Optimum Design Model of Energy-Efficient Affordable Housing Units in UAE: Two Cases Study of Affordable Housing units in Dubai

نموذج التصميم الأمثل للوحدات السكنية الميسورة التكلفة في الإمارات:
دراسة حالتين للوحدات السكنية الميسورة التكلفة في دبي

by

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Abstract

In response to UN-Sustainable Development goals to provide a sustainable and comfortable living for people in all society segments and to Sheikh Mohammed Bin Rashid 50-Year Charter vision to attain self-sufficiency in energy, food and water in most citizens homes, it is essential to explore and study process, strategies and methods that improve the energy performance and quality of living for the building especially the residential units, which achieve environmental, economic and social sustainability goals.

The selected case studies of this research are housing units belonging to Mohammed Bin Rashid Housing Establishment and Sheikh Zayed Housing Programme Government organization. They aim to provide appropriate housing units for UAE nationals.

The simulation software used to conduct the assessment method of the research is the IES-VE, where the base cases computational models created and analyzed regards the energy consumption performance. The base cases' simulation outcomes were used to develop refurbishment models based on various passive design strategies and renewable energy technologies. Which later analyzed in terms of the life cycle cost to identify the total expanses of the cases study developed models.

A comprehensive comparison was carried out between the base case models and their developed sub-models to obtain the optimum model for the total life cycle cost and energy conservation.

The outcomes indicate the possibility of designing and constructing energy-efficient housing units and affordable in terms of the life cycle cost throughout its lifespan.

Moreover, the simulation results present that the models created based on the integration between the PV system technologies and passive design strategies significantly impact saving energy and reducing the life cycle cost of houses. An appropriate selection of construction material and lighting system plays a crucial role in minimizing electricity consumption for both cases overbuilding life cycle. Building energy performance indicates a significant enhancement when proper passive cooling design methods are implemented, such as shading devices, courtyard and green roof system.

الملخص

استجابة لأهداف الأمم المتحدة للتنمية المستدامة لتوفير حياة مستدامة ومريحة للناس في جميع شرائح المجتمع ورؤية ميثاق الشيخ محمد بن راشد الخمسين لتحقيق الاكتفاء الذاتي في الطاقة والغذاء والمياه في معظم منازل المواطنين ، ضروري لاستكشاف ودراسة العملية والاستراتيجيات والأساليب التي تعمل على تحسين أداء الطاقة ونوعية المعيشة للمبنى وخاصة الوحدات السكنية التي تحقق أهداف الاستدامة البيئية والاقتصادية والاجتماعية.

دراسات الحالة المختارة لهذا البحث هي وحدات سكنية تابعة لمؤسسة محمد بن راشد للإسكان ومؤسسة برنامج الشيخ زايد للإسكان الحكومية. تهدف إلى توفير وحدات سكنية مناسبة لمواطني دولة الإمارات العربية المتحدة.

حيث يتم إنشاء النماذج الحسابية للحالات الأساسية وتحليلها IES-VEبرنامج المحاكاة المستخدم لإجراء تقييم البحث هو فيما يتعلق بأداء استهلاك الطاقة. تم استخدام نتائج محاكاة الحالات الأساسية لتطوير نماذج جديدة بناءً على استراتيجيات التصميم السلبي المختلفة وتقنيات الطاقة المتجددة. والتي تم تحليلها فيما بعد من حيث تكلفة دورة الحياة لتحديد المساحات الكلية لحالات دراسة النماذج المطورة.

تم إجراء مقارنة شاملة بين نماذج الحالات الأساسية ونماذجها الفرعية المطورة للحصول على النموذج الأمثل من حيث التكلفة الإجمالية لدورة الحياة والحفاظ على الطاقة.

تشير النتائج إلى إمكانية تصميم وبناء وحدات سكنية موفرة للطاقة وبأسعار معقولة من حيث تكلفة دورة الحياة طوال فترة حياتها.

علاوة على ذلك ، تظهر نتائج المحاكاة أن النماذج التي تم إنشاؤها بناءً على التكامل بين تقنيات النظام الكهروضوئي واستراتيجيات التصميم السلبي تؤثر بشكل كبير على توفير الطاقة وتقليل تكلفة دورة حياة المنازل. يلعب الاختيار المناسب لمواد البناء ونظام الإضاءة دورًا مهمًا في تقليل استهلاك الكهرباء لكلتا الحالتين فوق دورة حياة البناء. يشير أداء طاقة المبنى إلى تحسن كبير عند تنفيذ طرق تصميم التبريد السلبي المناسبة ، مثل أجهزة التظليل والفناء ونظام السقف الأخضر.

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List of Abbreviation

WORD	**DEFINITION**
AAC	Autoclaved aerated concrete blocks
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers.
COP	Coefficient of performance
CSP	Concentrated Solar Power
EER	Energy Efficiency Ratio
EPS	Expanded Polystyrene insulation
GHG	Greenhouse Gas
HVAC	Heating, ventilation, and air conditioning
IES-VE	Integrated Environmental Solutions- Virtual Environment
ISO	International Organization for Standardization
LCA	Life Cycle Analysis
LCCA	Life Cycle Cost Analysis
LED	Light-Emitting Diode
LEED	Leadership in Energy and Environmental Design
MBRHE	Mohammed Bin Rashid Housing Establishment
MENA	Middle East and North Africa
MEP	Mechanical Electrical and Plumping
PIR	Polyisocyanurate
PV panel	Photo-voltaic panel
RE	Renewable Energy
SHGC	Solar Heat Gain Coefficient
SZHP	Sheikh Zayed Housing Programme
UAE	United Arab Emirates
U-Value	Thermal transmittances
UV radiation	Ultraviolet radiation
VAT	Value Added Tax

Chapter 1
Introduction

1- Introduction

1.1 Overview

In recent decades, environmental specialists and scientists present the crises and disasters generating from the continuity of humans' behaviors in producing energy from non-renewable resources like fossil fuel, deforestation and improper use of land (Roufechaei, Hassan Abu Bakar and Tabassi, 2014). Climate change is one of the most significant environmental issues facing the world, which requires severe reactions from the governments, organizations and world industry (Schaffner et al., 2017).

The industry of building construction produces around 40% to 50% of the global production of GHG emissions. Moreover, it used 40% of the worldwide material production. The residential sector is also responsible for 15-30% global energy consumption, where most of this energy consumed in cooling, heating, and lighting appliances (Khasreen, Banfill and Menzies, 2009). In the UAE, the housing sector consumes around 29% of the total energy consumption (Dubai Carbon and UNDP, 2014).

Therefore, the residential sector industry must necessarily change its conventional construction and operation methods to be more regard to the environment, human health and comfort. Nevertheless, introducing sustainable design methods of housing will enhance the quality of life, increase energy efficiency and reduce the negative impact on the environment (Roufechaei, Hassan Abu Bakar and Tabassi, 2014).

It is better to implement sustainability strategies and methods for all housing segments of society, even affordable housing. Although incorporating sustainable design strategies with houses may slightly increase the cost, the housing energy performance and the life cycle cost, such as operational cost, will be enhanced (Gan et al., 2017).

1.2 Sustainability and housing sustainability

The concept of sustainability is defined in several ways and used in various fields. Generally, sustainability is presented as developments that provide the present generation's needs without affecting the future generation's needs (Gan et al., 2017). In Atolagbe and Fadamiro (2014) research, the concept of sustainable development should be more comprehensive, as it encompasses all relationships and interactions between humans and the environment, such as farming, mining, manufacturing, building, destroying, etc. This concept began from human settlement and then it extends further to identify housing and neighborhood development issues. In the housing context, sustainability is defined as the reduction of adverse effects on the environment. Simultaneously, other researchers have a broader perspective of sustainable homes that encompass the social besides the environmental impacts (Wiesel et al. 2012).

The notion of sustainable home establishes a framework for incorporation between environmental regulations and development methods. Moreover, it is embracing development based on an efficient and environmentally responsible use of the available resources to meet human needs and enhance the quality of life (Roufechaei, Hassan Abu Bakar and Tabassi, 2014). Sustainable housing provides a significant means for treating global and local environmental worries in relevance to energy, water, inhabitant's health, efficiency of material, production of waste and recycling.

Consequently, several strategies and policies should be implemented during housing design and construction phases, such as passive and active design strategies. Also, using renewable energy like solar, wind, etc., to enhance energy performance, reduce water consumption, minimize pollutants generation, enhance user’s health, etc. (Ali and Alzu'bi, 2017).

1.2 Affordable housing

According to Wallbaum et al., (2012), the growth of the urban population in the world will dramatically increase the need for housing. Unfortunately, the current condition of the housing sector can't cope with this growth in housing demand. Therefore, recently the quality of dwelling becomes lower while its prices are increased more than the household income capacity. Consequently, finding affordable and proper housing is one of the main issues most middle and low-income households face.

Affordable housing term is defined in several ways in the research according to the research area's economic conditions. Generally, the affordable housing definition is used to determine the housing units whose total housing costs are considered affordable to median-income households. While other researchers defined it as the ability of low- and middle-income families to own a comfortable home or rent it at a reasonable price for the household's income and at the same time, they can meet their living necessities (Urban Research Centre, 2008). Furthermore, it is explained as the house that a household can obtain with a specific period, which generally extends from 15 to 30 years. This period is related to the family's ability to get financial support through loans and subsidies (Wallbaum et al., 2012).

The Levels of affordability differ from county to country; however, the most applicable concept is the proportion between family income and housing cost, which does not exceed more than a specific percentage of household income that extends between 25% to 35% (Ali and Alzu'bi, 2017).

According to Wiesel et al. (2012), many government initiatives focused on enhancing low-income families' living conditions. Therefore, low-income households will have a decent standard home with a better quality of life. Moreover, establishing affordable housing projects in the country will decrease income stress and allow housing inhabitants to spend their income on other essentials needs, such as health, education and food. In UAE, the government establishes the Sheikh Zayed Housing Programme at the federal level to offer its low-income citizens prefab homes or housing loans to gain a decent life (Government. ae, 2019).

