Optimizing Natural Ventilation to Improve Energy Efficiency in Residential Buildings in Hot Climates in Abu Dhabi, UAE

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ABSTRACT

This research addresses the critical need to enhance energy efficiency and indoor comfort in high-rise residential buildings located in hot climates, focusing on Abu Dhabi (AD), UAE. With the increasing prevalence of full glass facades in such buildings, the demand for air conditioning (AC) rises significantly due to higher heat gain. This study aims to provide practical solutions for architects, engineers, and policymakers to optimize energy performance while ensuring occupant comfort and well-being through efficient natural ventilation systems. By investigating the potential of architectural passive design principles and natural ventilation strategies, the research seeks to minimize AC energy consumption by maximizing natural airflow. Methodologically, a mixed-method approach incorporating quantitative and qualitative analyses is employed. Utilizing tools such as questionnaires, documents, records, and case studies, the study examines the existing energy performance of buildings, identifying opportunities for improvement. Additionally, simulation tools like eQuest are utilized to model energy consumption patterns under various scenarios, allowing for the evaluation of different strategies. The research focuses on the hot and humid climate, particularly during peak months like August, using realistic weather data to inform the analysis. The findings underscore the potential of optimizing natural ventilation to alleviate the energy burden on cooling systems while maintaining indoor comfort. By identifying and implementing effective strategies, such as optimal operable window sizes and architectural design modifications, the study aims to contribute to the development of more sustainable and comfortable living environments. In conclusion, optimizing natural ventilation emerges as a promising approach to address energy efficiency challenges.

Keywords: Natural Ventilation; Energy Efficiency; High-Rise Residential Building; Hot Climate.

STATEMENT OF THE PROBLEM

Abu Dhabi is characterized by high glass buildings and this increases energy consumption on one hand and increases the island template on the other hand. The use of glass building facades has increased in Abu Dhabi. Glass façade usually comes with a high air-conditioning cost due to the higher heat gain. Figure 1 represents the most famous fully glass residential high-rise buildings in Abu Dhabi which shows the high use of glass façades.

Al Etihad Towers Al Dar HQ The Capital Gate

Figure 1: Famous full glass high-rise buildings in Abu Dhabi, UAE.

One of the most effective approaches to conserving energy in buildings is through thoughtful facade design. Optimal natural ventilation, achieved by adjusting the size of existing openings in the facade, presents a promising energy reduction.' While the latter offers architectural flexibility and various benefits, including thermal comfort and daylight optimization, optimizing natural ventilation can similarly contribute to energy savings. The literature review has highlighted the advantages of natural ventilation techniques, demonstrating their potential to control cooling loads and enhance occupant comfort.

In Abu Dhabi, like in the research case study, many residential buildings feature high-rise fully glass facades, leading to continuous energy consumption, particularly in residential contexts where usage is constant. The inherent properties of glass, such as its high U-value, contribute to increased energy consumption. Effective detailing systems are crucial to mitigate heat transmission through conduction, convection, and radiation processes. To address the rising energy consumption associated with fully glass facades in high-rise buildings, this research focuses on assessing and simulating optimal facade designs and glass types to improve thermal performance and reduce energy consumption, particularly in air conditioning and electricity usage. Abu Dhabi is characterized by high-rise glass buildings, and this increases energy consumption. So, this glass used in more buildings leads to the hotter place which needs more cooling. However, Abu Dhabi 2030 plan is to reduce the energy consumption in buildings. Thus, this research follows Abu Dhabi new vision of sustainability to reduce energy consumption. A suitable solution could be achieved by utilizing the optimal natural ventilation, achieved by adjusting the size of existing openings in the facade type with the best glass material and a suitable cavity between the facade layers. Therefore, this research recommends the optimum natural ventilation, achieved by adjusting the size of existing openings in the façade design for residential high-rise buildings to reduce the energy consumption in high-rise residential buildings in Abu Dhabi Hot climate.

1.1 Energy Consumption

Buildings are the major consumer of energy among other industries. The building consumes up to 40% of the universe's energy [1,2], with a high percentage of carbon dioxide production reaching 30% [3] and as the International Energy Agency estimates, the energy consumption will surpass the 50% by 2025 (IEA, releases first clean energy progress report, 2011). The residential buildings reached 27% compared with other industries as shown in Figure 2 [4].

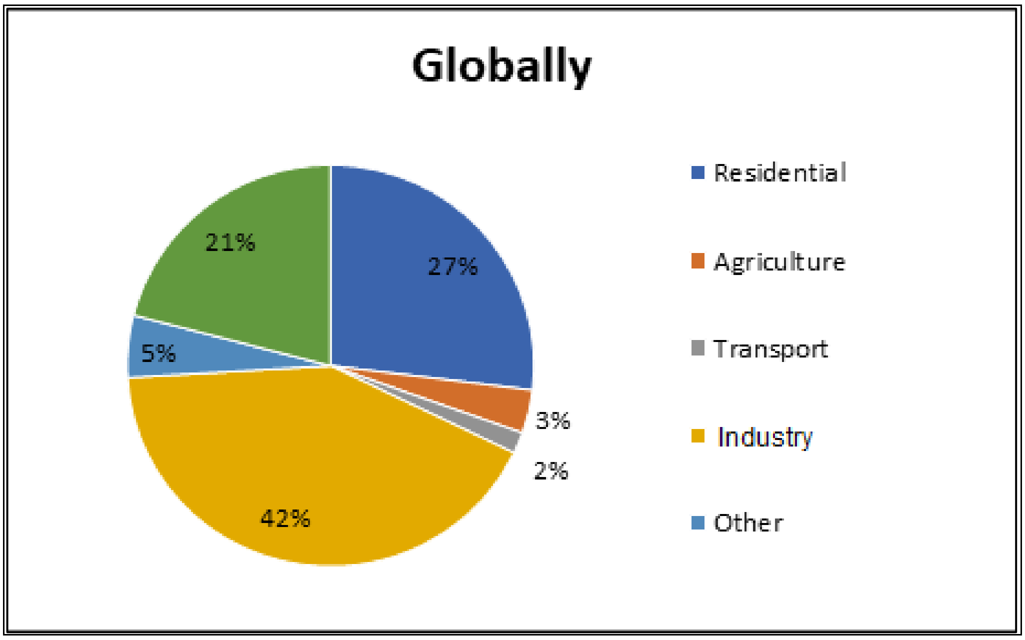


Figure 2: Energy consumption by sectors globally.

A large share of electric energy consumption was noted in Abu Dhabi. Some buildings in the UAE consume 220-360 kWh/m2/year [5]. Due to the United Arab Emirates (UAE) hot climate, building cooling systems consume around 80% of this energy. Figure 3 shows the local energy consumption by sector.

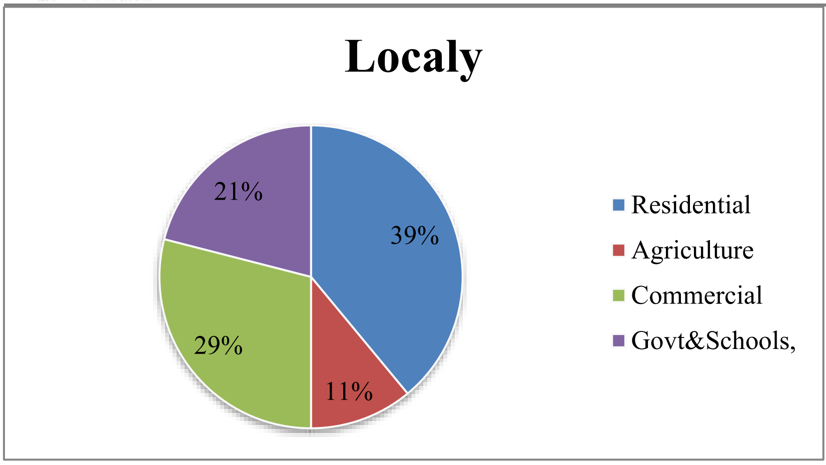


Figure 3: Energy consumption by Sector in the UAE (Bureau, 2015).

The facts of energy consumption and its price were investigated for a residential building in UAE a hot, dry, and humid region where the cooling load is extremely high [6]. See Figure 4 for Energy Household usage in Abu Dhabi.

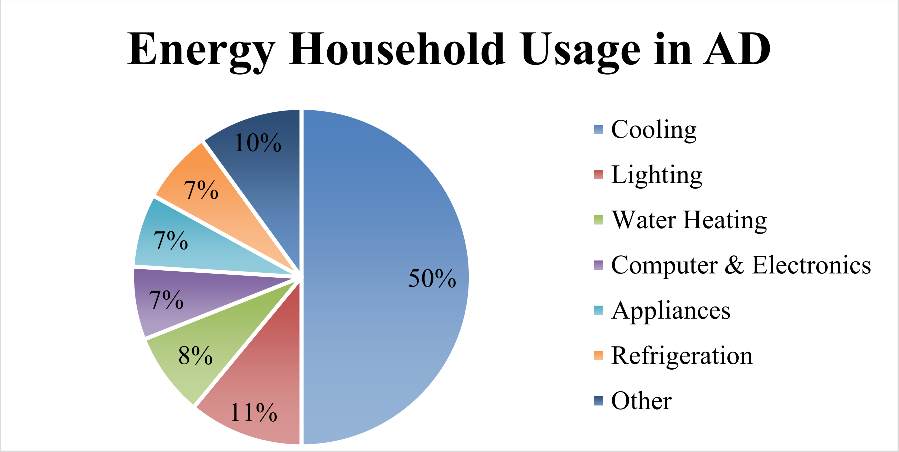
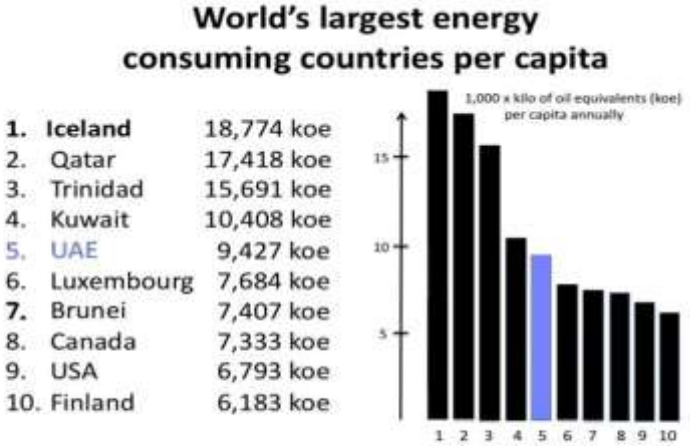


Figure 4: Energy household usage in Abu Dhabi (EnergyDubai, 2020).

The UAE is presently the world's seventh most energy-consuming country per capita [7]. Figure 5 depicts the world's highest per capita energy consumption. As a result, the UAE government must begin taking the necessary steps to reduce energy expenditure and provide a better living environment. Residential and commercial buildings consume more than 40% of total energy consumption globally [7, 8] with electricity accounting for a significant portion of this energy. 36% of electricity in the UAE is used for cooling (Demand-Side Management for Electricity and Water Use in Abu Dhabi- Final Report. EAA, RTI, 2009).


World's largest energy consuming countries per capita

1.	**Iceland**	18,774 koe
2.	Qatar	17,418 koe
3.	Trinidad	15,691 koe
4.	Kuwait	10,408 koe
5.	UAE	9,427 koe
6.	Luxembourg	7,684 koe
7.	Brunei	7,407 koe
8.	Canada	7,333 koe
9.	USA	6,793 koe
10.	Finland	6,183 koe

Figure 5: UAE is the 5th world's largest energy consumption per capita (Al-Shehri, 2008).

A closer look discloses that the energy preservation of buildings in the UAE, Currently, an extensive amount of research focuses on the topic of energy consumption due to the new types of buildings envelope by enhancing lighting of buildings by just changing strategies; A huge amount of energy consumption was noticed in Abu Dhabi. Buildings in the UAE consume 220-360 kWh/m2/year [5]. Building Air conditioning used around 80% of this energy due to the hot climate. UAE a hot, dry, and humid country [6], also it’s the world's 5th highest country in energy consumption per capita [9, 10]. Hence, the authority needs to adopt immediate actions to decrease energy outflow and to provide a better life condition. All types of buildings consume more than 40% of the total energy around the globe [11], and a major amount of this energy by electricity sources. In UAE, 36% of the electricity is used for cooling (Demand-Side Management for Electricity and Water consumption in Abu Dhabi, 2009).

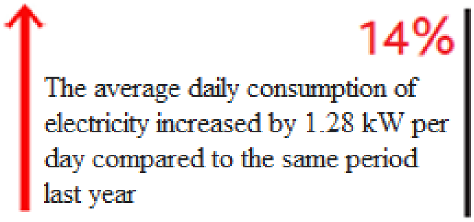
1.2 Building Façade

Glass facades are a prevalent choice in modern building exteriors, offering architects a range of aesthetic possibilities while playing a pivotal role in the building's energy efficiency. Optimal glass models for facades allow natural light to penetrate, reducing the need for artificial heating and cooling and enhancing resident comfort by minimizing noise. Technological advancements aim to enhance glass performance in terms of heat reduction, light transmission, and safety (Alaa El Di & Fikry, 2019).

Recognized as a crucial component in building design, glass facades serve to protect interiors from external weather conditions while maintaining separation. As energy consumption in buildings becomes increasingly significant due to limited resources, designers are focusing their research on energy-efficient construction materials and practices, including glass [2].

1.3 Research Questions

The electricity and air-conditioning consumption bill of residential high-rise fully glass façade explains that the electricity consumption increases by 14% every year see Figure 6. So this is the main aim to have these questions answered to get a solution for reducing energy consumption. The annual electricity consumption bill of residential high-rise fully glass building façades is raising as shown in bills in Appendix 2.



14%

The average daily consumption of electricity increased by 1.28 kW per day compared to the same period last year

Figure 6: The annual electricity consumption bill of residential high-rise fully glass building façade shows increasing of 14% yearly (Appendix 2).

Meanwhile, residential building consumes 40% of the energy consumption. Therefore, the following questions have been raised, attempting to have a clear answer to achieve the research outcomes. "In hot climate residential buildings, how can energy efficiency and indoor comfort be improved by optimizing architectural passive design principles and natural ventilation strategies, considering optimal operable size dimensions and aiming to maximize natural ventilation to minimize AC energy consumption?"

