.0	3.7	-17.1	0.2
Total	-2918.9	-0.2	4353.1	-4185.6	-541.0	2690.7	409.4	425.3	18.5	-762.4	1.0
During heating (MIXED h)	-90.9	105.6	20.4	-66.8	-55.8	9.5	3.2	3.9	18.5	0.0	0.5
During cooling (MIXED h)	-2498.1	-184.0	4036.2	-3804.1	-352.4	2461.1	364.1	376.6	0.0	-762.5	0.1
Rest of time	-329.9	78.2	296.5	-314.7	-132.8	220.1	42.1	44.9	-0.0	0.1	0.5



Appendix 3. Delivered Energy Report Integrating Solar Energy System



EQUA SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

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Simulated	18/06/2024 3.30.53	Envelope area per Volume	1.164 m^2/m^3

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Overall Energy Performance (ISO 52000-1, Chapter 9.6)

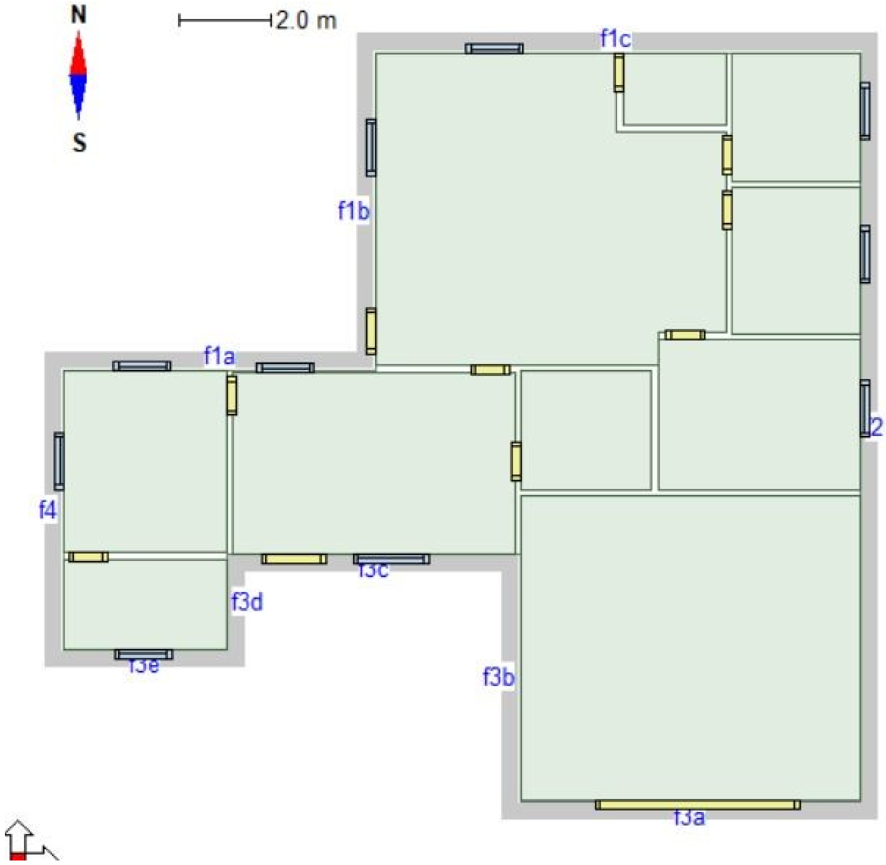
	Total		**Total primary energy**		**Non-renewable primary energy**		**CO2 Emission**	
	kWh	**kWh/m^2**	**kWh**	**kWh/m^2**	**kWh**	**kWh/m^2**	**kg**	**kg/m^2**
Produced by PV	8228.3	45.6	8228.3	45.6	0.0	0.0	0.0	0.0
Purchased by facility (el)	6342.9	35.1	15857.1	87.9	14588.6	80.8	2664.0	14.8
Exported by facility (el)	-934.2	-5.2	-2335.6	-12.9	-2148.7	-11.9	-392.4	-2.2
Total Electricity	13636.9	75.5	21749.9	120.5	12439.8	68.9	2271.6	12.6
Overall energy performance			21749.9 (2)	120.5	12439.8 (3)	68.9	2271.6	12.6
RER*			0.428	0.0				
RER on-site**			0.378	0.0				