1.3 Sustainable, affordable housing

Generally, in the context of affordable housing, most of the researcher has defined and evaluated it in terms of economic standards and indicates to any low-cost housing without concentrating and mentioning anything about housing quality, comfortability or environmental impact (Mulliner and Maliene, 2011). Integrating the affordable housing concept with sustainable housing concepts the affordable housing will eventually be enhanced. Therefore, it will become environmentally friendly as well as higher living quality, better indoor thermal comfort and lower operation cost.

Affordable housing can be defined as the housing constructed either by governments or non-profit by establishing various housing programs used in environmentally friendly materials. Further, they have long-term environmental, social and economic advantages without a raise in the life cycle cost and allow for both the present and future generations to gain their housing needs for medium-low income households (Oyebanji, Liyanage and Akintoye, 2017).

Several sustainable criteria can be implemented to improving affordable housing sustainability. However, this study will assess sustainability through energy retrofit strategies for selected existed cases and develop an efficient design model to be more energy-efficient and environmentally friendly in the United Arab Emirates without ignoring the life cycle cost analysis.

1.4 Energy efficiency

The appropriate selection and uses of energy efficiency parameters in the housing design, construction and operation phases can play a crucial role in enhancing housing energy consumption and achieving better sustainable housing development (Roufechaei, Hassan Abu Bakar and Tabassi, 2014). Previous studies suggested that around 20% to 50% could be reduced to current energy consumption by implementing more effective and efficient energy strategies and policies to the existing building or new ones (Schaffner et al., 2017).

Two main factors affect the housing's energy performance, which are the regional climatic characteristics of the region and hosing design information and conditions. The region climate conditions substantially affect the indoor housing environment, the housing envelope's design, and the amount of energy inhabitants need. As an example, the climatic conditions in UAE are sweltering most of the year, which requires a large amount of energy to enhance the users' indoor thermal comfort. Moreover, the housing design information as the orientation, material envelope, thermal insulation, opening sizes, etc., impact the energy performance of the building. Poor housing design implementation leads to inefficient homes with a massive waste of energy. Consequently, the production of power will increase and negatively impact the environment, economy, and society (AlFaris, Juaidi and Manzano-Agugliaro 2016).

Usually, the energy-efficient homes encompass many low energy strategies such as passive design methods, thermally efficient built configuration and the utilization of renewable energy technologies (Schaffner et al., 2017).

1.5 Problem Statement and Interest of the research

In several countries, the governments are responsible for constructing low-cost housing units affordable and adequate with acceptable quality to the low-income households. Yet, environmental and sustainable housing-related issues are very marginalized (Ganiyu, 2016). Moreover, the developers and clients in the construction industry associate housing affordability to the household financial ability to own a house and the initial cost of the building without addressing anything about housing lifecycle performance and expenses. They design and construct far-away small housing units of low-cost material and use cheap MEP equipment (Syed Jamaludin, Mahayuddin and Hamid, 2018).

Consequently, the poor design and construction of affordable units will generate several problems related to human health, environmental and economical, which imposes extra expenses on the household throughout the lifecycle of the building. This issue needs to be changed by introducing sustainable practices into affordable housing design and construction, which significantly impact housing quality, inhabitants' health and well-being, and economic situation (Isnin et al., 2012).

However, many are facing opposition to implement sustainable strategies in the affordable housing projects, primarily due to concerns regarding initial cost and whether sustainable building strategies and technologies provide cost-benefits and a return on the investment made by developers and investors (Trachtenberg et al., 2016).

According to Ali and Alzu'bi (2017), the balance between affordability and sustainability concepts in housing can be attained by utilizing passive and active design strategies, establishing the sustainability standards to be achieved and concentrating on the life cycle cost analysis. But there is a lack of studies that focus on combination of sustainability and affordability in housing design and their integration benefits.

Moreover, there is an apparent concern in providing zero energy housing projects in UAE and affordable housing but as separate projects. To bridge this gap of knowledge and meet Emirates' housing needs while tackling environmental problems has motivated me to conduct this research.

This research will focus on assessing a selection of existing affordable housing units constructed by the government. The author then works on enhancing their design standards in terms of energy performance and life cycle cost to develop a sustainable and affordable housing model in UAE. in lighted by article #7 (self-sufficiency in Dubai homes) in the 50-Year-Charter.

1.6 Research hypothesis and main question

The study was conducted on the conceptual theory that the housing units in Dubai could be designed based on sustainable parameters and be affordable for median and low-income households. By the end of this study, the author aims to conduct appropriate outcomes that support the theory and answer the study question. The main question is how sustainability could be implemented in the affordable housing unit by considering the life cycle cost of the housing in the UAE.

1.7 Aims and Objectives

The research aims to investigate the energy performance and analysis of the life cycle cost of selected affordable housing in Dubai before and after implementing passive and active design strategies and using renewable energy resources, with an eye to carry out a sustainable and affordable housing model. These strategies shall respect the climatic conditions of the region. The following are the objectives that will be used to attain the research aims:

i. Conduct a comprehensive literature review to investigate the recent similar studies and carry out the significant points that serve the research.
ii. Study the current situation of affordable housing in the UAE.
iii. Select various cases-studies of existing affordable housing located in UAE and introduce several energy-efficient strategies.
iv. Investigate the energy performance of the cases before and after implementing the strategies through computer simulation.
v. Assess the life cycle cost before and after the retrofitting strategies.
vi. Compare and study the results of the assessment and identify the appropriate outcomes.
vii. Set a list of recommendations based on the research results and finding to be used in the future.

1.8 Scope of work

In this study, the cases study selected from different housing organizations located in UAE. The first one provided by Mohammed Bin Rashid Housing Establishment and the 2nd one constructed by Sheikh Zayed Housing Programme. Which both are responsible for establishing housing services for UAE citizens such as housing loans, free lands, constructed units, etc.

The author focused on these cases since they are considered as affordable housing units. Therefore, the study outcomes could be applicable for various types of housing, share the same location and climatic conditions.

This research will use different research energy-efficient strategies such as passive and renewable energy techniques. The passive design strategies will be implemented on housing envelope as shading devices, construction materials, green roof, etc. Further, the research will adopt PV panels as renewable energy resources.

Moreover, the research will focus on the life cycle cost analysis for each housing unit by defining the initial cost, operational cost and the demolish cost.

1.9 Research outline

To meet the objective of this research; this study will be divided into six chapters. The 1st chapter presented a brief of the research's main ideas related to sustainability and affordability, especially for housing units. Also, it offered some definitions and insights into efficient energy parameters

The 2nd chapter provides a comprehensive literature review of sustainable and affordable housing. Furthermore, it shows a preview of the selected cases' geographical location, climatic conditions and the status of sustainability and affordability of the area. And it concludes with the efficient energy parameters that impact the performance of the cases.

The 3rd chapter presents the research methodology that covers a comprehensive study that requires the approaches and tools applied in similar topics to compare their pros and cons. Besides, it will present a justification and validation for the methodology.

The 4th chapter covers the process of developing computer simulation models through IES-VE software. Additionally, it will provide a comprehensive investigation of the proposed variables that will be utilized in the selected cases in various scenarios. The current situation of the selected cases will be identified as the base case of the research.

The 5th chapter provides life cycle cost analysis for the selected cases-studies and additional scenarios developed in the previous section.

The 6th chapter includes the outcomes and findings generated from the previous chapters and compares them to find the best scenarios of energy performance and life cycle cost.

The final chapter introduces the research recommendations for future studies.

Chapter 2

Literature Review

2- Literature Review

2.1 Introduction

In order to develop an affordable and sustainable housing prototype in the UAE, a comprehensive review of the factors that affect the research success needs to be conducted. Therefore, this chapter will provide a literature review of the sustainable development, housing sector issues, an overview of UAE and energy-efficient strategies

2.2 Sustainable Development

The sustainable development concept has been subjected to different development phases since it was created. The sustainable development term was initially aforesaid in the Nature Conservation and Natural Resources Strategy of the International Union for Conservation of Nature issued in 1980. Firstly, the term had concentrated on the ecological aspect, and later it was extended to include both the social and economic perspectives (Klarin, 2018).

In 1987 the World Commission on Environment and Development defined the concept as the development that achieves the demands and the needs of the present without infringement on the future generation's ability to attain their own needs.

Recently, several nations fora concentrated on the importance of sustainability and the development of its concepts and objectives, which present that it can progress economically and socially without negatively affecting the environment (Halmaghi and Neag, 2019).

Environmental, social and economic aspects are integrated to configure the sustainability concept by ensuring the growth in industrial and technological fields and enhancing social activities at all levels with preserving the surrounding eco-system (ISO, 2012).

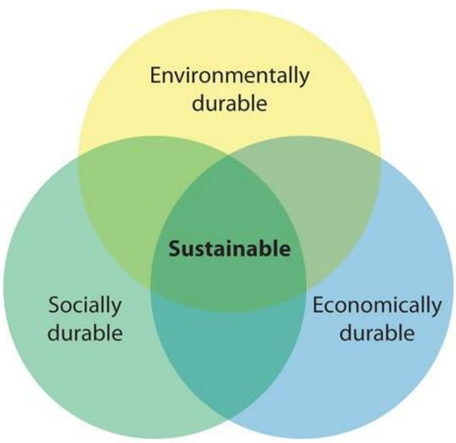


Figure 2.1: The three pillars of sustainability source: Nps.gov, 2020

- The definition of environmental sustainability is giving to our future generation natural resources without any destruction. Therefore, using natural resources must be controlled to preserve the equilibrium, durability of ecosystems and minimize the burden on the environment.
- Economic sustainability refers to the processes and practices that increase economic growth by considering social fair matter and environmental issues.
- Social sustainability concentrated on the fundamental rights of human beings, including freedom, equality of opportunities, enhancing the life quality for individuals, and providing the human needs for all people in the long term (Yılmaz and Bakış, 2015).

In Transforming our World: the 2030 Agenda for Sustainable Development, several goals and policies were settled by United Nation in 2015, concentrated on eliminating poverty and hunger, spreading literacy, safety, justice and equality, providing clean and affordable energy with preserving the life on land and below the water. Implementing these goals will vary from one region to another due to each country's priorities being different to achieve their sustainability (Holden, Linnerud and Banister, 2016).