1.4 Aim and Objectives

The primary aim of this research is to provide practical solutions for architects, engineers, and policymakers to enhance the energy performance of residential buildings in hot climates while promoting occupant comfort and well-being through efficient natural ventilation systems. This will be achieved through the following objectives:

- Evaluate current natural ventilation strategies: Conduct a comprehensive review of existing natural ventilation systems implemented in residential buildings located in hot climates. Analyze their effectiveness in terms of energy efficiency, occupant comfort, and overall building performance.

- Identify key challenges and opportunities: Identify the major challenges faced in optimizing natural ventilation systems in hot climates, such as temperature variations, humidity levels, and building orientations. Explore potential opportunities for improvement and innovation in design and technology.

- Assess occupant comfort and well-being: Investigate the impact of natural ventilation systems on occupant comfort and well-being in hot climates. Utilize subjective and objective measures to assess factors like indoor air quality, thermal comfort, and psychological satisfaction.

- Develop guidelines and recommendations: Based on the findings from the evaluation and assessment, develop practical guidelines and recommendations for architects, engineers, and policymakers to enhance the energy performance of residential buildings through optimized natural ventilation systems. These guidelines should prioritize both energy efficiency and occupant comfort.

- Validate proposed solutions: Validate the effectiveness of the proposed solutions through simulations, case studies, and real-world implementations. Assess the actual energy savings achieved and the improvement in occupant comfort and well-being in buildings where these recommendations are applied.

1.5 Research Structure

The research structure represents five chapters that explain the research literature, research process, approach, and results. In addition to the research questions and methods, each chapter has different components and sections to clearly define the research. The research design followed different methods to achieve a clear address for the problem, to have very clear results, and direct answers to the research questions. Figure 7 shows the division of the research structure.

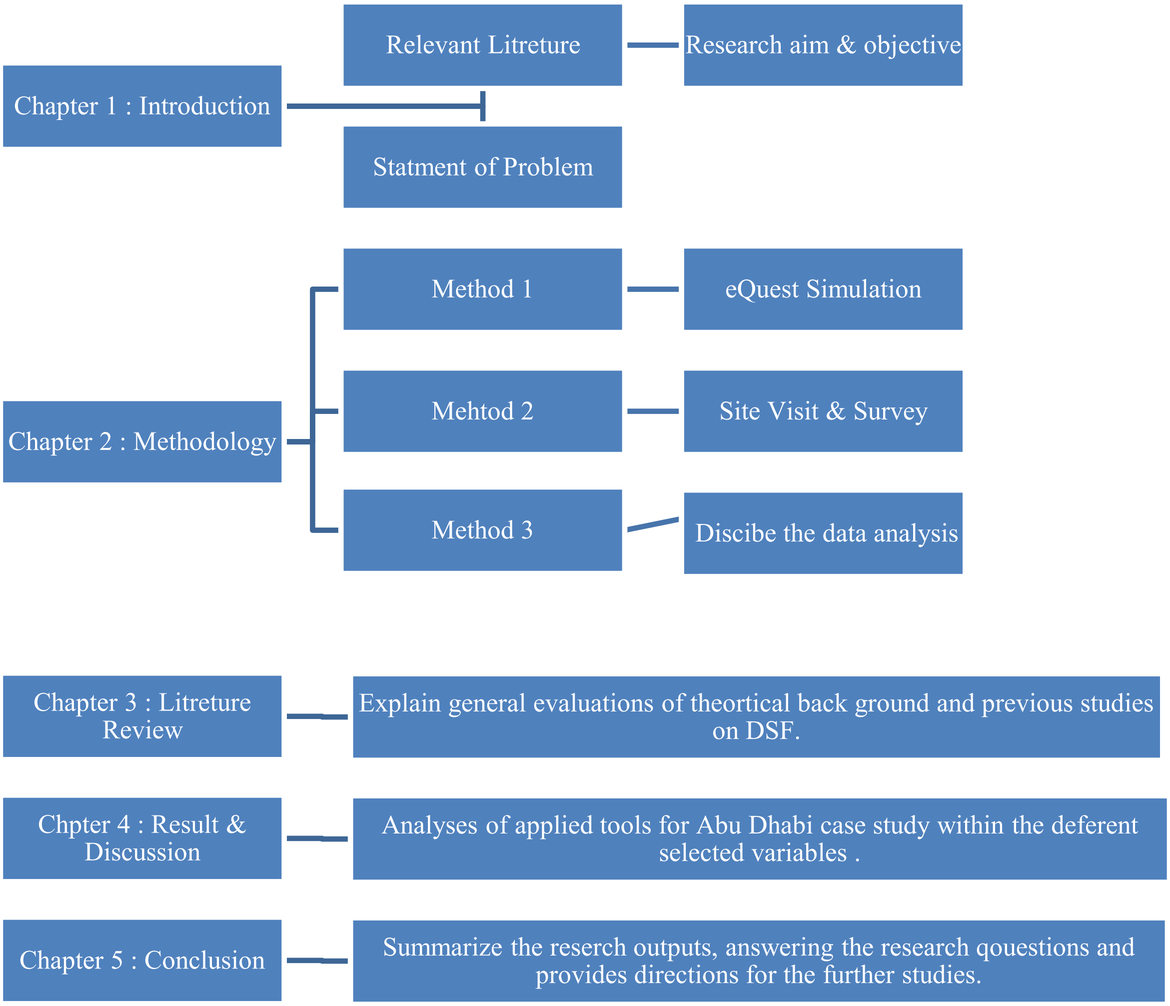


Figure 7: The research structure includes the research process sections.

The first chapter introduces the study and gives an overview of relevant literature and clear aims, objectives, and a statement of the problem. The second chapter is about research methodology, which provides details about the chosen research methods. The third chapter is the literature review, which explains the general theoretical background and previous studies for DSF. This chapter evaluates and assesses the variables used in the simulation to get the best results. The chapter describes and analyzes the results of the case study data analysis. Finally, the conclusion chapter summarizes the research outcomes and opens many directions for future work.

The study applied the qualitative and quantitative method that requires the development of a theoretical framework before the studies and literature review. The framework will be synthesized through related literature analysis, and best practices with information extracted from a survey shown by people who are living in the location of the United Arab Emirates public and private residential sectors. In addition, case studies, interviews, questionnaire of the users, and simulations.

METHODOLOGY

The research methodology encompasses key considerations such as the scope of the study, the researcher's perspectives, and practical implementation, as well as insights gleaned from existing literature [12]. Employing a mixed-method approach, this study combines quantitative and qualitative techniques to comprehensively explore the energy performance of high-rise residential buildings with fully glass facades. Data collection methods include questionnaires, field observations, case studies, and the use of eQuest software.

By focusing on Marina Square in Abu Dhabi, where detailed energy consumption data and information on existing building facades are readily available, the study aims to shed light on the impact of energy performance in such architectural configurations. Through careful selection, problem formulation, and research question establishment, the case study approach facilitates a thorough exploration of key features and implications, challenging existing norms and contributing to future research directions.

Theoretical frameworks in case studies emphasize specific details and their connection to existing theories, enriching understanding and potentially advancing theoretical perspectives. The iterative process of problem selection, literature review, researcher feedback, and simulation ensures a systematic exploration, culminating in synthesized results addressing research questions and enhancing understanding of energy performance in high-rise residential buildings with existing glass facades and varying window opening sizes.

2.1 Investigating Tools

A mixed-method technique was applied in this research, which is defined as the combination of qualitative and quantitative processes to achieve the study goals and objectives. The applied methodologies provided the accessibility to be covered by observation of the existing set of energy performance for DSF high-rise residential buildings, to run a qualitative method that provides a deep description and illustrations that can explore the potential for improving analysis, results, and presenting differences, which may include essentials, guidelines, and prototypes structure. The following facts describe the data collection which is used to reach significantly the research outcomes and highlight the research questions.

a) *Quantitative Analysis*

Quantitative methodologies involve the systematic scientific research of quantitative phenomena and their interactions through the use of mathematical models to test natural world theories and hypotheses [13]. These methodologies include:

- Questionnaire (online survey): the data collected through the online survey by offering closed questions to have a specific answer for each question. Additionally, limited open-end questions are offered for any general feedback. These answers were analyzed to determine the research problem. This online survey enables the responders to clarify replies or request clarification on certain topics on the questionnaire. The terms of the complexity and quality of the data obtained, this mode of survey distribution has a number of advantages over mail and official application. The age, gender, employment status, number of families, and number of rooms in the residential units were considered in this survey.

- Documents and records: The full set of drawings including the floor plans, elevations, sections, and the building details, and the electricity consumption bills record which offers the consumption data and the rate of consumption. In addition, to the several layouts, façade direction, glass percentage, and energy-consuming details over time was been collected from the competent authorities. The spatial concentration of the building and the energy consumption bills were taken from the municipality and Abu Dhabi Distribution Company (ADDC).

b) Qualitative Analysis:

Qualitative research focuses on processes and meanings through the use of in-depth interviews, focus groups, and participant observation [13]. Rather than relying on quantitative data, qualitative research employs description approaches to produce meaning and insight about the topic under study.

Case study: statics are used to identify the problem and the characteristics of the building. This data is important in this study because of the concentration of the area. All factors were considered in the site visit. The qualitative method is based on observation, description, and interpretations of the experience of people in the area. The energy performance of the high-rise residential building will be investigated and examined based on this method.

The developer of the building: The developer website and formal pages helped for collecting data about the building such as the units' number and the type of glass used, and the feedback of the residents about the resources and the environment. It provides the images and the data used to build up the case study.

2.2 Assessment Methods

This research employs a combination of qualitative and quantitative research methods to comprehensively explore the energy performance of Marina Square in Abu Dhabi. Qualitative techniques, such as site visits and online surveys, are utilized to understand the case study and identify key issues. Quantitative methods are then employed to explore and propose alternatives for improving energy performance. The inverse simulation technique is utilized to study the building's energy behavior, analyzing energy-saving processes and costs.

The simulation of energy consumption involves three phases: input parameter definition, construction structure and system modeling, and output variable analysis. Forward modeling predicts output parameters based on input parameters and system characteristics, while reverse simulation fine-tunes system parameters based on pre-programmed energy consumption data.

Various scenarios are evaluated to assess the energy performance of high-rise residential building facades. Data collection involves surveys with experts in building design, facade engineering, and technical control, as well as analysis using eQuest software. Case study data, including building plans and energy consumption records, are obtained from municipal archives and official resident bills. Multiple iterations are conducted to ensure accurate results, with surveys and simulations serving as assessment methods.

2.3 Simulation Tool (eQuest)

Several Building Energy Simulation (BES) applications are widely utilized by designers and architects to implement designs, with eQuest being a prominent choice due to its open-source nature and comprehensive features. eQuest, funded by the U.S. Department of Energy, facilitates simulations of energy consumption in buildings, covering lighting, HVAC, and plug-and-process loads. While the software requires manual inputs for parameters such as material properties and thermostat settings, it can be integrated with other software packages like Autodesk Revit and Design Builder to streamline the modeling process.

To conduct energy simulation analysis using eQuest, users input various building details such as location, weather, envelope information, and HVAC parameters. These inputs are organized in the eQuest input file (IDF editor), ensuring accuracy for reliable results. The simulation process involves setting information in the input files, configuring lighting, personnel, and building needs, zoning the building based on function and temperature control, and inputting air conditioning system parameters.

During calculation, eQuest maintains temperature settings hourly and zones the building to estimate heat loads accurately. Building surfaces are categorized based on temperature management, and equivalent surfaces are defined to simplify modeling. Various factors such as staff, lighting, equipment, air infiltration, and ventilation influence indoor load calculations.

In this research, eQuest is used to evaluate the energy performance of high-rise residential buildings with existing glass facades. The simulation process involves modeling the building, testing recommended values for cavity size and glass type based on literature review, and comparing results against the base case. The steps include adding building details, developing a table to track variables and results, and finalizing recommendations based on energy performance analysis. This iterative process ensures a thorough evaluation and provides insights for optimizing energy efficiency in buildings with existing glass facades.

2.4 Selection of Case Study Abu Dhabi

This section explains the climatic condition of the selected area of Abu Dhabi. Additionally, it highlights the selected case study which is deeply described in chapter four. This data is collected from official resources including Abu Dhabi Municipality and Abu Dhabi Distribution Company to find out the needed information to be used to archive the research outcomes based on the methodology mentioned in the previous section.

2.4.1 Marina Square in Al Reem Island, Abu Dhabi, UAE

Marina Square towers offer occupants and investors different apartment types starting with the studio, up to 4-bedroom designs, as well as 5-bedroom penthouse suites with internal lifts and internal swimming pools. Marina Heights represents a luxury real estate chance for significant capital development and possible investments ahead. Marina Square was selected as a case study due to the following reasons:

- Marina Square is one of the recent Residential Complex with residential buildings that have fully glass façades, high energy consumption, and it has high electricity and finally the AC bills:

- Marina Square has typical 5 buildings with similar exterior façades with available data which can be used to get accurate results. Figure 8 shows the standard residential high-rise buildings in Marina Square at Al Reem Island, Abu Dhabi.

Figure 81: The location of marina square in Abu Dhabi and the exterior view of the buildings.

This project started in 2008 and was completed in 2010. It consists of a mixed-use community with residential, commercial and hotel buildings. It covers a total of over 1.13 million square meters. There are 13 residential towers and an offices tower with a hotel, and a market mall.

This glass residential building façade investigated will be according to the thermal performance in two methodologies to simulate the optimum window opining size façade and compute its impacts on building energy performance in a community tower in Marina Square, Al Reem Island, and Abu Dhabi with forty-five floors. In this, tower the window-to-wall ratio (WWR) is set to 85% to draw a fully glazed working environment. The glass, in this tower, is a double-glazed façade with 24mm thickness, the first layer on the interior side is 6mm clear glass then a 12mm cavity, and finally, the last layer is 6 mm with colored glass. This glass type has a U-value = 2.8 W/m2. K. For the wall material, the solid part is fully painted on gypsum board which covers the construction elements such as beams and columns with the super deluxe level of finishing, and for the opening part, the window glass is double glazed single layer window with a silver aluminum frame.

2.5 Abu Dhabi Climate

Abu Dhabi has difficult desert weather, which is sunny most of the year (Köppen categorization). The months of May through November are so hot and humid with maximum temperatures averaging above forty-one centigrade. Throughout this time, sandstorms appear occasionally, in some cases dropping visibility to a few meters [14]. The colder period is from November to April, which ranges between moderately hot to moderate. This time may come up with fog some days and little rain. On average, January is the coolest month of the year, while August is the hottest. However, despite the coolest month being around eighteen centigrade on average, its weather is extremely dry.

