OPTIMIZING VERNACULAR BUILDING DESIGN TOWARDS NET-ZERO ENERGY

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by

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Abstract

Construction industries may play a critical role in dominant energy usage as pressure mounts to reduce greenhouse gas emissions. Energy efficiency investments can be a profitable way to reduce carbon emissions. Solar buildings with Net-Zero Energy are emerging as a promising way for reducing buildings' environmental impact. In Lebanon, there is a transition from vernacular to modern architecture in the early twentieth century. It is tightly related to the implementation of concrete in construction and the formation of the national cement industry, which paved the way for the creation of new building types. Not to mention the second industrial revolution, which had a significant impact on energy consumption. Yet the transition from vernacular to modern architecture created a missing link in architectural development. The vernacular type depended on several strategies for passive design, whereas modern architecture lost many of these characteristics. The focus is to study the Vernacular Architecture that will be used to investigate the early solutions and passive strategies. These strategies will be developed and implemented to improve energy efficiency while also incorporating active strategies, which will be analyzed in the Net-Zero Energy techniques and implemented in the optimization and results. Existing buildings will be addressed focusing on the residential typology of the coastal zone which is the most urbanized area that has undergone several changes and still has both the vernacular and modern identities. This research intends to fill the missing link of architectural development by trying to reach the optimal combination between passive and active techniques. The applicability and value proposition of Net Zero Energy, on the existing residential typology of the coastal region in Lebanon, will be assessed through different methods and simulations.

1. Introduction

Several architectural domains exist: the first is new construction, and the second is the existing building stock. While most of the new buildings involve new technologies, the real focus should be on the already existing buildings. The latter consume more than thirty-five percent of total energy, around half of all power, and are responsible for at least thirty-three percent of world CO_2 emissions (CIB, world congress 2010). In the past fifteen years, there has been a significant increase in the number of new residential construction projects in Lebanon. New building constructions are massively increasing especially along the coastal zone, where the majority of the Lebanese population resides. This contributes to uncontrolled urban expansion (CDR, 2005). Accordingly, the need per capita from 2002 to 2020 increased by 63% of Watt/capita (NPMPLT, 2005 and NEEAP, 2016). In addition, sustainable development does not seem to be a factor in the design process of most of these buildings. "It's a copy/paste kind of process where we don't really rethink the context" (Personal Interview with Abillamaa, 02, 12, 2020). Vernacular Architecture in Lebanon is well known for the thermal comfort in interior spaces, the thermal capacity of its thick walls, the air distribution inside due to natural circulation, and additional characteristics that are based on passive strategies in the design and construction (Melki, 2006). Even though vernacular structures are fading fast in Lebanon, they remain an effective learning tool due their evolution, natural environmental features, and passive strategies that can still be traced (Melki, 2006). The evolution of vernacular houses like the Central Hall house, a hybrid suburban structure, underwent a process of transformation. This process seeks to adapt to new functional restrictions and siting conditions as a result of continued urban growth and continuous urbanization of the periphery (Saliba, 2004). Evolving into luxury and upper-cost apartments, ‘stacked villas’ (Saliba, 2004) until the emergence of a new residential type: the ‘speculative’ (Saliba, 2004) apartment building that can be extended vertically, with a ground floor of stores and residential apartments above (Saliba, 2004).

A building that is connected to the energy grid and maintains a balance between the energy consumed and the energy produced is referred to as a ‘Net Zero Energy Building’ (Igor et al., 2012). It is necessary to address the connection between buildings and energy grids. Several terms are used to refer to buildings with zero net energy usage, including net zero building, also known as a Zero Net Energy (ZNE) building, a Net-Zero Energy Building (NZEB), or a Net Zero Building (Scotti, 2015). In this case, the total amount of energy consumed by the building on an annual basis is approximately equal to the amount of renewable energy generated on the site or offsite (Scotti, 2015). Building energy efficiency techniques are methods for reducing a building's energy usage while maintaining or improving its level of comfort (Sustainable energy regulation and policymaking training manual). Net Zero Energy differs from previous energy efficiency approaches in two ways: First, ‘Zero’ is the baseline and *goal (instead of a percentage improvement over prior performance)*; second, the used energy should be from renewable sources (Official website of the United States government) (Scotti, 2015). Most Net Zero Energy buildings get half or more of their energy from the grid and give it back at a later stage. (Scotti, 2015). The building industry accounts for more than twenty-five percent of national greenhouse gas emissions and has a large potential to reduce greenhouse gas emissions. This building industry must enforce the net-zero energy building (NZEB) since construction is responsible for a large amount of CO_2 emissions and greenhouse gas emissions (Changala, 2013). Between the traditional, Vernacular Architecture in Lebanon and the contemporary sustainable architecture which started to evolve worldwide, we have a gap in the already existing buildings that we need to make up for, to reconstruct the disrupted chain of development. This thesis will investigate existing residential buildings; will study the active strategies, and the passive strategies derived from the Vernacular Architecture. These, are to reach the main goal, reduce the energy consumption of the existing residential buildings to reach Net-Zero Energy. In the following section, the background will provide an overview of the topic explaining what will be further explored in the second chapter entitled the literature review. Hence, we will be able to get to the scope and purpose while proposing the research questions and objectives.

1.1. Background

According to the World Meteorological Organization (2021), the last twenty years on record witnessed an increase in the temperature, with the warmest occurring in the last four years: 2015 to 2018. The global average temperature is now 1°C higher than it was before the industrial revolution (UN Climate Change Conference, 2021). Even this small increase in global temperatures is causing climate change in the form of extreme weather patterns (Khozema et al., 2020).

The construction industry consumes a huge amount of non-renewable energy and emits a significant amount of CO_2. Buildings account for about 39% of worldwide CO_2 emissions each year (Ali et al., 2020). Residential energy use and emission generation, such as greenhouse gas emissions, particulate matter, sulfur dioxide, carbon monoxide, and nitrogen oxide, are also substantial (Khozema et al., 2020). Buildings are responsible for a significant proportion of energy use both locally and globally. Heating, cooling, and ventilation contribute to one-fifth to one-third of total energy use in residential buildings both locally and globally (National Academy of Sciences, 2010 and Agha et al., 2018). Water heating systems consume over one-fifth of all energy consumed annually (Umbarek et al. 2020). The cooling demands were discovered to be more than 5 times the heating one. Water heating, space cooling, and interior lighting, on average, absorb around 60% of total energy requirements, with a roughly equal part for each. Equipment consumes a maximum of 35% of the total, leaving about 5% for the rest (Umbarek et al. 2020).

As a result of this sector's increased energy consumption, the ambient CO_2 level has risen, resulting in massive CO_2 emissions (Ali et al., 2020). Since carbon dioxide is the most harmful and plentiful of greenhouse gases, it is proposed that reducing carbon emissions, reducing carbon footprints, or exploring low-carbon alternatives should be used to deal with climate change (UN climate change conference, 2021). Various sustainable building standards, codes, regulations, and guidelines have been implemented in many countries across the world to improve building energy efficiency and lower CO2 emissions (Ali et al., 2020).

The term “sustainability” has evolved into a broad concept that incorporates practically all aspects of human life on the planet, from local to global scales and across periods (Onions, 1964 and Liu, 2017). Sustainable architecture is a dynamic field that is rapidly growing and evolving, driven by a convergence of public concern about global climate change, energy costs and availability, and the built environment's effects on local nature, economy, and social environment (Salman, 2018 and Shehadi, 2020).

The concept of sustainable development gained widespread acceptance after the United Nations requested the Brundtland Commission's report, *Our Common Future*, in 1987 (United Nations, 1987). Our generation's requirements must be met without harming future generations' ability to meet their own. The United Nations charged countries around the world with combining technology, economics, and environmental development with a modern equity-based lifestyle. If the objective is to achieve sustainability, the design concerns related to ambient environmental resources must be addressed. We need to address the underlying impacts of political, economic, and social challenges that make up the cultural and spiritual context, where the desire to attain sustainability represents a fundamental value shift (Salman, 2018).

Net Zero Energy buildings benefit their users and the environment more broadly. Although the design and construction of energy-efficient buildings may be more expensive than traditional structures, the long-term return on investment makes them a better choice. Furthermore, retrofitting existing buildings makes them more energy-efficient (Chanchpara, 2019). Working towards Net Zero Energy construction has several benefits; among them: the utility system, risk management, and the environmental and economic benefits while always taking into consideration living conditions improvement (Kuriyama, & Arino, 2020). For the Utility System Benefits, energy efficiency will reduce total electricity demand, eliminating the need to invest in new electricity generation and transmission infrastructure in the long run. In risk management, energy efficiency can also help utility capital portfolios diversify and can be a buffer against the volatility of fluctuating fuel prices. For the environment, it is difficult to measure the environmental benefits of sustainable design due to the vast number of factors that have an impact on the environment (Pearce, 2008). As per the US environmental protection agency, increased efficiency can reduce greenhouse gas (GHG) emissions and other contaminants, as well as water consumption. However, not just for environmental research, but also for financial measures, energy usage and reliability provide an appropriate unit of measurement. As a result, adopting sustainable design will result in immediate environmental and financial benefits (Pearce, 2008). Renewable energy, such as solar and wind power generation, is now cost-effective for practical use and diffusion in these circumstances (Kuriyama, Arino, 2020). Electricity generated from renewable sources such as hydro, geothermal, or wind is substantially cheaper than electricity generated from petroleum. To accommodate this need, petroleum-based power is frequently brought in on a short-term basis, resulting in higher electricity costs (Sustainable energy regulation and policymaking training manual). As energy storage and related technologies develop, the role and importance of renewables in supporting socioeconomic activities will increase (Kuriyama, Arino, 2020).

Reduced energy use and greenhouse gas emissions are an overall social target. The motives for improving energy efficiency and introducing experimental advanced materials in buildings can be linked to rising energy costs combined with increased public awareness of environmental issues (Changala, 2013). Net- Zero Energy is adopted through two main strategies: passive and active strategies. The integration of passive techniques is a necessary component of zero-energy building design. It has a significant impact on the building's thermal balance and lighting loads, as well as the building's electro-mechanical systems (Garde et al., 2014). Taking into consideration some of the specific passive approaches that should be studied and adapted to the Lebanese environment will be derived from the traditional Vernacular Architecture in Lebanon, which is ideally ecological or, in other words, sustainable (El Hayek, 2005). The remaining energy load of the building which was not all reduced after applying passive design strategies is substituted by the energy generated through the active strategies that are divided into two categories: renewable energy and backup systems for renewable energy (Hong, 2017).

This research will focus on finding possible applicable methods and a combination of passive and active techniques to reach Net-Zero-Energy in existing residential buildings since the energy consumption in residential buildings increases considerably with time (Shehadi, 2018). These techniques will be implemented in an urban area of the coastal zone in the Lebanese context. This will be achieved through the analysis of Net-Zero Energy's techniques, the passive and active strategies elaborated in the second chapter, 'Literature Review', along with the analysis of Vernacular Architecture's passive techniques and solutions in Lebanon applied to a case study and analyzed in the third chapter, 'The Coastal Region: Ghazir in Keserwan' and the fifth chapter 'Analysis of buildings openings, materials, and construction techniques in Ghazir'.

1.2. Scope, Purpose, Research Questions and Objectives

In Lebanon, the majority of urbanization occurs along the coastline, according to the National Physical Master Plan of the Lebanese Territories (NPMPLT 2005), where the majority of the Lebanese population resides, contributing to uncontrolled urban expansion (CDR, 2005). Consequently, the high energy consumption in residential buildings recorded mainly for lighting, heating, and cooling, marks the highest in the Coastal Zone (NPMPLT

2005). But the major issue is the transition from vernacular to contemporary architecture that left a void in architectural growth. Due to rapid urbanization and significant economic, social, and cultural changes that occurred in the region throughout the second half of the twentieth century, Vernacular Architecture has been subjected to extensive deterioration and destruction (Salman, 2018). Contemporary architecture has lost many of the characteristics of Vernacular Architecture, which relied on a variety of passive design techniques that were left behind in the twentieth century when cement was imported to Lebanon and that facilitated the emergence of new architectural styles, while domestic cement production promoted the widespread adoption of modernist architecture. This thesis's main objective is to show the reduction of the energy consumption of the already existing residential buildings, in an urban area on a coastal zone, by analyzing their condition to reach Net-Zero Energy. The latter will be developed by proposing the techniques of Net-Zero Energy construction while taking into consideration the passive strategies derived from Vernacular Architecture in Lebanon. These techniques will be observed and analyzed in detail in the third chapter of the thesis, 'The Coastal Region: Ghazir in Keserwan', in the chosen case study, the old house. Materials are presented in the old house's elevation, picture and, wall, roof, slab, and window detailed sections in chapter five, 'Analysis of buildings openings, materials, and construction techniques in Ghazir'. Following the analysis, the techniques discussed will be implemented in the model simulations within the third section of chapter four 'Modeling and Energy Simulation method', and optimized in the first section of chapter six 'Optimization with passive strategies- Building materials and techniques'. The results will indicate the necessary implementation of active strategies studied in the second chapter 'Literature

Review' and implemented in the second section of chapter six 'Optimization with passive strategies' to reach our goal, Net-Zero-energy consumption.

Sustainable Architecture has a secondary positioning with the current regulations. Furthermore, Net-Zero-Energy comes as a later stage priority. After the optimization in the sixth chapter using passive and active strategies, the conclusion will present an optimal combination of construction materials and techniques to reach Net-Zero Energy in the already existing residential buildings of the coastal zone in Lebanon. Hence, these directions will serve as a guide for policymakers that have the authority to establish and implement the laws and regulations and will determine the future directions from the perspective of Net-Zero energy. The integration of the aforementioned directions in the codes and standards of construction will standardize the use of those techniques in existing residential buildings by energy researchers, and practitioners.

To achieve NET-Zero Energy buildings and after analyzing the passive techniques derived from Vernacular Architecture in Lebanon in the second chapter 'Literature Review' and the third chapter 'The Coastal Region: Ghazir in Keserwan' and considering the active strategies derived from Net-Zero-Energy techniques in chapter two, 'Literature Review', several questions arise:

How close to Net-Zero Energy, do existing residential buildings in the Lebanese coastal area, get?

How can passive strategies, in Net Zero Energy approaches, be transferred from the Vernacular Architecture in Lebanon's coastal zone today, into existing residential buildings?

How can the techniques of Net-Zero Energy construction, in particular the active strategies, in the already existing residential buildings in Lebanon, be implemented?

How existing building elements should be restructured to reach Net-Zero Energy while considering their financial cost and construction techniques?

The below research objectives will answer respectively the above questions.

- To understand the construction strategies, passive and active, used towards Net-Zero Energy Construction.

To confirm the reachability of existing residential buildings to Net-Zero-Energy, the strategies of Net-Zero-Energy should be studied. The latest will be elaborated in the second chapter, ‘Literature Review’ where active and passive strategies will be analyzed. Both strategies must be included in zero-energy building design to reach the concept of Net-Zero-Energy design. The energy generated by the active methods replaces the remaining energy load of the building that was not completely decreased after using passive design strategies.

- To understand the principles and passive strategies of Vernacular Architecture.

The below will be studied to understand the feasible applicability of passive strategies derived from the Vernacular Architecture in Lebanon’s coastal zone today, into existing residential buildings. This will be elaborated in the second chapter, ‘Literature Review’, by focusing on the techniques and materials used in relation to the surroundings and taking into consideration all-natural factors like orientation, climate, wind direction, and sun path. These will be further discussed in the third chapter, ‘The Coastal Region: Ghazir in

Keserwan', studying the Vernacular Architecture in a case study of an old Vernacular House. Analyzed furthermore in the fifth chapter 'Analysis of buildings openings, materials, and construction techniques in Ghazir' where an energy simulation will be done. This will lead us to the optimization of the second case study, applying the passive techniques derived from the Vernacular Architecture in chapter six 'Optimization'.

- To understand the necessity of active strategies in the process of transforming an already existing residential building to establish what is required to reach Net-Zero-Energy.

The implementation of active strategies, complementary to passive strategies, is a necessary combination to reach Net-Zero-Energy. Introducing active strategies of Net-Zero-energy will be in the second chapter, 'Literature Review'. To confirm the aforementioned literature, the understanding of the necessity of active strategies will be reached in the sixth chapter 'Optimization'. Despite the optimization with passive strategies, the remaining energy load will need optimization with active strategies to be fully eliminated. Hence, it is a requisite to use both strategies, passive and active strategies to reach Net-Zero-Energy.

- To find the adequate combination of building materials and construction techniques derived from passive and active strategies that should be implemented in the already existing residential building to reach Net-Zero Energy construction.

After the literature study of the strategies in the second chapter 'Literature Review', their analysis and applicability on two case studies will be elaborated respectively in chapter five 'Analysis of buildings openings, materials, and construction techniques in Ghazir', and chapter six ‘Optimization’. Chapter seven ‘Conclusion’ will reach the adequate strategies combination, and ideal restructuring of building elements and materials used to reach the main objective: Reaching Net-Zero-Energy in the already existing residential buildings of the Lebanese Coastal Zone.

1.3. Thesis Structure

Following the introductory chapter, chapter 2 entitled “The Literature Review” will address sustainable architecture along with the introduction to Vernacular Architecture and its passive strategies. Net-Zero Energy construction, will follow, where its active and passive strategies will be analyzed. The third chapter will cover the Lebanese context, Lebanon's Vernacular Architecture, its passive methods, and the current situation of the existing buildings. The fourth chapter, “The Methodology” will outline the selected project that will be analyzed along with the approaches required to complete the analysis that will be tackled in the fifth chapter. Leading to the “Optimization” chapter where buildings materials and techniques optimized will be discussed to reach the adequate combination of passive and active strategies that should be implemented in the last chapter, the Conclusion.

2. Literature Review

The unrestrained growth transformed the largest cities into metropolitan centers, shifting traditional lifestyles into contemporary ones (Salman, 2018). Architecture, as a place definer, will lose its environmental and historical heritage in case imported materials and sophisticated technology are not handled with an optimal approach (McLennan, 2006). All of these factors, combined with significant changes, resulted in a disrupted chain of development. Hence, Chapter 2 will be addressing the objectives and techniques that are used towards Net-Zero Energy construction and specifically residential buildings, in particular the already existing ones: how close they can get to Net-Zero Energy. In the techniques of Net-Zero Energy, the passive and active strategies will be studied with a concentration on the passive strategies that can be learned from Vernacular Architecture in Lebanon. Chapter 2 will initiate the process to find the adequate combination between 1- passive strategies derived from Vernacular Architecture and 2- active strategies from Net-Zero Energy construction. This combination will be implemented in residential buildings to minimize energy usage. The Literature Review will start with a general introduction discussing sustainability and Net-Zero Energy with its active and passive strategies. The passive strategies are derived from Vernacular Architecture since it has evolved over time employing local materials and technologies coming from the ambient natural and cultural context, resulting in the best possible relationships between people and their surroundings (Salman, 2018).

2.1. The interplay between sustainable and Vernacular Architecture

Sustainable Architecture refers to the interplay between natural, cultural, social, and economic resources to build optimal interactions between people and their environments to meet human needs (Salman, 2004). Architecture, vernacular in particular, is a product of people, place, and culture; it is one of several elements of identity (Abel, 200).

Sustainable architecture requires responsibility, as well as broad regard for environmental systems, resources, and respect for people and the life cycle (McLennan, 2006). It aims to achieve the best possible relationships between people and their surroundings. Planners, architects, designers, developers, and operators have the chance and obligation to preserve a place, people, and spirit’s identity (Salman, 2018). The sustainable architecture philosophy respects local characteristics and denies the idea that buildings should look and be built in the same way in every location (McLennan, 2006). According to Joseph Kennedy, Vernacular Architecture is a style of architecture that emerges from a location's unique environment and social conditions (Kennedy, 2004). To advance in the future of architecture and sustainable buildings, we must first get a thorough understanding of the past and then use these ideas as a well-balanced, methodical system to attain maximum energy efficiency (Edwards, 2011). The processes of constructing "regionalism" and "identification" through architecture in an international, global setting are shown in the construction of cultural identity in contemporary architecture. In essential ways, architecture should respond to place (McLennan, 2006). The physical environment is shaped with a pure understanding of the multidimensional relationships between nature, culture, social values, economy, and accessible resources of the region and its distinctiveness. Architecture must be designed to suit the wishes and demands of its people

(Salman, 2018). Traditional cultures and ideologies reflect ideas and principles on which sustainable living should be founded (Mortada, 2011). Paul Oliver emphasized the multidimensional relationship between culture and Vernacular Architecture in his book "Encyclopedia of Vernacular Architecture." The fact that each tradition is tightly linked to social and economic imperatives is a distinctive feature of Vernacular Architecture. The latter has evolved to satisfy specific demands within each specific culture (Oliver, 1998). Culture is one of the most important components in defining identity since it is linked to the people who created it. It has a strong connection to a place or region where the natural environment has a significant impact on humans (Salman, 2018). As the most visible physical artifacts of every culture, architecture has by far the most significant ability to draw from and adapt to the uniqueness of place (McLennan, 2006). Vernacular Architecture is built in accordance with the natural environment *(geography, topography, site, climate, local building materials, labor experience, and construction techniques)*, and it satisfies people's physical, economic, social, and cultural norms. It is a sign of national identity; it is the nation's "mirror," reflecting place, time, and culture. (Salman, 2018). These will be highlighted in the case study observed and analyzed starting the third chapter ‘The Coastal Region: Ghazir in Keserwan’ and the fifth chapter ‘Analysis of buildings openings, materials, and construction techniques in Ghazir’. The old house was selected, as a sample of the category that responds to the primary principles of Vernacular Architecture. These principles as mentioned above will be analyzed thoroughly from the house’s history, location, typology, local building materials, and construction techniques. The selected house reflects the place’s identity and culture, and fulfills a particular harmony for its residents’ norms. Whereas, other possible case studies, comprehend different obstacles: renovation that changed the architectural heritage and “caché”, modern addition to the house disrupting the natural wind flow, and limited access. Hence, we can clearly identify the interplay and connection between vernacular and sustainable architecture due to their harmony with the environment.

2.1.1. Materials and passive strategies of Vernacular Architecture

The vernacular building uses energy-efficient materials, which is one of the main reasons why it is appreciated. It is often considered to be more long-lasting than contemporary architecture.

Stone boundaries, for example, can last a thousand years or more with very little or no maintenance (Neo, 2020). Structures were typically composed of materials that were also part of the surrounding environment prior to the era of modern architecture, primarily mud, bricks, blocks, or stones stacked onto one another in compression due to a lack of machinery (Neo, 2020). Brick, for instance, as one of the oldest and most often used materials in dry places like the Arab World, necessitated specific technologies due to its shape, size, and durability. Builders had to construct new forms in accordance with the physical qualities of brick to solve the roofing problem; an arch was the creative solution. The arch motion produced more practical shapes: the vault was generated when the arch moved horizontally, and the dome was created when the arch rotated around itself. These innovative forms were both aesthetically and functionally compatible with the surrounding environment and climate (Salman, 2018).

Vernacular Architecture construction is well known for the thermal comfort in their inside space, the thermal capacity of the thick walls, the air distribution inside the house due to natural circulation, and many more characteristics. The latest is based on simple, passive strategies in their design and construction (Melki, 2006). Traditional dwellings are comfortable for a range of 60 to 65 percent only because of the impact of materials, orientation, and shading (Srivastav and Jones, 2009). Natural ventilation and daylighting, passive solar heating, and passive cooling techniques are all responsive to changing temperatures (Lubis et al., 2018).

Natural ventilation and daylighting: The significance of big opening windows and sun shading in the facade is critical for ensuring thermal comfort (Lubis et al., 2018). Kumari and Wanti (2020) examined passive cooling techniques in a vernacular house in India and as a result, they found that the relationship between the interior and outdoor environments, the building form, orientation, and the materials used in construction are the most crucial factors. The structure’s natural comfort is created by taking into account the sun's path and the wind's direction. The courtyard is a key aspect of Vernacular Architecture; all of the house's rooms will be encircled by this rectangular aperture, which will give natural light and ventilation as well as shaded areas. And since the window widths are tiny and the window sill is high, heat gain is reduced while light penetration is increased. The ventilators are also set to a high setting, which aids in the removal of hot air from the inside (Kumari and Wanti, 2020).

Passive solar heating: They disperse warmth by utilizing natural heat movement. We have three types: direct gain, indirect gain, and greenhouse addition. Direct gain, which allows solar energy to enter through south-facing windowpanes. The Indirect gain allows solar radiation to heat a wall before being gradually supplied into the house's interior. Convective currents are aided by openings in the wall *(known as a Trombe Wall)*, as cold room air enters the area between the glass panel and the wall through the bottom aperture. As the cold air warms up, it rises to the top of the building and enters via the top opening. For the greenhouse addition, an attached sunspace and/or solar greenhouse are heated by solar energy: some of the energy is used to grow the plants and some are used to heat the house's interior. (Duton, 2020).

Passive cooling techniques: Kumari and Wanti (2020) examined passive cooling techniques in a vernacular house in India and as a result they found that thicker walls work as a cooling technique since the intensity of heat decreases as it enters the inside, resulting in a more comfortable environment (kumari and Wanti, 2020). It is critical in a passive cooling design that all major parts of the building, blocks or rejects solar heat gain to keep the structure cool during the summer (Taleb, 2014).

People are drawn to Vernacular Architecture for reasons other than nostalgia. Nothing comes from nothing, as it could be said, and tradition can be both a benefit and a burden when it comes to fresh ideas (Abel, 2000). The architecture's sustainability and sensitivity to the climate, natural location, and locally available building materials are highly valued. The fact that they can be used as a model for new construction further adds to their value (Salman, 2018).

2.2. Net-Zero Energy

According to the Environmental Protection Agency (EPA), sustainable buildings, also known as green buildings, are intended to reduce the built environment's overall effect on human health and the environment by making the most efficient use of electricity, water, and other resources; enhancing employee efficiency and protecting occupant health, reducing waste, pollution, and the environment (Lachman et al., 2013). Therefore, building managers must assess the cost that should be expended to run and maintain existing buildings. The financial resources should be used effectively, as the cost is a major concern. This is where the question about the already existing buildings is raised. They are already a heavy load of energy consumption and there should be a way for them to be treated to minimize that energy consumption. Hence, Net-Zero should be taken into consideration (Lachman et al., 2013).

2.2.1. Net-Zero Energy Buildings

Net Zero Site Energy, Net Zero Source Energy, Net Zero Energy Cost, and Net Zero Energy Emissions are the four primary forms of NZEBs in the international setting (Aelenei et al., 2012). When measured at the site, a Net Zero Site Energy building is described as one that produces as much energy as it consumes. The Net Zero Source Energy building is a structure that, in comparison to the energy content at the source, produces as much energy as it consumes over the course of a year (Shehadi, 2020). The definition of Net Zero Energy Cost buildings is based on an economic balance. This means, the utility returns financial benefits to the owner by favoring renewable energy and feeding the grid.