2.3 Sustainable Building Construction

The construction sector is a pivotal element of any economy, but it is one of the largest consumers of energy, water and material resources. The construction field is a large polluter. Recently construction industry developers, engineers, architects and others began to focus on improving their activities to enhance their impact on the environment and reduce their damages (Akadiri, Chinyio and Olomolaiye, 2012).

According to Olanrewaju, Tan and Abdul-Aziz (2018), Buildings produce around one-third of CO_2 emission, utilize 25% of harvested wood, use more than 40% of the world energy, form approximately 40% of waste, consume 15% of usable water, extract 40% of greenhouse gas and responsible for of 50% of fluorocarbon generation.

Both sustainable architecture and sustainable construction concepts were integrated to apply the strategies and methods of sustainability in the construction field for finding solutions to environmental issues caused by buildings.

- Sustainable Architecture

Sustainable architecture referred to the body of processes and activities that decrease the production of damages on the environment and concern about ecological equilibrium — also utilizing materials, energy and water effectively during the making, using and demolishing phases. Moreover, protecting the user's comfort and health, conserving the existence and future of natural resources and managing the waste after destruction, either reuse it for other applications or dispose of it environmentally.

- Sustainable Construction

Construction sustainability is implementing the principles of sustainable development over a building life cycle from the construction planning, construction, extract the raw material to production to be used as construction materials, building demolishing and management of construction waste. Therefore, these principles are implemented at any stage through the construction life cycle (Yılmaz and Bakış, 2015).

In 2012, Akadiri, Chinyio and Olomolaiye identified three objectives in their study to shape the framework of implementing the sustainable construction principles are:

1- Resource preservation:

Means the management of human behavior regarding natural resources as energy, water, land and material to maximize the benefit to the present generation while conserving the ability to provide the needs for the next generation

2- The efficiency of the cost

The building sector shows in financial terms a significant and long-lasting investment. So, enhancing the effectiveness of the building cost will provide benefits for the clients, users and society, which occurs by implementing the life cycle costing analysis (LCCA) method. That is an assessment tool able to prophesy the cost of the building by calculating the initial cost, operation, maintenance and replacement cost until the end life of the building.

The sustainable building aimed to provide a comfortable and healthy environment to the users by considering several strategies and regulations to a needed specific building. Furthermore, applying the safety regulations to protect the building from fire, natural hazards, etc. Implementing sustainability in the building industry will decrease the negative impact on the environment, improve finance and economic saving, enhance social efficiency, improve the quality of life, and optimize building behaviors (Zabihi, Habib and Mirsaeedie, 2012).

2.4 Sustainable Housing

Nowadays, the housing industry has an essential influence on physical, economic development, minimizing natural disasters, environmental integrity, job availability, diversifying people's lifestyle and well-being, and developing sustainability. Therefore, housing plays a significant role in sustainable development (Ibem and Aduwo, 2015).

Ojoko et al., 2016 define the sustainable housing concept as an application of regulations, policies, systems, or actions created to establish safe, secure, viable and affordable homes for individuals. It adopts the tenets for triple pillars of sustainability, the social, economic and environmental in presenting the national housing policies and regulations with lower effects on the environment and future generation.

Further, sustainable housing referred to housing that integrated practices of enhancing the social quality of life with respect to the surrounding environment without neglecting economics's viability (Ibem and Aduwo, 2015).

According to Pakir et al., (2012), providing several suggestions and regulations for bridging the gap between the present housing situation and its objective for the future is the most critical work of sustainable housing. Each house situation has unique requirements, solutions, and specifications distinguish from others. Due to the several parameters as location, climate condition, local material, cultural patterns, etc. thus the housing industry organizations, leaders, engineers and stakeholders should study and consider all requirements related to housing to deliver a sustainable home.

Ibem and Aduwo (2015) noted in their study that the implementation of a sustainable development concept in the housing construction occurred has several stages, which are the housing process, housing product and housing services, as shown in Fig (2.2).

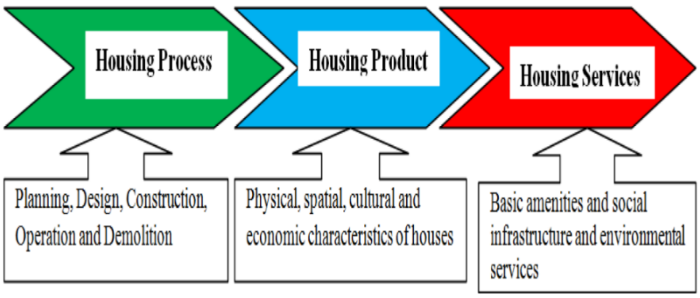


Figure 2.2: The three pillers of sustainability source: Nps.gov, 2020

Sustainable housing implementation provides benefits at the community and individual levels in all sectors. It enhances the resident's life quality and dignity, reduces energy consumption, conserves natural resources, improves the users' health, protects the ecological life, eliminates poverty, etc. (Ibem and Aduwo, 2015).

2.5 Housing sector

Everywhere shelters consider as a crucial need and right for all, however housing more comprehensive than just a shelter. Affordable and proper housing offers access to education and jobs. Moreover, it provides safety and security for their residents to make them able to enhance their homes, livelihood and improve their economic prospects. (Habitat for Humanity International, 2012).

Housing is one of the fundamental human rights where consecutive generations find it to maintain development, social communication, public health, security and education and achieving the appropriate life for users. Housing provides a comfortable and convenient experience for the residents and, at the same time, is characterized by cost and energy-efficient and united with region culture and environment. (Henilane, 2016).

2.5.1 Housing problem

The world growth population rate had increased from 2.6 billion in 1995 to around 3.5 billion in 2014, making many cities suffer from slums. The UN-Habitat (2016) estimated that about 881 million people live in slums, increasing in 2025. Further, they determined that around one billion homes are needed to be constructed worldwide in 2025. Besides the crisis of the required quantity, housing quality is formed a significant problem in the housing sector. Thus, Global Housing Strategy requests accurate prediction for housing demands, comprising enhancement to inadequate, abandoned and old residential buildings, that compose the qualitative deficit.

According to UN-Habitat in 2016, many significant crises faced the housing sector in 2016, which include poverty, unprecedented immigration effect, environmental worries, increasing inequality levels and rapid urbanization. Moreover, in the rapidly urbanizing sectors of the world, there is a general admission that the market has failed to provide affordable and adequate housing for low-income households; therefore, including the housing sector in international policy and future development plan is a crucial decision.

Housing crises are varied among countries and even within countries between better-off and low-income families. Moreover, in general, house prices are rising; thus, most people couldn’t afford it. Several reasons are responsible for this diversity:

- Insufficient construction land is more likely due to the ill-considered policies and regulations from actual physical restrictions on the land provision.
- Cities developers and planners on new housing developments require fancy, big sizes building with wider streets this end up with too expensive units are higher than household income.
- The limitations of converting the land from rural to urban applications mostly turn out, generating a deficiency of affordable land, ending in rising housing and land costs.
- Increasing the construction material prices.
- Several nations and governments have neglected the community-related policies; therefore, the affordable housing funding is decreased (Habitat for Humanity International, 2012& Gangwar, 2016).

UN-Habitat reported in 2017; everyone has a right to live in an adequate home and to be adequate house must meet at least the following conditions are the affordability, security and safety, accessibility, services and facilities availability, proper location and social culture, respectively

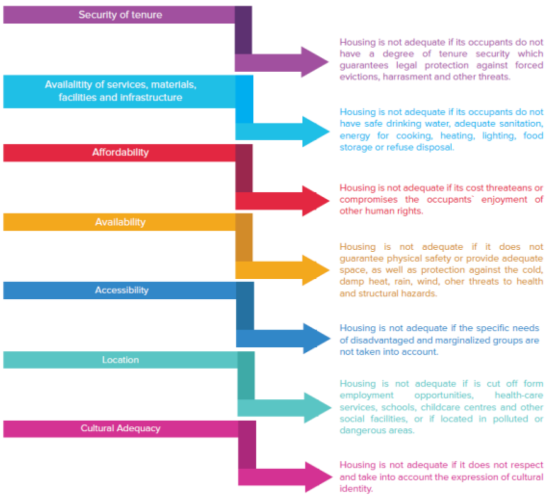


Figure 2.3: The minimum criteria to meet the appropriate housing for households source: UN-Habitat, 2017

2.6 Affordable Housing

According to the World Economic Forum (2019), affordability term means the ability of individuals to purchase or rent a house. Furthermore, the ability to bear the living expenses in it doesn’t include only maintenance and operations costs; it also comprises the services, transport and infrastructure expenses.

In 2017 Ali and Alzu’bi, presented that affordability is one of the worldwide curial issues and they defined it as the ability and potential of the household to purchase a house. Moreover, in the 2016 report, UN-Habitat explained that expenditure does not exceed more than 30% of the household income, which guarantees that a household has enough revenue for the non-housing expense.

Gangwar (2016) presented the term affordability as the paying capacity of owners. As, in India, the house can be considered affordable if the household could offer 40% of their income without affecting the rest of their needs, while Abelson (2009) show that in Australia if the housing prices exceed 30% of the total household incomes will be a burden over the household expenses.

2.6.1 Affordable housing development factors

The development of affordable housing is affected by two cost factors: the building cost, the maintenance cost and operational cost.

The building cost comprises the acquisition of the land, such as purchase cost and duties of registration, gaining the approval of planning. Also, the infrastructure services cost as installing a water system, heating and cooling systems, roads, electricity grid and sanitation system, moreover the cost of the construction comprising materials and labor.

The cost of maintenance cover retrofits or replaces MEP equipment and tiles, repainting, landscape cultivating, etc., while the operational cost includes water and energy consumption, tax of the property and insurance. (World Economic Forum, 2019).

Establishing the rules and policies of the affordable housing concept contributes to improving the well-being of individuals and the community, especially in education and health aspects. It also offers low-income households to access decent standard housing that they couldn't get them in the private market. Moreover, it reduces the crime rate and stress and enhances employment stability. (Gopalan and Venkataraman, 2015& Wiesel et al., 2012).