The weather around the UAE emirates is mostly the same; so, reading measures from either Dubai or Abu Dhabi can be used as a typical of that of other emirates. The temperature range statistics and chart for Dubai illustrate that the UAE has a very hot climate during most of the year, mainly during the day. Night has a cooler grade, particularly during the winter. Summer in the UAE can be described as extending from May to October. Temperatures range from 28oC to -36oC reaching a maximum of 48oC in the stifling months of July and August. The Sun Chart for Dubai shows that the south of the emirate needs shading plans to prevent solar access while the north is considered to be a more comfortable area due to a lack of immediate solar radiation. Wind in UAE comes from different directions with a few deviations according to speed. Given that the northwest side experiences relatively higher wind rates.

LITERATURE REVIEW

The literature review and theoretical foundation comprise information about the building façade performance, building façade function, natural ventilation strategies, wind pressure, air density, wind speed and case study that investigate the same energy consumption simulation with different variables such as the geometry features, the cavity, the opening size and the material properties in general. However, the research focuses on the cavity size and the glass material for a specific type of optimum multistory DSF with a 35 cm cavity with a double glass single layer for the inside and a Low-E double glass single layer as an outer layer. In addition, the software simulation follows the standards which were taken from the literature previous studies.

3.1 Building Façade

The major aim of a building's facade is to shield and divide the internal from the external weather conditions. Due to limited energy resources, energy consumption in buildings has recently been a crucial consideration; hence, building construction materials such as glass and procedures should be evaluated effectively during the design stage [2].

Glass has recently been widely used in the facades of modern structures, with its numerous aesthetical alternatives demonstrating the architects' ingenuity. Furthermore, the façade plays an important influence on the building's energy efficiency. Technologies are designed to improve the efficiency of glass in transferring light and heat [15].

There are many important purposes for façade such as control of heat absorbency, which plays a key role in energy consumption, ensures natural ventilation, heat insulation, and security, and adds aesthetics to the buildings. This study shows three main functions of glass facade performance and focuses deeply on one main factor which is the major concern behind this research; thermal performance. A glass facade for the building envelope separates the inside from the outer environment. Environmental impacts are generated by differences between the two environments. Both exterior temperature components [outdoor air temperature, solar radiation, and wind] cause a temperature burden, while interior temperature affects occupants' actions, fresh air, and heating equipment (Clarke & Johnstone, 2010). Façade function is shortly described but this research is focusing mainly on the thermal performance in detail. Figure 9 shows the Glass façade's main function for building envelope to separate the interior environment from the exterior one.

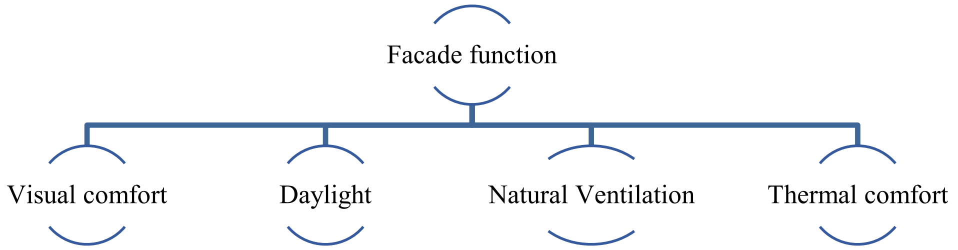


Figure 9: Glass façade's main function for building envelope.

3.1.1 Visual Comfort

Visual comfort refers to the state where the amount of light received by human eyes facilitates various activities without difficulty. This encompasses both artificial and natural light sources. Key indicators of visual well-being include clear visibility in the environment, balanced lighting levels, pleasant light distribution, minimal shadows, and access to exterior views, accurate color representation, and absence of glare. Glare, whether direct or indirect, can significantly hinder vision, with bright light sources causing discomfort or vision impairment. Lighting quality is crucial for optimal human performance, with research indicating its effects on health, productivity, and overall well-being. Factors such as color temperature and lighting type are important considerations. The materials used in building facades, particularly glass, influence visual comfort through their reflective properties, color appearance, and impact on acoustics.

3.1.2 Daylight

Daylighting, the practice of utilizing natural light to fulfill both aesthetic and thermal needs within buildings, is essential for creating a sense of place and time. Studies have shown its benefits in promoting healthy circadian cycles, reducing stress, and improving focus, mood, and productivity, leading to lower absenteeism and enhanced academic performance. By replacing artificial lighting with natural light, buildings can reduce utility expenses and environmental impact.

Effective daylighting design involves considering local climate conditions to minimize heat gain while maximizing natural light. In warmer climates, techniques should focus on reducing solar and conductive heat gain, while in colder climates, balancing heat gains from daylighting with heat losses. Energy efficiency has become a significant concern in modern architecture, particularly in developing countries where the residential sector accounts for a large portion of energy consumption. Daylighting plays a crucial role in energy efficiency, with both double-skin façade (DSF) and single-skin systems offering opportunities for natural lighting. However, the design and characteristics of the glass used can impact the amount of daylight admitted, with thicker glass potentially reducing daylight penetration.

3.1.3 Natural Ventilation

Natural ventilation has served as an effective passive cooling design strategy to reduce the energy used by air-conditioning systems. For tropical regions, where the air temperature and relative humidity are generally high, the effectiveness of natural ventilation is always should be there.

For appropriate air movement, it needs to achieve comfortable conditions. The climate can be classified into five groups according to the natural ventilation:

a) Hot air and natural ventilation do not work.

b) Warm air: high natural ventilation is needed.

c) Comfortable air: moderate ventilation is appropriate.

d) Humid air: natural ventilation is not appropriate.

e) Cool, humid air: minimal ventilation will help.

3.1.4 Thermal Comfort

The appropriate thermal comfort is typically achieved at temperatures between 21°C and 26°C [2]. When engaged in typical activities, the body facade temperature is 33°C to 34°C or less. Less than 16°C can potentially result in a dangerous cardiac condition, and temperatures of more than 45°C can permanently harm the brain. Hence, careful management of body temperature is essential for comfort and well-being. See Figure 10 shows the acceptable range of operative temperature and humidity for the thermal comfort zones.

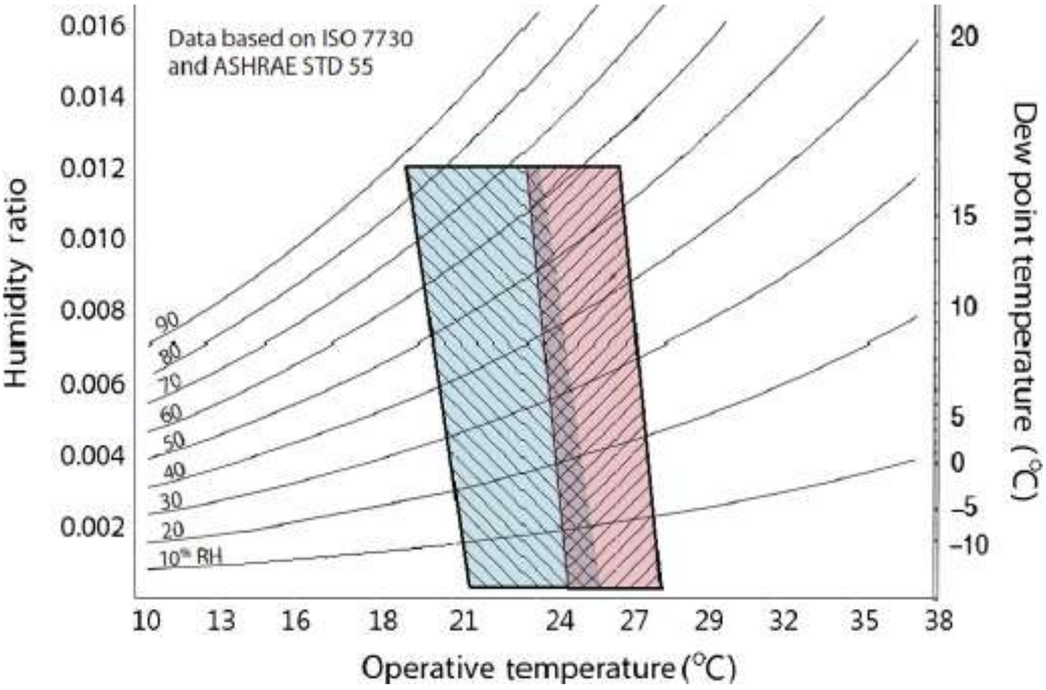


Figure 102: The acceptable range of operative temperature and humidity for the thermal comfort zones [2].

Thermal comfort in the hot climate of buildings typically faces three main influences concerning the thermal comfort functions:

a) Extreme thermal gain in summer.

b) Extreme thermal loss in winter.

c) Extraordinary relative humidity level.

In such hot climate regions, huge amounts of energy are used in buildings, hence, high cost is spent to offer a balanced temperature for occupants [16]. Natural refreshing works depending on two issues: wind and buoyancy. Natural air exchange between outdoor and internal spaces is created throughout the building facades by the difference in wind pressure and the difference in indoor and outdoor temperatures [15]. Likewise, natural cooling produces energy by the usage of exterior airflow, cooling it out and refreshing the building, without using any other electrical mechanical devices. Self-cooling systems are normally used in designing new buildings; also, there are additionally some cases where existing buildings can get an advantage from using the same rules [17].

3.1.5 Wind Speed Velocity

Previous studies have examined the influence of wind speed velocity and temperature differentials on stack effect in medium-rise buildings, particularly in cold regions. Maatouk Khoukhia (2005) conducted numerical simulations to analyze the stack effect in medium-rise buildings in Harbin, China, a severe cold region. The study emphasized the impact of wind speed velocity and temperature gradients on pressure differences within buildings, highlighting the need for mechanical ventilation systems to compensate for energy loss and maintain indoor air quality [18].

Additionally, research by Yu et al. (2005) [18] evaluated the stack effect in high-rise buildings and investigated the influence of architectural elements on indoor air quality. The study underscored the importance of addressing stack effect issues in tall residential buildings to improve indoor environmental quality and energy efficiency. Similarly, Koo et al. (2005) [18] studied the influence of architectural design on stack effect problems in tall residential buildings, emphasizing the role of mechanical ventilation systems in controlling pressure differences [18].

3.1.6 Airflow Patterns and Stack Pressure Simulation

Khoukhi et al. (2007) investigated airflow patterns and stack pressure simulation in a high-rise residential building located in Seoul, emphasizing the impact of stack effect on energy loss, elevator functionality, and indoor comfort. The study utilized the COMIS model to simulate airflow dynamics, demonstrating the significance of exterior wall air-tightness in mitigating stack pressure and airflow infiltration/exfiltration [19].

3.1.7 Impact of Exterior Wall Air-Tightness

The research findings highlighted by Khoukhi et al. (2007) underscore the critical role of exterior wall air-tightness in controlling stack pressure and airflow behavior in high-rise buildings. Variations in air-tightness levels significantly influenced total air infiltration/exfiltration rates, with tighter wall constructions exhibiting reduced energy losses and improved indoor air quality [19].

3.1.8 Lessons for Hot Climate Residential Buildings

While conducted in a cold climate context, the insights from the study by Khoukhi et al. (2007) offer valuable lessons for optimizing natural ventilation strategies in residential buildings located in hot climates like Abu Dhabi. Considerations regarding exterior wall air-tightness, airflow patterns, and stack pressure dynamics are pertinent for enhancing energy efficiency and thermal comfort in high-rise residential structures [19].

In summary, the literature review highlights the importance of optimizing natural ventilation systems to improve energy efficiency in residential buildings situated in hot climates such as Abu Dhabi, UAE. Insights from studies like Khoukhi et al. (2007) provide valuable guidance for designing sustainable ventilation strategies tailored to specific climatic conditions, ultimately contributing to more environmentally friendly and comfortable living environments [19].

The investigation of airflow patterns inside tall buildings, as conducted by Maatouk Khoukhi et al., sheds light on the stack effect phenomenon and its implications for building design and operation [20]. The study highlights the importance of understanding airflow dynamics, particularly in high-rise structures, to mitigate energy loss caused by airflow and related issues such as elevator malfunctions and noise disturbances [20]. Additionally, the research emphasizes the role of exterior wall air-tightness in minimizing air infiltration and optimizing natural ventilation [20].

Previous studies on natural ventilation in various climatic conditions provide valuable insights into designing energy-efficient buildings. For instance, research by Yu et al. explores the evaluation of stack effect according to building shape and window area ratios in high-rise buildings, offering implications for improving natural ventilation strategies (Yu et al., 2004). Furthermore, investigations by Khoukhi et al. in cold regions of China emphasize the impact of wind speed velocity on stack effect, underscoring the need for climate-specific design considerations [20].

Theoretical frameworks such as the COMIS model have been extensively utilized to simulate airflow patterns and assess building performance in terms of energy efficiency [20]. By employing multi zone models like COMIS, researchers have been able to analyze airflow distribution and identify opportunities for optimizing natural ventilation systems [20].

Synthesizing findings from previous research on airflow patterns stack effect, and natural ventilation optimization, this literature review provides a foundation for exploring strategies to enhance energy efficiency in residential buildings in hot climates like Abu Dhabi, UAE. By integrating insights from existing studies, future research can focus on developing tailored approaches to leverage natural ventilation effectively, thereby reducing energy consumption and promoting sustainable building practices in the region.

Natural ventilation plays a crucial role in enhancing energy efficiency in residential buildings, particularly in hot climates such as Abu Dhabi, UAE. The following review examines the utilization of natural ventilation, focusing on airflow patterns within tall buildings, as well as the implications of stack effect and exterior wall air-tightness on ventilation effectiveness.

Khoukhi et al. (2007) conducted a study aiming to demonstrate that complex tall buildings can be effectively modeled using simplified procedures. They addressed the challenges posed by tall buildings' airflow patterns, driven by stack pressure, which influences energy consumption and indoor comfort. Utilizing the COMIS software, the authors simulated airflow patterns and pressures within tall buildings, emphasizing the need for a simplified modeling approach due to software limitations. The study highlights the significance of accurately representing airflow patterns to optimize natural ventilation strategies [21].

The study by Jo et al. (2007) explores pressure distribution and solutions to stack effect-related issues in high-rise residential buildings [21]. Stack effect, caused by temperature differentials between indoor and outdoor air, influences airflow patterns and energy consumption. The authors emphasize the importance of understanding and mitigating stack effect to enhance indoor air quality and energy efficiency in tall buildings. Their findings underscore the relevance of natural ventilation optimization in high-rise residential structures.