Whereas in the case of Net Zero Energy Emissions, buildings produce and export at least as much emissions-free renewable energy as they import and use from emission-producing sources (Torcellini 2006).

In the construction sector, efforts should be made to convert existing homes and other structures into zero-emission houses (ZEHs) and zero-emission buildings (ZEBs) (Kuriyama, and Arino, 2020). As a result of ongoing concerns about energy supply limits, diminishing energy resources, increasing energy costs, and the rising impact of greenhouse gases on the global climate, Net Zero-Energy Buildings (NZEBs) have gained more attention in recent years (Aelenei et al., 2012). When Net-Zero Energy is implemented, it impacts buildings in several aspects including environmental, social, and economic. Regarding the environmental aspects, an increase is noticed in the use of renewables: energy efficient and natural techniques. A decrease in the pollution: of CO2 and NO2, in water and materials waste, and an increase in brownfield use, ecological value, and sustainable timber house (Hemsath et al., 2015). In these aspects, we will realize that there’s a decrease in toxicity and an increase in natural material and sound insulation. Regarding people’s well-being, we will see an increase in natural daylighting, view of the sky, and external private spaces. Evidence has shown that healthy home programs provide measurable public health benefits in the relationship between energy and health. Environmental health and energy conservation have many direct and indirect benefits for the occupants of the house (Hemsath et al., 2015). As for the cost-efficiency, we will notice a growth in the real-estate value but a decrease in the running costs and the utility bills. The number of investors will multiply as well as the planning permits and regulatory compliances.

Residential building energy usage was reported to account for a significant share of world energy consumption (Li, 2011). The structure's construction, and how it is operated and maintained, have a major impact on the total amount of energy and water used by the world's resources (Gellings, 2009). To achieve energy balance, optimize passive solar energy principles, reduce building energy consumption, and generate ample electrical energy from renewable energy sources (Garde et al., 2014), these targets are developed and divided into four main objectives: 1-Reduce energy demand, 2-Improve indoor environmental quality, 3-Provide renewable energy share, and 4-Reduce primary energy and energy emissions (Hijazi et al., 2020).

Reduction of energy demand can be done by: 1- reducing building heating and cooling loads with efficient heating and cooling equipment, 2- reducing building envelope load and HVAC equipment energy consumption (Shehadi, 2020 and Farshid, 2015). To improve indoor environmental quality, a minimum fresh air per person should be set up: Enable Natural lighting, Set up a maximum occupant density (Farshid, 2015 and Hijazi et al., 2020). To provide renewable energy share, produce energy from renewable sources on-site *(generation technologies such as photovoltaic)*, and introduce renewable energy delivered from nearby or offsite (Hijazi et al., 2020). To reduce primary energy and carbon emissions, reduce the primary energy demand, and reduce the carbon emissions related to delivered energy (Farshid, 2015).

Therefore, the advantages of Net Zero Energy applied to residential buildings include increased value, savings, and reduction of greenhouse gas emissions (Gohardani et al., 2013). Increased Value where NZEBs can help in gaining or keeping a competitive advantage over other buildings by increasing the value of your land, reducing market risk, and encouraging the health and well-being of your tenants. Those buildings are 60 to 90 percent more energy efficient than their predecessors. This means that a project can save money over the course of the equipment's entire lifecycle, as well as on energy and maintenance costs. Reduction of greenhouse gas emissions, an overall social target that affects all (Gohardani et al., 2013), can be accomplished by reducing or even eliminating the use of fossil fuels in buildings. NZEBs contribute to a more resilient future for us, future generations, and the environment (Chanchpara, 2019).

Since residential and commercial structures utilize the most energy, and especially residential since they outnumber commercial structures; resources are depleting at a significantly faster rate in recent decades (Shehadi, 2020). For that, to reach the previously mentioned objectives, a set of techniques using passive and active strategies needs to be implemented to achieve Net-Zero Energy in residential buildings.

2.2.2 Net-Zero Energy techniques

Although there is no single method for constructing a Net Zero-Energy residential building, there are numerous combinations of passive and active measures, utility equipment, and on-site energy generation technologies that can achieve net-zero energy performance (Aelenei et al., 2012).

The integration of passive techniques is a necessary component of zero-energy building design. It has a significant impact on the building's thermal balance and lighting loads, as well as the building's electro-mechanical systems. This results in a noticeable indirect decrease in heating/cooling, illumination, and ventilation energy usage, which is more than compensated for by renewable energy systems (Garde et al., 2014).

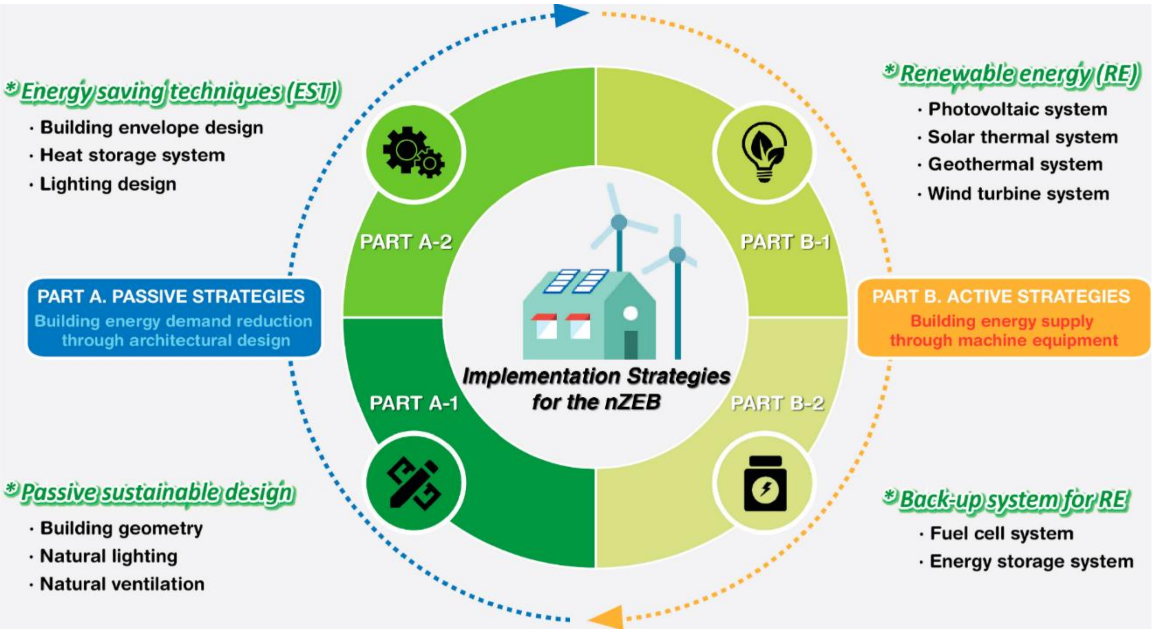


Figure 2.1: Active and passive strategies

Source: Hong T., 2017, p.2

A. Passive strategies

Since the use of passive solar energy in the building has affects the loads in the electro-mechanical system, passive strategies play an important role in Net-Zero Energy buildings (NZEB) architecture. These strategies help realize Net-Zero Energy buildings through the reduction of the building energy demand *(heating and cooling load, etc.)* by introducing architectural design techniques in the early design stage. There are two categories: passive sustainable design and energy-saving techniques.

Passive sustainable design

There are various methods for passive sustainable design *(site planning, layout planning site plan, natural lighting, natural ventilation, etc.)*, which can reduce energy consumption by considering the building's geographical and meteorological factors. From these elements, we have the most important three that are: 1- building geometry, 2- natural lighting, and 3- natural ventilation. (Hong, 2017 and Prowler, 2016).

1- For the building geometry, the composition and shape of a structure have a significant impact on its energy usage. As a result, practically all previous studies on building geometry focused on the surrounding environment, such as the site slope and the plan form, to assess the building energy performance (De Castro et al., 2017 and Mottahedi et al., 2015). De Castro and Gadi (2017), for instance, examined annual energy savings according to site slope within the range of 0 to 50 degrees to determine the best design by considering topography. Consequently, the 'EnergyPlus' software program shows that the 30-degree site slope and box-type design is the ideal design with the largest energy-saving potential (De Castro et al., 2017). Choi et al. (2012) used questionnaires and a field study to analyze energy consumption trends in four high-rise apartment plan layouts and two living types for evaluating building energy performance *(electricity consumption, gas consumption, and CO2 emissions)*. The power consumption of plate-type structures was lower than that of tower-type buildings, but their gas consumption was higher, according to this study (Choi et al., 2012). By evaluating a total of seven building forms *(L, U, T, H, triangle, rectangle, rectangle min-corner)* and 17 design factors *(orientation, insulation, occupant schedule, etc.)*, Asadi et al. (2014) and Mottahedi et al. (2015) analyzed the energy consumption using multilinear regression analysis and Monte Carlo simulation. The H shape of the structure in the Texas climate zone had the greatest yearly energy consumption of all the forms evaluated, according to the analysis of annual energy consumption based on the seven building types (Asadi et al., 2014 and Mottahedi et al., 2015).

2- For Natural lighting, there is an in-depth analysis of the sun’s altitude, and the amount of daylight (Hong, 2017 and Prowler, 2016). Because the geometry of the atrium is such a significant role in natural lighting, numerous types of research have been conducted for optimal atrium design (Assadi et al. 2011 and Modirrousta et al., 2016). One of them is Nasrollahi et al. (2015), using the Design Builder software program, they evaluated the impact of the atrium-to-total building area ratio on energy efficiency and indoor environmental conditions. As an outcome of this research, it was identified that a 1/4 atrium-to-total building-area ratio was the most beneficial in terms of energy efficiency, daylighting, and thermal comfort (Nasrollahi et al., 2015).

3- For natural Ventilation: where NZE buildings are implemented, an architectural design for inducing the reduction of the building energy demand through the effective influx of the outdoor air *(natural ventilation)* should be considered in the initial design stage (Hong, 2017 and Prowler, 2016). Natural ventilation can be divided into two types based on their mechanisms: The vertical and horizontal temperature differential drives buoyancy-driven ventilation, whereas the pressure difference between the front and back of the building drives wind-driven ventilation (Hussain et al., 2012 and Mei et al., 2017). First, buoyancy-driven ventilation has been the subject of several prior studies. Li and Liu (2014) investigated the thermal performance of a phase-change-material (PCM)-based solar chimney in laboratory circumstances with three different heat fluxes *(500, 600, and 700 W/m2)*. Based on the substantial thermal energy storage capacity of PCM, it was confirmed in this study that PCM-based sun chimneys can achieve time-shifting of solar energy, which can induce more effective natural ventilation than general solar chimneys (Li and Liu, 2014). Second, there have been several previous researches on wind-driven ventilation. One of them is Nejat et al. (2016) study where they used the Computational Fluid Dynamics (CFD) software program and wind tunnel tests to compare the wind-catcher-integrated wing wall to the standard wind catcher. As a result, the wind-catcher with a 30-wing wall angle outperformed the other designs *(45 degrees and 60 degrees)*. In addition, when compared to a traditional wind catcher, the novel design's ventilation effectiveness was improved by 50% (Nejat et al., 2016).

To conclude, past studies on building geometry have concentrated on energy savings based on the shape and density of the structure. Second, earlier research on natural lighting focused on decreasing lighting, cooling, and heating loads based on the design and size of the atrium as well as the building's orientation. Finally, previous studies focused on the energy-saving potential and ventilation effectiveness of buoyancy-driven ventilation and wind-driven ventilation from the perspective of natural ventilation. In other words, if building geometry, natural lighting, and natural ventilation are considered early in the design process, the following results can be achieved: Improvements in the energy efficiency of 20%, heating efficiency of 25%, and cooling load reductions of 10%–30%

are all possible (Parasonis et al., 2012 and Assadi et al., 2011 and Liu et al., 2017). However, considering only passive sustainable design while implementing Net-Zero Energy buildings is insufficient. As a result, future Net-Zero Energy buildings studies must include not only passive sustainable design but also energy-saving techniques (EST).

Energy saving techniques

In energy saving techniques, we have three types in terms of passive strategies: 1- building envelope design, 2- heat storage system, and 3- lighting design.

1- Building envelope design: Since the building exterior is physically exposed to the outside environment, it has a significant impact on energy usage *(heating and cooling demand)* (Hong et al., 2014). Many studies have been conducted regarding reducing building energy demand through three categories of envelope design: heat insulation, opening design, and shading device (Daouas, 2011 and Ye et al. 2016). The researches that have been conducted to reduce building energy demand in terms of heat insulation are as follows. Pomponi et al. (2015) compared several facade methods to assess CO^2 emissions and energy usage over the course of a building's life cycle *(double-skin facade, traditional up-to-standard, and single-skin)*. As an outcome of the study, it was found that using a double-skin building facade offers the greatest carbon-saving potential (Pomponi et al., 2015). Through a questionnaire survey, interviews, and field research, Tam et al. (2016) evaluated the technical performance and cost-effectiveness of the green roof as thermal insulation in Hong Kong. Furthermore, the results revealed that when a green roof is installed, the room temperature can be reduced by 3.4 degrees Celsius (Tam et al., 2016). Most prior studies on window design have primarily focused on the derivation of an optimal design solution, taking into account that the window is more vulnerable to heat gain and loss than the wall. Using the EnergyPlus software tool, Goia (2016) investigated the ideal window-to-wall ratio (WWR) for four cities in Europe's mid-latitude region *(Oslo, Frankfurt, Rome, and Athens)*. These cities all performed optimally in terms of energy efficiency between 30 and 45 percent of the WWR (Goia, 2016). Wen et al. (2017) set out to provide a guideline that would allow designers to assess the WWR's applicability early in the design process. As a consequence, the ideal WWR distribution in Japan was mapped out using window parameters *(U-value, visible transmittance, etc.)* as well as meteorological factors *(external temperature and global solar radiation)* (Wen et al., 2017). Several studies have been undertaken on the shading device to find a technique to reduce the building's energy demand. One of them, using the IES VE software program, Kim et al. (2012) evaluated the various types of external shading devices *(overhang, blind ...)* in terms of energy savings for heating and cooling. The external shading device had a superior technical performance than the interior shading device, according to this research (Kim et al., 2012).

2- Heat storage system: Various studies related to heat storage systems have been conducted because a building's heat capacity is a highly crucial factor from the perspective of Net-Zero Energy buildings. Prior research examined energy savings based on building thermal performance, with a focus on thermal mass and Trombe walls. Many earlier studies have focused on using the heat storage capacity of thermal mass to reduce a building's heating and cooling demand. Ma and Wang (2012) calculated the dynamic heat transfer performance of the interior planer thermal mass based on the thickness (0.025 meters) and kind of thermal mass *(wood, concrete, and steel)*. It was discovered that the thermal mass's ability to store heat is dependent on the thickness of the thermal mass to get a superlative value (Ma and Wang, 2012). The following is a previous research on the Trombe wall, which acts as a heat storage system. It's a black wall that's composed of heat-resistant materials and covered with a thin transparent cover. This transparent glass or plastic cover is attached to the wall at a distance of five to twenty centimeters. After the sun's radiation travels through the transparent layer, the wall is heated. Furthermore, as a result of this radiation passage, the inside air is heated, and it stores the heat in itself (Modirrousta, Boostani, 2016). According to the application of the Trombe wall, Bojic et al. (2014) conducted a comparative analysis of the environmental performance *(i.e., primary energy for heating during the winter and annual energy consumption)*. As a result of the investigation, it was discovered that using the Trombe wall can save 20 percent of annual energy (Bojic et al., 2014). Bajc et al. (2015) used CFD simulation to examine the impact of the building energy demand of a passive house with a Trombe wall in the Belgrade weather. The Trombe wall increased cooling demand in the summer; indeed, it is well suited to the Belgrade temperature in the winter due to its effective heating energy savings (Bajc et al., 2015).

3- Lighting design: In terms of Net-Zero Energy buildings implementation, this research looked at prior studies that looked at light-emitting diodes (LEDs), light shelves, and lighting control systems as strategies for decreasing lighting load. Based on the experimental test results, Principi and Fioretti (2014) conducted a comparative analysis of compact fluorescent and LED in terms of their environmental performance. Hence, utilizing LEDs instead of compact fluorescent lights can reduce global warming potential and cumulative energy demand by up to 41 to 50 percent (Principi and Fioretti, 2014). Meresi (2016) used the Radiance software tool to evaluate the effectiveness of daylight for the distribution of light shelves and movable semi-transparent exterior blinds under various design settings. As a result, combining a light shelf with semi-transparent moveable external blinds can improve daylight utilization and create a uniform illuminance distribution in a room by increasing light near the window and decreasing light near the back of the area (Meresi, 2016). Based on multi-sensors and wireless communication technology, Byun et al. (2014) developed an intelligent LED control system that considers energy consumption and user pleasure. By automatically altering the illuminance based on energy efficiency, the proposed LED control system saved 21.9 percent of energy (Byun et al., 2014).

To conclude, many research on building envelope design and energy demand have been conducted, taking into account heat insulation, window design, and shading device, due to the characteristics of the building envelope directly facing the external environment. Various studies are also underway in the heat storage system to improve a building's heat storage performance by using sophisticated materials such as PCM. Studies in lighting design are being conducted concerning the introduction of LEDs, to reduce lighting load through the use of a control system that takes into account daylight and shading devices. Several studies are being conducted to minimize building energy needs; in fact, focusing solely on energy-saving techniques is insufficient for practical Net-Zero Energy buildings implementation. So active methods must be included among energy-saving techniques as passive strategies, to achieve Net-Zero Energy buildings.

B. Active strategies

The remaining energy load of the building which was not all reduced after applying passive design strategies is substituted by the energy generated through the active strategies. We have two categories: Renewable energy (RE) and Backup systems for renewable energy (Hong, 2017). Renewable energy is obtained from renewable resources such as sunshine, geothermal energy, and wind. The backup system, on the other hand, is a necessary system for the effective implementation of renewable energy as a technique of compensating for its instability caused by external factors such as weather (Kim et al., 2017).

Renewable Energy

The focus is on four types of renewable energy, that are an active strategy for implementing Net-Zero Energy Buildings, by examining their suitability to buildings as determined by past studies: Photovoltaic (PV) systems, solar thermal systems, geothermal systems, wind turbine systems are all examples of renewable energy sources (Kim et al., 2017).

1- The Photovoltaic (PV) system includes two systems: a rooftop Photovoltaic (PV) system and a building-integrated Photovoltaic (BIPV) system (Hong, 2017). Various studies on the rooftop PV system from which; Ordónez et al. (2010), using the Autodesk AutoCAD software program, investigated the energy capacity of the PV system in Andalusia, Spain, taking into account residential building characterization *(detached house, townhouse, etc.)*, useful rooftop area, and PV panel installation design *(distance between solar panels)*. According to this study, the quantity of power generated by PV systems on a residential building's rooftop accounts for 78.89% of the overall energy needs (Ordónez et al. 2010). Elibol et al. (2017) tested the technical performance of PV panels outdoors for a year on the roof of Düzce University's scientific and technological research application and research center in Düzce Province, Turkey, according to the PV panel type *(mono-crystalline, polycrystalline, and amorphous silicon (a-Si))*. Consequently, the efficiency of the a-Si, polycrystalline, and monocrystalline PV panels were 4.79, 11.36, and 13.26 percent, respectively. Furthermore, the exterior temperature had a positive correlation with a-Si and polycrystalline PV panels, with a negative correlation with monocrystalline PV panels (Elibol et al., 2017). Regarding the studies on BIPV; Olivieri et al. (2014) used a set of particular software programs to analyze the technical performance of a window-integrated semi-transparent PV system and general glazing. When compared to the reference glass, the window-integrated semi-transparent PV system achieved 18–59% energy savings depending on the facade opening (Olivieri et al., 2014).

2- Solar thermal system: Solar heat can be used in a solar thermal system by absorbing, storing, and converting it for heating and cooling a building using unlimited solar energy (Hong, 2017). Based on experiments and two-dimensional models in COMSOL Multiphysics, Chialastri and Isaacson (2017) tested a prototype of a building-integrated PV/thermal air collector that can create thermal and electrical energy. As a result, the prototype's maximum temperature was 31°C, and its average thermal and electrical efficiencies were 31% and 7%, respectively (Chialastri and Isaacson, 2017).

3- Geothermal system: Based on a consistent annual subterranean temperature, it can reduce a building's heating and cooling demand (Hong, 2017). Sivasakthivel et al. (2012) calculated the possible reduction in CO2 emissions and electricity savings from installing a geothermal system during the winter in India's northern area, taking into account geographical characteristics and the geothermal system's coefficient of performance. According to this analysis, using a geothermal system can cut CO2 emissions by 0.539 GW and power usage by 708 GW (Sivasakthivel et al., 2012).

4- Wind turbine system: The wind speed is a critical consideration. It's used on high-rise structures or rooftops. The surrounding structures have a significant impact on wind speed amplification and wind loads (Hong, 2017). Wind tunnel tests were used by Li et al. (2013) to determine the feasibility of installing a wind turbine system in a tall building. As a result, the wind speed amplification and wind loads were found to be influenced by three factors: the building orientation, the bell-mounted shapes of the four tunnels with contracted inner sections, and the adjacent buildings (Li et al., 2013). Cao et al. (2017) used the mesoscale meteorological model Weather Research and the WRF v3.4 software program to assess the wind power resource around the 1000-meter scale of mega-tall buildings in China. According to the results of this study, the wind turbine system's technical performance is highest at distances of 300 and 200 meters from the ground, and when the building orientation is north or south, in terms of wind power density and electricity generated (Cao et al., 2017).

First, studies on the PV system focused primarily on techno-economic performance analysis based on PV panel type *(a-Si panel, polycrystalline panel, monocrystalline panel, and semi-transparent PV system)* and the development of a prediction model for the amount of electricity generated based on PV system design variables. Second, studies of the solar thermal system focused mostly on the thermal performance of a building as a function of the solar collector's properties *(color, capacity, temperature, etc.)*. Third, the majority of studies on energy savings and economic consequences for geothermal systems are dependent on design variables *(a geothermal system's coefficient of performance, location, borehole length, etc.)*. Finally, studies were undertaken mostly on high-rise buildings to examine the quantity of power generated and optimal design circumstances by taking into account climate, building layout, and other factors. Various attempts, such as the use of high-efficiency PV panels and analysis of optimal design conditions for the renewable energy (RE) system, have been made to improve a building's energy self-sufficiency rate through RE-related studies. However, implementing Net-Zero Energy buildings with only renewable energy would be extremely difficult.

Backup systems for renewable energy

In the Backup systems for renewable energy, we have two types: fuel cell systems and energy storage systems (ESS).

1- Fuel cell systems: It is a type of electricity generator that makes use of electricity generated by the chemical reaction of hydrogen and oxygen. Furthermore, when using renewable energy, the fuel cell system can be more effective since the power generated from renewable energy can be used in the electrolysis of water in the fuel cell system. (Hong, 2017). Ansong et al. (2017) used the HOMER software tool to undertake a techno-economic performance analysis of the hybrid electric power *system (PV system, fuel cell system, and diesel generator)* for an off-grid mine firm. Consequently, it was discovered that an ideal electric power system consisting of 50 MW of PV system, 15 MW of fuel cell, and 20 MW of diesel generator could create 152.99 GWh of electricity each year (Ansong et al., 2017).

2- Energy storage systems (ESS), renewable energy: Electricity generation is significantly influenced by exterior environmental factors *(solar radiation, wind strength, etc.)*. From there, we aim to use an energy storage system as a backup system, storing the electricity provided by renewable energy sources (Hong, 2017). Ali mohammad isagvand et al. (2016) used the concept of demand response (DR) to find a cost-optimal solution for a thermal energy storage system integrated with the geothermal system for a residential building in a cold climate *(a momentary DR control based on the real-time hourly electricity price, a backward-looking DR control based on the previous hourly electricity price, and a predictive DR control based on the previous hour)*. The results of the investigation revealed that using the predictive DR control algorithm is the most beneficial in terms of annual energy and cost savings (Ali mohammad isagvand et al., 2016). In Coimbra, Portugal, Vieira et al. (2017) looked at the ESS linked to a residential building's PV system as a system for matching energy production and consumption. According to the findings, the ESS connected to the PV system can lower the amount of energy sent to and consumed from the grid by 76 and 78.3 percent respectively, as well as the financial resources spent on energy (Vieira et al., 2017).

To conclude, the techno-economic performance analysis of the fuel cell system was mostly undertaken using simulation tools. Furthermore, many studies are being conducted on the energy storage system to examine the technical and economic implications of demand response techniques paired with RE. In terms of the backup system, it is thought to be more beneficial in terms of energy savings, especially for ESS-related research, because DR methodologies are used to examine technical performance while considering energy demand and supply.

A combination of passive and active strategies is required to reach Net-Zero Buildings. To find the best energy-saving strategies and reduce consumption these strategies must be complementary one to another.

2.3. Addressing existing residential buildings

Due to the high demand for human comfort and services, energy consumption in residential buildings increases considerably year after year (Shehadi, 2018). In addition to weather conditions, a variety of factors influence the energy consumption utilized to cool buildings, including wall structure, window-to-wall ratio, and building orientation (Dong et al., 2010). Due to its relationship to energy consumption reduction, the thermal properties of building envelopes have become increasingly important for designers and owners. When the relative humidity of the air is greater than 80% and the convective and radiant heat transfer coefficients of the outer walls are low, improper thermal insulation in buildings can increase the risks of surface condensation (Sadineni et al., 2001).

According to the World Green Building Council (World GBC), which is a global network of national green building councils, renovating existing homes is even better from a climate standpoint than constructing new residential units respecting the Net-Zero Energy techniques. Indeed, renovations lessen the demand for new building materials, which take energy to manufacture, transport, and install (Huminilowycz, 2020). Since there is a complete abandonment of local materials and the ambient environment, new construction materials and technology such as concrete, steel, large glass openings, and air-conditioning became required in most new buildings (Salman, 2018). Therefore, we should be focusing on converting existing homes and other structures into zero-emission houses (ZEHs) and zero-emission buildings (ZEBs) (Kuriyama, & Arino, 2020). Victoria Burrows, WorldGBC's head of promoting net zero, notes, that the most sustainable buildings may be the ones that already exist. We should choose Net-Zero renovations for new home construction since there are ways to reduce embodied carbon, such as raw material reduction. Those measures can help a home go beyond Net-Zero Energy and offset greenhouse gas emissions from materials to construction (Huminilowycz, 2020).