2.7 Sustainable Affordable housing

According to Oyebanji, Liyanage and Akintoye (2017), sustainable, affordable housing refers to the housing managed by the government through housing authorities. The house follows environmentally friendly standards with the utilization of sustainable material and able to afford economically, socially and ecologically without increasing the cost of the life cycle.

Further, in 2018, Abdul Hamid, Hidayah Syed Jamaludin and Mahayuddin explained it in their paper as the enhanced level of the sustainable housing project to achieve the housing desires and requirements of the current medium and low-income household.

2.7.1 Awareness

Generally, the idea of the affordable housing concept is associated with inexpensive and low-quality houses, so most of the housing market participants ignored the implementation of sustainable aspects in housing projects (Said et al., 2016).

According to Olanrewaju, Tan and Abdul-Aziz (2018), in the UK, one of the main barriers to establishing the sustainability criteria in the building is the lack of knowledge and awareness of sustainable benefits. Likewise, in Chile, the developers and clients haven't been interested in it due to insufficient information about the advantages of sustainability. In previous research conducted in 2006, including Canada, the UK, New Zealand and the USA, to raise the demand for sustainable, affordable housing, users and clients must be educated.

In the Intergovernmental Panel on Climate Change, in 2007, the report mentioned that the building industry has the highest potential to decrease greenhouse gas production at the lowest cost. Moreover, with the current market technologies conditions, both energy consumption and greenhouse gas can be minimized by 30 to 50% without significantly raising the cost of investment of new or refurbishment building. (Ang et al., 2017).

Increasing the awareness and knowledge of sustainable, affordable building benefits will reduce the barriers to spread the concept over housing stock decision-makers.

2.7.2 Sustainable, affordable housing benefits

The result of Olanrewaju, Tan and Abdul-Aziz study in 2018 classified the benefits of sustainable, affordable building in five groups:

- Environmental benefits that combined decrease in CO_2 emission reduces pollution percentage, minimizes constriction and household waste production and extend house lifespan.
- Energy benefits are summarized by reducing the energy consumption cost and improving the efficiency of the water, enhancing natural ventilation by using passive design and sustainable technologies.

- Cost benefits included the reduction in operating, demolition costs compared to conventional housing.
- Social benefits comprised of increasing the resident's performance, wellbeing and life quality of individuals and community.
- Status benefits, implementing the sustainability aspects of the housing project will increase the attractive and vibrant factors.

2.7.3 Sustainable, affordable housing criteria success factors (CSFs)

Abdul Hamid, Hidayah Syed Jamaludin and Mahayuddin (2018) classified the CSFs into three subsystems: environmental, economic and social. All these CSFs were conducted from previous studies.

- Environment factors

The main CSFs related to the environment are the utilization of sustainable and environmentally friendly materials, the implementation of energy-efficient equipment and fixtures, the proper utilization of land plans for averting land misuse and financial resources.

- Social factors

Social CSFs are improving the knowledge and awareness of the importance of a sustainable lifestyle for the public and enhancing the contribution of the stakeholders in the development process. Moreover, improving the welfare and life quality of residents and achieving their needs will enhance the livable sense of the place.

- Economic factors

The critical success factors of economic aspect are to ensure the implementation of sustainable, affordable housing, which are supporting the provision cost, initial housing purchase, rent, operational and rate of pledge loan, inserting the efficient management in research and design process and concerning on the resources, product quality, related standards and certificates to reduce life cycle cost and risks. Further, to provide practical and applicable policies and framework for housing by the industry players and government to support sustainable housing construction.

2.7.4 Sustainable, affordable housing examples

Recently, many organizations are support, contribute and provide housing construction projects for low-income households incorporated of sustainable criteria.

- Waitakere NOW Homes

According to Beacon Pathway Limited (2007) report, the Waitakere NOW Home has been built in Waitakere, New Zealand, in 2006 by Beacon Pathway Ltd company. Initially, the budget for house designing and construction was determined according to the regular New Zealand housing cost.

Despite the housing, the design contains some features like double glazing and a solar hot water system, leading to an increase in housing costs over low-income households. But the designer was able to integrate it through careful design and eliminated the extra areas such as corridors. Therefore, they preserved the budget as well as enhancing the house parameters.

The house construction material is a timber weatherboard, settled to timber frame on a heavily insulated concrete slab. The roof composed of concrete tile, similarly they covered the walls and ceilings heavily.

The housing was designed to maximize the passive solar heating system advantages by implementing the insulated envelope to absorb and conserve the sun's heat. Further, the designer adopted passive ventilation criteria to facilitate the movement of air without producing any draughts that enhance the indoor environment.

Figure 2.4:Waitakere NOW Home source: Ryan, 2020

They installed in roof houses a solar water heater and water tanks gather the rainwater; this water will be used for non-potable water applications. The lighting fixture type used in the place is high-efficiency compact fluorescent.

The house was monitored to assist the housing performance through collected measurement of electricity and water consumption; moreover, the indoor measurement such as temperature, humidity and CO_2 percentage, also the heat of solar water was measured

The result of the measurements showed a 45% reduction of the resident's energy consumption by comparing to their consumption in their previous house, which influenced their financial saving positively. Similarly, it recorded a significant reduction in water consumption due to the rainwater tank, which means the family consumed between 40 to 50% less than the average consumption of Waitakere city, with associated minimizes in bills of water.

The collected data of temperature and humidity from the first year to residents that identified both temperature and humidity rate were conserved within the comfortable and healthy levels of the household most of the time. Simultaneously, they only used portable heaters twice during the winter when it was colder than usual.

Interviews with house family presented a high level of satisfaction to live in the house. They referred their gratification for living in the house to the health and wellbeing benefits enhancement, comprising the lowered level of ill health, improved kids' confidence, and more social life activity (Beacon Pathway Limited, 2007).

- Portuguese pilot-project

According to Mateus and Bragança (2012), the Portuguese pilot project was constructed in the municipality of Matosinhos, Northern Portugal that was the second stage of the Ponte da Pedra housing state. The project is a multifamily social housing building, which comprises two blocks with a 3,105 m² footprint and 101 apartments.

The project intended to establish in Portugal the real feasibility of sustainable housing, and that happened by constructing a residential building with less impact on the environment, better comfort and lesser life cycle cost than conventional housing. In contrast, phase one Ponte da Pedra housing state had the same architectural features but was built with the traditional system of construction of Portugal.

The project team in the design phase set several criteria in order to develop a sustainable, affordable building, which was:

1) Using pre-developed land, the housing was constructed in a land that was occupied by old industrial buildings.
2) Enhancing the efficiency of the energy, the building's primary energy consumption is 25% of the maximum permissible use of the fuel—the housing equipped with efficient lighting fixtures in public spaces and hot water solar collectors.

3) Improving the water-efficiency, the housing is provided with a rainwater harvesting system, which is used to irrigate the green areas and toilets; moreover, low water flow fixtures are installed in the houses.
4) All window frames are installed with ventilation grids to enhance indoor air quality.
5) The kitchens of the housing are equipped with four types of containers to manage the solid waste of the household.
6) Cost management, the construction cost of buildings was higher by 9% than the 1st phase; however, the expected turn-off period of this higher capital cost from 5 to 6 years. Moreover, the houses were sold out by 20% lower than the Portugal average market.
   - Christi Walk, Adelaide, South Australia

The eco-city Christ Walk development community is located in Adelaide and developed by the Urban Ecology in South Australia. It comprises 14 housings; each consists of four connected three floors townhouses build of aerated concrete blocks, block with three-story and six flats, community facilities and four standalone cottages made of straw-bale. The dwelling construction material and finishes are made of non-toxic material. The concrete used in the housing slabs and mass walls consist of the maximum allowable percentage of fly ash.

The dwellings are following the highest ecological criteria, considering both passive and active solar heating. The design of the construction takes the benefit of high thermal mass and comprehensive insulation. The housing depends on natural ventilation without installing any mechanical means of cooling or heating except ceiling fans.

The housing equipped with photovoltaic panels located on the pergola above the apartments to generate electricity went for the grid despite most of the electricity drawn from the grid. Moreover, dwellings are provided with a rainwater tank of 1000 capacity liter used for toilets flushing and garden drip irrigation system. Further, the black water will be treated eventually in a chlorine-free system on-site, then used the produced water to irrigate the nearby public park.

The dwellings financial procurement adopted model developed around the construction project being created for a group of clients represented by Wirranenedi Cooperative Inc, which play a significant role in conserving the houses cost in acceptable range when compared with the conventional homes cost in Adelaide. Therefore, the dwellings cost like those in the local market. (World Habitat, 2005) & (Pullen et al., 2015)

Figure 2.5: The housing of Christi Walk, Adelaide in South Australia source: World Habitat, 2020

2.8 UAE overview

2.8.1 Geographical and Climate Data

This research will present the United Arab Emirates (UAE) and particularly Dubai city, as a base location to conduct the study. UAE is located on the eastern side of the Arabian Peninsula, surrounded by north and north-west by the Arabian Gulf and east by Oman Gulf. It has borders with Saudi Arabia from the west and south, while from the southeast, there is a border with Oman (UAE Annual Book, 2016).

The United Arab Emirates land area equals 83,600 Km^2, 87% of the land owned for Abu Dhabi and the total population in the latest estimation in 2018 is 9,630,959. (Data.worldbank.org, 2019) & (UAE Annual Book, 2016).

Despite most of the UAE land characterized as a desert, particularly in the western parts of the country, still, it comprises a wide diversity of landscapes such as red dunes of sand, natural oasis, coastal plains, and mountains. Further, around 200 islands are located in UAE territorial waters (UAE Annual Book, 2016).