Furthermore, Tamblyn (1991, 1993) and Lovatt & Wilson (1994) delve into the challenges and HVAC system effects associated with stack effect in tall buildings. These studies highlight the complexities of airflow management and energy consumption in high-rise structures, emphasizing the need for effective natural ventilation strategies to mitigate stack effect-related issues [21].

Feustel & Raynor-Hoosen (1990) provide insights into the fundamentals of multizone airflow modeling using COMIS software. Their work elucidates the intricacies of airflow distribution in multizone buildings and the significance of accurate modeling for optimizing ventilation strategies [21].

In summary, the reviewed literature underscores the importance of optimizing natural ventilation to improve energy efficiency in tall residential buildings in hot climates like Abu Dhabi. By understanding airflow patterns, stack effect dynamics, and the impact of exterior wall air-tightness, designers and engineers can develop effective strategies to enhance indoor comfort and reduce energy consumption in residential structures.

MARINA SQUARE CASE STUDY

This chapter aims to investigate the thermal performance of the building façades in the research case study, comparing the existing glass façades with simulations of proposed window optimum opening size Façades (DSF). The sections cover: a) Overview of Marina Square, detailing the residential building and façade performance; b) Data collection on construction properties, cooling system, and climatic conditions; c) Analysis of current façade energy consumption and bills; and d) Conclusion.

Marina Square, situated on Al Reem Island in Abu Dhabi, comprises interconnected towers within a mixed-use development. The compound features 13 residential towers accommodating 8,500 residents, alongside a commercial tower. With a variety of unit types and scenic views, Marina Square offers a diverse residential experience with waterfront and city vistas [22].

Marina Square is the first phase of the iconic multi-billion-dollar project on Al Reem Island. An exceptional waterfront development set on an area of 1.2 million square meters with a highly desired address supports the lifestyle of security and accessible living neighborhood. Featuring landscaped spaces, swimming pools, a private beach, a playground, marina facilities, parking, daycare centers, medical clinics, and a mosque, Marina Square is an enviable address with a planned two-level shopping arcade, multiplex cinema, and a marina for yacht owners.

4.1.1 Residential Building Façade

For this research, the vertical residential building façades are reviewed according to the thermal performance as explained in the research methodology in chapter 2. The thermal performance simulation of the proposed DSF was compared with the result of the existing glass façade, in addition to the building energy performance results in the high-rise residential building in Marina Square, Al Reem Island. Marina Heights II was selected because it is the compound's middle tower and has four orientations for each unit, which supported the research results. Marina Heights II tower has forty-five floors. In this tower, the window-to-wall ratio (WWR) is set to 85 % to draw a fully glazed façade, as shown in Figure 11.

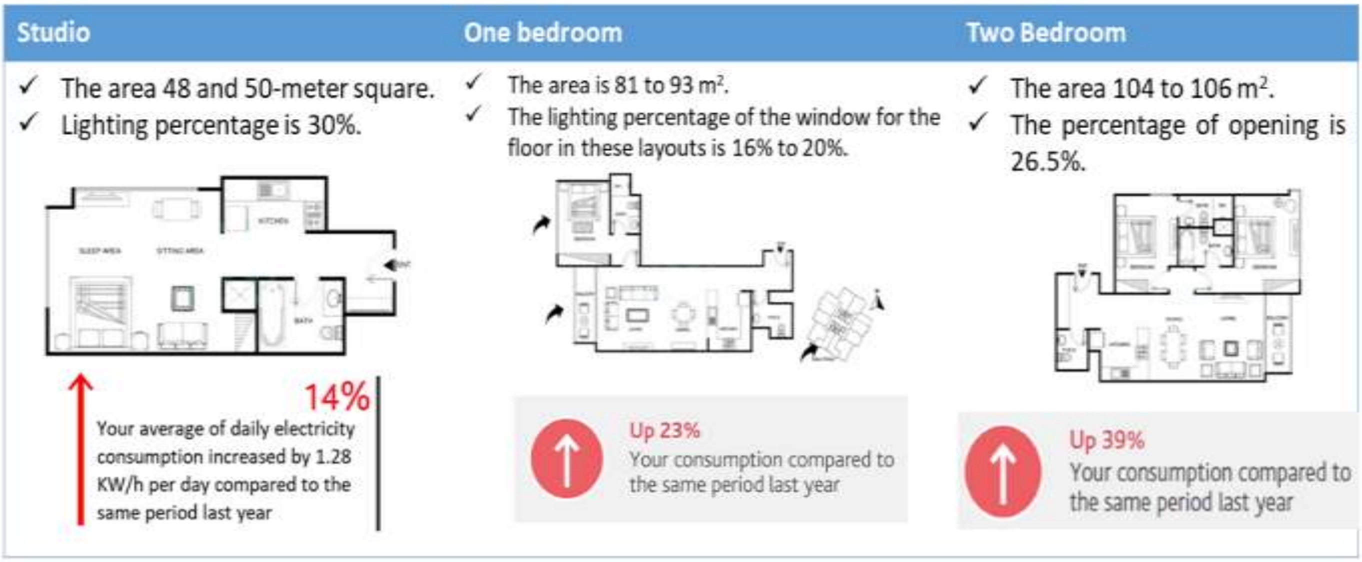
Figure 113: The full residential compound of Marina square towers [22].

The selected tower façade type is a curtain wall with a double-glazed single skin. The skin has a double-glazed single façade with 24mm thickness; the inner layer is 6mm clear glass, then a 12mm cavity, and the last layer, which is 6 mm with colored glass. This façade U-value is 2.8 (W/m2 K) from the ADM archive.

4.1.3 Building Façade Performance

The building façade performance model was done by rivet simulation developed by eQuest.. The general simulation inputs include envelope physical properties, internal loads, energy consumption, and schedules to conduct the energy analysis through eQuest. To focus on the performance of control strategies, modeling a specific HVAC system is avoided by assigning an 'Ideal Air Load' system. eQuest allows the modeling of a maximum of two reference points; it is also assumed that the glass system can be controlled only by one of the users who are seated perpendicular to the window to have (a direct view direction outdoors). Ultimately, the simulation output significantly improved the new optimum façade to achieve Thermal performance and reduce energy consumption.

Different units were selected to be tested to prove the research outcomes; the units were selected depending on the type, size, orientation, opening size, and floor height. Two plans were selected with different floor levels and orientations, including two studios, two layouts of one bedroom, and two layouts of two bedrooms. Figure 12 shows the different three layouts of the selected building.



Studio

- ✓ The area 48 and 50-meter square.
- ✓ Lighting percentage is 30%.

14%
Your average of daily electricity consumption increased by 1.28 KW/h per day compared to the same period last year

One bedroom

- ✓ The area is 81 to 93 m².
- ✓ The lighting percentage of the window for the floor in these layouts is 16% to 20%.

Up 23%
Your consumption compared to the same period last year

Two Bedroom

- ✓ The area 104 to 106 m².
- ✓ The percentage of opening is 26.5%.

Up 39%
Your consumption compared to the same period last year

Figure 12: Different selected units Studio, One-bedroom, and Two-bedroom.

4.2 Data Collection

This section includes the construction details of the existing properties, the mechanical equipment, the climatic data, and the field measurements. However, the survey was done, and AC consumption is also included in this chapter.

4.2.1 Wall Construction Properties

Wall construction properties of the building façade are listed in Table 1. The facade consists of Double-glazed merged in one layer, with colored and transparent glass sheets. The windows are operable units with no sills from the floor. Figure 13 shows the details of the window. One to two windows in each room allows the occupants to open for natural ventilation, usually in the wintertime. Table 1 shows the glass properties and its specification for the existing case study.

Table 1: Properties of the existing building façade construction.

Glass Type	Components	Structure	Thickness	U-Value (W/m2 K)
Existing building glass	Double glazed	Clear glass Gap Colored glass	6 mm 12 mm 6 mm	2.8
Existing building wall	External wall	Gypsum plasterboard Mineral fiber Brick Cement mortar Granite	0.95 cm 0.9 cm 10 cm 2 cm 1.3 cm	0.335

Figure 134: The window picture shows no sill and openable panel for natural ventilation.

4.2.2 Cooling System

The building utilizes a central chiller for air conditioning, with air handling controllers distributed on each floor and in each unit. The cooling system operates continuously, with peak usage during summer months. The study focuses specifically on this period as a benchmark. The building is serviced by a District Cooling Provider (DCP), which supplies chilled water for air conditioning. The DCP determines a Capacity Charge based on factors like Refrigeration Tonnage (RT) or Net Floor Area (NFA). District cooling systems, like the one utilized here, are favored for their efficiency and effectiveness, especially in densely populated areas. A District Cooling Provider operates by distributing thermal energy from a central source of chilled water to residential consumers for cooling and dehumidification purposes. It comprises heat rejection systems, a central chiller plant, a distribution system, and end users.

4.2.3 Climatic Data

Climatic data from field measurements represented realistic values and were taken from original resources. The simulation process used the hourly weather typical meteorological year profile of Abu Dhabi. This data is taken out from UAE Meteorological Institute data. Temperatures of wet and dry bulbs, relative humidity, cloud cover, wind speed and direction, solar direct and diffuse radiation, and atmospheric pressure are all measured hourly [23]. The extreme summer temperature for Abu Dhabi is 42.0°C, and the minimum winter temperature is 11.8ºC.

The red line shows Abu Dhabi's temperature in Figure 14, and the humidity line is blue; Figure 14 explains that the maximum temperature in Abu Dhabi is in July and August, which reach almost 42°C, but the rain is mainly in February. Humidity in Abu Dhabi has a positive relationship with high temperatures.

Figure 145: Abu Dhabi temperature and rainfall diagram for 10 years period.

The higher temperature value in Abu Dhabi is 42°C, with a minimum temperature value in August is 28.7°C [23].

4.2.4 Data Collection

This section contains the details of the AC energy consumption and the survey occupants and residences feedback according to the building façade, thermal performance, and the opinion of changing the façade to reduce energy consumption. In addition, the information was collected from the primary resources according to the electricity bills and AC energy (chilled water) bills.

A- Survey

This section includes the survey that was conducted to clarify the research problem. This survey includes several questions showing the rate of owners vs. the tenants, and the number of rooms was considered, in addition to the family size. The average family income and the percentage to be paid for the AC and electrical consumption are also included in the survey to get accurate answers. In this part, the results of the survey of the users according to energy saving showed that the users strongly agree that energy saving is essential to save energy, as shown in Figure 15. More information about the survey results and the users' opinions on the thermal performance and consumption results are mentioned in appendix 1. Figure 15, more than 60% of the interviewers strongly agreed with the energy saving and enhanced thermal performance by modifying the glass type to get best results than the existing single glass; the occupants and the residents support the research problem, and 20% agree that the energy consumption needs to be improved. However, the last 20% was neutral.

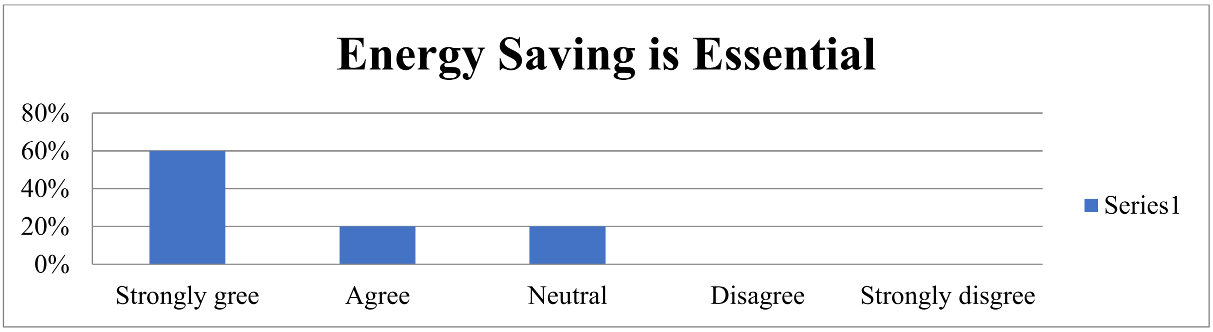


Figure 15: The results of the users about the thermal performance and energy saving.

B- Measurements in summer (AC Bills)

The AC bills in these buildings are separated from the energy consumption for other needs. On the other hand, the AC consumption is mentioned by square meter, as shown in Figure 16; the AC bill is for one unit as an example; this bill shows the consumption per sq. m and total consumption. As mentioned in the mechanical equipment, this building has chillers with a separate controller in each unit.

TAX INVOICE

Customer Support

BILLING DETAILS

METER DETAILS

CHILLED WATER STATEMENT OF ACCOUNT

CONSUMPTION CHARGES

Figure 16: AC consumption Bill template.

4.3 Energy Consumptions Analysis

This section presents the monthly energy consumption of the building for each unit; the energy consumption for each unit in August as a peak month was analyzed based on the existing data collection. After describing the residential units in section 4.1, this analysis was built based on the selected variables, such as the cavity between glass skins and the glass u-value described in section 4.4. Based on the glass properties, the heat transmission of the optimum facade achieved the highest percentage. However, the value is the primary variable behind selecting the optimum DSF. The calculated energy consumption for electricity and AC for each unit, as explained below, based on the existing bills and existing glass properties are mentioned in a) AC energy consumption results and b) Electricity consumption results.

4.3.1 Studio

The studio existing analyzed data based on the existing data in the peak period (August) is presented below in two sections:

a) Air Conditioning Energy Consumption

This part of the research discusses the results of the existing values of AC consumption. Here, Figure 17 shows the consumption graph; it shows the minimum and maximum values, but the research focused on August, which is the year's peak time. This graph was sketched depending on the existing AC bills for the existing double-glazed single-glass window with the U-value = 5.68 (W/m2 K). Figure 17 shows the minimum energy consumption in February (3.3 kWh) and the highest energy consumption in August (600 kWh).