The residential sector consumes more than one-third of all electricity generated worldwide (Umbarek et al., 2020). A study was made by Umbarek et al. (2020) on three different existing building styles, single-story apartments, duplex houses, and apartments, to assess and contrast energy consumption categories and their associated social and architectural factors. As a result, in all three building forms, interior equipment consumes the most energy, with interior lighting, space cooling, and water heating rounding out the top four energy users. These four energy loads account for 96 percent of the total yearly energy consumption in the first building style, 95 percent of the energy consumed in the second building style, and 97 percent of the entire energy consumed in the third building style (Umbarek et al., 2020). The annual energy consumption of the second building style's water heating system, equipment, and lighting is higher than that of the other building styles. This could be explained by the fact that the second building has two levels with the largest roof area with a higher number of residents. The following results of the second building style were identical to those of the first. The domestic water heating load is dominant during the winter season, while the cooling load is dominant during the summer season because the energy consumption of interior lights and equipment does not vary with the ambient weather conditions (Umbarek et al., 2020). The third building style has the same total energy usage in July and August, which is the highest of the year at 1375 kWh. Aside from the interior lights and interior equipment, which have fixed daily values, cooling is the most important category during the summer, while heating is the most important during the winter. Service hot water, on the other hand, accounts for over a fifth of total yearly energy consumption. The low share of cooling and heating in comparison to water heating is primarily due to the third building style's location. This apartment is on the second story of a high-rise structure with only one window on the north wall. The regions above and below the flat were supposed to be air-conditioned, hence the above and below surfaces in the simulation are considered thermostatic surfaces (Umbarek et al., 2020).

To conclude, for the already existing buildings, the analysis confirms that space cooling is one of the most energy consumer operations in local residential structures, accounting for over a quarter of total yearly energy consumption. As a general energy benchmark, water systems, space cooling, and interior lighting account for 60% of total energy consumption, with a roughly equal amount for each, while equipment accounts for just 35% of total energy consumption, leaving 5% for other things. Hence, we should focus on getting as close as possible to Net-Zero Energy in the already existing structures to help minimize that large amount of energy consumption.

2.4. Conclusion

The success of Net-Zero Energy buildings is heavily reliant on a thorough understanding of the impact that various design aspects have on a building's energy performance. Passive strategies relate to using an architectural design strategy to reduce a building's energy consumption early in its life cycle. Following the analysis of many studies, it was shown that while employing passive techniques in buildings, it is efficient in terms of energy savings, it is insufficient when it comes to adopting Net-Zero Energy buildings. As for the active strategies, they mainly represent energy generation as means of reducing building energy use. And, as previously said, renewable energy is still insufficient to achieve NZEB, and the technical and economic effects of the backup system, particularly ESS, may be lower since they supplement RE based on historical data. Therefore, to achieve NZEB, passive strategies *(passive sustainable design and ETS)* and active strategies *(RE and backup system)* should be implemented on a building in that order. In other words, a two-step process must be implemented, with the first step reducing building energy demand using passive technologies *(natural ventilation, heat storage systems, etc.)* where these will be derived from Vernacular Architecture as well and the second step substituting residual building energy demand using active technologies *(PV system with ESS)*.

So, the ultimate set of strategies to implement on already existing buildings to reach Net-Zero Energy will be all the passive and active strategies studied working on the already existing structures. By this, the first objective of the thesis will be reached ‘To understand the construction strategies, passive and active, used towards Net-Zero Energy Construction’. Some passive and active strategies cannot be applied and will be according to the case study that will be analyzed in the upcoming chapters. Orientation, location, materials availability, and cost will take part in the analysis to be able to reach the best applicable strategies. Hence, it is vital to develop an optimization model that will be elaborated in the analysis chapter for determining the appropriate solution by considering design elements to successfully integrate passive and active techniques.

3. The Coastal Region: Ghazir in Keserwan

3.1. Introduction

The chosen research area to be studied, Ghazir town, is introduced in this following chapter. Its climate will be provided with its geography using the area as a sample of the country's coastal zone. The openings design and ratio, materials, and construction techniques used in the building envelope will be analyzed. All these elements have a significant impact on the level of energy demand, the operation, and consumption of energy in the residential buildings of this urban setting. To be able to observe clearly, we will choose a typical Lebanese vernacular house in Ghazir town as a case study and analyze all the above-mentioned elements to determine the optimal opening ratio, materials, and building methods. In chapter five, these will be compared with a contemporary residential building in Ghazir area, in the same orientation as the old house, and at a similar altitude.

3.2. Geographic Description

Lebanon is a small country on the Mediterranean Sea's eastern coast. It is situated at the crossroads of three continents. It features a narrow coastal plane and two parallel north/south mountains (Figure 3.1). The country's total area is 10,452 square kilometers *(4,035 square miles)*. Its coastline is around 225 kilometers long *(140 miles)* and averages 56 kilometers wide *(35 miles)* (Figure 3.2).

Figure 3.1: Lebanon’s Location

Source: Encyclopedia Britannica, retrieved from https://www.britannica.com/place/Lebanon

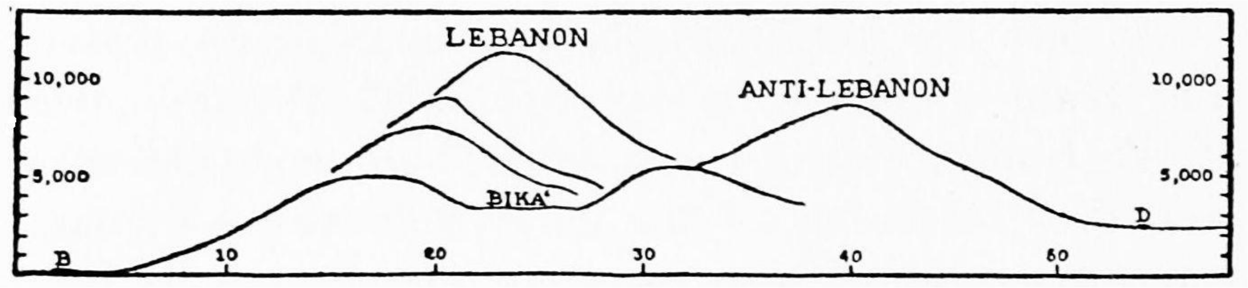


Figure 3.2: Lebanon’s schematic section representing altitude in meters (y axis), and the width in Kilometers (x axis).

Source: Wikimedia commons, retrieved from https://commons.wikimedia.org/wiki/File:SL_1914_D094_geographical_cross_section_between_beirut_and_damascus.jpg

The Lebanese coastal zone, in its scientific meaning, comprises almost one-third of the entire Lebanese surface (CDR, 2005) including the west side of Mount Lebanon between 0 and 800 meters in altitude, as well as vast zones of North and South Lebanon (NPMPLT 2005).

The residential density by morphological zone can be observed on the map below. With a density of more than 1000 persons per square kilometer, highlighted in blue, we have Sour, Saida, Beirut to Jbeil zone, and Enfeh to El Abdeh zone. All of the aforementioned locations are located in the Lebanese territory's coastal zone, making it the first area to be addressed in the thesis research.
To objectively select an area that will be representative of the criterion required to make an optimal analysis to reach the main thesis’ objective, the following characteristics will be used.

First, the area should be in the coastal zone, with a high residential density, as mentioned above.

Second, the selected area should have a rich history and most importantly, it shall conserve the old Vernacular Architectural identity, preserving its heritage.

Third, the area should consist of both architectures, the old Lebanese Vernacular houses and the new contemporary residential developments. Taking into consideration that the contemporary development shall have both, a constructed part to be able to perform the analysis, and another one under construction, so the thesis will serve as a guideline to proceed with the optimal construction materials and techniques.

Fourth, both study cases, the old house and the contemporary residential building, located in the same coastal area, should have the same orientation to analyze the openings, window-to-wall ratio (WWR), wind flow, and sun exposure. This is required to do a clear comparative analysis of the mentioned elements along with their materials, thermal value, and building techniques in chapter five ‘Analysis of building openings, materials, and construction techniques in Ghazir’.

Fifth, both study cases, the old house and the contemporary residential building, should be at a similar altitude for materials insulation purposes and weather conditions that will affect the selection of the active strategy implemented in the optimization process in chapter six ‘Optimization’.

After thorough research, reaching out to municipalities for data gathering, and areas study, Ghazir was the optimal coastal region with its architectural heritage ‘caché’ and its new large contemporary development located both in the same orientation and at a similar altitude above sea level.

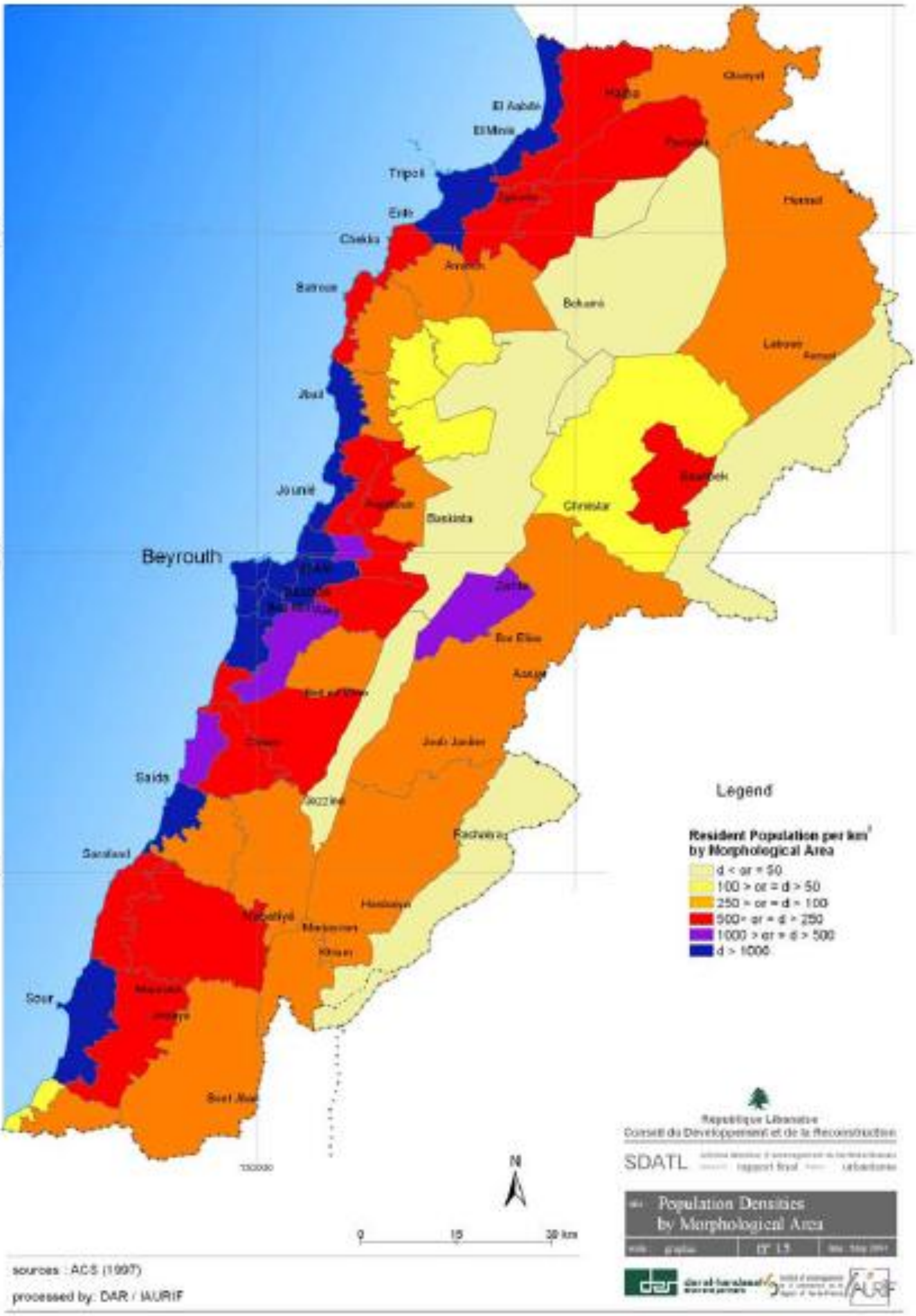


Figure 3.3: Population densities per morphological zones.

Source: NPMPLT, 2005

Dropping in the Mediterranean Sea at the end of Jounieh Bay, Ghazir is a village with a seemingly slender contour (L'orient le Jour, Grandchamps C., 2019) with an average elevation of 380 meters above sea level.

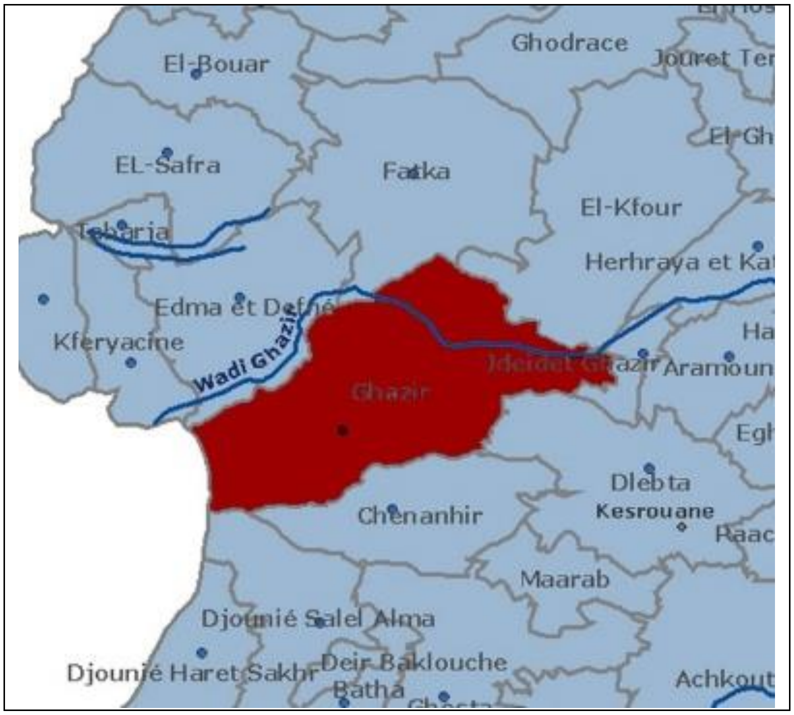


Figure 3.4: Ghazir's Location

Source: Localiban, 2008, Retrieved from http://www.localiban.org/ghazir-4460

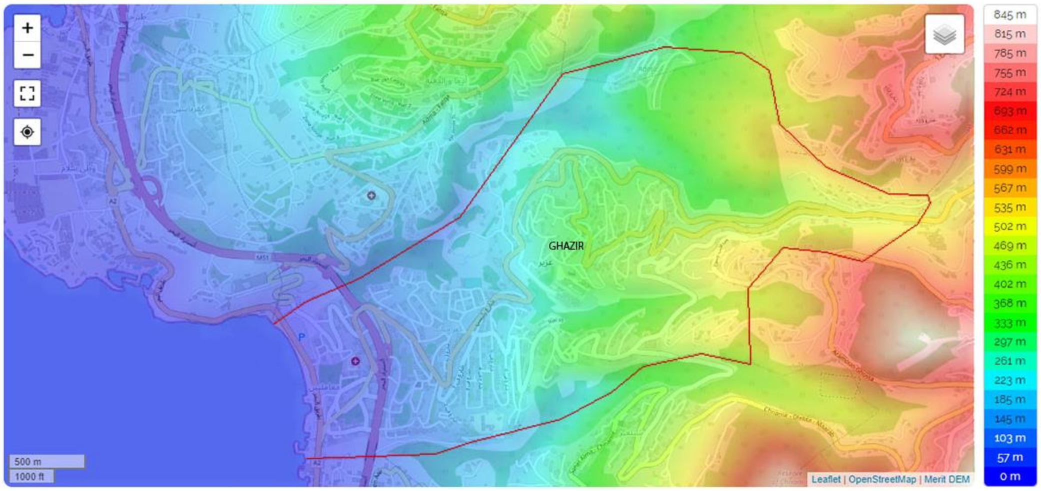


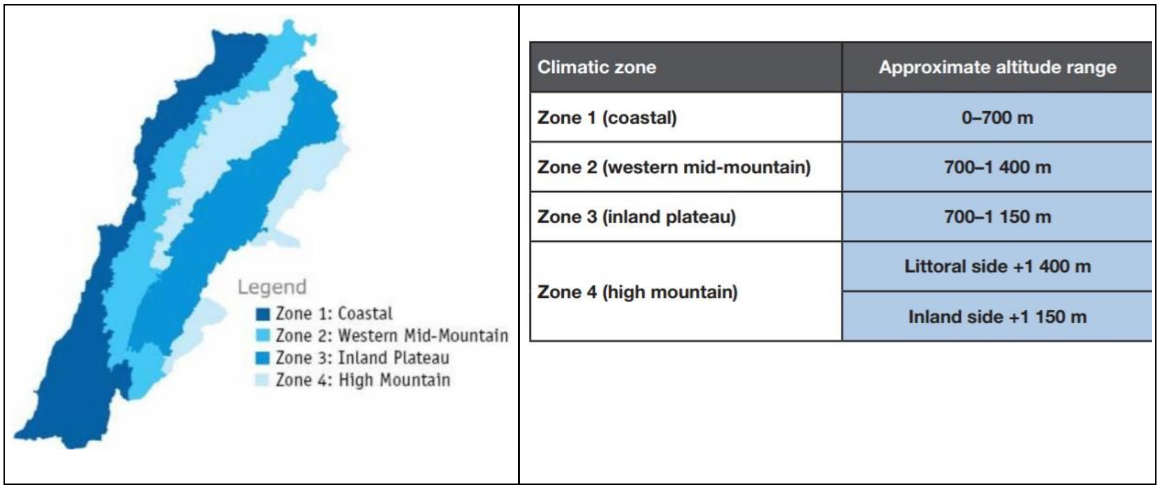
Figure 3.5: Ghazir's topographic Map

Source: Topographic-map.com https://en-ca.topographic-map.com/maps/avul/Maameltein/

Even though the country's maximum width is seventy kilometers and its territory is ten thousand four hundred fifty-two square kilometers, it has four different climate zones (NPMPLT, 2005, pp. 2-27).

3.3. Climatic Classification

Based on temperature, relative humidity, and solar radiation, Lebanon is divided into four zones. These zones have different altitudes, climatic parameters and thermal demands (UNDP, 2005, p.10).



Climatic zone	Approximate altitude range
Zone 1 (coastal)	0–700 m
Zone 2 (western mid-mountain)	700–1 400 m
Zone 3 (inland plateau)	700–1 150 m
Zone 4 (high mountain)	Littoral side +1 400 m
	Inland side +1 150 m

Figure 3.6: Map of Lebanon showing the different climatic Zones

Source: UNDP, 2005

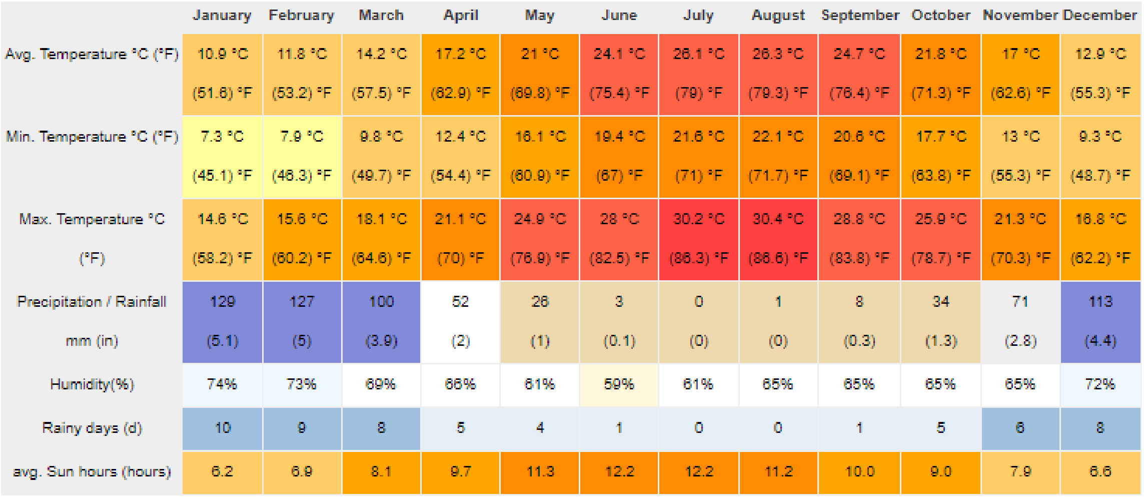
The first classified zone is the coastal zone which begins at sea level and rises to a height of 700 meters. It has a dry bulb region between 18-19 degrees Celsius and 30-31 degrees with the corresponding 20% to 90% relative humidity. The second, is the Mid Mountain Zone, located on the western mountain slopes, starts at 700 meters and rises to 1400 meters. It has between 17°-18°C and 29°-30°C dry bulb temperature with the corresponding 20%

to 90% relative humidity. Third, the Island Zone, which lies between the eastern and western mountains, between 15°-16°C and 30-31°C dry bulb temperature with the corresponding 15% to 90% relative humidity. And fourth, the High-mountain Zone, which starts at 1,150 meters and goes up. It has between 14°-15°C and 28°29°C dry bulb temperature with the corresponding 15% to 90% relative humidity (UNDP, 2005).

The coastal region's winters are mild and brief, while the summers are hot and humid. The temperature difference between day and night is modest all year. This moderate environment; however, changes with altitude, with the weather becoming colder and more precipitous. (Hassan H. and Hamid Z., 2001, p.62). From May onwards, daily maximum temperatures exceed the comfort level, and in August, they hit the work limit. From June to September, average daily temperatures exceed the comfort level. Cross ventilation is the sole natural technique of climatization due to the excessive humidity. To give sun protection and enough thermal insulation, structures must be opened to the summer breeze from the southwest. During the winter, when there isn't much sunlight, heating becomes important (Architecture in Lebanon. Friedrich Ragette F., 1980).

3.4. Ghazir’s Weather

Topography, solar orientation, relative humidity, and wind direction are all unique to each location. The climate of Ghazir is described as warm and temperate. Ghazir receives significantly more rainfall in the winter than in the summer. According to the Köppen-Geiger climate classification, this climate classified as CSA *(Hot-Summer Mediterranean climate)*. Ghazir's average temperature is 19.0 °C | 66.2 °F. Rainfall is 664 mm | 26.1 inches each year.



	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature °C (°F)	10.9 °C (51.6) °F	11.8 °C (53.2) °F	14.2 °C (57.5) °F	17.2 °C (62.9) °F	21 °C (69.8) °F	24.1 °C (75.4) °F	26.1 °C (79) °F	26.3 °C (79.3) °F	24.7 °C (76.4) °F	21.8 °C (71.3) °F	17 °C (62.6) °F	12.9 °C (55.3) °F
Min. Temperature °C (°F)	7.3 °C (45.1) °F	7.9 °C (46.3) °F	9.8 °C (49.7) °F	12.4 °C (54.4) °F	16.1 °C (60.9) °F	19.4 °C (67) °F	21.6 °C (71) °F	22.1 °C (71.7) °F	20.6 °C (69.1) °F	17.7 °C (63.8) °F	13 °C (55.3) °F	9.3 °C (48.7) °F
Max. Temperature °C (°F)	14.6 °C (58.2) °F	15.6 °C (60.2) °F	18.1 °C (64.6) °F	21.1 °C (70) °F	24.9 °C (76.9) °F	28 °C (82.5) °F	30.2 °C (86.3) °F	30.4 °C (86.6) °F	28.8 °C (83.8) °F	25.9 °C (78.7) °F	21.3 °C (70.3) °F	16.8 °C (62.2) °F
Precipitation / Rainfall mm (in)	129 (5.1)	127 (5)	100 (3.9)	52 (2)	26 (1)	3 (0.1)	0 (0)	1 (0)	8 (0.3)	34 (1.3)	71 (2.8)	113 (4.4)
Humidity(%)	74%	73%	69%	66%	61%	59%	61%	65%	65%	65%	65%	72%
Rainy days (d)	10	9	8	5	4	1	0	0	1	5	6	8
avg. Sun hours (hours)	6.2	6.9	8.1	9.7	11.3	12.2	12.2	11.2	10.0	9.0	7.9	6.6

Table 3.1: Table showing the Temperature, precipitation, humidity, rainy days and average sun hours in Ghazir.

Source: Climate-Data.org, Retrieved from https://en.climate-data.org/asia/lebanon/qada-kisrwan/mafraq-ghazir-418935/#climate-graph

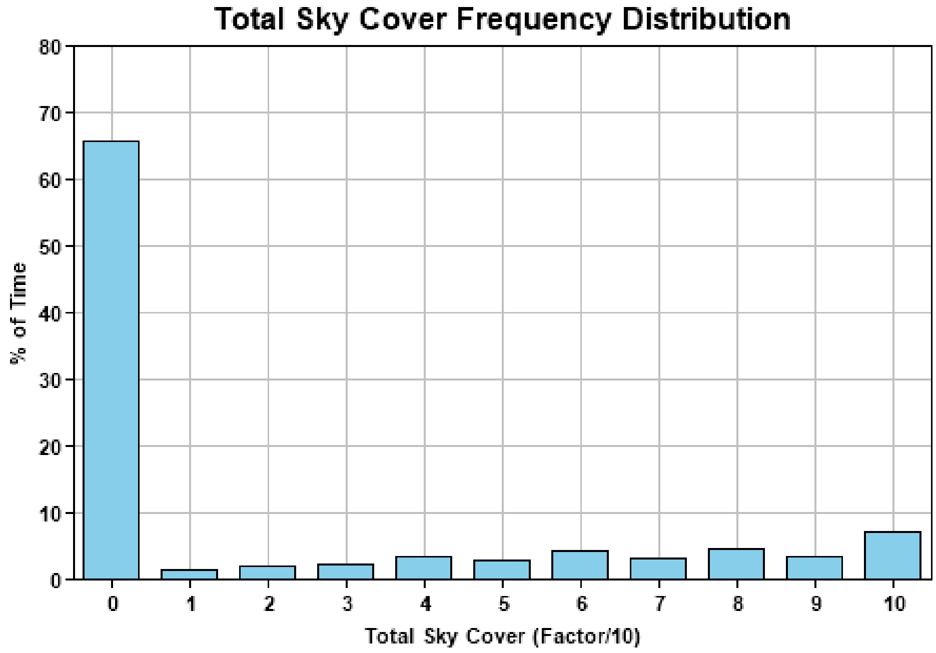


Figure 3.7: Graph showing the total sky cover frequency distribution in Ghazir per year.

Source: Green Building Studio- Data Input by Author.

Heating, is required for four to six months of the year, according to the table above. Heating, is required throughout the day and night in December, January, February, and March. The weather may begin to warm up between April and November. Thus, the temperatures in July and August surpass the comfort level, necessitating the use of a cooling system especially since the area is 65% of the time exposed to direct sun (Figure 3.7). The humidity mentioned in the above table is high. For that, it will require good ventilation.

All of the abovementioned climatic factors have an impact on the heating and cooling needs of local structures, which has an impact on energy consumption.