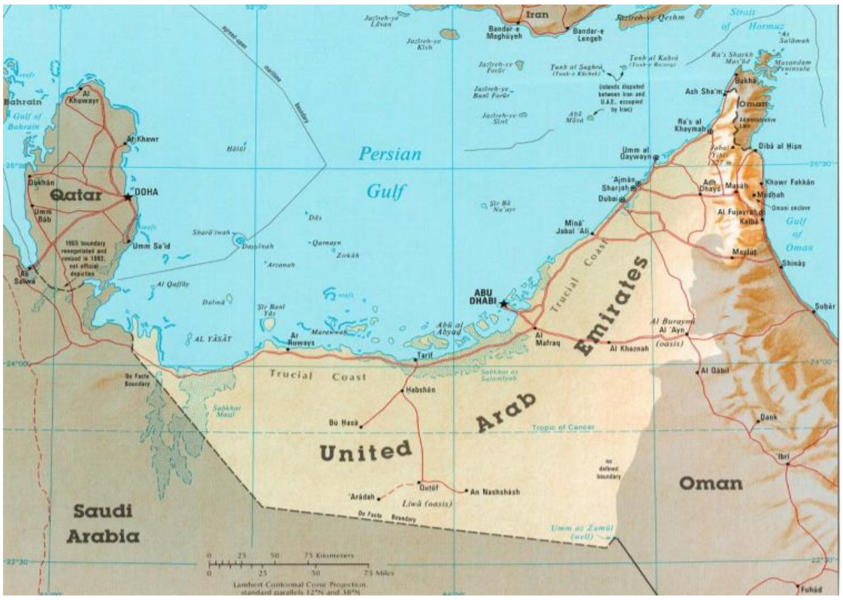


Figure 2.6: Map of UAE source: Legacy.lib.utexas.edu, 2020

According to Koppen-Geiger, one of the climate classification systems extensively utilized. Which is categorizes the climate into five main climate regions, depending on annual precipitation rate and temperature degree. As presented in the below map, the UAE climate code is BWH. Where 'B' refers to arid, which is the main climate region, while 'W' mentions to rainfall percentage rate, means UAE suffers from droughts most of the year and 'H' refers to temperature degrees show that UAE is the hot arid zone (Koeppen-Geiger, 2019).

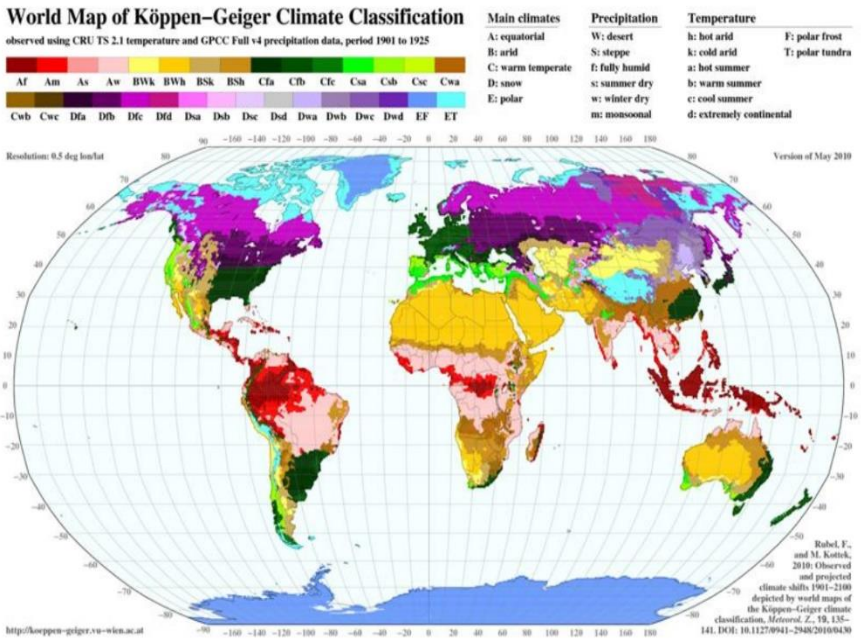


Figure 2.7: The World Map of Koppen-Geiger Climate cotgraization source: Koeppen-Geiger, 2019

Generally, the weather in the UAE is dry and hot most of the year, but it has cool and dry winter months. The peak temperature degree was recorded in August more than 42°C and the lowest degree was registered less than 15°C in February. Further, the UAE is enjoyed with a high level of solar radiation (Worlddata.info, 2020).

2.8.2 UAE Climate Change

According to Government.ae (2019), the UAE categorized as one of the highest rates of vulnerability to the potential influence of climate change in the world. As a result, the weather becomes warmer, rainfall rate low, droughts, sea-level rise and storms rate increase, etc.

The disadvantages of these effects are substantial on human health, county infrastructure, and ecological life. Therefore, various development sectors and policies will be affected, especially health, environmental, and socio-economic aspects.

On the other side, the economic development and the growth of the population maximize the need for energy, natural resources, and water, which indirectly impacts CO_2 emission level and change in the climate.

Consequently, the UAE has contributed with other countries against climate change problems due to its awareness of the risks of inaction to protect the environment.

Further, UAE plays a significant role in the world's energy economy as a fossil fuel producer, giving UAE a crucial responsibility to conduct solutions to eliminate pollutants.

Climate change impact negatively various aspects in UAE are:

- Water

The water sources supply and demand are affected by global warming, and this could increase the water availability gap worldwide. Some UAE areas will suffer from water shortage and drought, while some areas will flood frequently.

- Agriculture

Global warming has a significant impact on agriculture. The high temperature will raise weeds growth, and dangerous insects will negatively impact agricultural crops, which possibly lead to global food crises. In UAE, local food would rarely find because cultivation in UAE would suffer more from salty water, which is not appropriate for farming.

- Health of Human

Climate change influences human health in several ways. Contaminated and erratic rainwater increases the diversity of diseases and spreads. Moreover, warming maximizes the range of insect-borne conditions.

- Vegetation and animals

As a result of climate change, animals and vegetation will migrate their habitats to mountains and northern areas. Mostly if global warming out of control, many animals and plants will be expected to extinct.

- Air

Climate change is profoundly affected by massive pollution emissions. UAE experience a high pollution rate; it mainly produces around 80 tons per head of greenhouse gas carbon dioxide, while the USA produces only 14 tons per capita. CO_2 contributes worldwide in trapping the sun's heat in the air and increasing temperature. Moreover, increased dependence on air-conditioning for cooling, desalination plants and energy stations increase dependence on carbon-based fuel. Increased CO_2 levels in humans' bodies could increase human exposure more to toxicity.

- Sea levels

According to the Stockholm report, by the end of this century, UAE might suffer from losing 6% of its coastline as a result of increasing sea level, on account of rising sea surface temperature, which will drive to thermal expansion and alterations in sea eco-life. Therefore, coastal communities could start facing changes in storm frequency, movement, and intensity. Sea creatures will also be affected, and some species might migrate or extinct (Government.ae, 2019).

The United Arab Emirates has established the foundations for green growth and climate change and set a climate plan to identify the causes and influences of climate change. Moreover, it defined the transition plan into a climate-resilient green economy and quality of life enhancement.

The plan's objectives are to manage greenhouse gas production while preserving the growth of the economy. Also, it enhances climate flexibility by reducing risks and advancing the capacity of adaptive. Further, enhance the economic diversification agenda of UAE via novel solutions. (Ministry of Climate Change & Environment, 2017).

2.8.3 UAE energy consumption

The consumption of electricity and water is increasing at a fast pace due to the increase in population in the country. Which is direct affects economic growth and climate conditions. According to Business Monitor International, a sharp change in annual power needs all over the country is predictable during 2012-2021, with an expected yearly average consumption growth of around 5.6%.

UAE is one of the highest consumers of electricity per capita globally, depending on natural gas to achieve more than 90% of its demands of power production. Energy plays a significant role in the UAE economy and in establishing its internal and external policies. (Government.ae, 2019).

Most of UAE's primary energy is consumed by commercial and residential sectors, which equals 50% of the total UAE energy consumption.

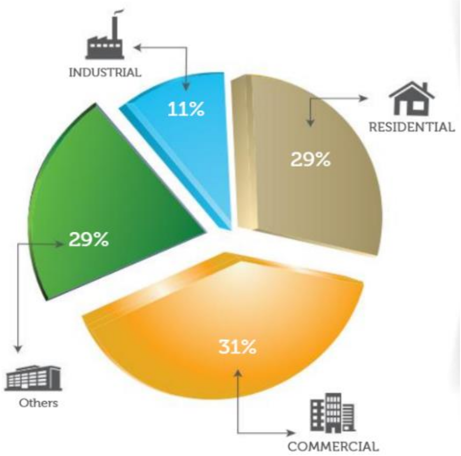


Figure 2.8: Main energy consumer sectors in UAE
source: Dubai Carbon and UNDP, 2014

Recently, UAE worked out to diversify energy production sources to preserve its economic progress, at the same time to reduce the negative impact of burning fuel on the environment. (Ministry of Energy and Industry in UAE, 2019).

As reported by The UAE State of Energy Report 2015, the natural gas share of electricity production will decrease from 98% in 2012 to lower than 76% in 2021 as green energy would enter the energy generation mix and enhance energy efficiency in the country.

UAE effort targets the energy field to facilitate access to affordable, modern, reliable energy services, enhance the share of renewable energy in the global energy mix and multiply the global rate of enhancement in energy efficiency.

The UAE energy strategy for 2050 aims to integrate different energy sources to achieve the UAE's economic needs and environmental objectives. The energy mix includes 44% clean energy, 38% natural gas, 12% clean coal and 6% nuclear. (Government.ae, 2019).

2.8.4 UAE Sustainability

Lately, sustainability has been one of the essential topics that are focused on by the UAE government to face climate change challenges and energy. UAE establish several regulations and policies in various sectors to meet United Nations 17 sustainable development goals on the social, economic and environmental aspects. (Government.ae, 2019).

UAE has several plans and initiatives for sustainable framework such as:

- 2030 Integrated Energy Strategy in Dubai

Dubai's government policy focused on using alternative sources of energy. Therefore, it set the Dubai integrated energy strategy 2030 to enhance decarbonization and guarantee efficient utilization of energy. Dubai plans to produce at least 5% of its electricity from renewable sources by 2030, further generate 12% from clean coal and 12% from nuclear plants. (Government.ae, 2019).