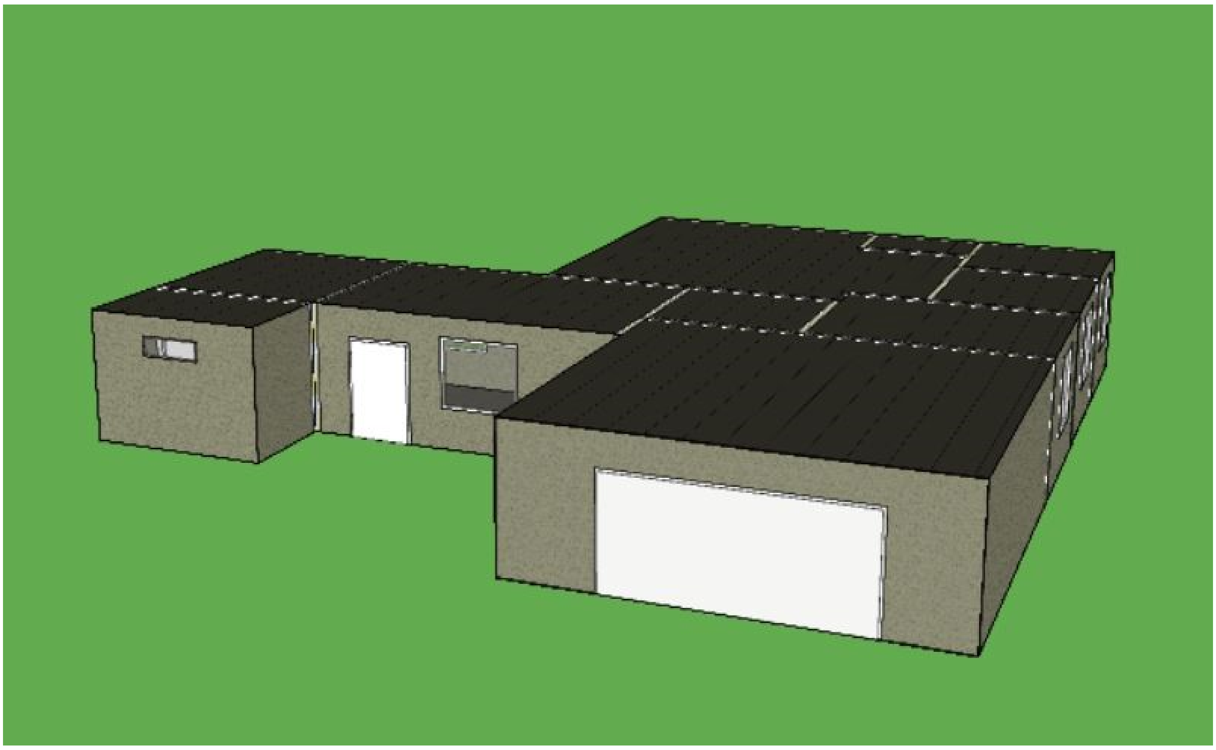
Monthly Energy Electricity

Hide months

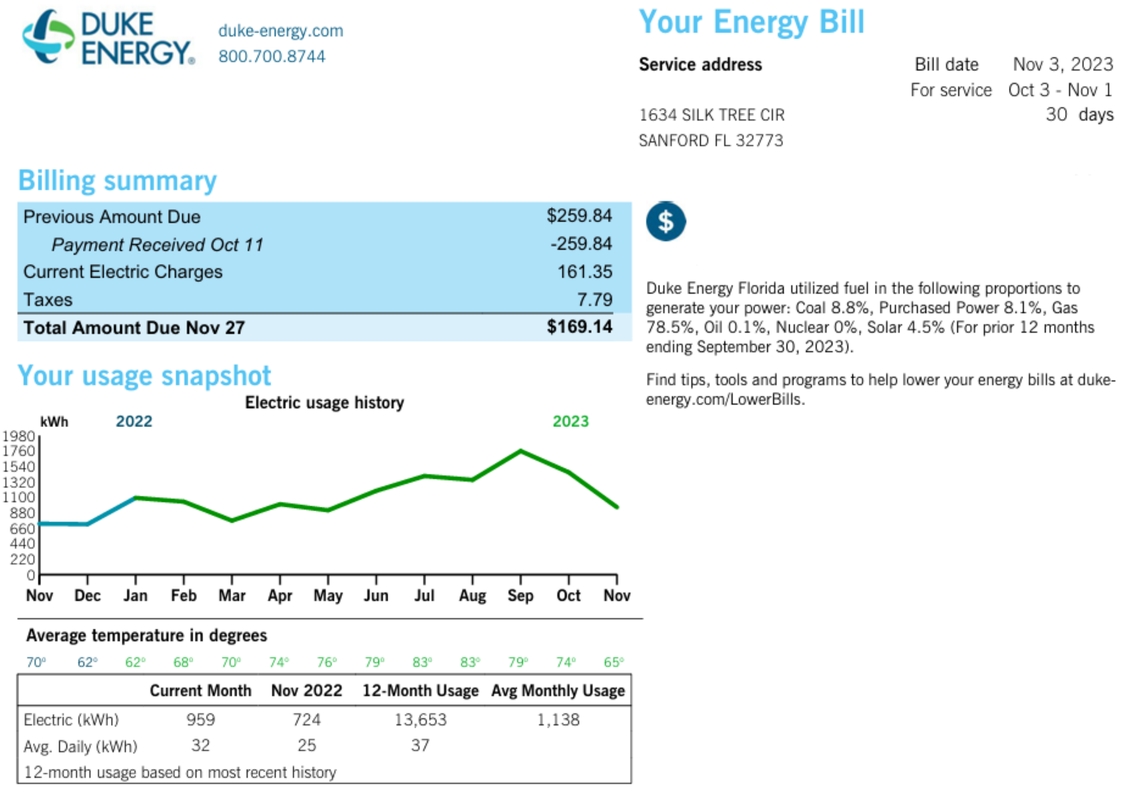
		Total		**Peak demand**		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
		kWh	**kWh/m^2**	**kW**	**Time**	**kWh**	**kWh**	**kWh**	**kWh**	**kWh**	**kWh**	**kWh**	**kWh**	**kWh**	**kWh**	**kWh**	**kWh**
🟩	Exported by facility (el)	-934.2	-5.2	-5.872	24 Apr 13:09	-41.07	-36.89	-122.9	-354.3	-186.8	-30.46	-30.2	-32.98	-34.92	-12.76	-23.15	-27.7
🟩	Purchased by facility (el)	6342.9	35.1	2.732	03 Aug 20:07	304.5	296.9	210.5	244.2	437.6	777.4	837.6	949.8	878.8	683.6	367.8	354.2
🟧	Produced by PV	8228.0	45.6	6.202	24 Apr 13:28	465.0	460.3	703.4	1030.0	929.7	809.3	845.2	845.0	719.4	509.8	469.1	442.1
	Total Electricity	13636.9	75.5			728.5	720.3	791.0	919.9	1180.5	1556.2	1652.6	1761.8	1563.3	1180.6	813.7	768.6
	Overall energy performance	13636.9	75.5			728.5	720.3	791.0	919.9	1180.5	1556.2	1652.6	1761.8	1563.3	1180.6	813.7	768.6

Appendix 4. Building’s 2D and 3D view in IDA ICE





Appendix 5. Energy Bill



DUKE ENERGY.

duke-energy.com
800.700.8744

Your Energy Bill

Service address

1634 SILK TREE CIR
SANFORD FL 32773

Bill date	Nov 3, 2023
For service	Oct 3 - Nov 1
	30 days

Billing summary

Previous Amount Due	$259.84
Payment Received Oct 11	-259.84
Current Electric Charges	161.35
Taxes	7.79
Total Amount Due Nov 27	**$169.14**

$

Duke Energy Florida utilized fuel in the following proportions to generate your power: Coal 8.8%, Purchased Power 8.1%, Gas 78.5%, Oil 0.1%, Nuclear 0%, Solar 4.5% (For prior 12 months ending September 30, 2023).

Find tips, tools and programs to help lower your energy bills at duke-energy.com/LowerBills.

Your usage snapshot

Electric usage history

Average temperature in degrees

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
70°	62°	62°	68°	70°	74°	76°	79°	83°	83°	79°	74°	65°

	Current Month	Nov 2022	12-Month Usage	Avg Monthly Usage
Electric (kWh)	959	724	13,653	1,138
Avg. Daily (kWh)	32	25	37	
12-month usage based on most recent history				