3.5. Ghazir’s History

The governors of Mount Lebanon, the Chehab, came to power in the eighteenth century, 1711 and established in Ghazir until the end of the nineteenth century. Prince Hassan Chehab began building a palace, a qaysaria, and a souk for regional trade in 1804. Ghazir was a political and commercial hub until the late nineteenth century. A few typical nineteenth-century residences with three arches were constructed. Mouzaffar Bacha, the Ottoman moutasarrif of Mount Lebanon, built a new seraglio in 1905. Once the territory, as a whole, was reformed in the twentieth century, the town started to decline. Many contemporary buildings were built in Ghazir during the 1975-1990 war, destroying the traditional architectural heritage that had prevailed until the 1960s. In the town's historic heart, modern buildings and roadways were added and widened. A section of the old souk and numerous old houses were demolished, to make way for the new infrastructure. The Ghazir Municipality began efforts in 2003 to conserve Ghazir's ancient architecture, including the old souk, the 'Assaf Mosque, and the old serail (Haddad R., 2003). However, this village is still known for its traditional Lebanese houses (Baldati, 2008).

3.6. Vernacular Architecture in Ghazir

Lebanon is known for its dynamic weather along the four seasons that have an impact on any architectural project, especially when it comes to the traditional Lebanese houses, which are known for their orientation. Most of the houses were oriented taking into consideration the topography, the sun and wind patterns which are the basics that imposed constraints. The sun orientation, rising from the East and setting in the West greatly affects the exposure of the different facades of the structure.

Three hundred sixty meters above sea level, with its central hall typology, orientation, typical Lebanese vernacular house materials: limestone, wood, clay roof tiles and the presence of the typical elements: triple arcade, vaults and windows, the house analyzed below represents the typical Lebanese vernacular house. The chosen old house serves as a sample of a category that responds to the fundamental principles of Vernacular Architecture. Other possible case studies encompass various obstacles: renovation that modified the architectural heritage and "caché", modern addition to the house interrupting the natural wind flow, and limited access to other houses.

The selected old house’s elements were identified after observing, taking measurements, and drawing the plans, elevations, and sections of the house. The house, constructed in 1910, in the early twentieth century, was few of the houses that prevailed after the 1975-1990 war that destroyed many architectural heritages in Ghazir. This house meets all the criteria of a Lebanese Vernacular House.

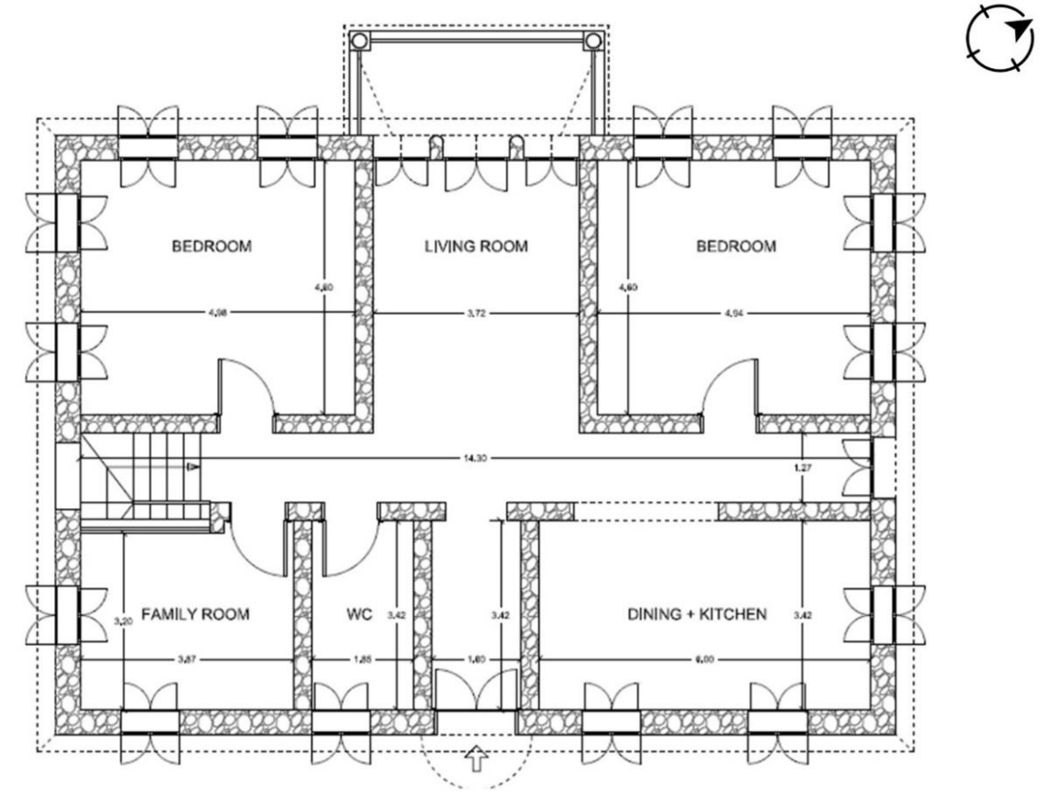
Figure 3.8: Old house Location- Ghazir

Source: Google Earth

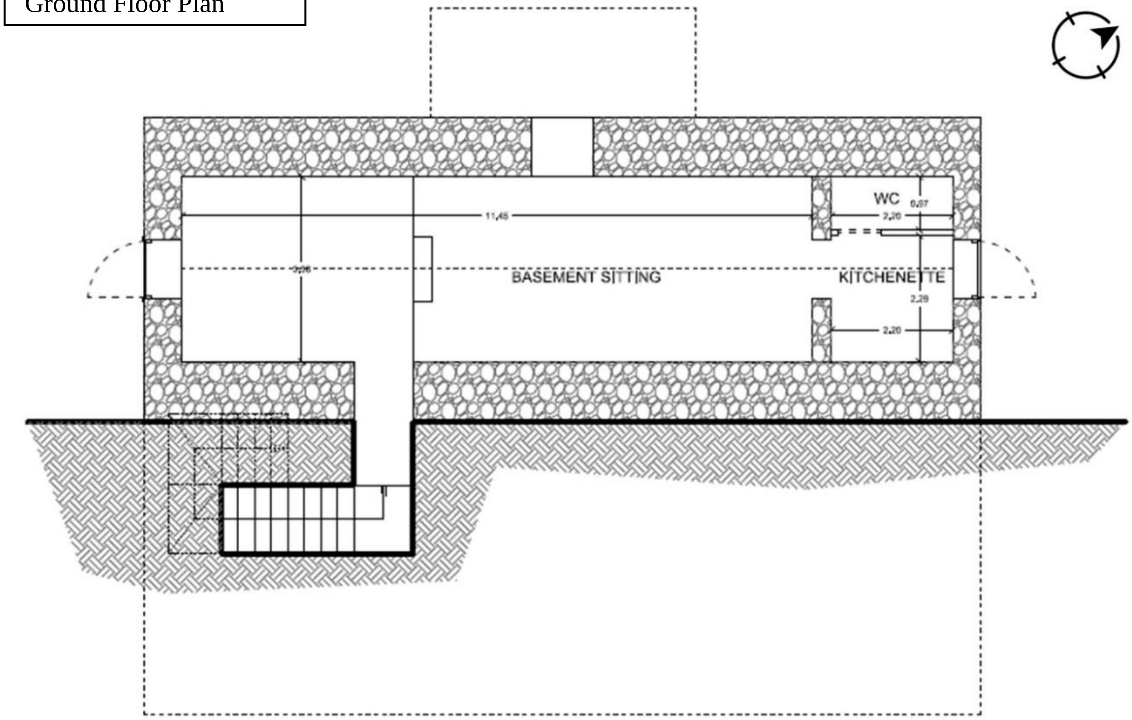
On the architectural level, we have the central space, a living area, as seen in the plan below (Figure 3.10), from which we can access the balcony with the triple arcade, which is apparent in the main elevation (Figure 3.1).

Figure 3.9: Main Elevation, North-West of the Old House- Ghazir

Source: Author



Ground Floor Plan

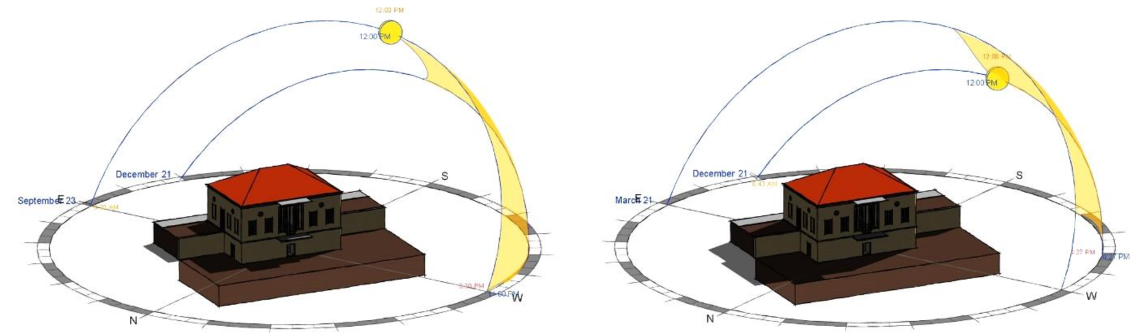


Basement Floor Plan

Figure 3.10: Ground Floor and Basement plans of the Old House- Ghazir

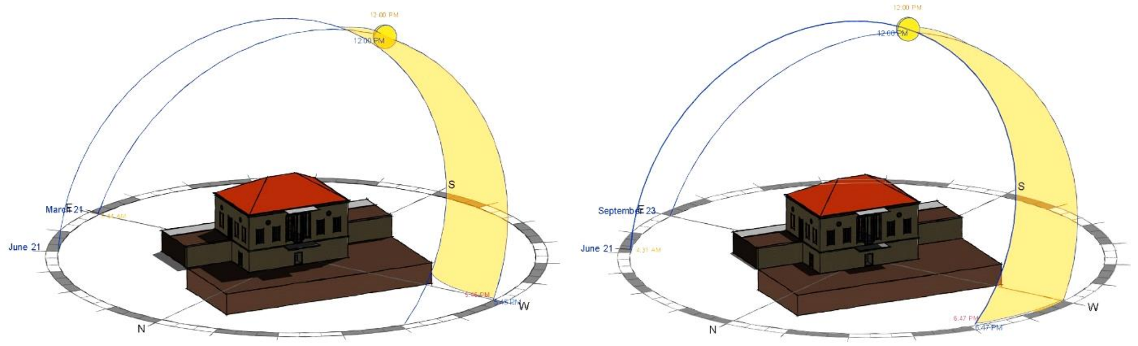
Reference: Author

This house has a sixty degrees rotation, with its main facade, North-Western. As can be seen in the sun paths below (Figure 3.11), this facade is exposed to the sun mostly in the summer afternoons and the North-Easter Elevation in the Summer mornings, gets the least amount of exposure. The South-Eastern facade receives the most, in the daytime solar exposure from the East, while the North-Eastern facade never does (Figure 3.11).



Fall Sun Path

Winter Sun Path



Spring Sun Path

Summer Sun Path

Figure 3.11: Sun Path during the four seasons.

Source: Author

The two main seasons of the year, summer and winter, have different solar paths for every building. In contrast to the winter sun, which is low, the summer sun is always higher. This fact allows passive design in keeping winter heat and shielding against summer sun heat simple. It is reflected also in the layout of the house's functions that depends on its orientation as well.

In Lebanon, the north facade typically provides the best summer shade and winter cooling. The main facade in our case is the North-Western, which is where we have the main living area and two bedrooms. The sides of a house facing South and West are among the warmest, with the west becoming particularly warm towards sunset in the summer. The south facade experiences the most heat in the summer and receives moderate sunlight in the winter. In our case, one of the Bedrooms with the Family Room are exposed to the South-West (Figure 3.13). The kitchen's location is mainly related to the direction of the wind from the South-West than it is to the path of the sun, which helped in evacuating moisture and odors as we can see in the below figure and plan (Figure 3.12; Figure 3.13).

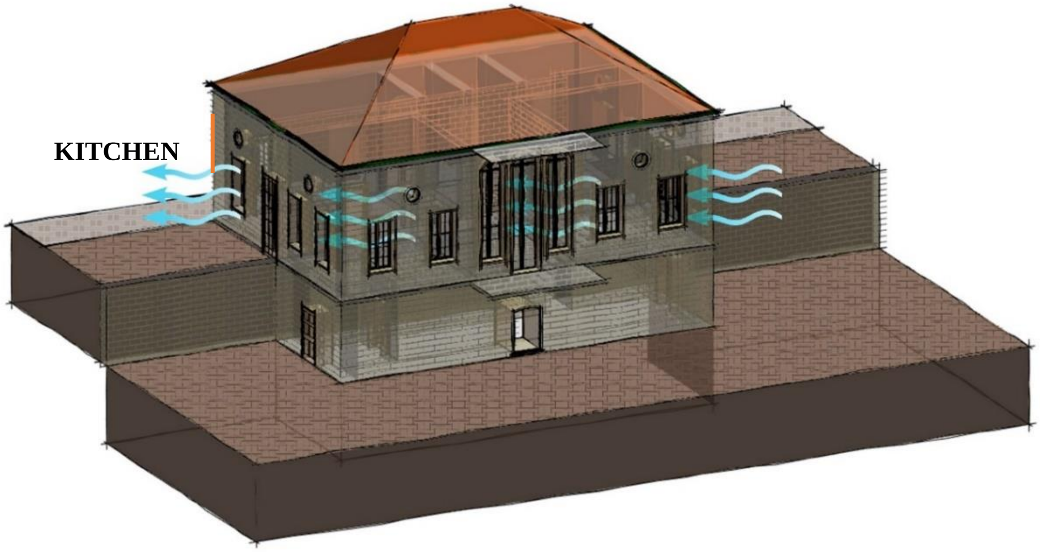


Figure 3.12: Wind direction and flow in the Old house- Ghazir.

Source: Author

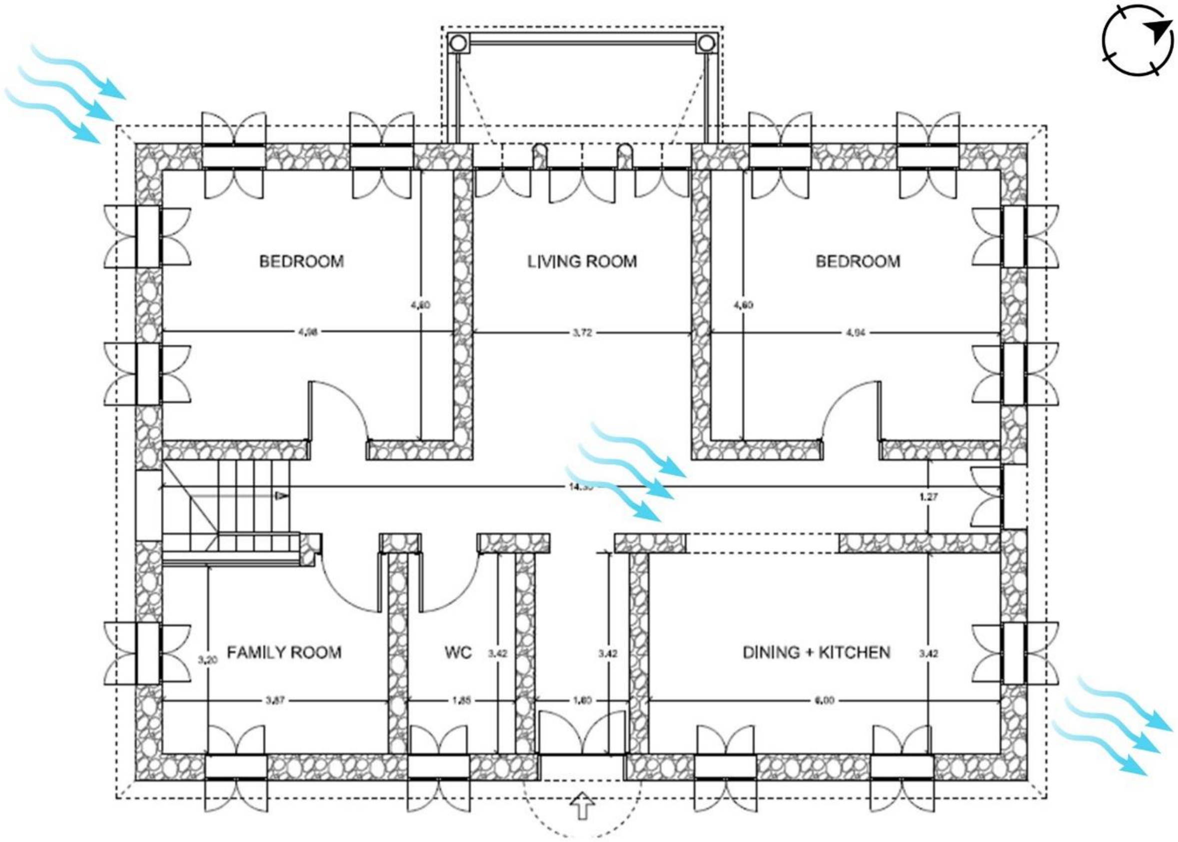


Figure 3.13: Wind direction and flow on the Ground Floor Plan of the Old house- Ghazir.

Source: Author

The humidity in the coastal zone necessitates effective ventilation. When considered in the orientation, Lebanon's predominant southwesterly winds are another simple and affordable method of passive design that has been used for centuries due to the need for cooling and ventilation. A sea breeze that comes from the sea towards the land can arise in moderately sunny weather when the land is warmer than the sea. This can be a significant characteristic in a coastal area and is most likely to happen in the afternoon. At night, these breezes frequently change direction. Buildings must be opened to the summer breeze coming from the South-West to provide sufficient thermal insulation and sun protection (Ragette, 1974).

This is represented perfectly in our case; the old house is oriented in a way to fully receive these winds as can be seen in the above figures (Figure 3.12; Figure 3.13).

Typically, windows are used to provide air and light into the interior space. It can also be used as a design feature. Windows vary in size, components, placement, and material depending on age and geographical location. Regardless of their size, they should be respecting the window-to-wall ratio- WWR, which will be analyzed in chapter five. The large windows and doors we have are essential for solar penetration, which is required to warm the house, as well as for air circulation, which is necessary to eliminate humidity in a coastal zone as shown in the above plan (Figure 3.13). We mainly have rectangular windows with dimensions of 1.06 meters wide by 1.96 meters height. The doors and triple arcade are arched as shown in the four elevations below (Figure 3.14). In the South-West, North-West and North-East elevations, we can clearly notice the small openings, and oculus. Small openings, were used to enhance natural ventilation and natural lighting environmental strategies. To attain the objectives; their accurate placement was crucially significant, especially during the winter when the main rectangular window shutters were closed due to rough weather. With the right angle, light can penetrate the room regardless of how thick the thermal-mass wall is, and the sun's rising or setting has a significant impact (Melki, 2006).

North- East Elevation

North-West Elevation

South-West Elevation

South-East Elevation

Figure 3.14: Four Elevations of the Old house- Ghazir.

Source: Author

These windows built of flawlessly cut stones, glazed with vivid glass, designed with wood all around, and distinguished by their majestic height served as symbols of culture as well as beauty and, in other cases, when we have the presence of an arch, structural function.

Figure 3.15: Windows and Small Opening, oculus of the North-West Elevation of the Old house- Ghazir.

Source: Author

The thickness of the stone walls, as we can see in the above plans (Figure 3.13), allows the absorption of heat in the winter when the interior space is heated, storing it rather than losing it. And at night, when the heating is turned off, the stone will begin to release the energy it has been storing rather than losing it. When it gets hot in the summer, the stone heats up from the outside inward; as a result, when the sun sets, the stone will begin to cool, and the inner space will not get hot.

3.7. Components from both the old and the contemporary

The orientation of the house and the placement of the function have a significant impact on the wind pattern, ventilation, and sun exposure the house receives. So, the facades have various exposures throughout the day, night, and entire year depending on that orientation. By examining these facades, as analyzed in the previous section, one can learn how the interior is impacted by climate variations. Therefore, it is crucial to consider these elements while designing to reduce energy usage and encourage sustainable design.

Both, old and new structures, built at various times, allow letting in natural light. However, the proportions of an old structure compared to a new one is different as well as the materials. As discussed in the second chapter, 2.1.1 paragraph titled ‘Materials and Passive Strategies of Vernacular Architecture’, energy-efficient materials have been used in Vernacular Architecture. They made use of local natural materials like gravel, wood and tree branches, dirt and mud, straw, hay, bricks and stones (Daghfal, 2019). However, natural stone has significantly less environmental impact than concrete, specifically precast concrete which is mostly adopted in the most recent developments in contemporary architecture. It involves multi-step and energy-intensive processes as we can see in the below figure along with the fact that precast concrete has a higher global warming potential (GWP) than natural stone (Vierra, 2022).

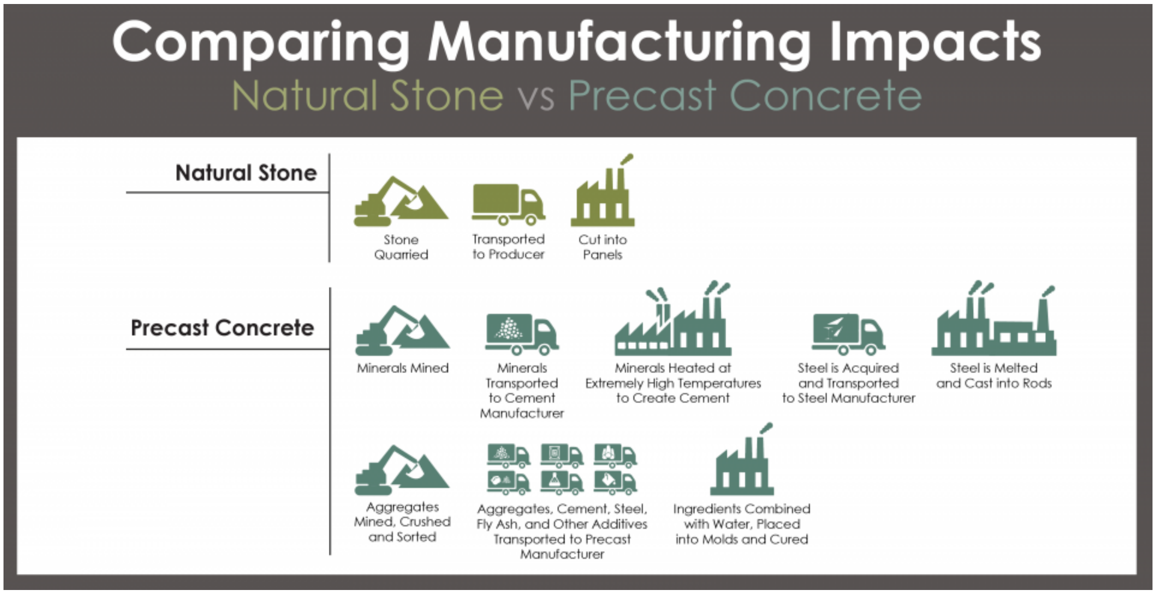


Figure 3.16: Comparing manufacturing impacts, Natural Stone vs Precast Concrete.

Source: Vierra, 2022 extrated from https://usenaturalstone.org/manufacturing-impacts-natural-stone-vs-precast-concrete/

As referred to in paragraph 2.1.1 ‘Materials and passive strategies of Vernacular Architecture’, the construction methods of Vernacular Architecture are passive methods. Old traditional homes are better insulated against extreme weather and environmental factors than modern structures, which despite significant technical advancements, still fall short of the durability of old houses. Thick walls in vernacular houses working as a cooling technique (Kumari and Wanti, 2020). They help prevent the impact of solar radiations (Sayigh, 2019) since these "Kalline" walls might be up to a meter thick and constructed using a variety of cut and uncut stones from the exterior and "Dabsh" from the interior; mud, hay, and gravels filled the spaces between these two layers of stones as shown in the below wall (Figure 3.17) (Daghfal, 2019). Contrary to modern wall construction methods, which use the One-go method with twenty-five centimeters thickness exterior walls or two ten centimeters thick layers of masonry blocks spaced with a five centimeters void between them.

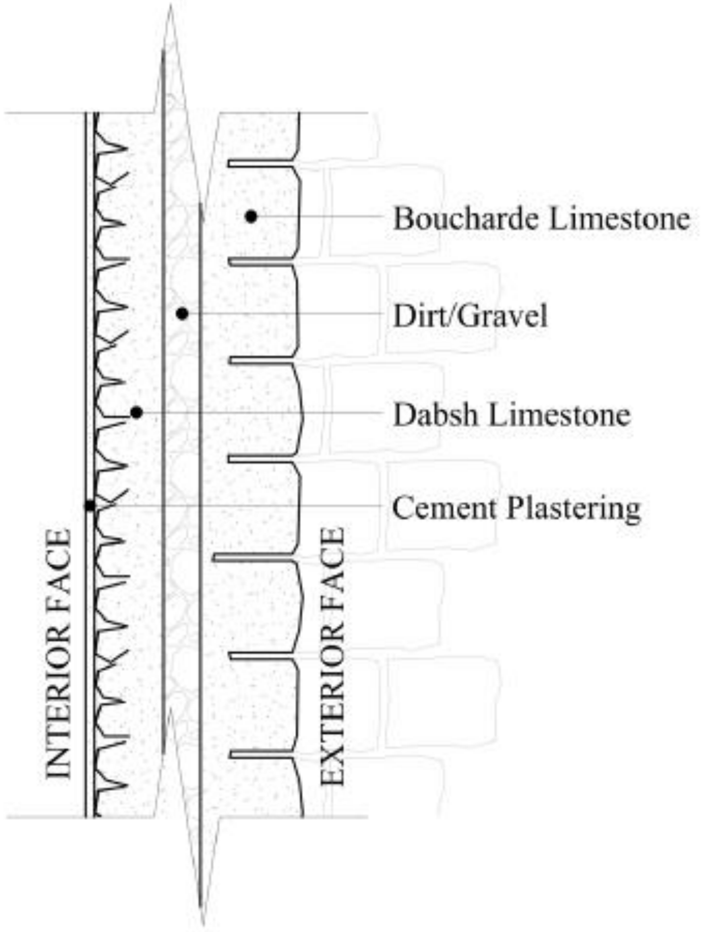
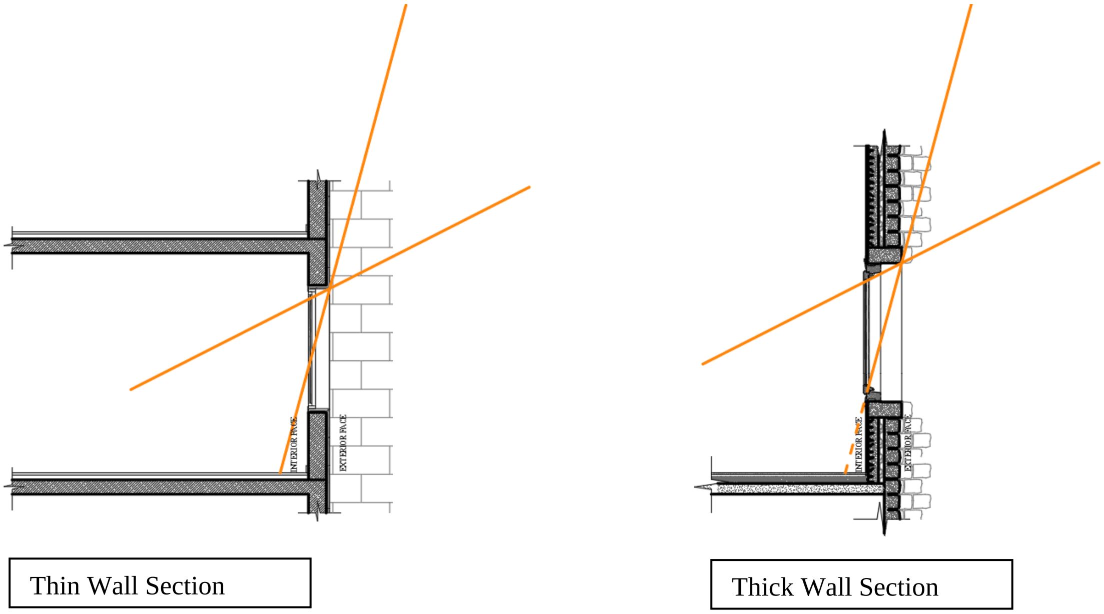


Figure 3.17: Wall section Drawing with materials of a vernacular house

Source: Author

The thermal behavior of the house structure is closely related to the energy component, and is influenced by, a variety of factors such as the type of materials used, the wall composition and thickness, and so on. Such architectural parameters, can be combined into one, namely the building's thermal capability (El Hayek M. 2005). When it comes to thermal mass, the Vernacular Architecture house has an obvious advantage. The thick massive walls, as seen in the previous paragraph, reduce the amount of direct sun rays, acting as a shading device in addition to maintaining controlled interior comfort (Figure 3.18); however, despite their small size, the openings allowed the winter sun to enter. The tapering of the wall towards the interior added to this effect. The Vernacular Architecture house have the strongest correlation between thermal mass and window openings. Small openings, as we previously saw in the elevations of the old house (Figure 3.14), were used in Lebanese Vernacular Architecture to improve natural ventilation, daylighting and environmental strategies (Melki, H. 2006). The importance of maintaining comfort through constant levels of temperature gradually gave way to criteria of view, natural ventilation, solar gain, and social activities as exterior wall thickness was reduced and window size increased. Therefore, greater solar gain and loss (Melki, H. 2006) implied an excessive use of energy to maintain the interior comfort.