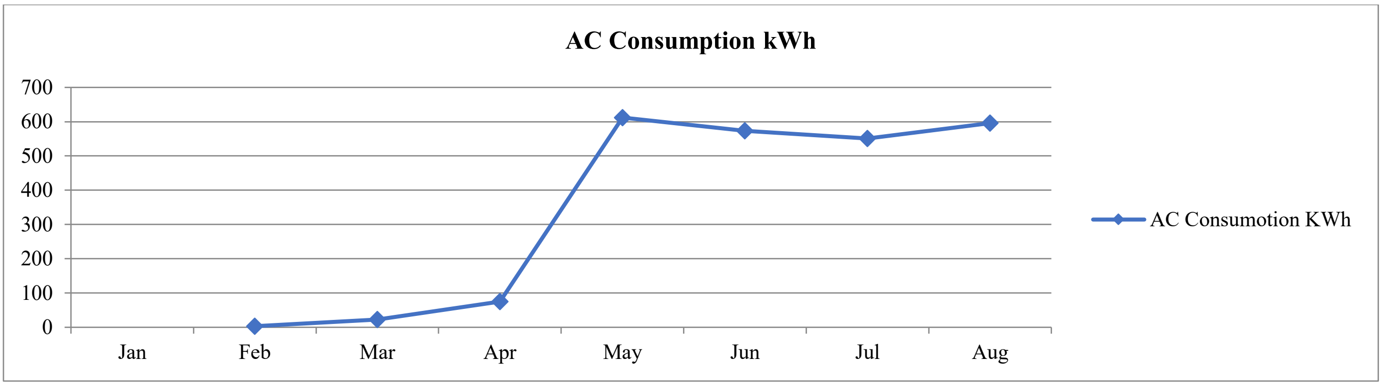


Figure 17: AC consumption for the whole year.

As shown in Figure 18, the AC peak time is shown from May to August. This period shows the highest AC energy consumption, and the other part of the year shows a noticeable significant drop in AC energy consumption, proving the hotter weather in the peak time.

4.3.2 One-Bedroom

The one-bedroom AC consumption based on the existing bills and glass properties are discussed below.

a) *AC Consumption*

In this section, the research discusses the existing values of AC consumption throughout the year. Figure 18 shows the graph of the current consumption depending on the bills and data collected from ADDC, which shows the minimum and maximum values of AC usage. However, the research focused on August, which is the year's peak time, as mentioned before. This graph was sketched depending on the current data consumption of AC bills for the existing double-glazed window with the U-value of 5.68 (W/m2 K) for the existing glass type.

As shown in Figure 60, the minimum electrical energy consumption was noticed between January and April (157 kWh), and the highest energy consumption was in August (just above 1000 kWh). However, the peak period is from May to September, and the drop in AC consumption is evident for the other months.

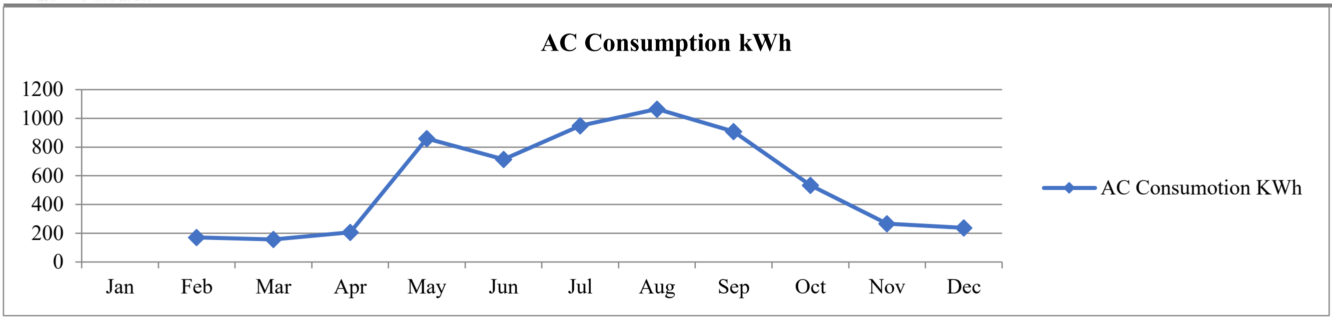


Figure 187: AC consumption for the whole year.

4.3.3 Two-Bedroom

This section discusses the outcomes of the two-bedroom AC and electricity consumption based on the existing bills for the existing double-glazed window with the U-value of 5.68 (W/m2 K). These results were compared with the improved results based on changing the cavity and the glass type.

a) AC Consumption

In this part, the research analyzes the existing values of AC consumption through the year, focusing on August month. Figure 19 shows the graph of AC consumption's minimum and maximum values. As shown in Figure 19, the highest energy consumption of this unit is in September. It reaches 1800 kWh.

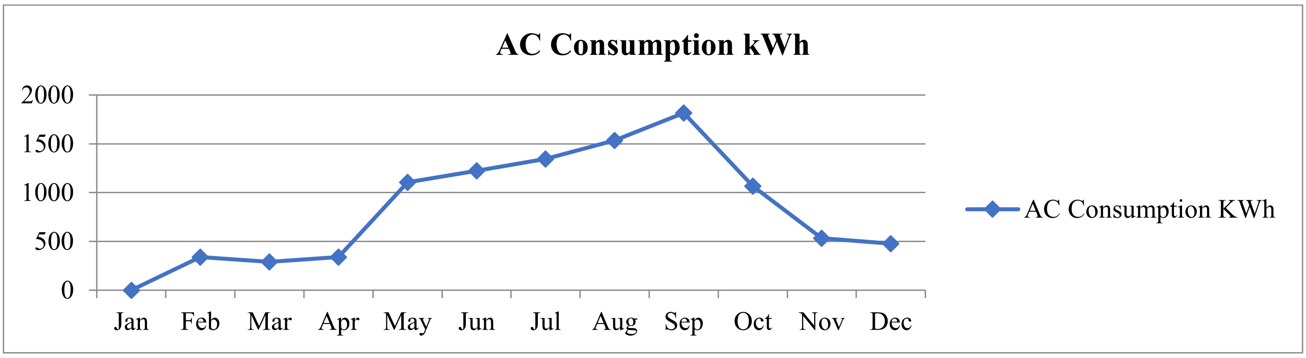


Figure 19: AC consumption for the whole year.

ADJUSTING WINDOW OPENING SIZES

This research incorporates opening size variables as a key component in assessing energy performance. By adjusting the size of window openings, the study aims to analyze their impact on energy consumption and indoor environmental quality. The investigation includes gathering data from surveys with experts in building design and facade engineering, as well as utilizing simulation software like eQuest to evaluate various scenarios. Through careful analysis of these variables, the research seeks to optimize building facade design to enhance energy efficiency and occupant comfort.

5 Energy Consumption simulation and Results

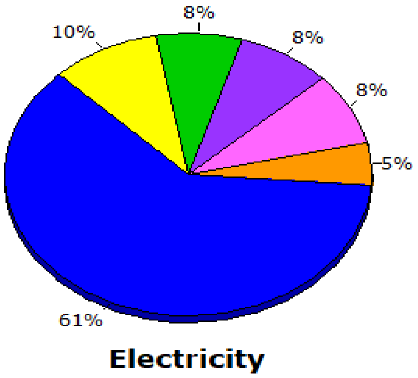
In the process of model creation using existing data, various variables were tested, with a primary focus on the size of openings. These variables were explored to understand their impact on the performance of natural ventilation systems within residential buildings. Each orientation was analyzed separately to account for the influence of solar exposure, prevailing wind directions, and building layout on airflow patterns and ventilation effectiveness. The results obtained for each orientation revealed insights into the optimal opening sizes required to achieve desired airflow rates, ventilation efficiency, and thermal comfort levels in different areas of the building. By systematically testing these variables and assessing their outcomes across various orientations, the study aimed to inform design decisions and strategies for optimizing natural ventilation in residential settings.

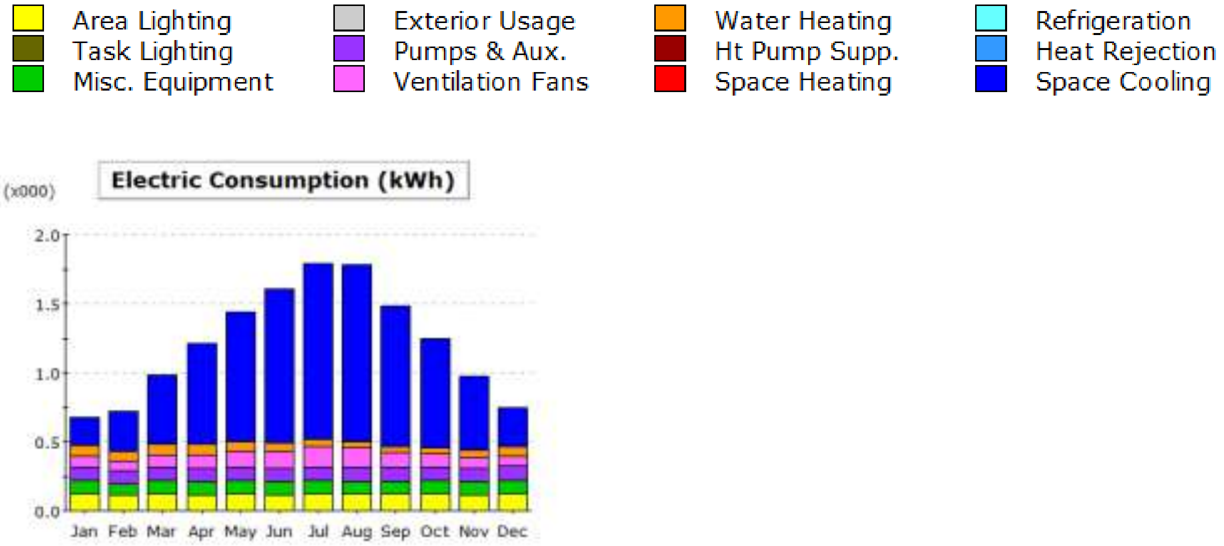
Figure 20: the Software set up for the all units.

4.5.1 Studio

Annual Energy Consumption by Enduse

	Electricity kWh	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	8,954	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	-	-	-	-
HP Supp.	-	-	-	-
Hot Water	714	-	-	-
Vent. Fans	1,207	-	-	-
Pumps & Aux.	1,218	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	1,116	-	-	-
Task Lights	-	-	-	-
Area Lights	1,429	-	-	-
Total	14,638	-	-	-

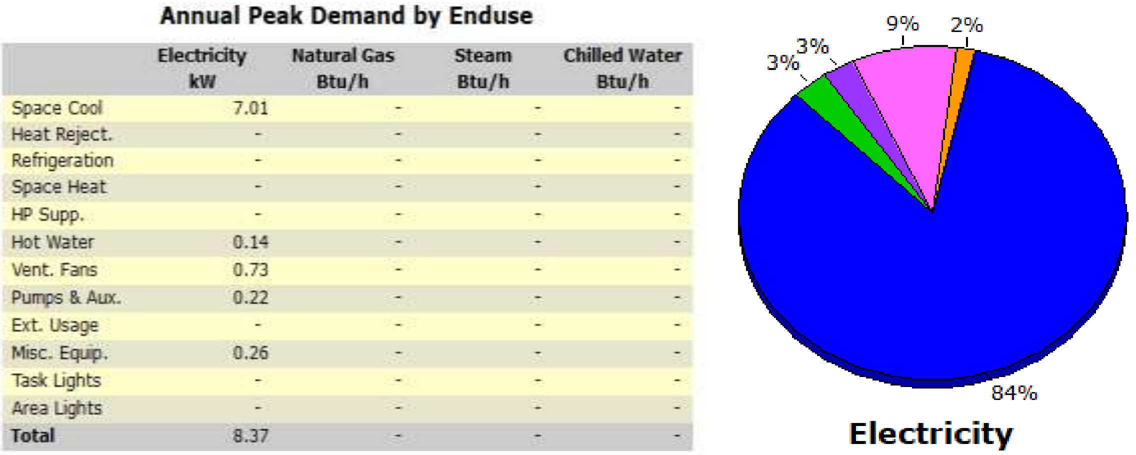




Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.20	0.29	0.49	0.73	0.94	1.11	1.28	1.28	1.02	0.78	0.54	0.28	8.95
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.07	0.07	0.08	0.07	0.07	0.05	0.05	0.04	0.04	0.05	0.05	0.06	0.71
Vent. Fans	0.08	0.07	0.08	0.10	0.11	0.13	0.15	0.14	0.11	0.09	0.08	0.08	1.21
Pumps & Aux.	0.10	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	1.22
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	1.12
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.12	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	1.43
Total	0.67	0.72	0.98	1.21	1.44	1.60	1.79	1.78	1.49	1.24	0.98	0.74	14.64

Figure 10: Yearly and Monthly Energy Consumption by Enduse for studio.

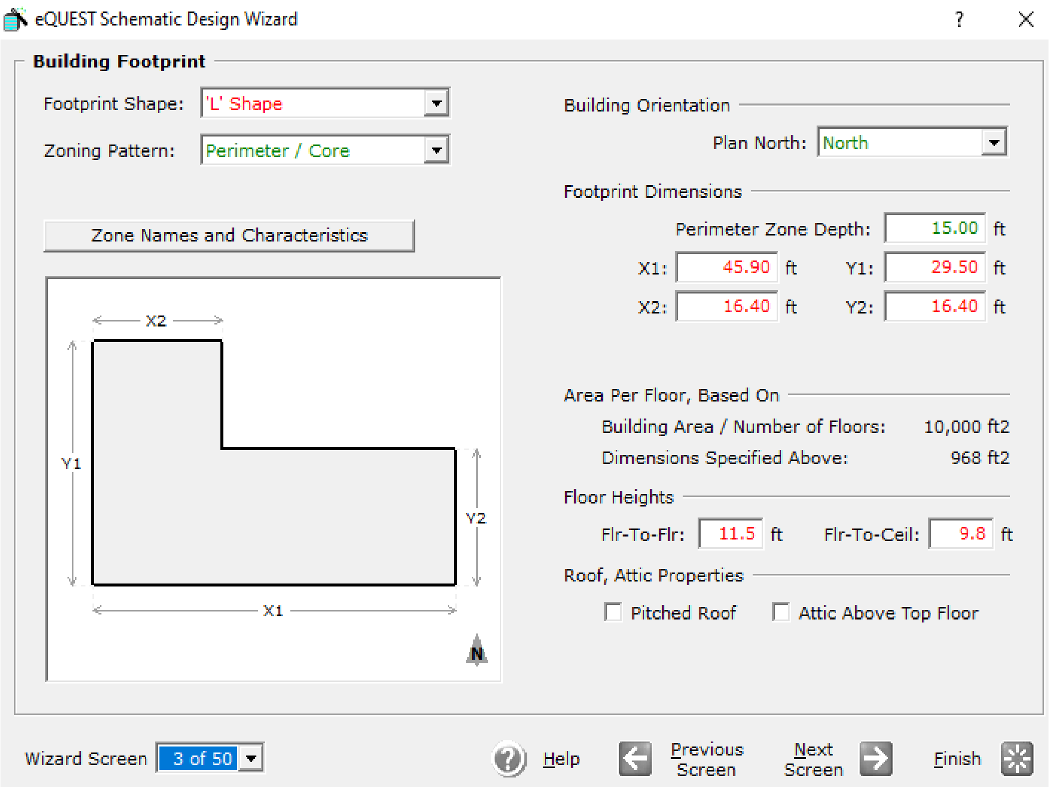


Annual Peak Demand by Enduse

	Electricity kW	Natural Gas Btu/h	Steam Btu/h	Chilled Water Btu/h
Space Cool	7.01	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	-	-	-	-
HP Supp.	-	-	-	-
Hot Water	0.14	-	-	-
Vent. Fans	0.73	-	-	-
Pumps & Aux.	0.22	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	0.26	-	-	-
Task Lights	-	-	-	-
Area Lights	-	-	-	-
Total	8.37	-	-	-

Figure 21: Annual Peak Demand by Enduse.