- 2050 Dubai Clean Energy Strategy

Dubai declared its targets for 2050 to generate around 75% of its power production from a clean energy source. Furthermore, it targets to make the city a global center of clean energy and a green economy. It includes five major pillars:

1. The Infrastructure pillar consists of several initiatives, such as Mohammed Bin Rashid Solar Park. It considers the largest solar energy producer in the world.
2. The legislation pillar concentrates on establishing the legislative structure to support the clean energy policies.
3. The funding pillar comprises establishing the Dubai Green Fund that will facilitate financial loans of clean energy investments.
4. The fourth pillar targets to develop the capabilities of human resources via global training programs in the clean energy field.

5. The last pillar concentrated on creating an eco-friendly energy mix consisting of 25% of solar energy, 7% clean coal, and 61% natural gas by 2030. The combination will gradually raise the share of clean energy sources over the years. (DEWA, 2017).

- 2050 UAE Energy Strategy

The country targets to enhance the share of clean energy percentage in the total energy mix from 25% to 50% by 2050. Further, it decreases the carbon footprint by 70% of power production, which seeks the economic benefits of the country. It moreover leads to improve individuals and corporations ' consumption efficiency by 40%.

The strategy aims to produce around 44% of green energy, 38 % natural gas, 12% clean coal and 6% nuclear to meet UAE's economic needs of energy. (EWS-WWF, 2018).

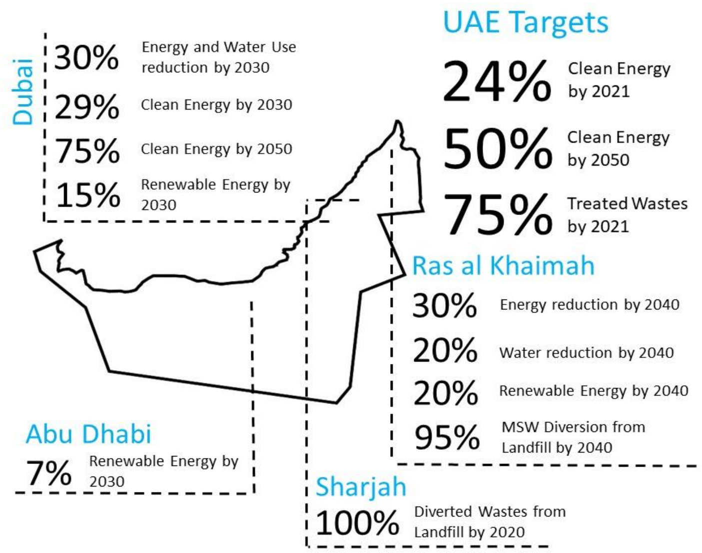


Figure 2.9: UAE sustianability initiaitves by each city source: Emiratesgbc.org, 2020

Moreover, UAE governments and municipalities established new regulations and policies to support the new vision of energy in the country. Such as Estidama and Dubai Green Building Regulations and Specifications.

- Estidama

Estidama is a green building rating system issued in 2008 by the Abu Dhabi Urban Planning Council. Estidama aims to establish more sustainable communities, cities and global organizations. Also, it aims to create between the four pillars of Estidama, which are the environmental, cultural, social and economic. It develops a Pearl rating system that objects to identify the sustainability of a project during its lifecycle from design through construction than to operation phases (Abu Dhabi Urban Planning Council, 2016).

- Dubai Green Building regulations and specifications

It was established in 2011 by Dubai Municipality and DEWA. It aims to enhance Dubai's building performance by decreasing the consumption of water, energy, and material and enhancing public safety and health. Further, its object of improving the building through its lifecycle phases from design to demolish to create a city based on the best standards of comfortable and sustainable life (Dubai Municipality, 2011).

- UAE sustainable building

UAE introduces lots of efforts and practices in sustainable building, with respect to the energy performance, conservation of natural resources, and adopt in the design stage various sustainable strategies (Yas and Jaafer, 2020). Such example, the buildings located in Masdar City, which is erected with low-carbon cement. Further, they are designed to decrease energy and water consumption by around 40%, at least. One of these buildings is the Eco-Villa.

- Eco-Villa

Masdar City has provided a prototype villa located in Abu Dhabi. The villa design is based on smart techniques and passive strategies constructed by insulated concrete form (ICF) walls with external U-value=0.16 $W/m^2.K$ and reused and certified timber. Windows on east, west and south facades are shaded with external shading devices. Moreover, the villa is equipped with high-efficiency LED lighting installed with motion sensors and variable refrigerant volume air conditioning as a cooling system.

Furthermore, it is provided with PV panels located on the roof beside a solar hot water system that makes it a net-zero energy villa. This villa design achieves around 72% energy efficiency and 35% water-efficient compared to the conventional villa design in UAE (Masdar, 2020).

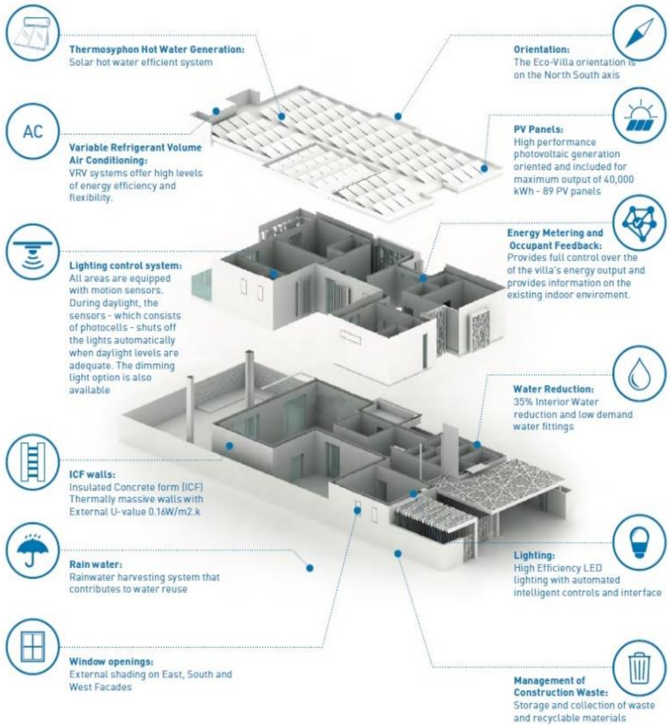


Figure 2.10: Eco-Villa smart system and sustainable strategies source: Masdar, 2020

2.8.5 UAE Residential Sector

The UAE aims to depend on a sustainable and diversified economy and flexible in integrating new economic models to provide an appropriate and comfortable life for UAE nationals' current and future generations. (Government.ae, 2019)

According to the UAE Ministry of Economy (2018), The construction and building sector plays an essential role in UAE economic growth that constitutes 8.4 % economic growth.

Recently in UAE, the residential house prices and rents continued to drop compared with previous years. While in 2018, Dubai residential provision concentrates on the affordable category. Several developers launched lots of projects for low-income households with appropriate payment plans. (Delloitte, 2019)

The Affordable housing definition varies from market to market according to the country's local economy. In both the UK and USA, households afford around 20% of their housing income, while in UAE, they spend approximately 32%-37% on housing (Colliers International, 2018).

2.8.6 UAE Affordable housing initiative

UAE seeks to provide convenient, comfortable and affordable housing for its citizens. The government assigns lands or provides housing loans or free homes, residential facilities and maintenance to the needy Emiratis.

Moreover, the UAE government initiated many activities in the housing sector, for example, establishing Sheikh Zayed Housing Programme at the federal level, Abu Dhabi Housing Authority, and Mohammed Bin Rashid Housing Establishment at the local level. (Government.ae, 2019)

- SZHP

It is founded at the federal level in 1990, supply repayable free-interest loans to support low-income households. Also, it provides for the most unfortunate citizen grants and non-reimbursable help. The department aims to attain the residents' welfare, introduce several innovative and sustainable services and implement the best international standards that achieve happiness and satisfaction of users (Government.ae, 2019 & Szhp.gov.ae, 2019).

- MBRHE

MBRHE department initiate to provide suitable housing for the citizen living in Dubai by supplying housing services via granting either residential lands or free houses, renovating old houses, and providing housing loans. It contributes to enhancing the national economy by constructing investment projects and stimulating cooperation with both the public and private sectors. Further, it redevelops and retrofitting the urban, rural, and desert zones and enhances the developing areas environmentally, socially and their living level (Establishment, 2019).

Most of the affordable housing projects erect in the UAE depend on the traditional housing construction system, which follows only municipality general building regulation without attention to sustainability standards. That will be presented in the next chapters.

2.9 Energy efficiency

In the developed country, around 90% of the population spends most of their time inside the buildings. Therefore, the indoor environment has a high impact on the inhabitants' thermal comfort, well-being, satisfaction and health level (Frontczak, Andersen and Wargocki, 2012).

According to Subhashini and Thirumaran (2018), many natural factors affect the quality of indoor thermal comforts, such as ventilation, air quality, noise, daylight, temperature and humidity. Achieving a comfortable level for occupants requires a significant amount of energy, especially for zones featured with a hot or cold climate most of the year.

The energy used by the buildings is equivalent to 40% of global energy consumption. So, many countries initiated to decrease this rate by implementing energy-conserving design strategies and regulations to enhance the energy efficiency of the building. Thus, selecting the appropriate building passive design strategies and materials will reduce energy consumption, control the heat flow between indoor and outdoor environments of the building, and provide a comfortable temperature for the users.

Many factors impact the quantity of building energy demand as an example of the building's physical features and systems, climate conditions, inhabitants' behavior and their activities, economic and social aspects of the location, and the quality level of the indoor environment. Therefore, assessing climatic conditions of the building site in the early design stage is vital for identifying building characteristics such as orientation, geometric form, building design strategies, materials and operation systems (Natephra, Yabuki and Fukuda, 2018).

Designing the house consists of several techniques to enhance the energy efficiency of the building is one of the main targets to achieve a sustainable home (Roufechaei, Abu Bakar and Tabassi, 2013).

The first step to designing a sustainable house is to enhance house energy efficiency and thermal comfort through implementing passive design strategies. An appropriate selection of passive design strategies can decrease the amount of energy that has been used to provide cooling or heating load. Previous investigations presented that proper insulation for walls alone can reduce around 50% of energy in the Middle East and North Africa (MENA) region.