Thin Wall Section

Thick Wall Section

Figure 3.18: Winter and Summer sun rays entering the window from a thin wall vs thick wall

Source: Author

3.8. Chapter Conclusion

These Vernacular stone houses designed with only a few basic tools, genuine practices, and respect for both Mother Nature and mankind are the most sustainable construction in the residential typology. Each house had its unique approach to details. By this, the second objective of the thesis will be reached 'To Understand the principles and passive strategies of Vernacular Architecture.' Today's dominant contemporary construction houses began to disregard two basic principles: the house as an integral part of the landscape and its reciprocity with nature. In addition, government rules and regulations, which are far from being environmentally aware, are the primary determinants of every detail in today's house construction from window size and location to orientation, scale, and form. Everything turned out to have one goal; commercial, which is an important factor to consider with the increase in population, thus the increase of the demand for residential units. In these circumstances, restrictions should be compensated by adopting alternate construction methods, using suitable materials, and studying the openings. Starting with a recent development, first in its vicinity, that is still being built where any recommendations resulting from this research can help with the completion of the remaining project components and be applied as future recommendations. A thorough analysis of the old house and the residential contemporary building will be in chapter five. The information acquired will allow us to establish a solid base for the construction and simulation processes that come after. This will give us insight into precise data and values that will allow us to draw the conclusion.

4. Methodology

4.1. Introduction

This thesis's main objective is to show the reduction of the energy consumption of the already existing residential buildings in an urban area on a coastal zone by analyzing their condition to reach Net-Zero Energy. The research approaches used to develop this thesis will be examined in the sections that follow along, with an analysis of the opening ratio, construction techniques, and materials in the selected projects, the old house and the contemporary residential building. Observation, energy modelling and simulation, along with comparison, will be used to reach the ultimate results and get as close to Net-Zero as possible. The findings of the study of these components can inform developers about the optimal solutions to take into consideration early in the design process. This is pertinent to the contemporary case study since it is still under construction. The results can guide the design of the remaining project components and be used as future recommendations. The sections that follow will assist in studying each technique used to identify the methodology as energy modelling and simulation, as well as bringing out its benefits and drawbacks.

4.2. Observation method

For this research, observation is used as a tool to identify the factors affecting energy consumption, such as materials used, construction techniques, and opening ratio in residential buildings. In addition, the site survey of the old house allows us to replicate it with accurate measurements. The information obtained from that observation will strengthen the results' accuracy and reliability. Keeping in mind the mentioned elements, these will be shown in various construction technique cases. The results of this method will be provided as a supporting document for the simulations conducted at a later stage that will allow a deeper and more accurate analysis of these variables impacting energy consumption since observation is an impartial way to obtain data.

4.3. Modeling and Energy Simulation method

Any tool or method could be used to estimate a building's energy usage, but they all have their limitations, so combining those methodologies can assist each method's shortcomings to be overcome. Both manual recording and simulation software can be used to measure energy consumption. However, only simulation software can be used to estimate energy consumption. Software for energy simulation enables the design, analysis, projection, and evaluation of the energy consumed in models at a given location, orientation, and climate (Fasi & Budaiwi, 2015). Revit software will be utilized for the construction. It provides advanced building information modelling (BIM) to create accurate and thorough models (EL Emira et al., 2015). To quantify the forms of energy consumed or needed in buildings, Green building studio and Insight 360 will be used (Autodesk, 2022). To construct the models using BIM 360, and to simulate and analyze them, several steps must be followed. Two different scenarios with different opening ratios, construction techniques, and materials that differ in terms of U-values, and thermal resistance, will be simulated and assessed. The first scenario is the old house, and the second, is the contemporary residential building. For this, the first step is to locate the case study and note its orientation. Then, ascertain the characteristics and thermal properties of the studied materials. The third step is to determine the wall and window-type scenarios. Different wall components and thermal combinations are covered by the experimental phase. The fourth step is to use simulation-based software, Green building studio and Insight 360. A benchmark will be established to compare it to all possible scenarios. The last step is to convert these software models and findings into tables and diagrams for analysis, draw a conclusion, and choose the best optimization that can be done.

Therefore, the goal of this study, is to identify the ideal wall configuration with openings and materials that require the least amount of energy.

4.4. Chapter Conclusion

In conclusion, using both qualitative and quantitative research methods together helps to overcome the drawbacks of each method. To achieve the most reliable outcomes, the second procedure covers the gaps left by the first. The chosen methods organized the approach to be employed and served as an inspiration for further analysis and data gathering. The right building techniques, materials, opening ratios and construction techniques that reduce energy usage, can be obtained by using this process. Additionally, employing these various techniques enables us to identify the energy consumption in the residential units of contemporary development in a coastal area allowing the thesis's objectives to be addressed and examined.

5. Analysis of buildings openings, materials and construction techniques in Ghazir

5.1. Introduction

The methods used to conduct the analysis and reach the conclusions will be discussed in this chapter. Following the analysis of the old house in chapter three, a further study, will be executed with detailed construction drawings, simulations and calculations that will be compared to a current building with an emphasis on the opening's ratio, materials and construction techniques. Therefore, a study will be conducted on a new residential development following contemporary architecture methods and construction techniques, targeting the socio-economic middle class. The selected project will be Admir. Located at an altitude of three hundred fifty meters above sea level and has the same orientation as the old house. The current state of both projects will be presented in the next section. The observation of the orientation, materials used in this area, and construction techniques, will assist in the construction of an accurate model with accurate factual numbers that will be covered in the third section. In these models, climatic factors will be analyzed, window-to-wall ratios (WWR) will be calculated, and simulations will be run to validate the calculations and objectives of this thesis in the fourth section. All these will help us draw a clear conclusion about the factors that affect energy consumption.

5.2. Ghazir's old House and Admir observation

As mentioned in the third chapter, the old house is located in Ghazir at an altitude of three hundred sixty meters above sea level and a sixty degrees rotation angle (Figure 5.1). Admir is three hundred fifty meters above sea level with the same rotation angle as the old House (Figure 5.2). The construction of the old house began in 1910, whereas Admir started in 2015. Therefore there is a clear difference in the construction techniques and materials that we will analyze in the following sections. However, the construction date and age of the materials, won’t be numerical factors considered in the simulation process of the two case studies.

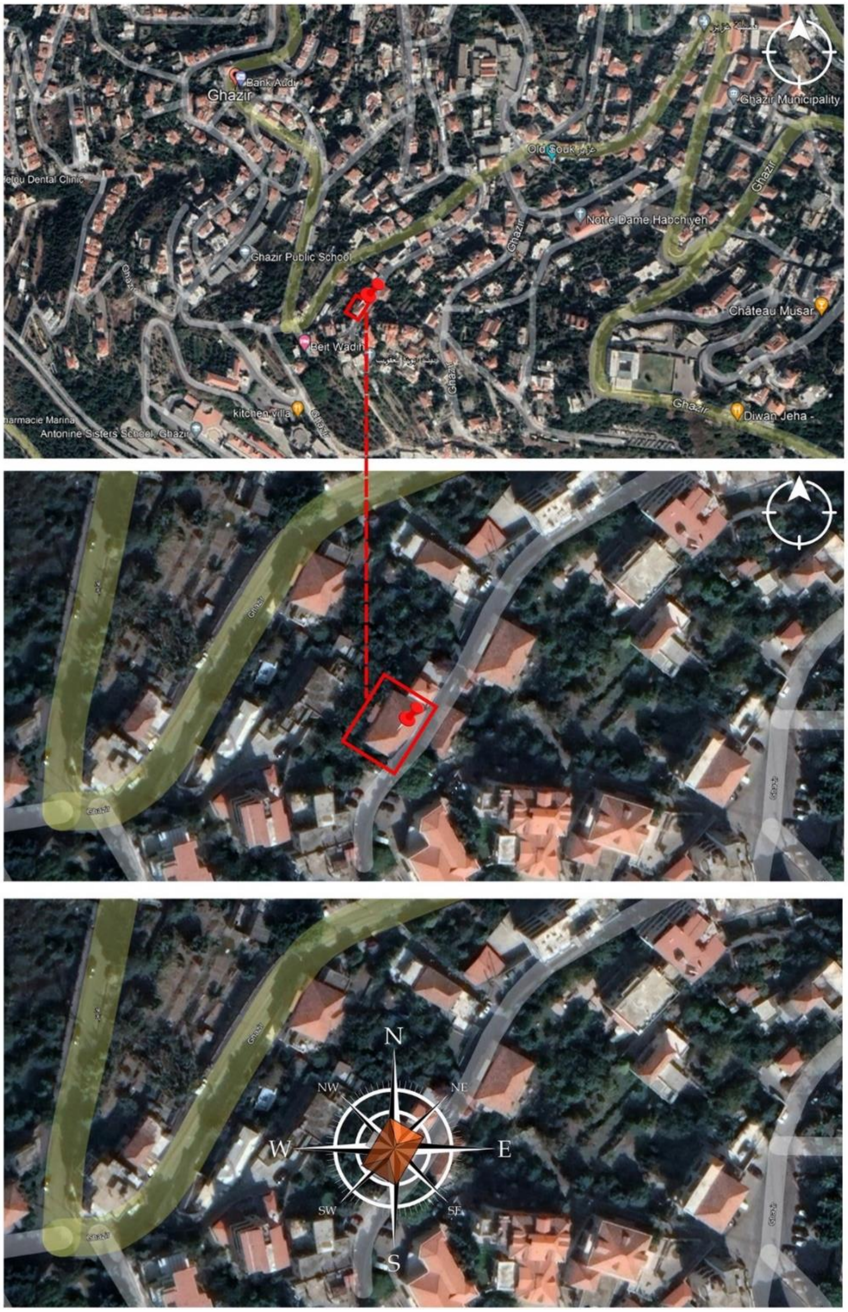


Figure 5.1: Old house location and orientation- Ghazir

Source: Google Earth and Author

Figure 5.2: Admir location and orientation- Ghazir

Source: Google Earth and Author

The focus area's building materials will be identified using the observation approach. To identify the construction materials used for further simulations, a site inspection was conducted in Ghazir area. The main old house’s materials found are stone, wood, glass, concrete and clay roof tiles, as shown in the drawings below (Figure 5.3; Figure 5.4). On the other hand, in Admir, the materials detected are concrete, ceramic tiles, glass and aluminum (Figure 5.5; Figure 5.6).

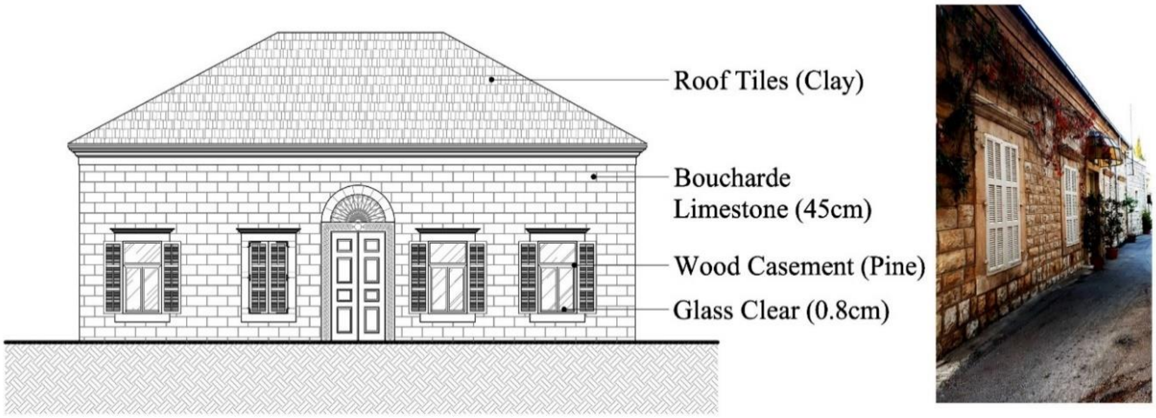


Figure 5.3: Main Elevation Drawing with materials and image of the Old house - Ghazir

Source: Author

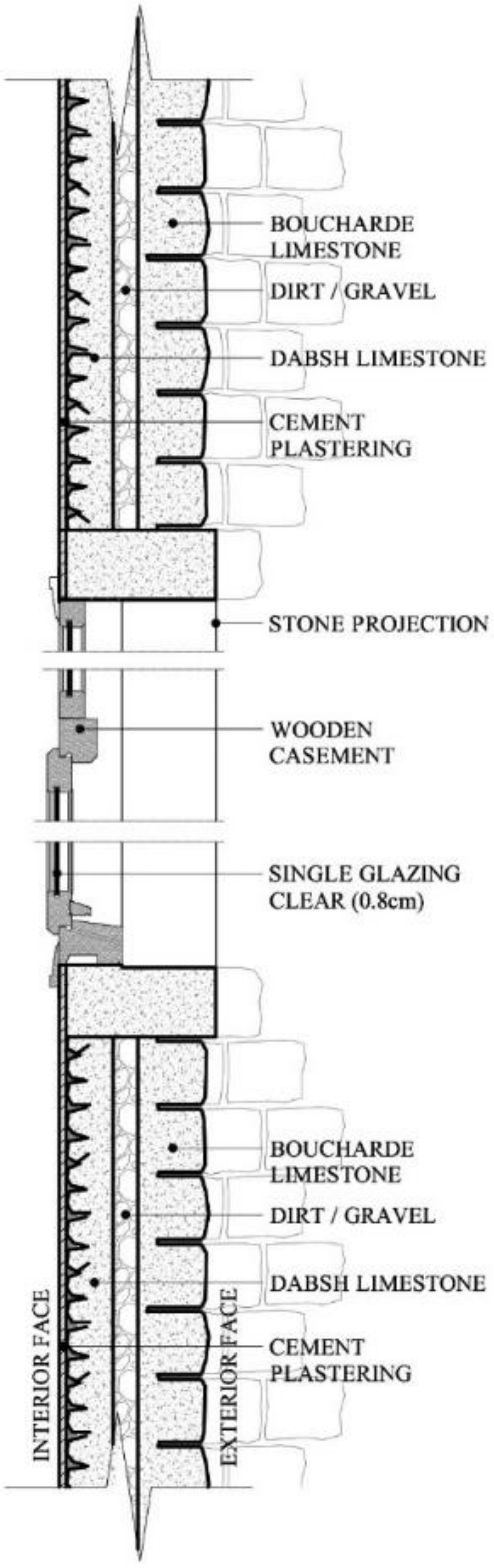


Figure 5.4: Wall section Drawing with materials of the Old house - Ghazir

Source: Author

Figure 5.5: Main Elevation Drawing with materials and image of Admir - Ghazir

Source: Author

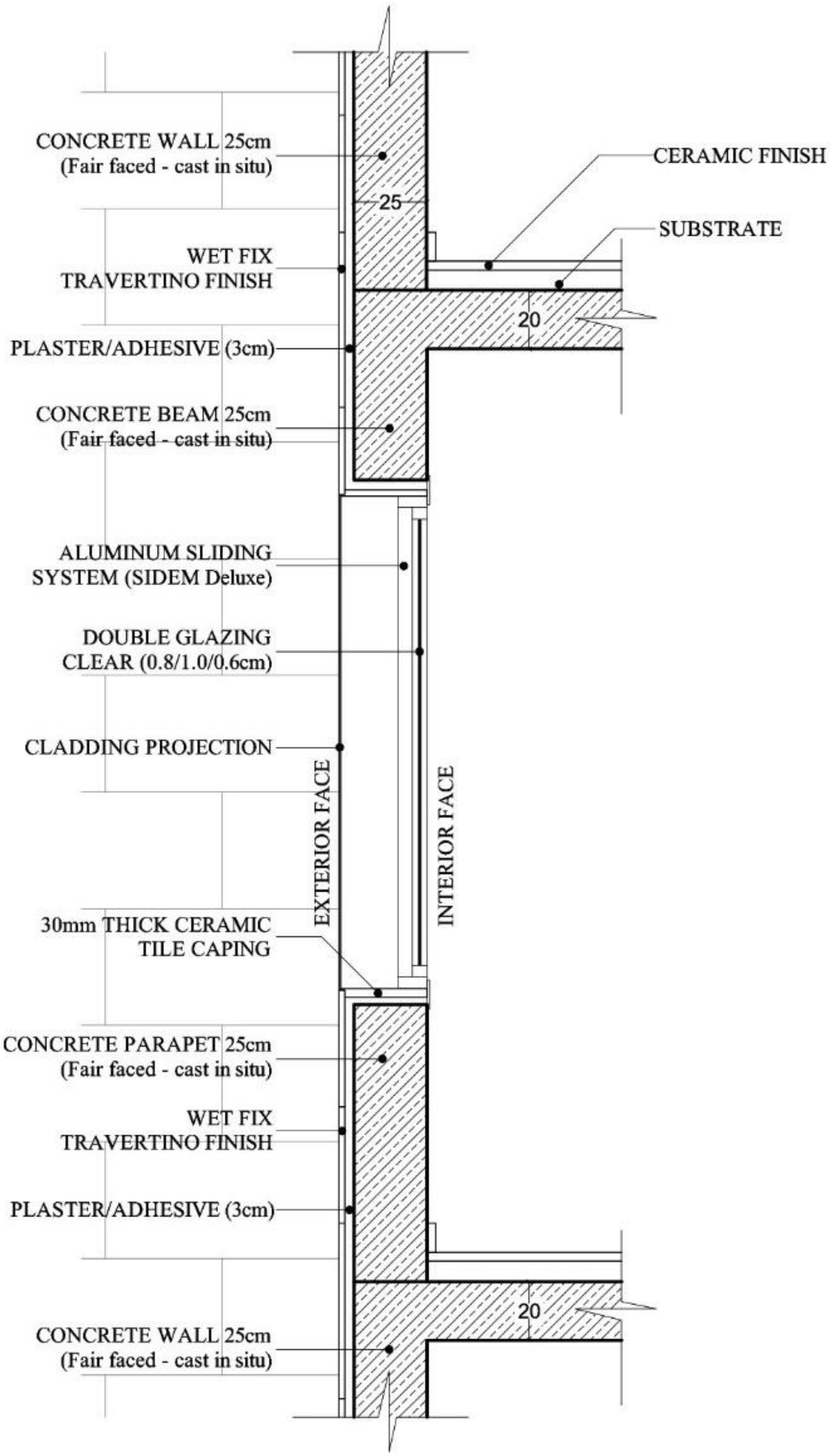
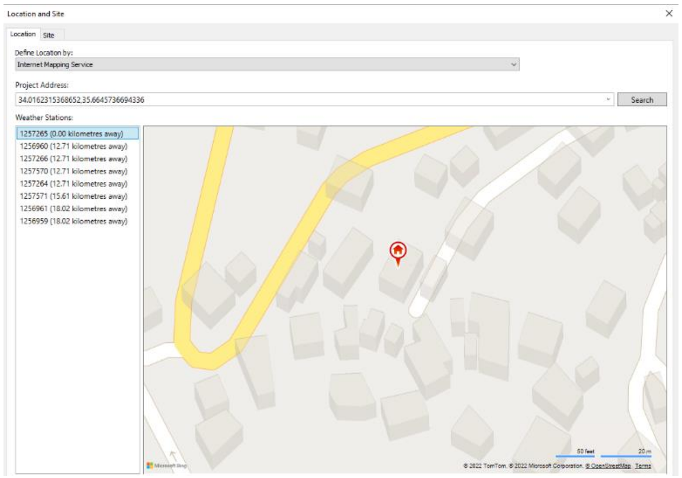


Figure 5.6: Wall section with materials of Admir - Ghazir

Source: Author

5.3. Ghazir’s old House and Admir Modeling, and Construction

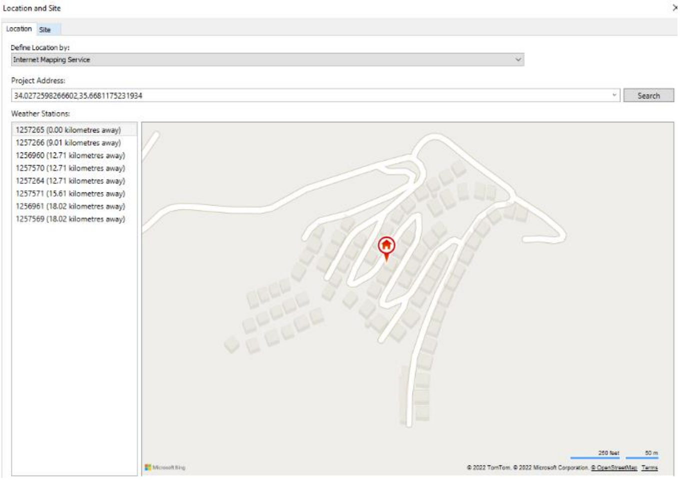
After the data was gathered from the observation and measurements of the old house taken on-site to be able to replicate it, the construction was done using Revit Autodesk 2023 software. Each project’s location and weather data file for the analysis period is obtained from the nearest weather station (Figure 5.7). The data obtained from observations made on the materials used for external building envelopes, determines the choice of building materials for each scenario. Their specific properties (Table 5.1), along with the construction techniques presented in the below wall sections (Figure 5.8), were determined following the observation and the data from the literature review chapter.



Define Location by: Internet Mapping Service

Project Address: 34.0162315368652,35.6645736694336

Weather Stations:
1257265 (0.00 kilometres away)
1256960 (12.71 kilometres away)
1257266 (12.71 kilometres away)
1257570 (12.71 kilometres away)
1257264 (12.71 kilometres away)
1257571 (15.61 kilometres away)
1256961 (18.02 kilometres away)
1256959 (18.02 kilometres away)



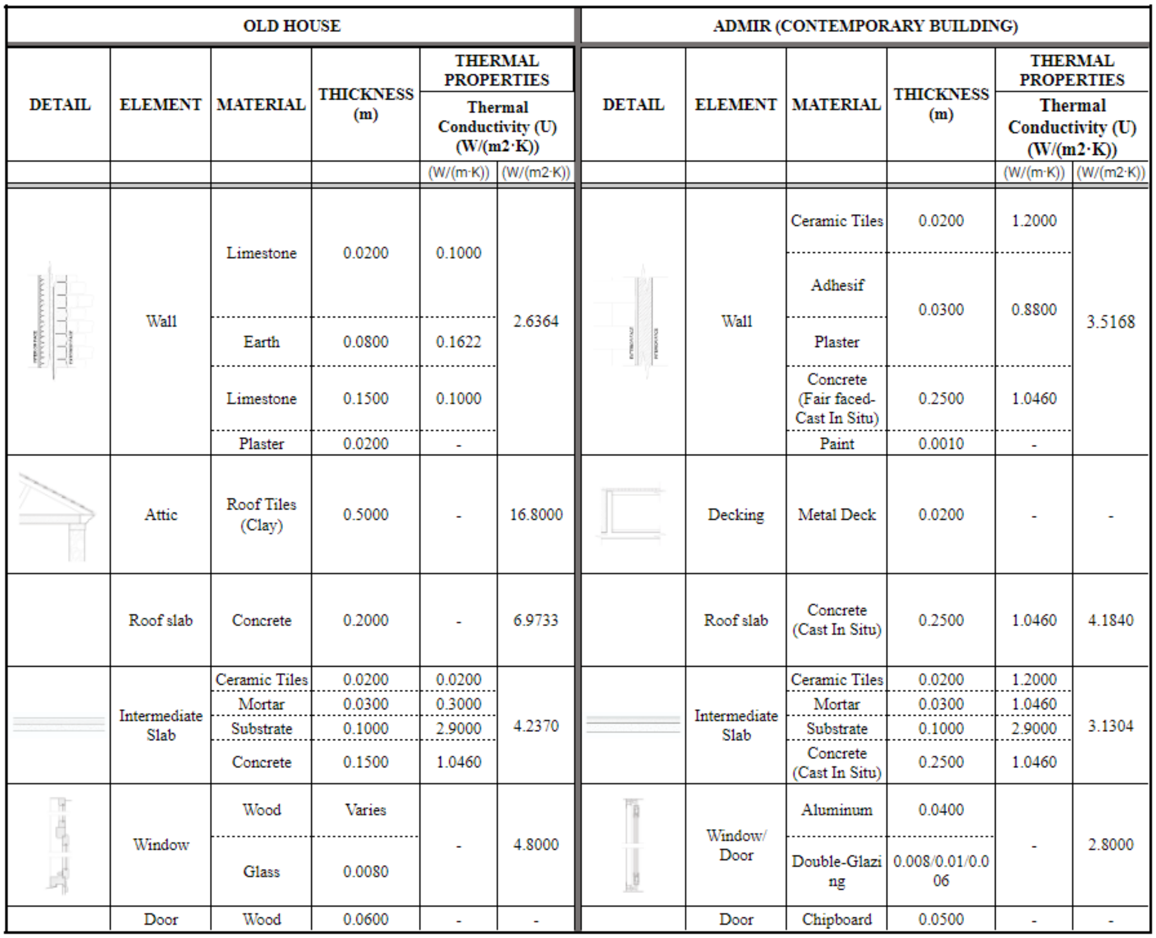
Define Location by: Internet Mapping Service

Project Address: 34.0272598266602,35.6681175231934

Weather Stations:
1257265 (0.00 kilometres away)
1257266 (9.01 kilometres away)
1256960 (12.71 kilometres away)
1257570 (12.71 kilometres away)
1257264 (12.71 kilometres away)
1257571 (15.61 kilometres away)
1256961 (18.02 kilometres away)
1257569 (18.02 kilometres away)

Figure 5.7: Locations and Weather Stations set in Revit for the old house and Admir.