4.5.1 One Bedroom:



Building Footprint

Footprint Shape: 'L' Shape

Zoning Pattern: Perimeter / Core

Building Orientation

Plan North: North

Footprint Dimensions

Perimeter Zone Depth: 15.00 ft

X1: 45.90 ft Y1: 29.50 ft

X2: 16.40 ft Y2: 16.40 ft

Area Per Floor, Based On

Building Area / Number of Floors: 10,000 ft2

Dimensions Specified Above: 968 ft2

Floor Heights

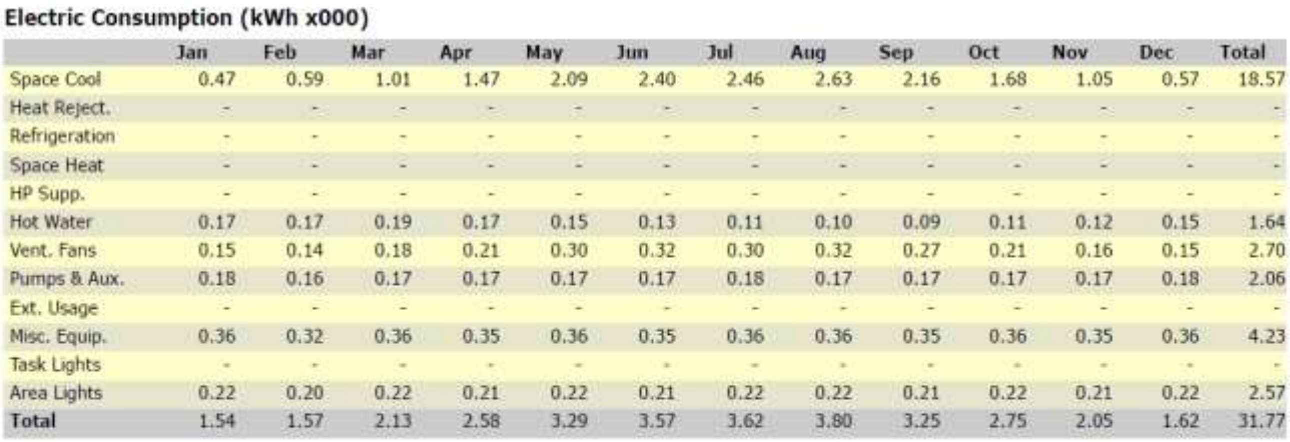
Flr-To-Flr: 11.5 ft Flr-To-Ceil: 9.8 ft

Roof, Attic Properties

☐ Pitched Roof ☐ Attic Above Top Floor

Wizard Screen 3 of 50

Figure 22: One bedroom Simulation existing plan.



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.47	0.59	1.01	1.47	2.09	2.40	2.46	2.63	2.16	1.68	1.05	0.57	18.57
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.17	0.17	0.19	0.17	0.15	0.13	0.11	0.10	0.09	0.11	0.12	0.15	1.64
Vent. Fans	0.15	0.14	0.18	0.21	0.30	0.32	0.30	0.32	0.27	0.21	0.16	0.15	2.70
Pumps & Aux.	0.18	0.16	0.17	0.17	0.17	0.17	0.18	0.17	0.17	0.17	0.17	0.18	2.06
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	0.36	0.32	0.36	0.35	0.36	0.35	0.36	0.36	0.35	0.36	0.35	0.36	4.23
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.22	0.20	0.22	0.21	0.22	0.21	0.22	0.22	0.21	0.22	0.21	0.22	2.57
Total	1.54	1.57	2.13	2.58	3.29	3.57	3.62	3.80	3.25	2.75	2.05	1.62	31.77

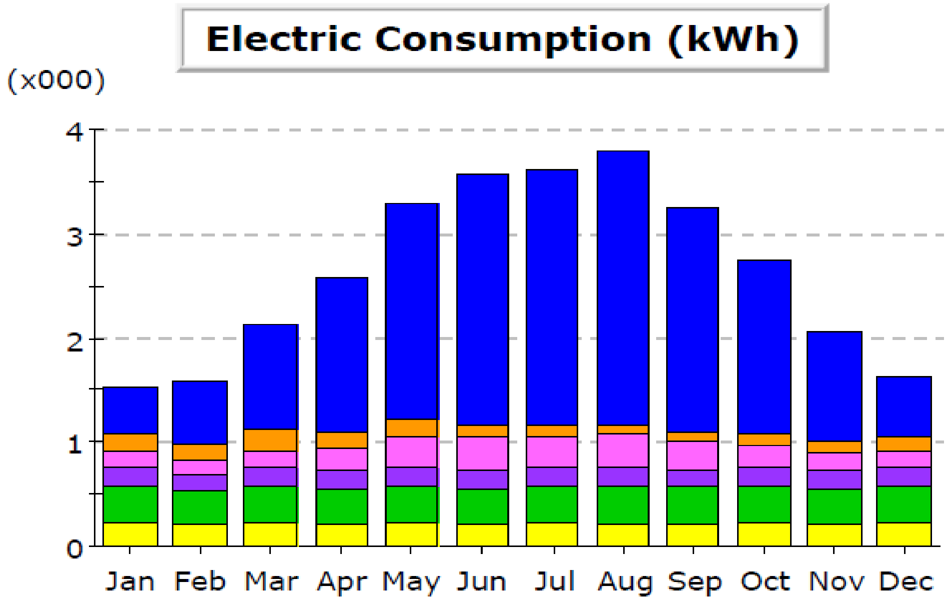


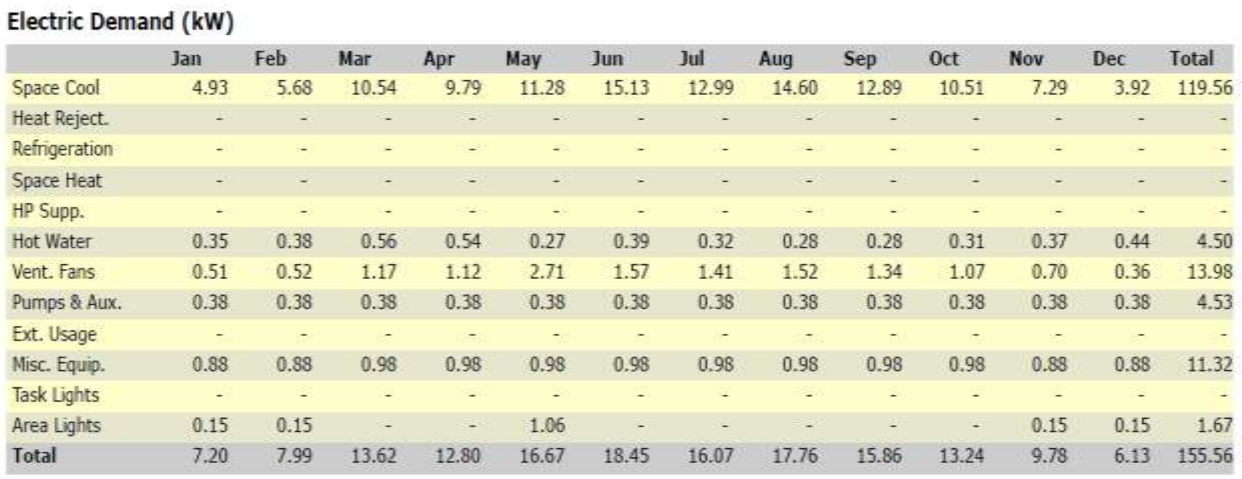
Figure 23: One bedroom Monthly Energy Consumption by Enduse.

🟨 Area Lighting
🟫 Task Lighting
🟩 Misc. Equipment
⬜ Exterior Usage
🟪 Pumps & Aux.
🟪 Ventilation Fans
🟧 Water Heating
🟥 Ht Pump Supp.
🟥 Space Heating
🟦 Refrigeration
🟦 Heat Rejection
🟦 Space Cooling

Annual Energy Consumption by Enduse

	Electricity kWh	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	18,571	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	-	-	-	-
HP Supp.	-	-	-	-
Hot Water	1,644	-	-	-
Vent. Fans	2,699	-	-	-
Pumps & Aux.	2,058	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	4,226	-	-	-
Task Lights	-	-	-	-
Area Lights	2,569	-	-	-
Total	31,767	-	-	-

Figure 24: One bedroom Annual Energy Consumption.



Electric Demand (kW)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	4.93	5.68	10.54	9.79	11.28	15.13	12.99	14.60	12.89	10.51	7.29	3.92	119.56
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.35	0.38	0.56	0.54	0.27	0.39	0.32	0.28	0.28	0.31	0.37	0.44	4.50
Vent. Fans	0.51	0.52	1.17	1.12	2.71	1.57	1.41	1.52	1.34	1.07	0.70	0.36	13.98
Pumps & Aux.	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	4.53
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	0.88	0.88	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.88	0.88	11.32
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.15	0.15	-	-	1.06	-	-	-	-	-	0.15	0.15	1.67
Total	7.20	7.99	13.62	12.80	16.67	18.45	16.07	17.76	15.86	13.24	9.78	6.13	155.56

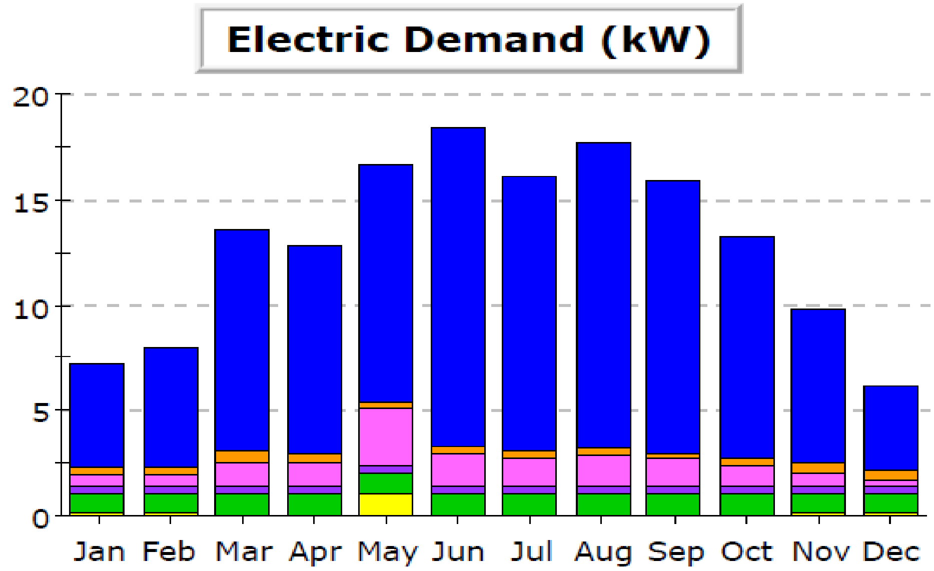


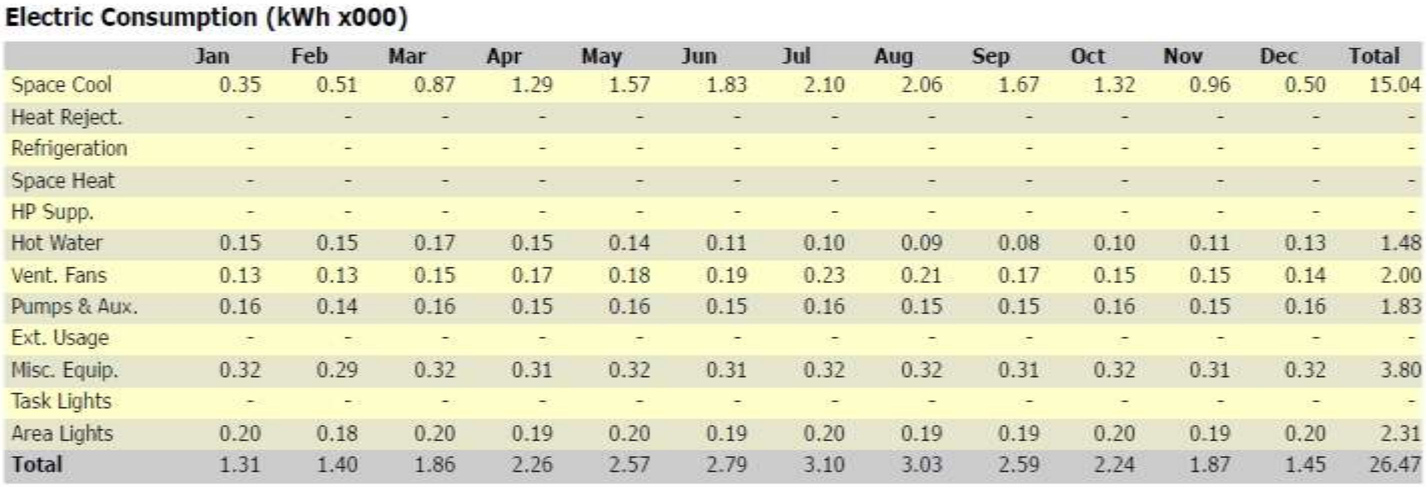
Figure 25: One bedroom Monthly Peak Demand by Enduse.

Annual Peak Demand by Enduse

	Electricity kW	Natural Gas Btu/h	Steam Btu/h	Chilled Water Btu/h
Space Cool	15.13	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	-	-	-	-
HP Supp.	-	-	-	-
Hot Water	0.39	-	-	-
Vent. Fans	1.57	-	-	-
Pumps & Aux.	0.38	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	0.98	-	-	-
Task Lights	-	-	-	-
Area Lights	-	-	-	-
Total	18.45	-	-	-

Figure 27: One bedroom Annual Peak Demand by Enduse.