This research will adopt and simulate the passive design strategies that could be used in a hot and dry climate zone to enhance the indoor thermal comfort for a cases-study located in Dubai.

The second step is to utilize renewable energy sources such as solar energy, wind turbines, etc., which can contribute to generating green energy and upgrading the energy performance of the building. In this research, PV panels will be used in the house as a practical solution due to solar energy is plenty available in the UAE region.

2.10 Passive design strategies

Passive design term refers to a concatenation of the architectural design process utilized to create a building considering climatic requirements, among other design requirements. The implementation of passive design strategies is targeted to use the available environmental factors to reduce the dependence on mechanical loads. Moreover, it is used to enhance indoor building thermal comfort (Bansal, 2018).

Maintaining indoor thermal comfort in hot and dry climatic regions requires a reduction in solar heat gain rate by selecting the appropriate orientation and size of the building envelope and controlling the reflection and interception of solar energy gain. Furthermore, the thermal heat gains should be minimized through the proper selection of materials and insulations. Also, thermal comfort is enhanced via improving the evaporative and radiative cooling, movement of air and convection of the building (Gupta and Tiwari, 2016).

2.10.1 Building orientation

According to Bansal (2018), considering the location of the sun in designing the buildings is crucial as well as the prevailing winds movement in all seasons in hot climate regions. Using the climatic date of sun and wind movement contributes to defining the appropriate orientation of building spaces, which leads to enhance comfort levels for the occupants without neglecting the functions of the building because each building type requires a sufficient amount of light and heat.

In hot and arid climate regions, buildings' northern façade has the lowest exposure rate during the year, so in order to achieve the best orientation of the building is to extend the long facade towards the east-west axis while the short face extends over the north-south axis. Further, in summer, both eastern and western elevations are more exposed to the sun so, it is preferable to shade these areas via trees or neighboring buildings. Moreover, the southern façade in winter absorbs most solar energy; thus, it is better to install shading devices to enhance the indoor environment. Also, rotate the building slightly east of the south improves building efficiency, which reduces the absorption rate of the western wall to the solar energy (Lavafpour and Surat, 2011).

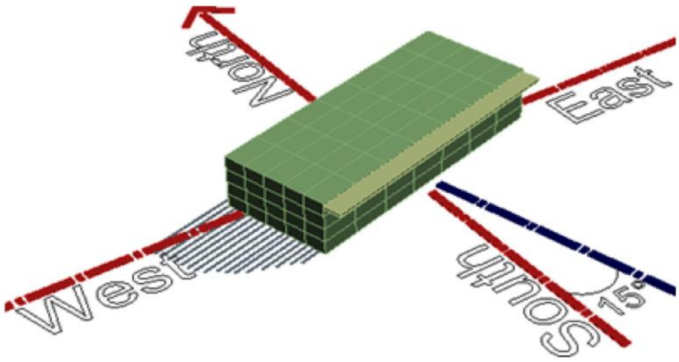


Figure 2.11: The best orientation of the building in hot-arid climate
source: Lavafpour and Surat, 2011

2.10.2 Building material

Suitable building material has several functions that serve the building and its occupants as well as protect it from harmful environmental impact and climate conditions. The material contributes to enhancing the building's energy efficiency by keeping the heat and moisture away from the building. Integrating insulation with the reflective coating will decrease heat transfer via roofs and walls. Moreover, low-emissivity glass and glazed windows will promote the amount of light transmittance. Also, the vapor barrier is required inside the building to prevent moisture (Baeza, 2013).

According to Bansal (2018), the primary standards for choosing the appropriate building materials are the local availability, low environmental impact, small waste amount and suitable to the local climate conditions.

- The material of construction

steel structural bars to support it, with or without layers of insulation, covered with plaster layers on both wall sides. The physical properties of the material, such as resistivity, transmission, reflectivity and thermal conductivity, have a great impact on controlling the heat flow between the house and the surrounding environment (Lavafpour and Surat, 2011).

Utilizing materials characterized by low heat conductivity and high thermal mass will decrease the heat flow over the building in hot and dry climate regions, which leads to a reduction in energy consumption and cost (Baeza, 2013).

Thermal conductivity term describes the material performance regarding heat conduction, which is the amount of heat flow per unit of thickness under temperature variation. A high thermal conductivity material indicates a good conductor; on the other hand, the low one is an excellent insulator. Many materials tend to be poor conductors, such as organic material as wood. Also, aerated materials are very poor heat conductors and good insulators because they contain air or gas gaps in their composition (Lavafpour and Surat, 2011.

Moreover, knowing the thermal transmittance value is essential to know the ability of materials or overall composition (wall or roof) to isolate the building from heat transfer into it (Baeza, 2013). According to the Dubai Municipality, building regulations about construction permit the maximum heat transmittance (U-value) allowed for the walls is 0.57 W/m²K and for the roof 0.30 W/m². Also, according to ESTIDAMA local standards for new-build villas, the minimum requirement of the U-value of the wall is 0.32 W/m²K and 0.14 W/m²k for roofs to achieve the minimum credits of energy performance.

Therefore, to achieve the U-value requirements in UAE, either using masonry block with large thickness or utilizing appropriate insulation material in the building. There are other criteria besides the thermal conductivity to select structure materials as density, strength, heat capacity, cost and carbon footprint. The primary purpose of the research is to reduce the energy consumption of building with respect to their price; therefore, the thermal conductivity of construction materials is the critical value. (Baeza, 2013).

- Insulation materials

Integrating insulation material within the building envelope will decrease the heat transfer between the building's external and internal sides. Previously air was one of the most important isolators used in construction because it is deficient in transferring heat. The composed layers of walls, roofs and windows separated by air gaps to enhance the resistance against heat transfer (Lavafpour and Surat, 2011). Recently, several materials worked as a good insulator, such as polyurethane, fiberglass, wool, calcium silicate, etc. It can exist in many configurations as foam, rigid boards, blankets and loose fill (Baeza, 2013).

2.10.3 Window

Designing windows and glass doors in a sustainable house is a challenge for designers. Although glazed areas present the aesthetics and identity of the building, they also show the highest range of heat gains per surface area. When windows covered around 20% to 30% of the building walls, they will be responsible for generating approximately 45% to 60% of the cooling load. (Bhamare, Rathod and Banerjee, 2019).

The window performance relies on optical and thermal properties of glazing such as solar heat gains coefficient (SHGC), U-value and visible transmittance (Rathod and Banerjee, 2019). According to the Dubai municipality regulation, if the glazing percentage is equal to or greater than 60% of the external wall's total area, then the glazing elements properties must not exceed 1.9 W/m²k for U-value, 0.25 for SHGC and not less than 0.1 for visible transmittance.

The traditional design of the window contains two or three layers of glass separated by air spaces. Air worked here as an insulation layer; however, there are other fluids with lower conductivity or move slowly that can be replaced with air, such as argon and krypton, which can enhance heat resistance (Lavafpour and Surat, 2011).

Further, can the windows have films, could be implemented either inside or outside the glass, that decrease the UV and infrared radiation amount, but at the same time, they minimize the visible light. Low-Emissivity films are developed recently, which are selective spectral reflective coatings. That allows only visible light to pass through the window and neglect both heat and UV radiation. The sealant is an integral part of designing windows, for example, silicone and polyurethane, which are used to maintain the air or gas inside faraway from humidity. In hot climate regions using external and internal shading, like curtains, shutters, blinds and draperies, are recommended (Baeza, 2013).

2.10.4 Reflective materials

The solar radiation impact also besides the ambient temperature on the building cooling loads. So, when the radiation reaches the building surface, the temperature of the surface will increase. Using a proper reflective coating can reflect some of the solar radiation and enhance the building efficiency (Lavafpour and Surat, 2011).

Generally, dark color paints used in the exterior envelope will increase the absorption of solar radiation, which will raise the inside temperature degrees. So, in hot regions reflecting solar radiation is required; therefore, light color paints are preferable. Utilizing the white color paint can reflect around 50% of radiation (Baeza, 2013).

2.10.5 Shading

Using shading devices and sun control elements is one of the significant aspects of several energy-efficient building passive design techniques. In hot climate regions, they enhance receiving natural lighting and reduce the solar heat gains. Shading can be created by surrounding buildings, vegetation and human-made devices (Bhamare, Rathod and Banerjee, 2019).

- Neighboring building shading

According to Sharma (2016), buildings in a cluster, separated by space, can give shade for each other mutually. Shading effectiveness can be defined according to building clusters type. There is three building clusters classification, which are courts, streets and pavilions. The courtyards referred to open spaces circumvented on all sides by buildings. While the roads are rows of buildings arranged in parallel and separated by real streets in open areas. And the pavilions type are isolated buildings, could be individual buildings or in clusters circumvented by open areas.

- Vegetation shading

In conventional courtyard houses, trees act as shading devices in hot climate countries, protect the homes from sun radiation and reduce the ambient warm air temperature. Tree leaves absorbed solar radiation to use it mainly in photosynthesis and evaporative heat losses. Some of the solar rays are stored by the fluids as heat in plants (Lavafpour and Surat, 2011). Generally, in hot regions, both west and east building façades suffer from sun radiation compared with north and south directions. Therefore, the shady trees should be cultivated beside west and east façades, especially in front glazes areas. Moreover, it's better to cultivate deciduous trees on the building's south façade (Sharma, 2016).

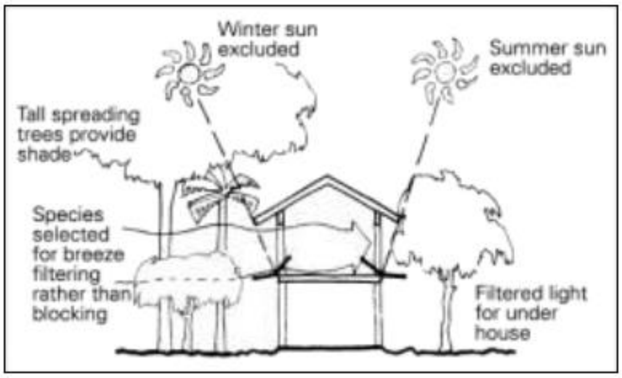


Figure 2.12: show several shading elements source: Sharma, 2016

- Shading devises

Shading elements such as overhangs, light shelf, horizontal louvers and blind system, etc., can be applied to the building envelope, particularly windows, to provide shades (Bhamare, Rathod and Banerjee, 2019). Shading devices can be categorized regarding their location to the window as external, internal or intermediate. Also, they classified their operation, either fixed or movable.