Source: Author



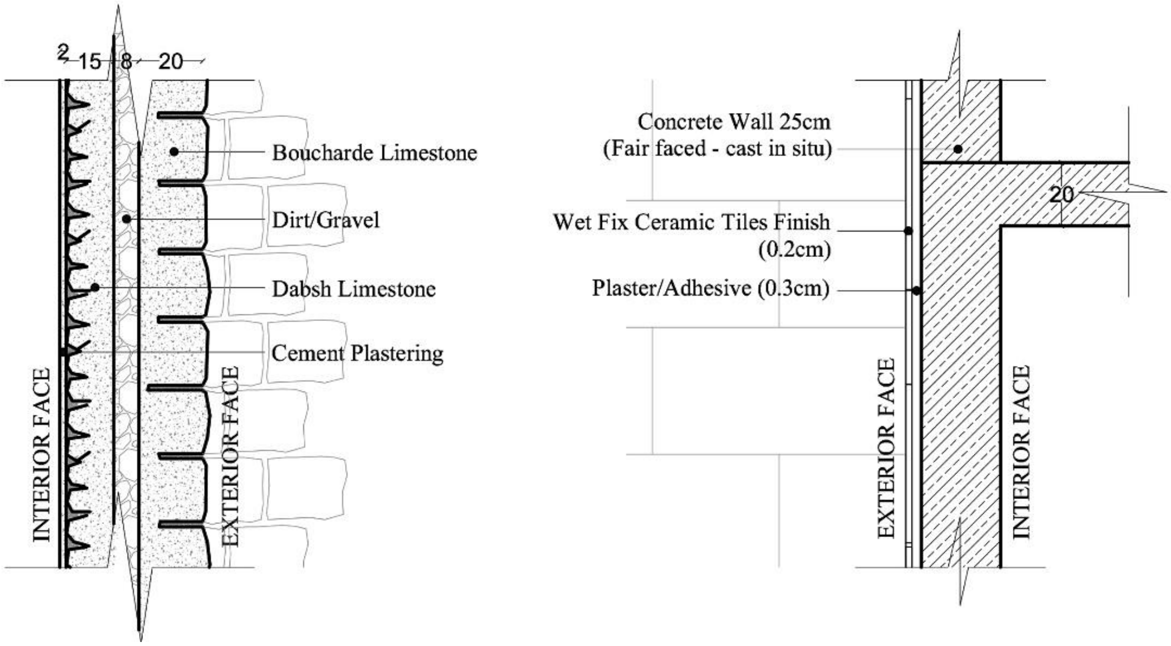
OLD HOUSE					
DETAIL	ELEMENT	MATERIAL	THICKNESS (m)	THERMAL PROPERTIES	
				Thermal Conductivity (U) (W/(m2·K))	
				(W/(m·K))	(W/(m2·K))
	Wall	Limestone	0.0200	0.1000	2.6364
		Earth	0.0800	0.1622	
		Limestone	0.1500	0.1000	
		Plaster	0.0200	-	
	Attic	Roof Tiles (Clay)	0.5000	-	16.8000
	Roof slab	Concrete	0.2000	-	6.9733
	Intermediate Slab	Ceramic Tiles	0.0200	0.0200	4.2370
		Mortar	0.0300	0.3000	
		Substrate	0.1000	2.9000	
		Concrete	0.1500	1.0460	
	Window	Wood	Varies	-	4.8000
		Glass	0.0080		
	Door	Wood	0.0600	-	-

ADMIR (CONTEMPORARY BUILDING)					
DETAIL	ELEMENT	MATERIAL	THICKNESS (m)	THERMAL PROPERTIES	
				Thermal Conductivity (U) (W/(m2·K))	
				(W/(m·K))	(W/(m2·K))
	Wall	Ceramic Tiles	0.0200	1.2000	3.5168
		Adhesif	0.0300	0.8800	
		Plaster			
		Concrete (Fair faced-Cast In Situ)	0.2500	1.0460	
		Paint	0.0010	-	
	Decking	Metal Deck	0.0200	-	-
	Roof slab	Concrete (Cast In Situ)	0.2500	1.0460	4.1840
	Intermediate Slab	Ceramic Tiles	0.0200	1.2000	3.1304
		Mortar	0.0300	1.0460	
		Substrate	0.1000	2.9000	
		Concrete (Cast In Situ)	0.2500	1.0460	
	Window/ Door	Aluminum	0.0400	-	2.8000
		Double-Glazing	0.008/0.01/0.006		
	Door	Chipboard	0.0500	-	-

Table 5.1: Comparative table showing the materials used in the construction in Revit software, their thickness and thermal properties in the Old house and in Admir.

Source: Author

We can see from the table above that the wall of the old house composed of limestone, earth, limestone, and plaster, with a U value of 2.6364 W/(m2*k), has a lower U value than Admir's wall of 3.5168 W/(m2*k) composed from ceramic tiles, plaster, and adhesive, cast in place concrete and paint. The lower the U value, the less energy will be required to get the occupants at a comfortable thermal level. The thickness of the concrete in the slabs, which are built of the same materials composition, affects their U values; the slab U value of the old house is 4.2370 W/(m2*k), while that of Admir is 3.1304 W/(m2*k). The configuration varies in windows. The windows in the old house have wood frames whilst Admir's windows have aluminum frames. In the case of the old house, the single clear glazing has a U value of 4.800W/(m2*k); however, in Admir's case, the double clear glazing has a U value of 2.800 W/(m2*k).

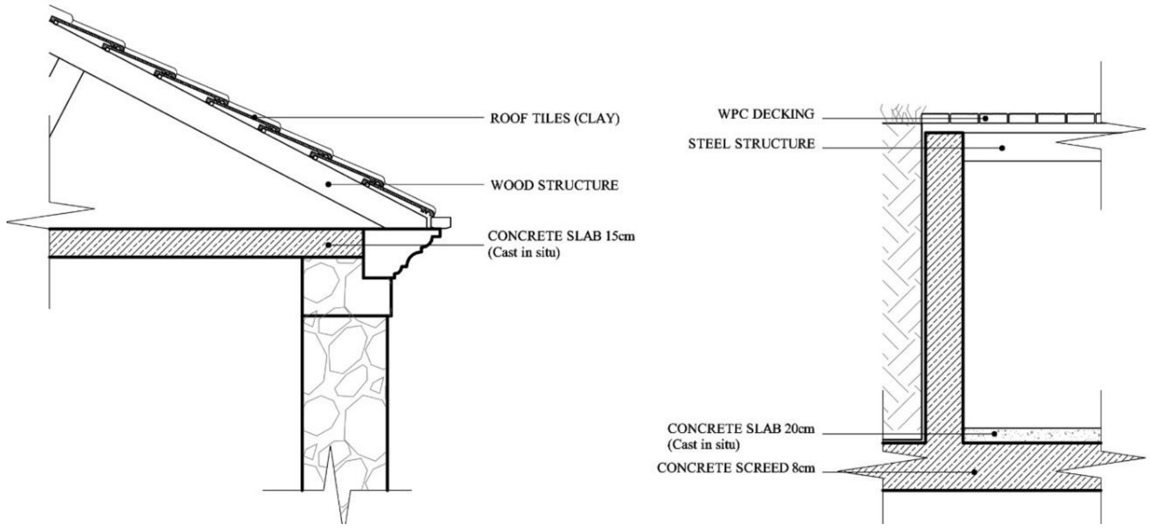


Old House Wall Section

Admir Wall Section

Figure 5.8: Wall Section details of the Old house and Admir.

Source: Author

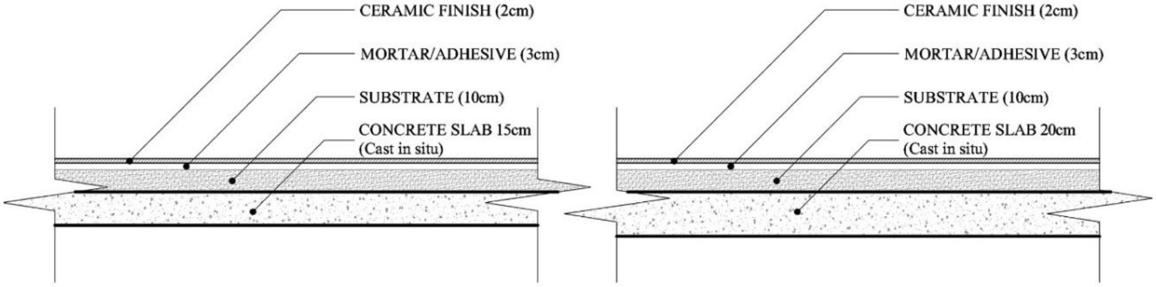


Old House Attic detail

Admir Decking detail

Figure 5.9: Roof Section details of the Old house and Admir.

Source: Author

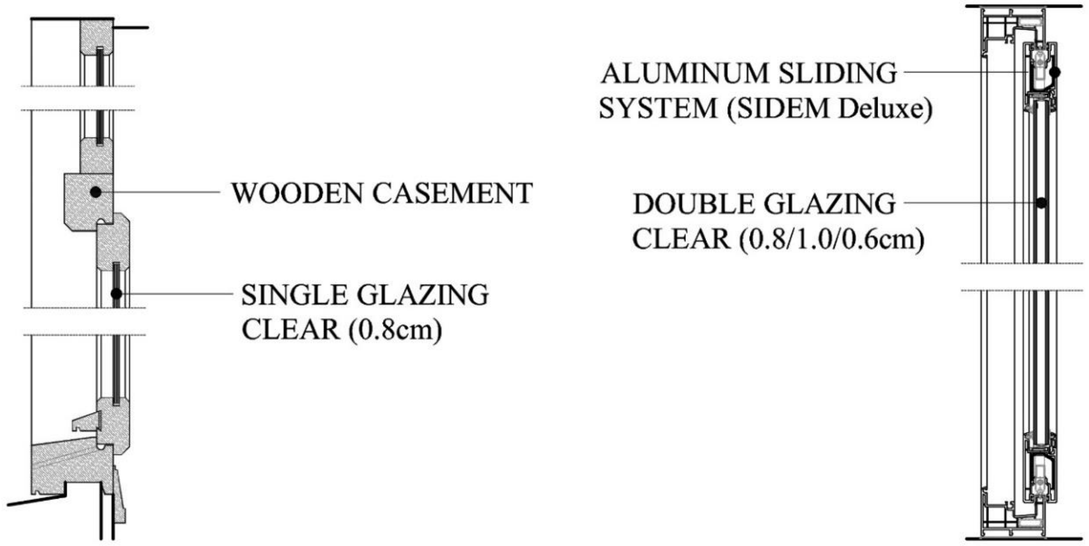


Old House Slab detail

Admir Slab detail

Figure 5.10: Slab Section details of the Old house and Admir.

Source: Author



Old House Window detail

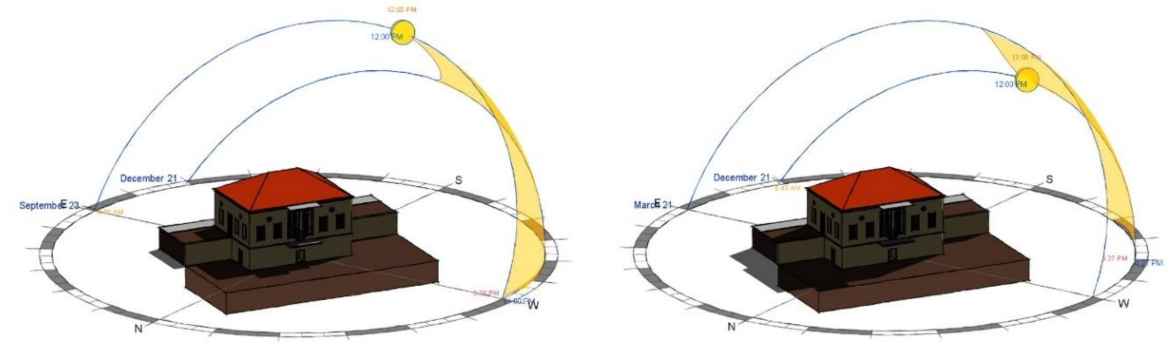
Admir Window detail

Figure 5.11: Window Section details of the Old house and Admir.

Source: Author

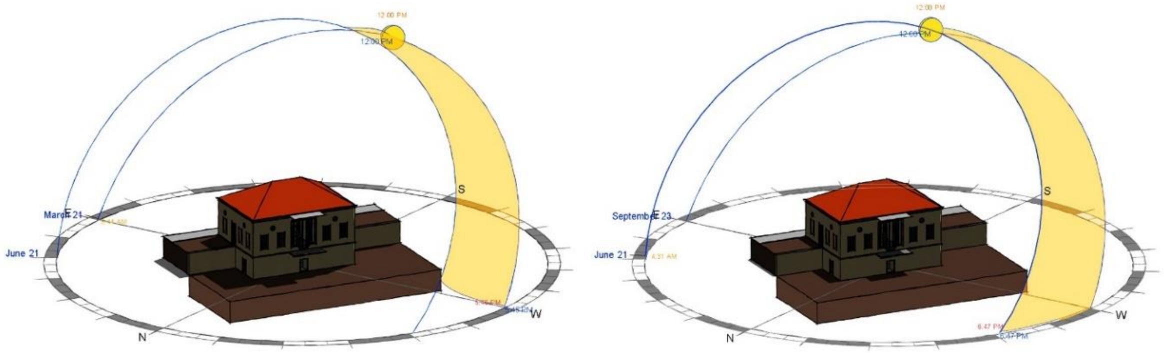
5.4. Ghazir's old House and Admir Energy Simulation

After a thorough assessment of the research on building materials, their thermal performance, and how this affected the amount of energy consumed in the literature chapter, we conclude that the thermal performance of each project in the specific location cannot be indicated rather it must be simulated. Since the comparison between all of these construction materials, and their combinations depends on the specific climate and location of the house. The two scenarios are similar in terms of, the studied area, elevation above sea level, weather, and orientation. Each scenario's location, construction materials combination, and techniques are different from the others. Following the construction, simulations were done using Insight 360 (Autodesk), a Revit related online tool, that produces an energy model for each scenario, as it relates to the energy analysis. The online tool Green Building Studio exports energy reports and displays energy consumption that will allow us to assess the energy demand and consumption.



Fall Sun Path

Winter Sun Path

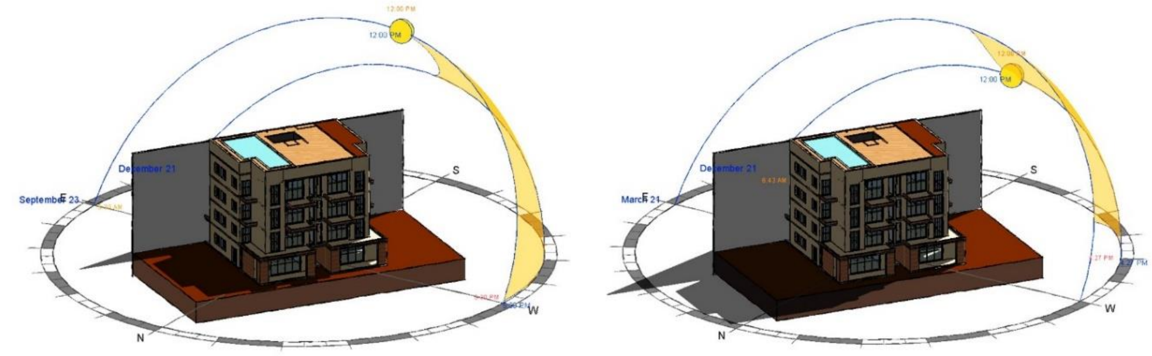


Spring Sun Path

Summer Sun Path

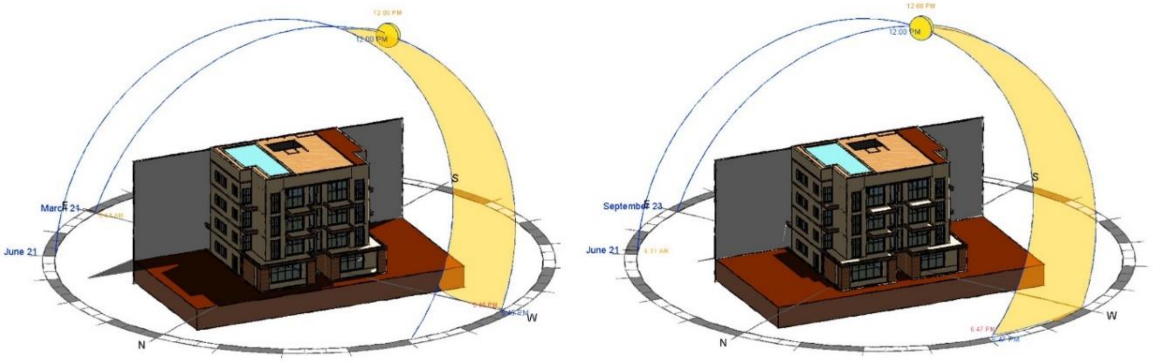
Figure 5.12: Solar path in the four seasons of the Old House - Ghazir

Source: Author



Fall Sun Path

Winter Sun Path



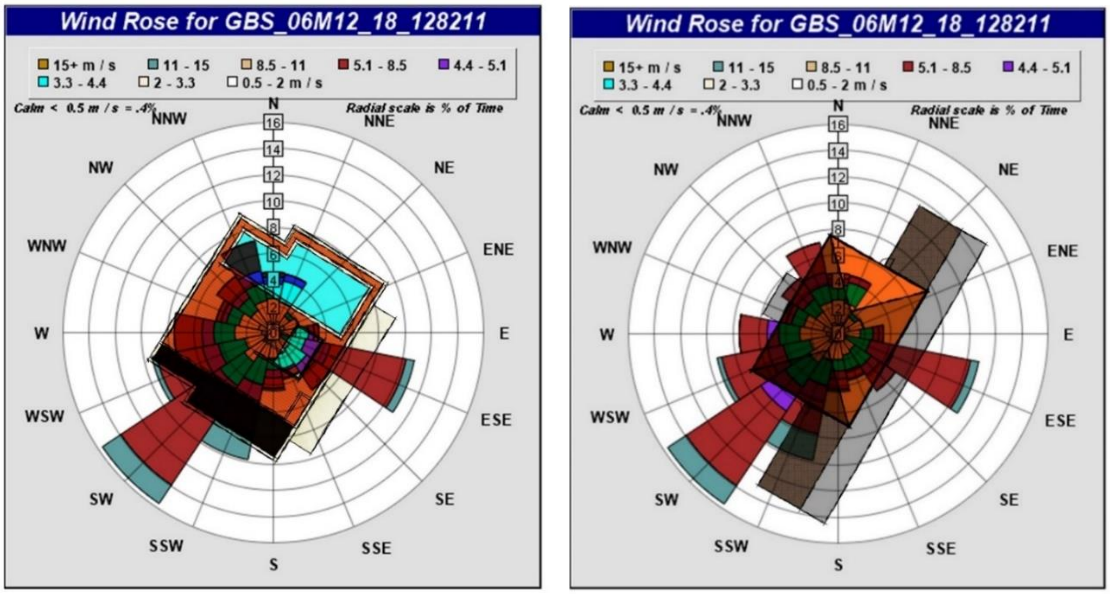
Spring Sun Path

Summer Sun Path

Figure 5.13: Solar path in the four seasons of Admir - Ghazir

Source: Author

In reference to the solar pathways shown above, we can see that both scenarios rotated at an angle of sixty degrees to the north, the North-Western facade receives almost no sunlight, particularly during the early-setting winter months. While the South-Eastern and South-Western facades are better exposed and receive direct sunlight in the morning and afternoon, respectively. The North-Eastern facades receive no sunlight at all. All exposure is influenced by the position of the sun's path, which varies from season to season and is lowest in winter and highest in summer.



Old House- Ghazir

Admir- Ghazir

Figure 5.14: Mass plan overlapping the wind rose showing the wind direction in the old house on the left and in Admir on the right- Ghazir

Source: Author

Windows have a big impact on a building's efficiency; they affect the demand for heating and thermal comfort. The ratio of an exterior wall that consists of windows, is referred to as the window-to-wall ratio (WWR) (Troups et al. 2019). An actual physical link between the indoors and the outdoors is referred to as fenestration. It is referred to as a way to let solar radiation into space through natural light and also to facilitate heat gain into space (Ashrae, 2017). Therefore, it is a crucial component to take into consideration during the design process.

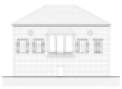
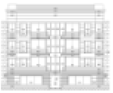
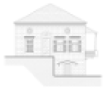
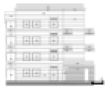
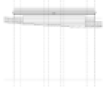
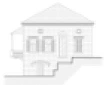
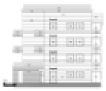
	OLD HOUSE				ADMIR (CONTEMPORARY BUILDING)			
	Elevation Drawing	**Gross Façade Area**	**Openings' Total Area**	**WWR**	**Elevation Drawing**	**Gross Façade Area**	**Openings' Total Area**	**WWR**
NW Façade		122	26.3	21.6%		286	131.8	46.1%
NE Façade		69	14.9	21.6%		252	53.15	21.1%
SE Façade		76	18.1	23.8%		68	0	0.0%
SW Façade		72	16.2	22.5%		252	53.15	21.1%

Table 5.2: Comparative table showing the calculations of the Window to Wall Ratio (WWR) of the Old house and Admir.

Source: Author

The main facade of Admir, which faces North-West, has a significantly higher percentage of 46.1% than the Old House, which has a percentage of 21.6%, as can be seen in the above table comparing the WWR values of the two scenarios. This is where the amount of glazing surface should be compensated by the type of glass selected to maintain an average level of thermal comfort and energy consumption. The North-East and South-West facade have a close percentage; where in the first facade, the old house has a value of 31.6% and Admir 21.1%; while in the second facade, the old house has 22.5% as WWR and Admir 21.1%. Since Admir's South-East facade is totally blocked with no openings, it cannot be compared.

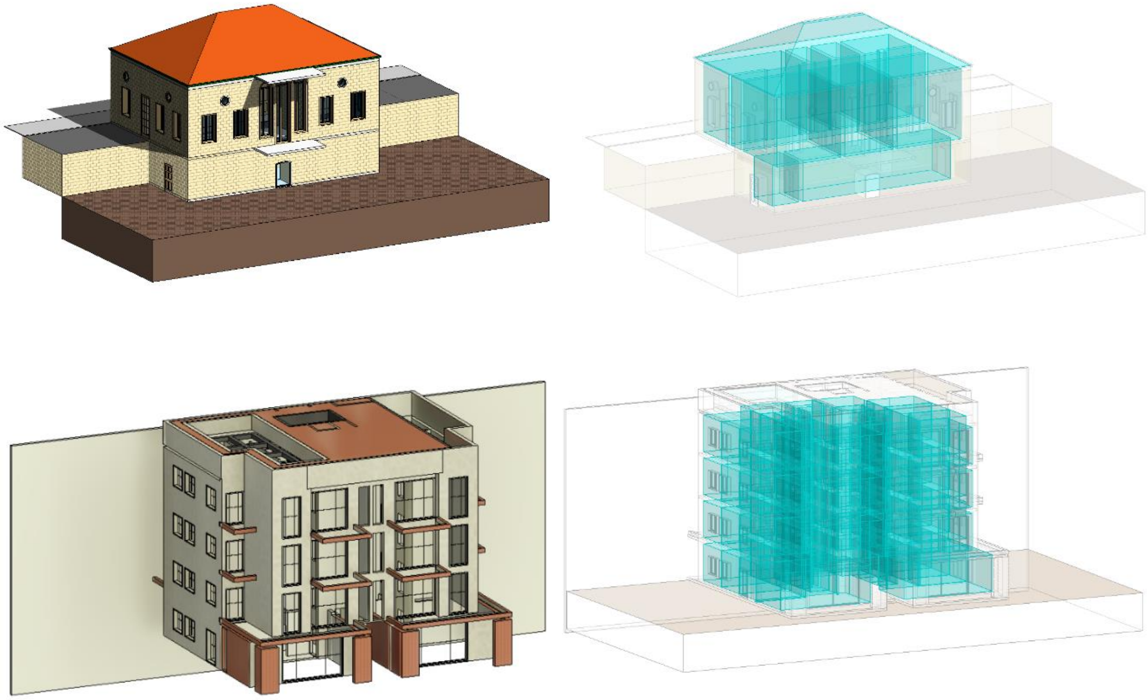
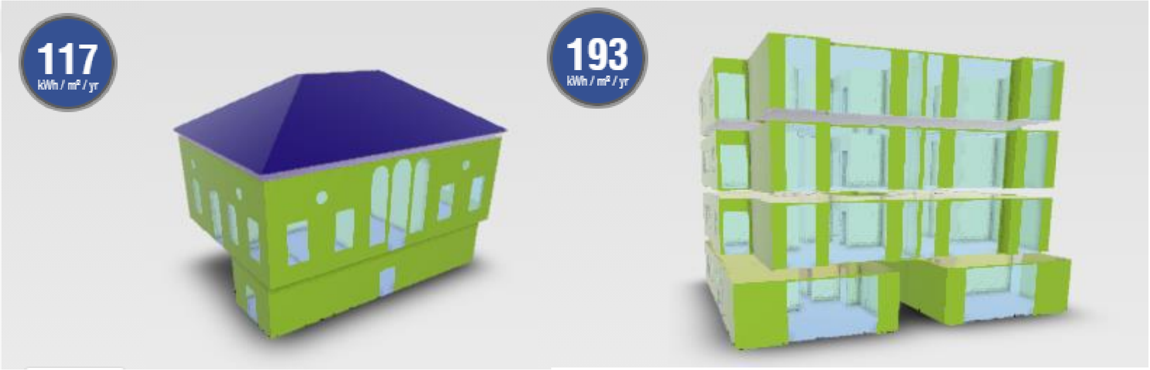


Figure 5.15: Analytical Spaces created by Revit software on the two scenarios.