4.5.1 Two Bedroom:



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.35	0.51	0.87	1.29	1.57	1.83	2.10	2.06	1.67	1.32	0.96	0.50	15.04
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.15	0.15	0.17	0.15	0.14	0.11	0.10	0.09	0.08	0.10	0.11	0.13	1.48
Vent. Fans	0.13	0.13	0.15	0.17	0.18	0.19	0.23	0.21	0.17	0.15	0.15	0.14	2.00
Pumps & Aux.	0.16	0.14	0.16	0.15	0.16	0.15	0.16	0.15	0.15	0.16	0.15	0.16	1.83
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	0.32	0.29	0.32	0.31	0.32	0.31	0.32	0.32	0.31	0.32	0.31	0.32	3.80
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.20	0.18	0.20	0.19	0.20	0.19	0.20	0.19	0.19	0.20	0.19	0.20	2.31
Total	1.31	1.40	1.86	2.26	2.57	2.79	3.10	3.03	2.59	2.24	1.87	1.45	26.47

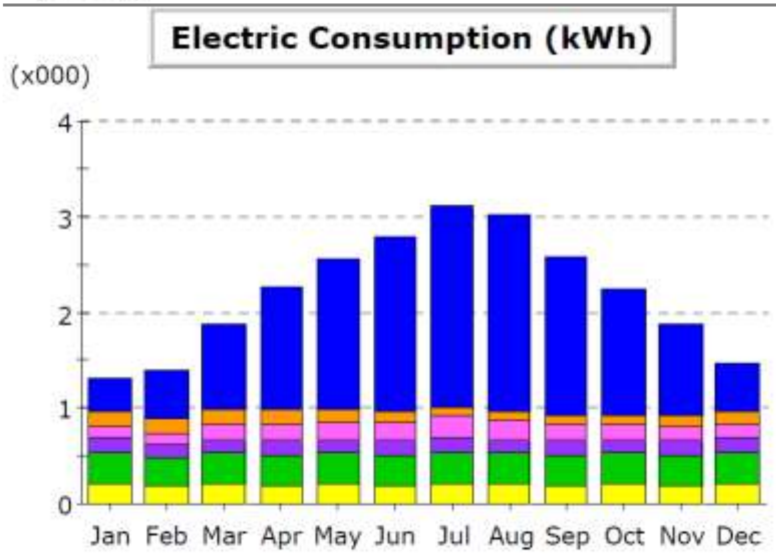
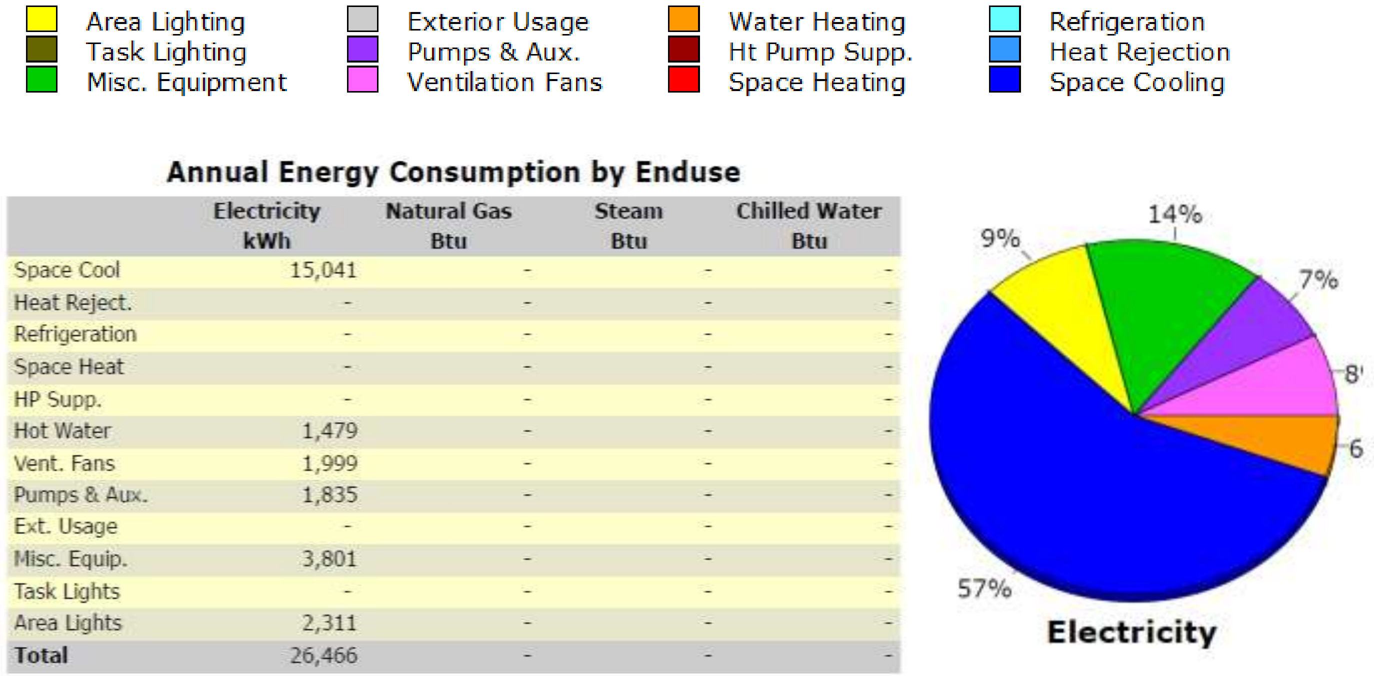


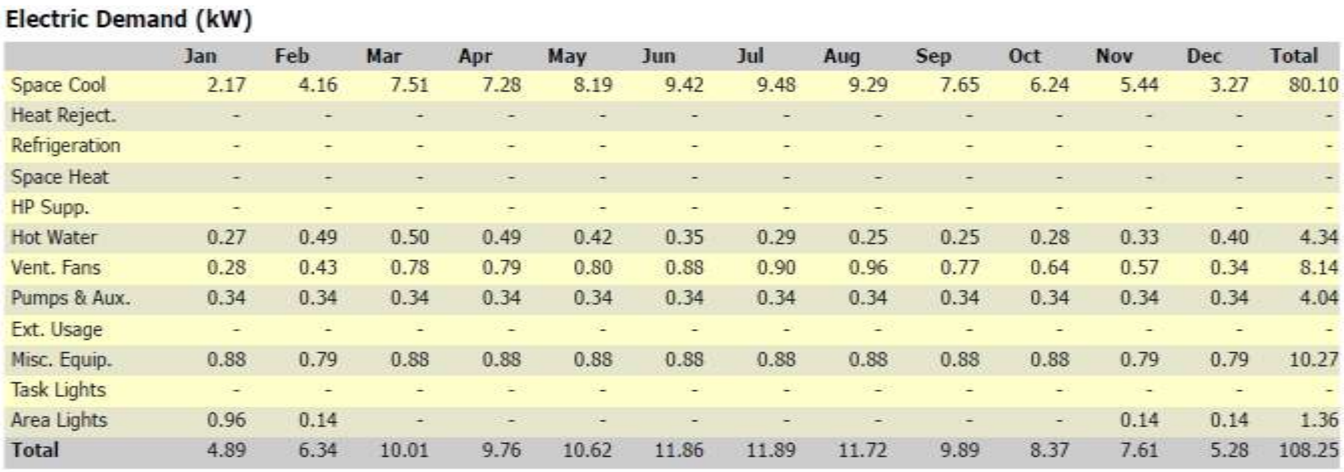
Figure 28: Two Bedroom Monthly Energy Consumption by Enduse



Annual Energy Consumption by Enduse

	Electricity kWh	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	15,041	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	-	-	-	-
HP Supp.	-	-	-	-
Hot Water	1,479	-	-	-
Vent. Fans	1,999	-	-	-
Pumps & Aux.	1,835	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	3,801	-	-	-
Task Lights	-	-	-	-
Area Lights	2,311	-	-	-
Total	26,466	-	-	-

Figure 29: Two Bedroom Annual Energy Consumption by Enduse



Electric Demand (kW)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	2.17	4.16	7.51	7.28	8.19	9.42	9.48	9.29	7.65	6.24	5.44	3.27	80.10
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.27	0.49	0.50	0.49	0.42	0.35	0.29	0.25	0.25	0.28	0.33	0.40	4.34
Vent. Fans	0.28	0.43	0.78	0.79	0.80	0.88	0.90	0.96	0.77	0.64	0.57	0.34	8.14
Pumps & Aux.	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	4.04
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	0.88	0.79	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.79	0.79	10.27
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.96	0.14	-	-	-	-	-	-	-	-	0.14	0.14	1.36
Total	4.89	6.34	10.01	9.76	10.62	11.86	11.89	11.72	9.89	8.37	7.61	5.28	108.25

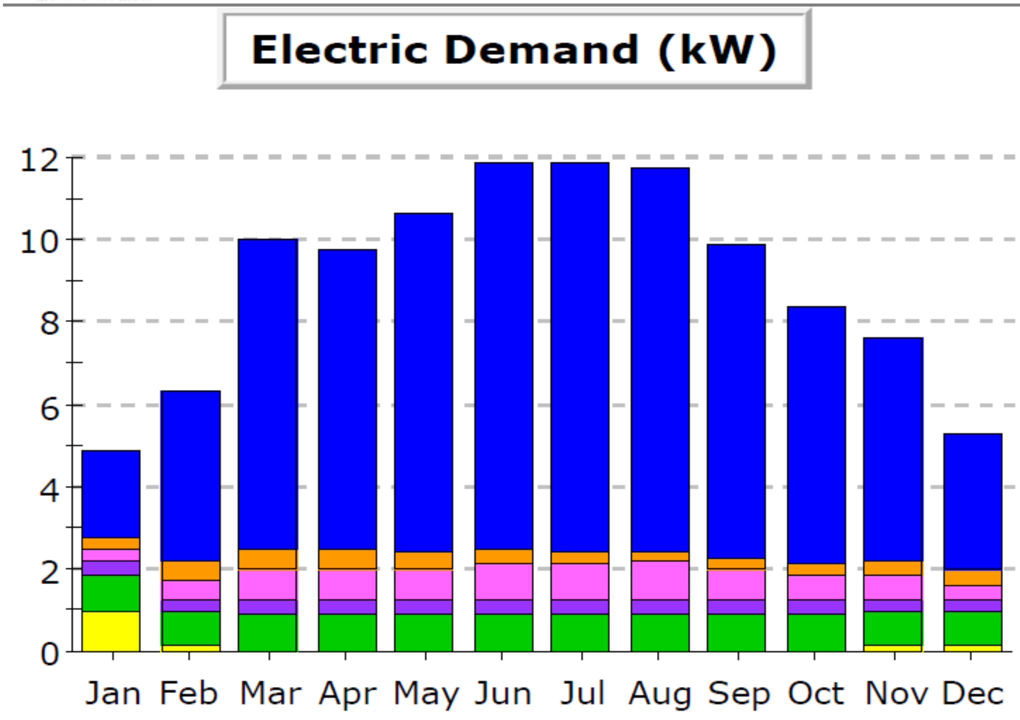
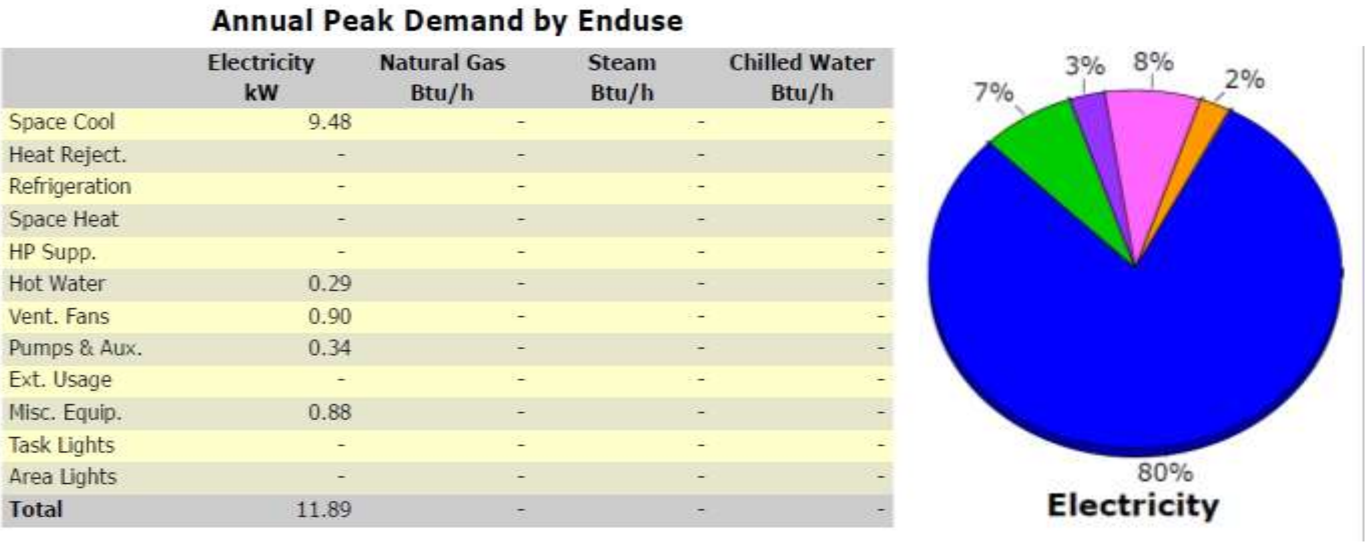


Figure 30: Two Bedroom Monthly Peak Demand by Enduse.