Source: Author

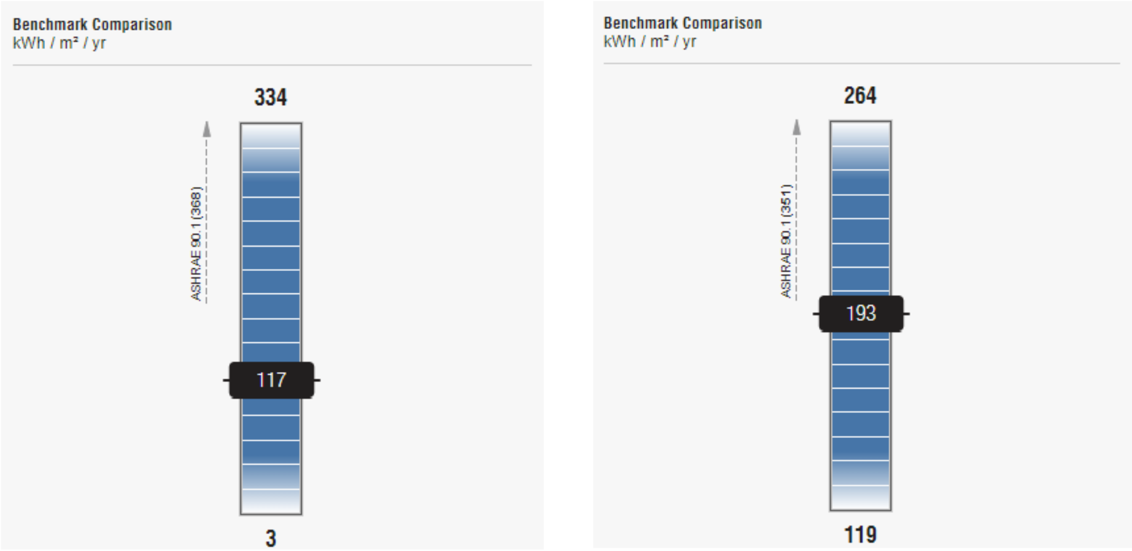


Old House- Ghazir

Admir- Ghazir

Figure 5.16: The two scenarios simulated using the Insight 360 software, which displayed the annual energy consumption per square meter.

Source: Author

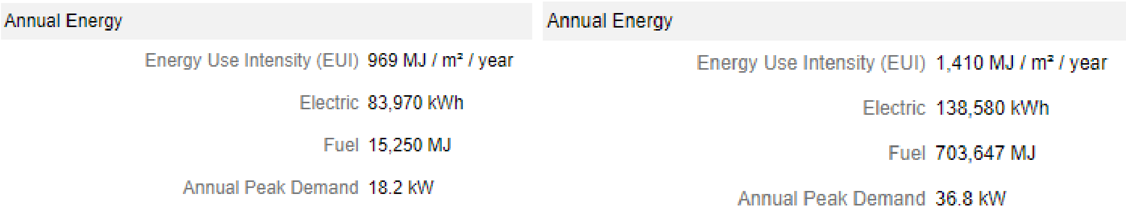


Old House- Ghazir

Admir- Ghazir

Figure 5.17: The energy consumption value with the benchmark comparison of the two scenarios generated by Insight 360 software.

Source: Author



Annual Energy

Energy Use Intensity (EUI)	969 MJ / m² / year
Electric	83,970 kWh
Fuel	15,250 MJ
Annual Peak Demand	18.2 kW

Annual Energy

Energy Use Intensity (EUI)	1,410 MJ / m² / year
Electric	138,580 kWh
Fuel	703,647 MJ
Annual Peak Demand	36.8 kW

Old House- Ghazir

Admir- Ghazir

Figure 5.18: The annual energy consumption value of the two scenarios generated by Green Building Studio online tool.

Source: Author

After receiving the two scenarios' analytical spaces from the Revit software, Insight 360 analysis provided the energy usage for each scenario. Compared to Admir, which consumes 193 KWh/m2/year, the Old House requires 117 KWh/m2/year (Figure 5.16).

The annual consumption values of the two scenarios were provided to us by the online tool of the green building studio. The Old House uses 83970 kWh of electricity, while Admir uses 138580 KWh, almost twice as much as the Old House does (Figure 5.18). The construction methods used in contemporary architecture are faster, less time-consuming, and less expensive than the previous materials used in vernacular construction, which explains the difference in numbers. They compromise energy consumption and thermal comfort since aesthetics play a significant part without taking the opening's ratio, WWR, into account.

5.5. Conclusion

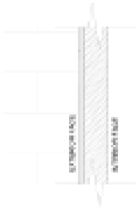
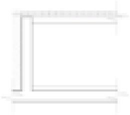
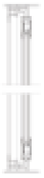
The observation of the Old House and Admir, both in Ghazir, with the same orientation and similar altitude, provided information on the construction methods, materials, and opening ratio. We were able to move forward with a complete comparative study according to the results of the energy modelling simulations and calculations. The outcomes of the two scenarios evaluated how the mentioned elements above would affect energy consumption.

Section 6: Optimization

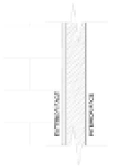
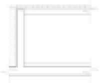
Following the comparison between the Old House and Admir conducted in the preceding chapter, the differences between the two were evident in terms of U-value and energy usage. The optimization of the materials used will be performed since the orientation and opening ratio of the already constructed buildings cannot be modified while causing the least amount of harm to the existing skeleton. The objective of this chapter is to find the optimal material combinations of a house for the walls, slabs, and glass to reach values *(in terms of thermal conductivity- U value)* authentic to Lebanese Vernacular house materials values that adhered to passive strategies. The next step will be to integrate active strategies to get as near to Net Zero as possible and accomplish the thesis' main goal.

6.1. Optimization with passive strategies- Buildings materials and techniques

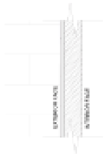
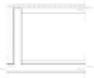
Using the model previously constructed using the Revit Autodesk 2023 software, the optimization process began by changing the building materials of the facade walls. Along with the building techniques shown in the below wall sections (Figure 6.1; Figure 6.2; Figure 6.3) and their specific properties listed in the table below (Table 6.1).

ADMIR (CONTEMPORARY BUILDING)					
DETAIL	**ELEMENT**	**MATERIAL**	**THICKNESS (m)**	**THERMAL PROPERTIES**	
				Thermal Conductivity (U) (W/(m2·K))	
				(W/(m·K))	(W/(m2·K))
	Wall	Ceramic Tiles	0.0200	1.2000	3.5168
		Adhesif	0.0300	0.8800	
		Plaster			
		Concrete (Fair faced-Cast In Situ)	0.2500	1.0460	
		Paint	0.0010	-	
	Decking	Metal Deck	0.0200	-	-
	Roof slab	Concrete (Cast In Situ)	0.2500	1.0460	4.1840
	Intermediate Slab	Ceramic Tiles	0.0200	1.2000	3.1304
		Mortar	0.0300	1.0460	
		Substrate	0.1000	2.9000	
		Concrete (Cast In Situ)	0.2500	1.0460	
	Window/ Door	Aluminum	0.0400	-	2.8000
		Double-Glazing	0.008/0.01/0.006		
	Door	Chipboard	0.0500	-	-

ADMIR OPTIMIZATION (Scenario 1)

DETAIL	ELEMENT	MATERIAL	Cost ($/sqm)	Total Cost ($/sqm)	THICKNESS (m)	THERMAL PROPERTIES	
						Thermal Conductivity (U) (W/(m2·K))	
						(W/(m·K))	(W/(m2·K))
	Wall	Paint	0.50 - 1.00	9.5 - 14	0.0200	-	0.5676
		Plaster	4.00 - 5.00		0.0300	0.8800	
		Mesh			0.0020	-	
		EPS	5.00 - 8.00		0.0500	0.1200	
		Original Wall	-		0.3000	3.5168	
	Decking	Metal Deck	-	-	0.0200	-	-
	Roof slab	Screed	18.00 - 20.00	23 - 28	0.1000	1.0460	0.3133
		EPS	5.00 - 8.00		0.1000		
		Concrete (Cast In Situ)	-		0.2500	1.0460	
	Intermediate Slab	Ceramic Tiles	-	-	0.0200	1.2000	3.1304
		Mortar			0.0300	1.0460	
		Substrate			0.1000	2.9000	
		Concrete (Cast In Situ)			0.2500	1.0460	
	Window/ Door	Aluminum	-	-	0.0400	-	1.9000
		Argon Double-Glazing Low-E		13.90 - 15.00 $	0.008/0.01/0.006		
	Door	Chipboard	-	-	0.0500	-	-

ADMIR OPTIMIZATION (Scenario 2)

DETAIL	ELEMENT	MATERIAL	Cost ($/sqm)	Total Cost ($/sqm)	THICKNESS (m)	THERMAL PROPERTIES Thermal Conductivity (U) (W/(m2·K))	
						(W/(m·K))	(W/(m2·K))
	Wall	Ceramic Tiles (Mechanical Fixation)	20.00 - 30.00 $	25.5 - 39	0.0200	1.2000	0.3199
		Air gap	-		0.0300		
		Radiant Heat Barrier	0.50 - 1.00 $		0.0035	0.2500	
		EPS	5.00 - 8.00 $		0.0500	0.1200	
		Original Wall	-		0.3000	3.5168	
	Decking	Metal Deck	-	-	0.0200	-	-
	Roof slab	Screed	18.00 - 20.00 $	23 - 28	0.1000	1.0460	0.3133
		EPS	5.00 - 8.00 $		0.1000	0.1200	
		Concrete (Cast In Situ)	-		0.2500	1.0460	
	Intermediate Slab	Ceramic Tiles	-	-	0.0200	1.2000	3.1304
		Mortar			0.0300	1.0460	
		Substrate			0.1000	2.9000	
		Concrete (Cast In Situ)			0.2500	1.0460	
	Window/ Door	Aluminum	-	600 - 1200$ per window	0.0400	-	1.4000
		Argon Triple-Glazing Low-E			Varies		
	Door	Chipboard	-	-	0.0500	-	-

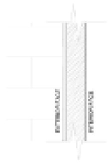
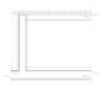
ADMIR OPTIMIZATION (Scenario 3)							
DETAIL	ELEMENT	MATERIAL	Cost ($/sqm)	Total Cost ($/sqm)	THICKNESS (m)	THERMAL PROPERTIES Thermal Conductivity (U) (W/(m2·K))	
						(W/(m·K))	(W/(m2·K))
	Wall	Ceramic Tiles (Mechanical Fixation)	20.00 - 30.00 $	45.5 - 61	0.0200	1.2000	0.1895
		Radiant Heat Barrier + Air Gap	0.50 - 1.00 $		0.0300	0.2500	
		EPS	5.00 - 8.00 $		0.0500	0.1200	
		Aerated Concrete	20.00 - 22.00 $		0.0500	0.5100	
		Original Wall	-		0.3000	3.5168	
	Decking	Metal Deck	-	-	0.0200		
	Roof slab	Aerated Concrete	20.00 - 22.00 $	25 - 30	0.1000	0.5100	0.2799
		EPS	5.00 - 8.00 $		0.1000	0.1200	
		Concrete (Cast In Situ)	-		0.2500	1.0460	
	Intermediate Slab	Ceramic Tiles	-	-	0.0200	1.2000	3.1304
		Mortar			0.0300	1.0460	
		Substrate			0.1000	2.9000	
		Concrete (Cast In Situ)			0.2500	1.0460	
	Window/ Door	Aluminum	-	1500 - 3000 $ per window	0.0400	-	0.5100
		Xenon Quintuple-Glazing Very Low-E			Varies		
	Door	Chipboard	-	-	0.0500	-	-

Table 6.1: Comparative table showing the materials used in the construction in Revit software, their thickness, and thermal properties of Admir's current state and the three scenarios optimized.

Source: Author

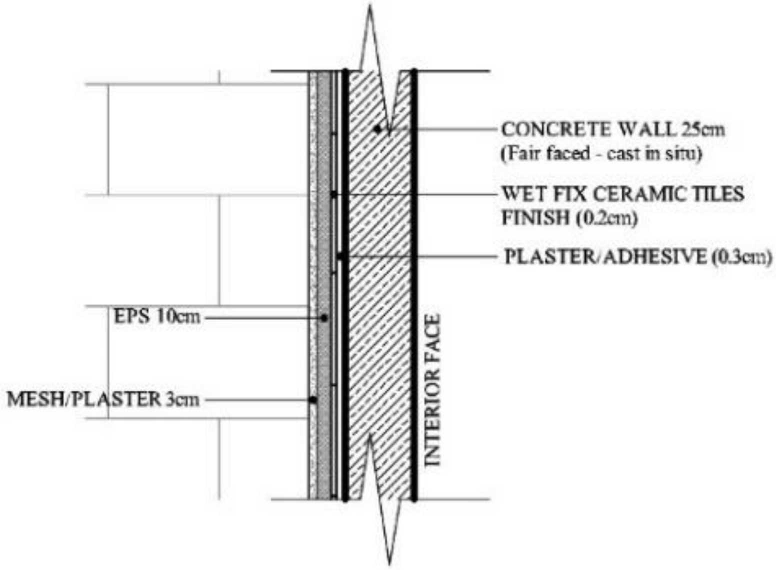
The materials used for construction in Admir's current state are listed in the table above (Table 6.1) along with their thickness and U value, as we saw in the previous chapter. Following is a classification of the three other scenarios that were optimized: Cost-effective scenario 1 with a lower U value than scenario zero (the original). The second scenario is upgraded from scenario 1 in terms of optimization and will eventually have a lower U value. The third scenario, which has a higher material cost and a lower U value, is the most optimized one. All three scenarios have their materials as variables; their layering as the details below shows (Figure 6.1; Figure 6.2; Figure 6.3), with their thickness and thermal properties.

Comparing the walls where their materials layering is shown in the below detailed wall sections (Figure 6.1): In scenario zero, the wall is made of fair-faced concrete, paint, adhesive and plaster, and ceramic tiles, with a total thickness of 0.3 meters and a total U value of 3.5168 W/(m2K). In scenario 1, we added a 0.05 m EPS layer, a 0.002 m mesh layer, a 0.03 m plaster layer, and paint with a 0.02 m thickness to the already existing wall, resulting in a wall with a total U value of 0.5676 W/(m2K) significantly lower than scenario zero and an additional cost between 9.4 and 14$/sqm. For scenario 2, we added a 0.05 m EPS layer, a 0.0035 m radiant heat barrier, a 0.03 m air gap, and a 0.02 m mechanically fixed ceramic tiles layer to the previous wall, which had a total thickness of 0.3 m. With a value of 0.3199 W/(m2K), this wall composition provided us with a U value that is even lower than scenario 1 but higher in cost, between 25.5 and 39 $/sqm. In the third and last scenario, we added a 0.05m layer of aerated concrete, a 0.05m EPS layer, a 0.0035 m radiant heat barrier with an air gap and a 0.02 m mechanically fixed ceramic tiles layer to the previous wall, which had a total thickness of 0.3 m. With a value of 0.1895 W/(m2K), this wall composition provided us with a U value that is significantly lower than all the previous scenarios and significantly higher in cost with a price between 45.5 and 61$/sqm.

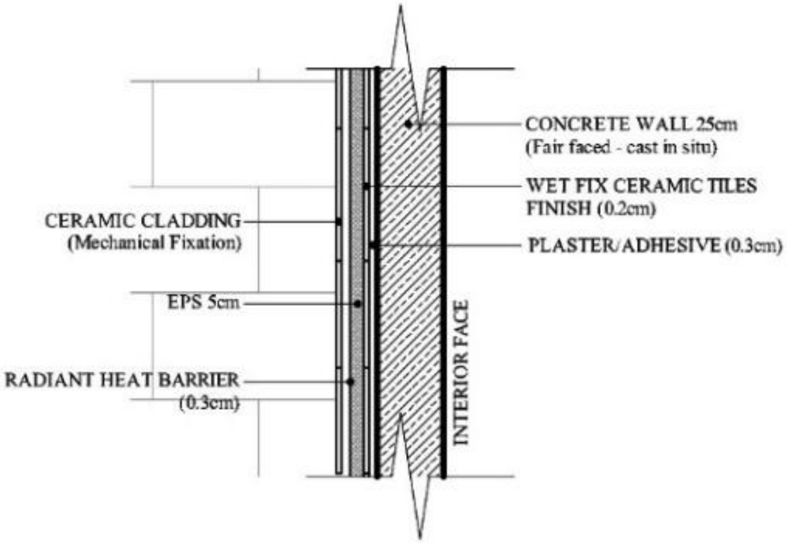
Comparing the roof slabs where their materials layering is shown in the below detailed sections (Figure 6.2): In scenario zero, the 0.25-meter-thick roof slab is constructed of cast-in-place concrete with a 4.1840 W/(m2K) U value. When a 0.1 m EPS and 0.1 m screed are added to the 0.25 m concrete slab in the first and second scenarios, the U value instantly dropped to 0.3133 W/m (m2K) but with an additional cost of 23 to 28$/sqm. In the third case, a 0.1 EPS layer and 0.1 aerated concrete layers are added to the 0.25 m concrete slab, giving us an even lower U value of 0.2799 W/m (m2K) and an even higher cost of 25 to 30$/sqm.

Comparing the windows where their composition is shown in the below detailed sections (Figure 6.3): With a total U value of 2.8 W/(m2K), the windows in scenario zero are made of aluminum and clear double-glazing glass. In the first scenario, low-E double-glazing argon-filled glass was upgraded, resulting in a total U value of 1.9 W/(m2K) with the aluminum frame and an additional cost between 13.5$/sqm and 15$/sqm. In the second scenario, an argon-filled window with an aluminum frame and low-E triple-glazing glass is used, and the window's U value is 1.4 W/(m2K), and the cost is between 600 and 1200$ per window element. The third and last scenario has an aluminum frame, Xenon-filled glass with quintuple-glazing, and very low-E, which allowed for a U value of 0.51 W/(m2K), which is significantly lower than all of the previous scenarios. On the other hand the price is much higher, with a window costing between $1500 and $3000 per unit.

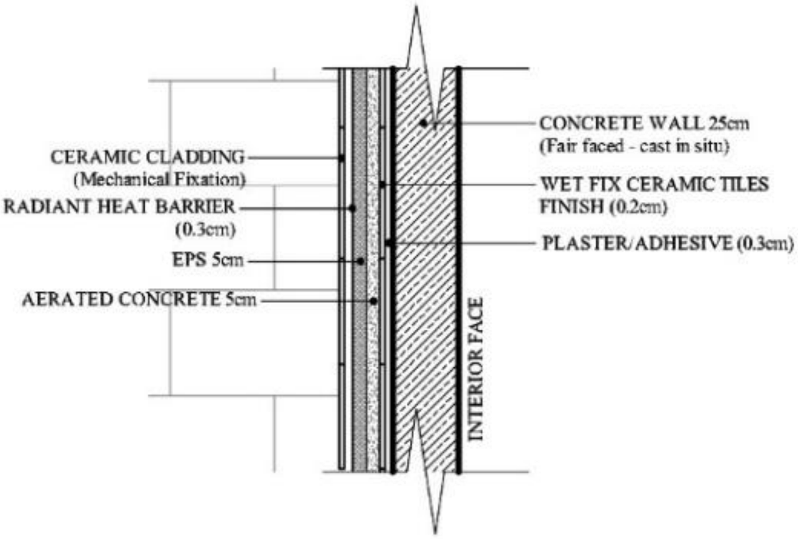
Since the intermediate slab is not an outside envelope that is susceptible to climate change, no intervention was made there. It is primarily impacted by the apartment's interior heat.



Wall detail- Scenario 1



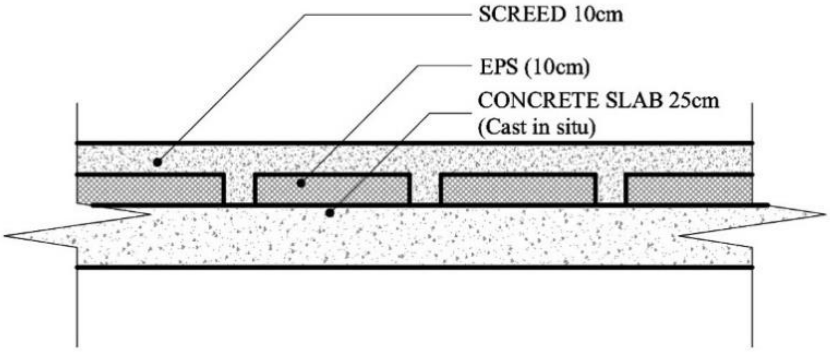
Wall detail- Scenario 2



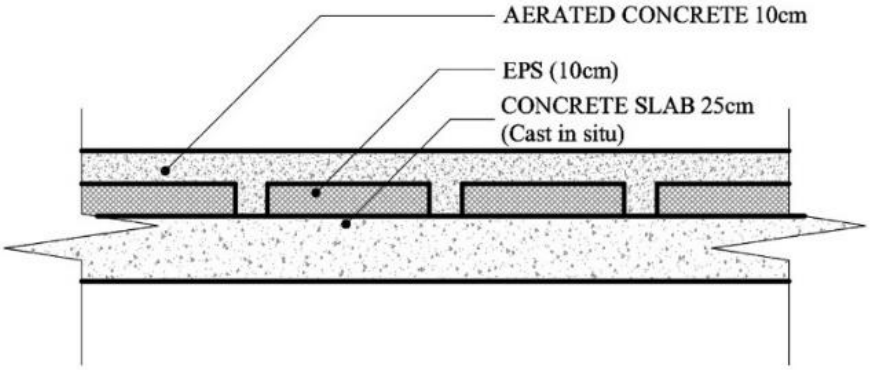
Wall detail- Scenario 3

Figure 6.1: Wall Section details of Admir three scenarios.

Source: Author



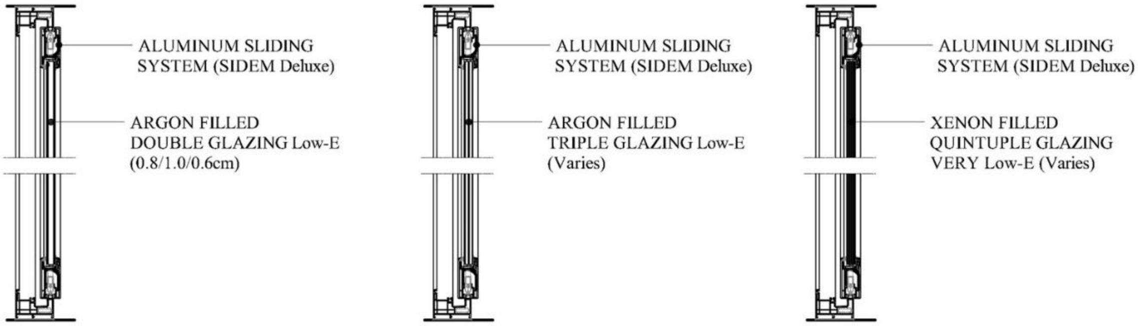
Slab detail- Scenario 2



Slab detail- Scenario 3

Figure 6.2: Slab Section details of the Admir in scenarios 2 and 3.

Source: Author



Window detail- Scenario 1

Window detail- Scenario 2

Window detail- Scenario 3

Figure 6.3: Window Section details of Admir in the three scenarios.

Source: Author

Using Insight 360 (Autodesk), a Revit-related online tool that generates an energy model for each scenario as it relates to the energy analysis, simulations were conducted after materials selection. We will receive precise data from all four scenarios, which we can compare to reach a strong conclusion.

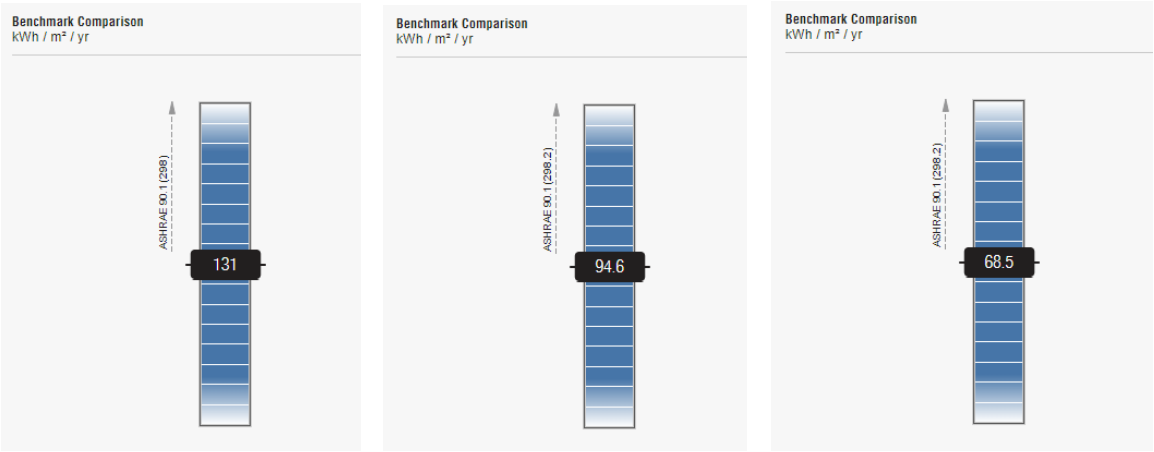
Scenario 1

Scenario 2

Scenario 3

Figure 6.4: The three new scenarios of Admir simulated using the Insight 360 software, which displayed the annual energy consumption per square meter.

Source: Author



Scenario 1

Scenario 2

Scenario 3

Figure 6.5: The energy consumption value with the benchmark comparison of the three new Admir scenarios generated by Insight 360 software.

Source: Author

The energy usage for each scenario was provided by Insight 360 analysis after the three scenarios had been optimized. The first scenario optimized consumes 131 KWh/m2/year, the second 94.6 KWh/m2/year, and the third 68.5 KWh/m2/year in comparison to scenario 0 (original), which uses 193 KWh/m2/year (Figure 6.5). Using the green building studio's online tool, we were able to obtain the annual consumption estimates for the three scenarios.

To achieve the lowest energy use, three optimization scenarios were developed. After the third scenario was provided, testing of all other scenarios produced the same factual results; as a result, in our case, we reached 68.5 W/m2 by altering the external wall composition of an already existing residential building (m2K). As a result, this is the highest level of optimization that can be achieved using passive strategies, where we interfered with the materials and construction techniques in which, we cannot modify the orientation, and preferred not to intervene in the outer skeleton of the wall, the openings.

6.2. Optimization with active strategies

Following the optimization done with passive strategies in the previous section, the active strategies are an important pillar in Net-Zero Energies as we previously stated in the second chapter, ‘Literature Review’. The energy produced by the active strategies is used to replace the building's remaining energy load, which was not completely cut after applying passive design strategies in the previous section. This is where active strategies will then be used to continue the optimization process and completely cut the energy load that remained after applying the passive strategies.

According to the climatic table of Ghazir's area in chapter 3, ‘The Coastal Region: Ghazir in Keserwan’ (Table 3.1), and the below map (Figure 6.6) showing that in our area the global horizontal irradiation is around 4.8KWh/sqm, the sun is the primary climatic factor when conducting research in a coastal zone. We will use heat and sun exposure to conclude that the PV panels system is the most practical active method in our area of study.

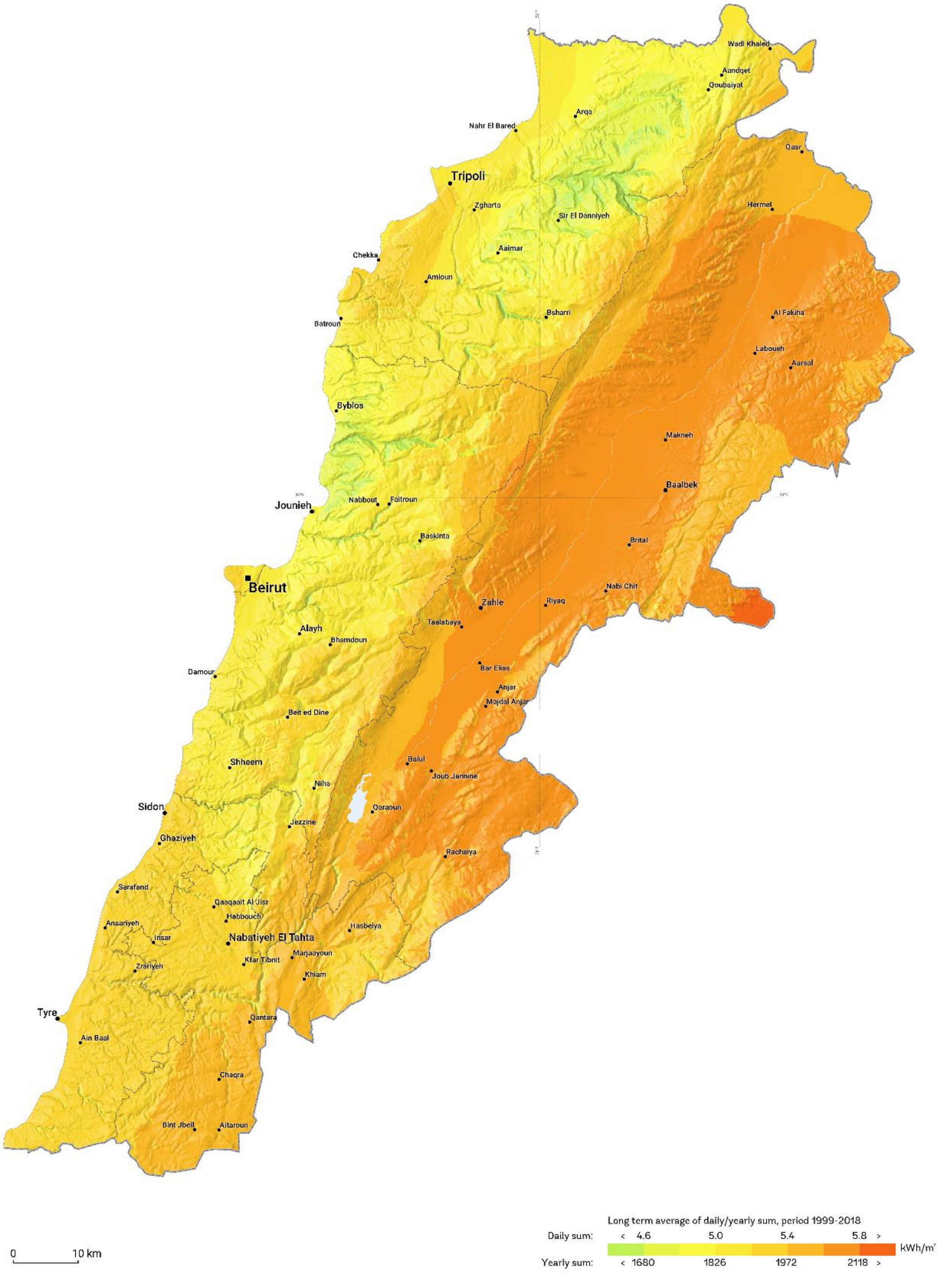


Figure 6.6: Map showing the global horizontal irradiation in Lebanon.

Source: Solargis. Retrieved from Globalsolaratlas.info/download/Lebanon

There are two different types of PV panels, according to chapter two, ‘Literature Review’. The roof-installed panels and the window-integrated semi-transparent PV system. In Admir, our case study, we observed and analyzed the sun's path in the previous chapter through the four seasons, concluding that the primary facade with the highest WWR ratio is exposed to the North-West, which receives almost no sunlight, specifically during the early-setting winter months. In that case, installing PV panels on the roof will be the appropriate solution.

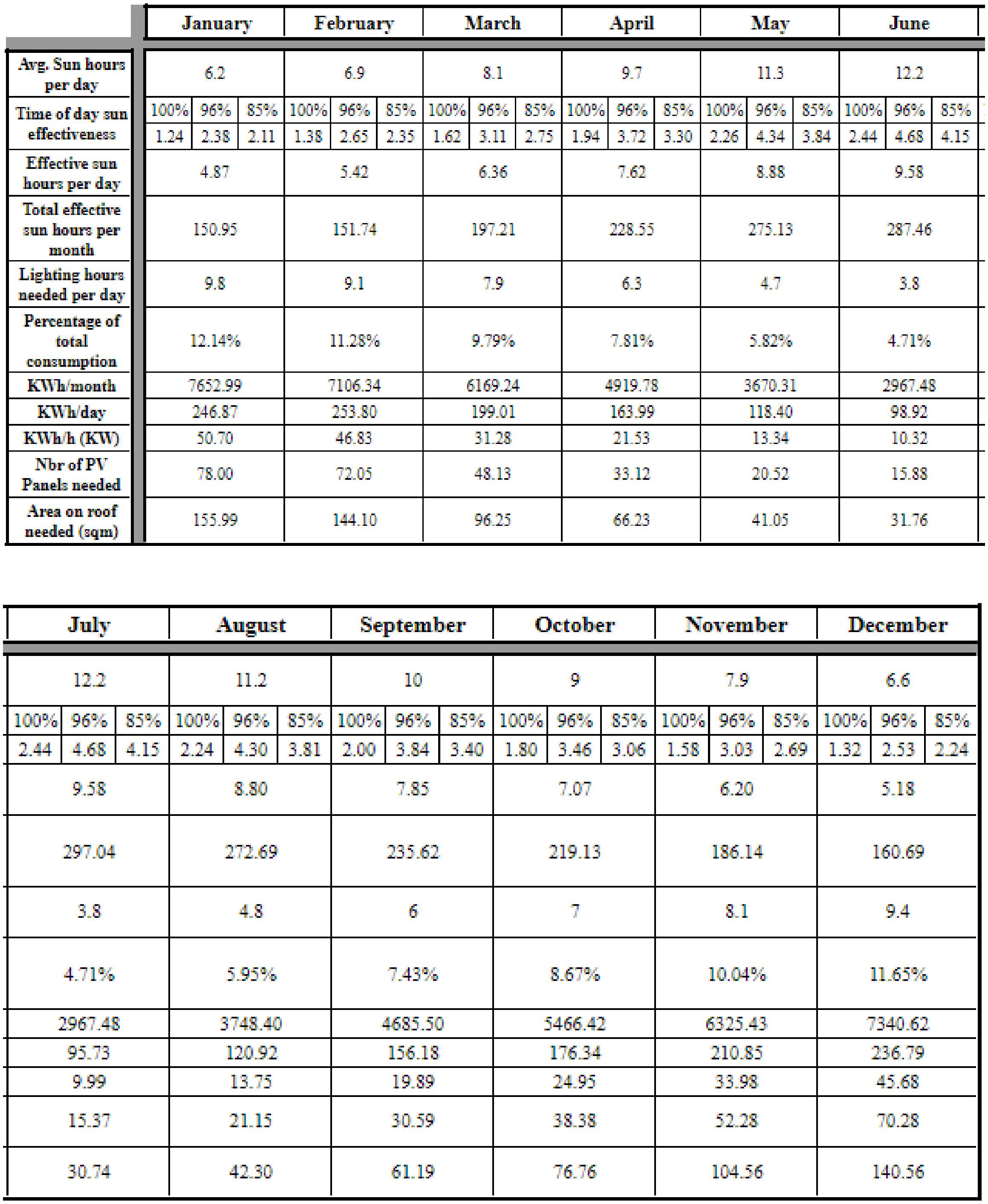
Irradiation 1866 kWh/m²
187% of 1 MWh/m²
Panel: 23°
34° 01' 41''N
35° 40' 13''E

Irradiation 1866 kWh/m²
187% of 1 MWh/m²
Panel: 23°
34° 01' 41''N
35° 40' 13''E

Figure 6.7: Daily average of solar radiation in Admir.

Source: Solar Consult Application

The effectiveness of solar radiation in relation to the location of the sun during the day is seen in the figure above (Figure 6.7). It is divided into five rays, each of which stands for an average proportion between 100% and 85%. One of the five rays is 100%, two of them are 96%, and two of them are 85%.



	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Sun hours per day	6.2	6.9	8.1	9.7	11.3	12.2	12.2	11.2	10	9	7.9	6.6
Time of day sun effectiveness	100% 96% 85%	100% 96% 85%	100% 96% 85%	100% 96% 85%	100% 96% 85%	100% 96% 85%	100% 96% 85%	100% 96% 85%	100% 96% 85%	100% 96% 85%	100% 96% 85%	100% 96% 85%
	1.24 2.38 2.11	1.38 2.65 2.35	1.62 3.11 2.75	1.94 3.72 3.30	2.26 4.34 3.84	2.44 4.68 4.15	2.44 4.68 4.15	2.24 4.30 3.81	2.00 3.84 3.40	1.80 3.46 3.06	1.58 3.03 2.69	1.32 2.53 2.24
Effective sun hours per day	4.87	5.42	6.36	7.62	8.88	9.58	9.58	8.80	7.85	7.07	6.20	5.18
Total effective sun hours per month	150.95	151.74	197.21	228.55	275.13	287.46	297.04	272.69	235.62	219.13	186.14	160.69
Lighting hours needed per day	9.8	9.1	7.9	6.3	4.7	3.8	3.8	4.8	6	7	8.1	9.4
Percentage of total consumption	12.14%	11.28%	9.79%	7.81%	5.82%	4.71%	4.71%	5.95%	7.43%	8.67%	10.04%	11.65%
KWh/month	7652.99	7106.34	6169.24	4919.78	3670.31	2967.48	2967.48	3748.40	4685.50	5466.42	6325.43	7340.62
KWh/day	246.87	253.80	199.01	163.99	118.40	98.92	95.73	120.92	156.18	176.34	210.85	236.79
KWh/h (KW)	50.70	46.83	31.28	21.53	13.34	10.32	9.99	13.75	19.89	24.95	33.98	45.68
Nbr of PV Panels needed	78.00	72.05	48.13	33.12	20.52	15.88	15.37	21.15	30.59	38.38	52.28	70.28
Area on roof needed (sqm)	155.99	144.10	96.25	66.23	41.05	31.76	30.74	42.30	61.19	76.76	104.56	140.56

Table 6.2: PV requirements analysis table

Source: Author

Calculations were carried out to obtain accurate numbers for the table above. From the climatic table of Ghazir's area in chapter 3 (Table 3.1), the first row's average sun hours per day is taken (Table 6.2). The second row displays, based on an analysis of the solar radiation in the image above (Figure 6.7), the percentage of the time of the day sun effectiveness. Considering January as an example of the following calculations in the table. The second row evaluates the time of the day sun effectiveness by multiplying the average daily sun exposure (6.2h) by (1 over 5) by 100% to get 1.24. To be on the safe side and not assume that the sun effectiveness is 100% during these hours, the above values of sun effectiveness (1.24+2.38+2.11) are multiplied by (85%) to reach a number of 4.87 hours per day, which is displayed in the fourth row of the table. The following row calculates the total number of hours where the sun is effective each month. January has 31 days, thus 4.87 x 31 = 150.95 hours per month. The average number of hours the sun shines each day is 6.2, and when we subtract 8 hours of nighttime sleep from the 24-hour cycle, we arrive at 24-6.2-8 = 9.8 hours of lighting per day. 9.8 hours of lighting each day multiplied by the total number of hours of lighting annually yields 12.14% as the percentage of total consumption. The kWh per year must first be determined to calculate the kWh per month; 115 sqm (apartment area) x 8 (apartments number in a building) = 920 sqm x 68.5 kWh/sqm/year (The insight analysis result of the third optimized scenario, Figure 6.5) = 63020 kWh/ year; and then this number, 63020 kWh/year x 12.14% = 7652.99 kWh per month. The last number is divided by the number of days in this month to get the kWh per day: 7652.66 / 31 = 246.87 kWh per day. The last number, 246.87, is divided by the amount of effective solar hours per day, 4.87, to obtain 50.70 KW. Since the most popular PV panel on the market has a power of 650 W, the calculation for the number of PV panels needed is 50.70 KW over 0.65 KW, which equals 78 panels. Since each panel requires 2 square meters of surface area when installed horizontally, the space needed on the roof is 78 x 2 = 155.99 sqm.

An inclination of 23 degrees is needed to provide the maximum inclination to achieve the highest effectiveness, as indicated in the above image (Figure 6.7). Consequently, a bigger space will be required to install the PV panels. The roof surface of the case study, Admir, is 350 sqm, which provides a safe margin for the surface installation of the panel.

Noting that January was chosen as the month to base the number of PV panels and the area they cover, since it has the highest consumption percentage (12.14%) and the least amount of sun exposure, 6.2 hours per day, as indicated in the above table. It should be noted that, to store the greatest amount of energy captured by the PV panels that will be used during the day, we will technically require batteries and inverters.

In this case study, the remaining energy from the passive methods is covered by the active strategy, the addition of PV panels, which finally allowed us to achieve Net-Zero Energy on an already-existing residential building, taking into account that the optimization neutralized the heating and cooling needs. By this, the third objective of the thesis will be reached, ‘To understand the necessity of the active strategies in the process of transforming an already existing residential building to establish what is required to reach Net-Zero-Energy’.

Section 7: Conclusion

The objective of the thesis is to achieve Net-Zero Energy by reducing the energy use of the already-existing residential buildings in a coastal area considering passive strategies derived from the vernacular Lebanese house. Construction was disrupted by the transition from traditional to contemporary architecture. A distinctive difference was found, in the construction materials, their properties and techniques, as well as the window-to-wall ratio. That difference is highlighted while comparing two study cases in the same area with the same orientation; one is an old house, and the other is a contemporary residential building being part of a large development that targets the middle class.

To evaluate the thesis's problematic, research on sustainable architecture was done in the literature review section, leading us to the conclusion that active strategies are required as a complement to passive strategies to achieve Net-Zero energy. After considering the context and climate of the study area chosen, Ghazir, two main study cases were observed, developed, simulated, and analyzed to support the previous theoretical approach. First, the vernacular old house in Ghazir and second, the contemporary residential development, Admir, where a representative building was carefully examined.

The relevance of facade exposures and orientation in relation to the sun's path is highlighted. Both the Old House and Admir have a sixty-degree rotation, with the main North-Western facade. From here, both case studies have the same amount of sun exposure. This main facade in the old house has a WWR value of 21.6% compared to Admir's main facade WWR, which is more than double with a 46.1%, as previously noted in chapter five, (Table 5.2) (WWR table). The results quantified the differences in the material's thermal properties between the old house and Admir. The wall in the old house has a U value of 2.6364 W/(m2*k) lower than the wall in Admir with a U value of 3.5168 W/(m2*k), demonstrating that as the U value decreases, insulation quality and occupant thermal comfort improve (Table 5.1).

Since we are unable to change the orientation of an existing building or alter the outer skeleton to change the ratio of the openings, this led us to move forward and simulate three optimization scenarios of Admir by changing the parameters for the external elements' materials, the ones that are the most susceptible to climatic factors (Table 6.1).

- Scenario 0: The original scenario of the current state of Admir's residential building with the wall's U value being 3.5168 W/(m2*k), the roof slab's U value being 4.1840 W/(m2*k), and the window/ door's U value being 2.800 W/(m2*k). This results in total consumption of 193 kWh*m2*year.
- Scenario 1: Most affordable scenario with a lower U value than scenario zero with the U value of 0.5676 W/(m2*k) for the wall, 0.3133 W/(m2*k) for the roof slab, and 1.900 W/(m2*k) for the windows and doors. This results in a total consumption of 131 kWh*m2*year.
- Scenario 2: Within a higher cost range than scenario 1 and slight optimizations, the wall's U value is 0.3199 W/(m2*k), and the window/ door's U value is 1.4 W/(m2*k). This results in total consumption of 94.6 kWh*m2*year.
- Scenario 3: Disregarding the cost and aiming for maximum optimization, the wall's U value reached 0.1895 W/(m2*k), the roof slab's U value is 0.2799 W/(m2*k), and the window/ door's U value is 0.5100 W/(m2*k). This results in total consumption of 68.5 kWh*m2*year.

After these three simulations, we come to a conclusion that emphasizes the first principle, everything depends on the location and the orientation. The cost of passive optimization will then be reduced if, throughout the design phase, the orientation, WWR, materials, and techniques are thoroughly taken into consideration since the cost has a considerable impact on the materials chosen to reduce energy consumption. After using passive design strategies, the building's remaining energy load, which was not entirely reduced in the maximum optimization possible, that could be provided by the simulation softwares, needed to be compensated by an active strategy. As mentioned in the previous chapter, chapter six, the dominant climatic element in the coastal zone is the sun. Where its presence was the main bias in choosing PV panels as an active strategy to attain the thesis' main objective, reaching Net-Zero Energy in the already-existing residential building. As mentioned in the previous calculation of the PV requirements analysis table in chapter six (Table 6.2), the average sun hours per day related to the sun effectiveness, lighting hours needed and total energy consumption per year, month, day, and hour, allowed us to reach the number of PV panels for each month of the year separately. Based on the consumption percentage and the sun exposure per day, January was chosen to determine the number of PV panels needed, 78 panels. Taking into consideration the actual technology in PV panels present in Lebanon is 650W per panel. The number of panels required to cover a given roof surface will decrease as power per panel increases since fewer panels will be required.

The results provided multiple material combinations to reduce energy consumption with cost-effectiveness. These results presented the ideal scenario, where we reached the minimum energy consumption level in terms of passive strategy optimization before adding active strategies. The latest, rely heavily on location and orientation since climatic factors play a significant role in choosing the appropriate strategies for achieving Net-Zero Energy. This led us to reach the last objective, 'To Find the adequate combination of building materials and construction techniques derived from passive and active strategies that should be implemented to the already existing residential building to reach Net-Nero-Energy construction'.

These simulations, analysis, and calculations demonstrated that it is possible to achieve Net-Zero Energy in a residential building that is already in use. The majority of our urban tissue is made of already-built structures. These future directions will give energy researchers, practitioners, architects, engineers, officials and anyone involved in that sector a perspective from which to act to reduce the energy consumption in the already-built structures and even achieve Net-Zero Energy when active strategies are added. These guidelines will be helpful for new projects as well as passive methods will be used early on, while only minimal active strategies, which will be more affordable, will be required.

As the global energy crisis escalates, these recommendations ought to be given to the officials to get their validity. How will they be able to integrate it into Lebanon's existing laws and regulations? Given that adding more high-performance equipment may not always improve energy performance, a choice to implement new sustainable rules and make them a priority should be made at the national level. In addition, can new photovoltaic technologies that provide smaller elements in size and are more effective in terms of power production be imported? To minimize the cost of the components and materials, will it be possible to produce them locally?

This thesis established a range of potential solutions. To apply them properly on site, including cost calculations, specific guidelines and available materials need to be put in place along with national decisions and revisited laws. This opens up a considerable possibility for further research and analysis to offer pertinent answers and solutions on a national level.

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Appendix A. Architect Raed Abillama Interview Transcription

An individual online interview with architect Raed Abillama was conducted as a part of the master's studies courses. Raed Abillama is a prominent Lebanese architect who is widely recognized for incorporating sustainable architecture into his buildings using passive design principles. He believes that architects are responsible for the environment. The interview topics ranged from particular, discussing two of his projects in Lebanon, Mitsulift Headquarters in the Dbayeh and FNB Bank Headquarters in Beirut, to a broad overview of sustainable design in Lebanon and reaching Net-Zero. We discussed how he integrates sustainable architecture, the approaches he uses, the issues he faces with clients and stakeholders, and the cost of these projects.

An excerpt from the interview transcription mentioned in the first paragraph of the Introduction chapter, is included below.

Me (Interviewer): You are a well-known architect, and known for your sustainable architecture that you are using through your projects. So, from your projects, we can see how *eum* sustainable architecture is being applied and through passive techniques. (Raed: yh)

Taking FNB HQ in Beirut and Mitsulift HQ in Dbayeh, these 2 projects had different approaches but the same result.

Architect Raed Abillama (Interviewee): Yes

Me: Comparing these two *eum*, I would like to ask you first; *small pause* in these projects, the owners asked for a cost-efficient building. But if they didn't would you still integrate sustainable architecture and in the same way?

Architect Raed Abillama: Eum Yes, now now actually *eum*, the *small pause* First National Bank they did the require (sentence cut), they did ask I guess it's more of a, of a, for me it's a bit more of policy, but they did ask certification for *eum*, lead architecture. *Euh…* so they were, we we we got *eum eum eum* silver *eum* medal for that *eum* for that building in means of calculation and now obviously, *eum euh euh* I personally *eum* have a lot of *eum* reserve when it comes to *euh euh* certification. *Euh…* in, in leads specially when *eum* our *euh eum* geo-position and the, the also the *eum euh* the, the bridging method and the *eum* city infrastructure is not always aligned with the way that calculates *eum euh* their points for *eum* their certification.

But besides that, as you said, *euh* our approach is not waiting or *eum euh* or *eum* motivated by *euh euh* by that approach. We we, we do feel responsible *euh* and we, as an architect, that we are *eum euh euh* a heavy industry that's taxing a lot the environment *euh* and that we, when we build *eum euh euh* an infrastructure we have to think obviously how much energy it took to build it but how much energy it will take to sustain it. *Euh…* so it is a responsibility and it's inclined in a smaller or bigger project. *Euh…* so we, we always are interested to do something that's intelligent; and part of it is to really understand the, the the thermal load of the building *euh* and the energy consumption of the building. So *euh euh* we are much more inclined something we can control *euh* architecturally and obviously fit the rest in mechanical sense. But *eum* but we, we hardly believe that a lot of decisions can be solved architecturally before even going into (sentence cut) and we are, always say we got to be as architects and the industry got to be very lazy lately where we are, are relying so much on the technology to solve problem of architecture that used to be really part of *eum* of the way we used to build. *Euh* for me, *eum* the greenest *euh* buildings are you know for us, are the tradition Lebanese home, *euh* they did understand the concept of thermal *eum* mass transfer, the concept of, of a volume, the concept of the amount of, *eum* then shading, the light, the light intake (Me: In vernacular architecture), yh *eum* the openings in the morning, in the evening, I mean the way the house was (sentence cut) because they didn't have a choice, they didn't have technology to, to make the room cooler *eum euh* or to make them warmer. So they were, they were using u know, they only had the chimney in some cases and the "sobia", but they were really using the, the the thermal mass as a concept, the cross ventilation as a concept, the shaded area of the volume as a concept, and all of, all of those are very *eum euh* basic senses that we, we lost in our contemporary ways of dealing with the building; and we are relying too much on, on you know, air conditioning and heating and cooling and and getting more more complicated because you know we always want to be comfortable but the thing we can *euh* achieve *euh* at least of that amount of *eum* of complication by just you know minimizing that load. So that approach awards *euh euh* very well if you understand the basic principle *euh* of of *eum* the, the building *euh euh euh* process technologies. *Euh* the other way is also to *eum euh…* to try to be smart in understanding also the method of construction. *Euh eum* architecture is starting to be very globalized approach but we we build here or actually the building that you see here that looks the same than the building that you see across the planet or over the city starting to be homogenized, completely homogenized and and we stop thinking but you know our climate here is the not the same climate that is in London, it's not the same climate that is in New York, it's not the same climate that in Tokyo. So *eum euh* we we *eum* we got somehow *eum euh…* lazy, it's kind of a copy paste kind of process where we don’t really re… rethink *eum* how we (Me: Contextualize), contextual contextual, *eum* never the less the technologies that are, that kind of grew and made, made the intelligence and made the, the economy call sense. You know *eum* an example, I’m taking the curtain glass facade that’s the cheapest way to actually create a tight facade, right? *Euh* glass per square meter is the cheapest facade material *euh* it’s great for you know London that needs a lot of light, you know that might you know heat up the space but it doesn’t work for us because we have too much you know, sun. *Euh* and this is one of the examples of, for example the FNB saying ok let’s take the most cost efficient and tight system *eum* that also have the least amount of liabilities *eum* with the interconnection of different trades.

One of the problems we have is is, is that *euh* nobody’s responsible you know *laugh* there’s a leak someone and everybody say no I did the window I did the sub frame, no the leak is coming from the concrete, it’s a waterproofing issue, is… (Sentence cut) so you end up having too many *eum* interface *euh* and and one the idea is that ok let’s get, let’s get one system that has no interface; it’s one *eum* it’s one skin *euh* that is studied, that has you know been proven does like technically seen and the responsibility into only one sub-contractor, one one, one system *euh euh euh* and we applied this because it’s cost efficient; we came up with you know *eum* with a facade that within the budget, within *eum* you know the market *euh euh* ratios that, that they, they judge us on. *Eum* and we use one system that they have that that nobody used. So, they have a system those *euh euh* glazing *euh* unitized system *euh* where you can come up with these small brackets to hook your thing; so, we use those *eum* detail *euh* to actually hook a new skin outside. *Eum* so we didn’t interfere in the technicity and the, the warranty of the system but we, we solved the other one that we created the shading devices that does create what we wanted as *euh* minimize the sun intake, the, the heat coefficient is reduced *euh* in the building. So you know, obviously, *euh* sky is the limit we can do everything but when we start to work on, on on on the reality, on the market, we have to *eum euh* to create solution that *euh eum* on the design stand of view we'll hold all the way. We'll hold the *eum* the challenges of, of the requestioning of the contractor, of of the system. So, when you design it from the beginning, if it's solid enough it will, the idea will survive for the process of the construction. And this is another issue specially that we have in Lebanon where if you are not controlling well enough your, your method of construction *eum* the trades will deform it. So they will take an idea, the client might love the look of it and stuff like that and you know sign off on it, and say you know, go ahead and build it then you go on to the contractor and the contractor say I cannot build this, it's too expensive why don't you build this instead; then another problem rise and then how about this and how about that and you end up with the project that is not actually, the design intent is not there anymore. *Eum* and most of the time this is what's happening. So, if you do control well enough your concept that it is solid from the end, you have much bigger chances for it to be *eum* to survive actually that process. So all those ideas *euh* interlock into saying ok let's do something simple, let do something proven, let's expend the the, the process, let's give him easy solution *eum euh euh* that our just *euh* intelligent I think, you know (Me: cost efficient) yh, solutions.