Annual Peak Demand by Enduse

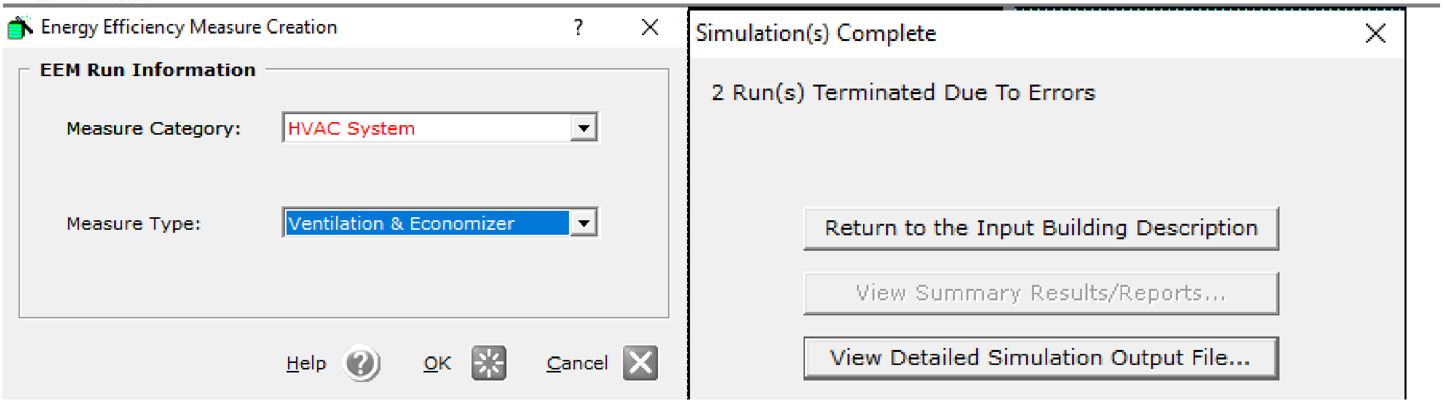
	Electricity kW	Natural Gas Btu/h	Steam Btu/h	Chilled Water Btu/h
Space Cool	9.48	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	-	-	-	-
HP Supp.	-	-	-	-
Hot Water	0.29	-	-	-
Vent. Fans	0.90	-	-	-
Pumps & Aux.	0.34	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	0.88	-	-	-
Task Lights	-	-	-	-
Area Lights	-	-	-	-
Total	11.89	-	-	-

Figure 31: Two Bedroom Annual Peak Demand by Enduse.

4.5.2 Changed Variables

The Rivet Model was employed to simulate the units and derive insights into potential enhancements. A significant alteration introduced was the implementation of a 45-degree opening in all units, a modification aimed at maximizing natural ventilation and improving indoor air quality. Based on literature findings, awnings emerged as the most suitable solution for high-rise residential buildings, offering effective shading while allowing for adequate airflow through the openings. This adjustment aligns with best practices recommended in existing research, highlighting the importance of strategic design interventions in optimizing ventilation and enhancing occupants' comfort within high-rise environments.

Enhanced Ventilation: Awning windows, characterized by their outward-opening design from the bottom, facilitate natural airflow, making them particularly suitable for areas with ample ventilation, such as kitchens and bathrooms. Improved Energy Efficiency: Recognized for their energy-saving features, awning windows contribute to enhanced thermal performance within buildings.



Energy Efficiency Measure Creation

EEM Run Information

Measure Category: HVAC System

Measure Type: Ventilation & Economizer

Simulation(s) Complete

2 Run(s) Terminated Due To Errors

Figure 32: Simulation setting up.

5.3 Results for the changed variables

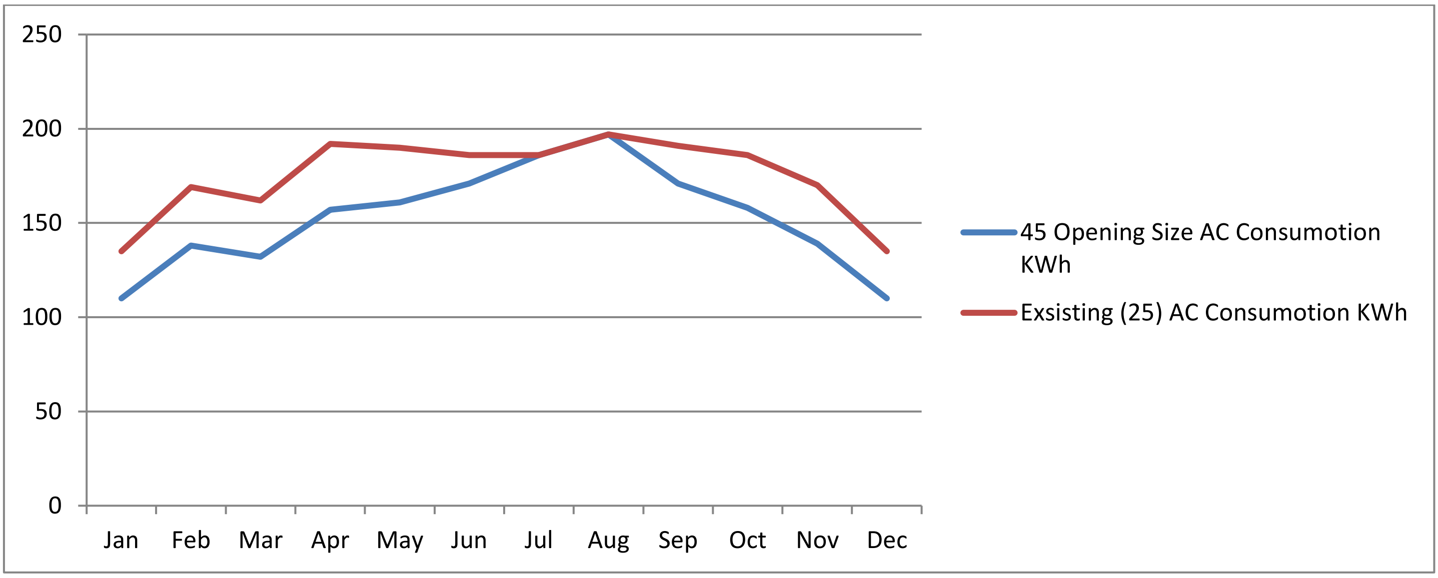


Figure 33: Studio.

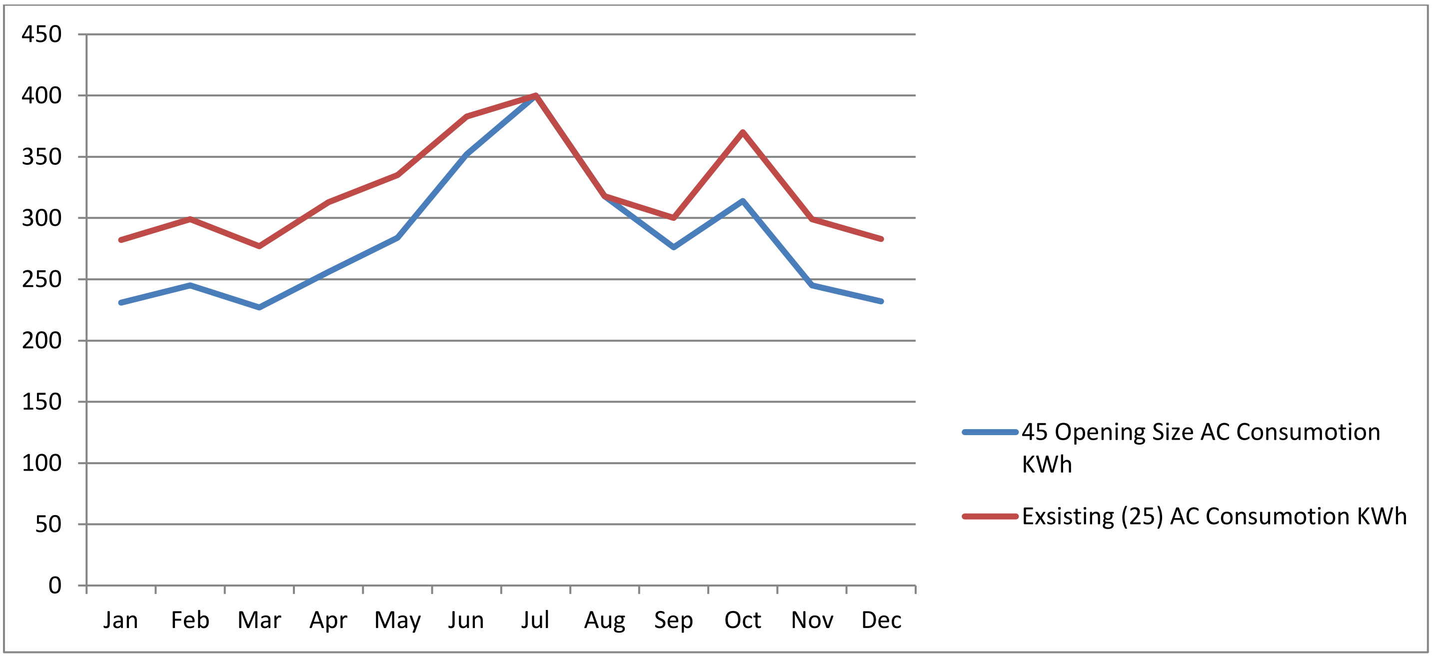


Figure 34: One Bedroom.

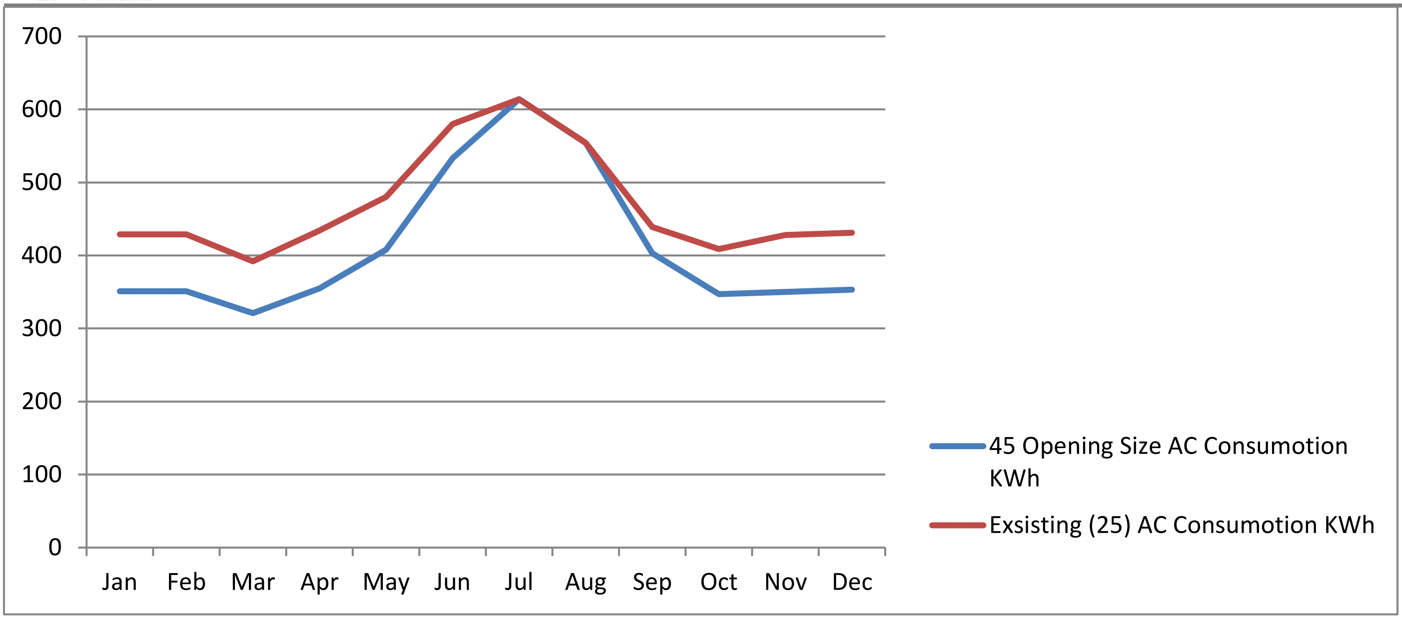


Figure 35: Two Bedrooms.

The optimal simulation results for the study cases demonstrate the potential for significant improvements in thermal comfort and energy performance. Specifically, it is feasible to enhance thermal comfort by up to 5% in naturally ventilated rooms and achieve up to an 18% increase in energy performance for air-conditioned rooms compared to the original case in winter time but in hot climate does not change the performance because residents do not open the windows. These improvements are achievable through a design approach that strategically combines passive strategies such as thermal inertia and natural ventilation.

Optimizing natural ventilation in residential buildings in hot climates is a promising approach for improving energy efficiency and reducing reliance on mechanical cooling systems. Through careful analysis, experimentation, and implementation of effective strategies, we can create more sustainable and comfortable living environments.

DISCUSSION

The discussion on optimizing natural ventilation in hot climate residential buildings underscores the importance of proactive measures in addressing energy consumption and comfort challenges. Through a combination of research, design innovation, and practical implementation, opportunities emerge to mitigate the reliance on mechanical cooling systems. This discussion highlights the potential benefits of integrating natural ventilation strategies into building design and renovation processes. Furthermore, it emphasizes the need for interdisciplinary collaboration among architects, engineers, policymakers, and stakeholders to foster sustainable solutions and enhance occupant well-being. By continuing to explore and implement effective strategies for natural ventilation, we can pave the way towards more energy-efficient and comfortable living environments in hot climates. The reduction in HVAC system usage when comparing closed windows to ventilated windows can vary depending on several factors such as building design, climate conditions, and occupant behavior. However, studies have shown that incorporating ventilated windows can lead to substantial energy savings by reducing the reliance on mechanical cooling systems.

Research indicates that in naturally ventilated spaces with appropriately designed windows for cross-ventilation, the need for mechanical cooling can be significantly reduced or even eliminated during certain periods of the year. The natural airflow facilitated by ventilated windows can help maintain comfortable indoor temperatures by promoting air circulation and cooling the space through natural means, such as wind movement and the stack effect.

In some cases, the reduction in HVAC system usage achieved by incorporating ventilated windows can range from 20% to 50%, depending on factors such as building orientation, window design, insulation levels, and climate conditions. Additionally, occupant behavior, such as opening and closing windows based on comfort preferences, can influence the overall energy savings.

It's important to note that while ventilated windows can contribute to energy savings and improved thermal comfort, their effectiveness depends on proper design, installation, and integration with other building systems. Additionally, in climates with high humidity or air pollution, careful consideration should be given to window design and filtration to maintain indoor air quality while maximizing energy efficiency.

CONCLUSION

In conclusion, optimizing natural ventilation in residential buildings located in hot climates presents a promising avenue for enhancing energy efficiency and reducing dependence on mechanical cooling systems. By carefully analyzing, experimenting with, and implementing effective strategies, we can create more sustainable and comfortable living environments for occupants. This research underscores the importance of leveraging natural ventilation as a viable solution to address the challenges posed by hot climates, offering a pathway towards achieving greater energy efficiency and environmental sustainability in residential construction.

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