Although most of the residential building used internal shading as curtains, roller shades and venetian blinds, the presence of external shadings are more effective in decreasing cooling loads. Also, reduce the impact of overheating, as well as minimize incident sun radiation before it passes through window glass. However, external techniques are more expansive compared with internal shading devices and require frequent maintenance. External shading devices are vertical and horizontal louvers, fins, solid and louvered overhang, etc. can be implemented to the glazed areas or the part or whole building elevation (Carletti, Sciurpi and Pierangioli, 2014).

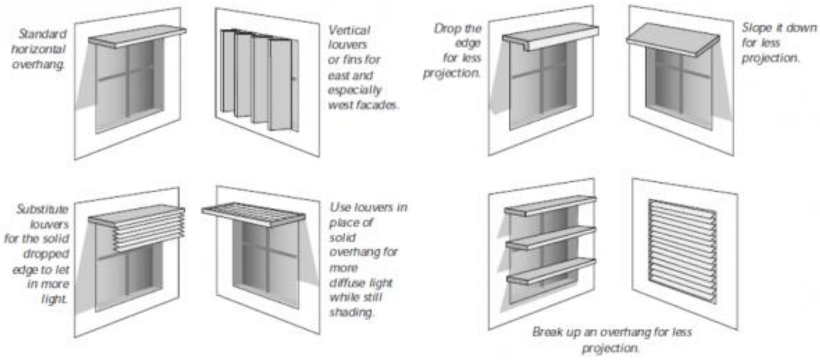


Figure 2.13: Different shading devices source: Building Performance Analysis, 2020

2.10.6 Courtyard

The courtyard is a universal design feature, which has been integrated into various buildings around the world for centuries. It used to provide cool air, natural sunlight, security, etc. courtyard in hot climate regions considered the heart of the house, which was designed to be compatible with nature. It works as a temperature and microclimate controller, plus a place for a social gathering (Hasehzadeh Haseh, Khakzand and Ojaghlou, 2018).

Integrating courtyards with the house contributes to improving the air movement within the building's interior spaces and draws hot air from the building. Therefore, it enhances house thermal performance through natural ventilation (Sharma, 2016).

2.10.7 Ventilation

The process of providing fresh air to the building from outside and getting raid from indoor pollutant air to provide thermal comfort is ventilation. Air flows an essential part of attaining natural ventilation entering the building, which is affected by building configuration, orientation and slots (Bansal, 2018).

Applying technical solutions to provide ventilation for buildings in hot countries had appeared since ancient times as the curved roof vent system used in Iran from 3000 BC and the wind tower was developed since 900 AD. A wind tower is a shaft extend high above the building with a slot that usually faced the prevailing winds (Lavafpour and Surat, 2011).

Wind tower has two various physical mechanisms to provide ventilation. The first mechanism is two openings, one of them placed towards the prevailing wind direction used to absorb the outdoor air and send it inside the house. While other slots are set in the opposite direction to remove the hot and polluted air from the building, then send it out. Mostly the wind tower worked with this principle requires windy conditions (Tolba, 2014).

The second one worked due to temperature variation. When there is no wind during the daytime, the surrounding outdoor air temperature is higher than wind catcher walls. In this situation, the windcatcher works in reverse. Therefore, the wind towers draw hot air onto it, and when hot air touches the tower walls, it loses its heat and cools, then it flows down into the building. These tower walls lost their heat during the previous night. But during night hours, the outdoor temperature becomes lower and colder so, it goes down through the windcatcher shafts. This process continues until the tower walls temperature becomes equal to the ambient temperature (Lavafpour and Surat, 2011), as shown in Fig (2.14).

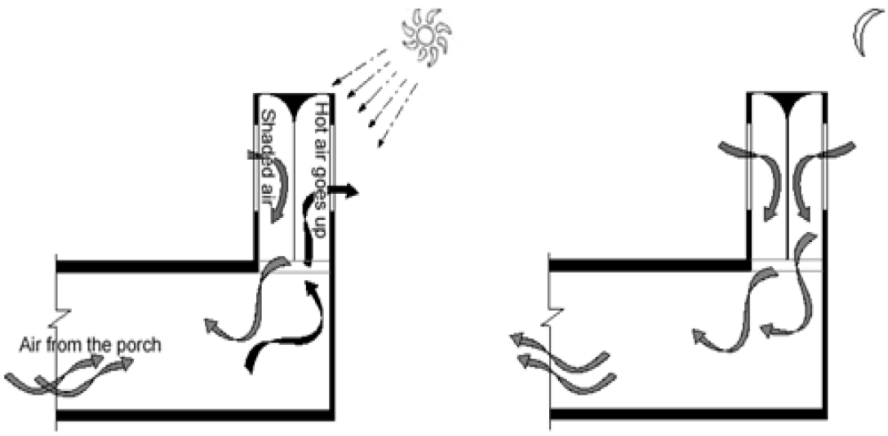


Figure 2.14: The air movement through wind catcher due to temp. difference
source: Lavafpour and Surat, 2011.

2.10.8 Green roof

Building roofs considered one of the main responsible for solar heat gains. Therefore, implementing a proper type of insulation can decrease heat transfer to the building interior. Appling, the green roof design concept, can improve roof thermal efficiency. It is referred to as the building roof covered with vegetation such as grasses and shrubs, which extends above the waterproofing layer. Using a variety of light plants is better for achieving a light layer for the roof. Further green roof generates oxygen for the environments, reduces ambient air temperature and the impact of heat island in the urban. Green roofs can decrease roof slab temperature by 30 °C and decrease the energy requirement by around 6% (Taleb, 2014).

A green roof is a traditional roof that integrates with a waterproofing membrane layer where drainage and vegetation layers are placed on top of it. Generally, a green roof comprises five layers arranged from the bottom to the top: a roof slab, roofing membrane, insulation, layer of drainage, cultivating media and plants layer. There are two main green roof types the extensive and intensive (Shishegar, 2012).

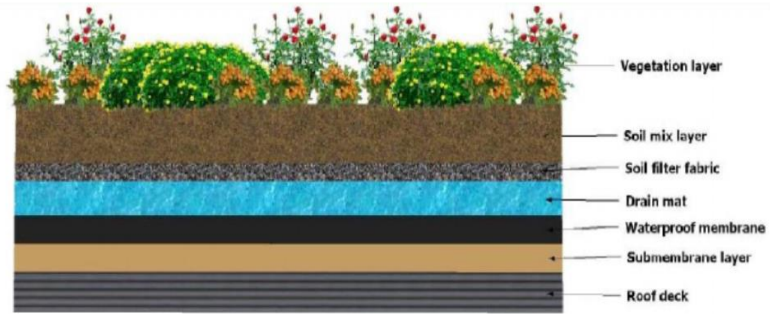


Figure 2.15: The layers that make up the green roof system
source: Shishegar, 2012

The intensive type is usually designed as public areas requiring a cultivating media between 150 to 1200mm. Trees and shrubs can be planted in this type. This type is more expensive than the extensive variety because it needs a significant amount of structural support to carry the vegetation loads and it requires more maintenance in contrast with the extensive. On the other hand, extensive green roof vegetation media thickness between 50 to 150 mm. It is more preferred by the customers due to its lightweight, low cost, less maintenance and the soil layers are shallow (Shishegar, 2012).

2.11 Renewable Energy

The geographical location of UAE makes it one of the leading producers of oil and natural gas in the world; thus, UAE rated among world countries the sixth oil reserves and fifth reserves of natural gas (Al-Amir and Abu-Hijleh, 2013). UAE and other Gulf countries have recorded the highest CO_2 production in the world. According to the World Energy Council (WEC), the GCC area is responsible for 2.25% of CO_2 emission and the UAE produces around 0.4% of it. Generally, reducing CO_2 generated for energy consumption can be achieved by enhancing building energy efficiency, utilizing renewable energy and capturing carbon and sequestration (Jamil, Ahmad and Jeon, 2016).

Renewable energy in UAE is a suitable alternative to fossil fuel in order to decrease CO_2 and other toxins emission as well as has a significant effect on the environment. Moreover, RE provides clean, safe, enhances industrial capabilities and improves the effectiveness of energy cost and the country's overall economy. It covers all energy sources generated from natural continuously and can be harnessed for social benefits. The main RE sources are wind, geothermal, biomass, solar thermal energy, solar PV and hydro energies (Al-Amir and Abu-Hijleh, 2013).

As mention before, the UAE climate is hot and arid, and it is located in the solar belt area between 40° north and 40° south. The average UAE reception for solar radiation is around 2200 kWh/m² per year; therefore, solar energy is widely available in the country. Besides solar energy, UAE harnessed other solar power such as wind, waste to energy, geothermal and ocean energy (Jamil, Ahmad and Jeon, 2016) & (Mohandes, El-Chaar and Lamont, 2009).

Many solar power technologies are used to produce energy, such as photovoltaic (PV) energy and concentrated solar power (CSP). This research will concentrate on PV panels as a source of renewable energy (Mohandes, El-Chaar and Lamont, 2009).

2.11.1 PV panel

A PV unit consists of interrelated photovoltaic cells that are encapsulated between a weatherproof cover (generally glass cover) and a black sheet (generally plastic laminate). These cells are interconnected in a form designed to provide a beneficial voltage and current at the terminal's output (Mohandes, El-Chaar and Lamont, 2009).

According to MESIA (2014), there are three PV models available in the UAE market, which are monocrystalline silicon cells, polycrystalline silicon cells, and thin-film panels.

- The monocrystalline model is composed of a cut-out of a single silicon crystal. The surface texture of it is thick and soft. Although the production of it is expensive, however, it is more efficient than others.
- The polycrystalline model is composed of a cut-out of a silicon block containing many crystals. It has a shiny and reflective surface. This type of production is less expensive than monocrystalline cells but, at the same time, has a lower efficiency than it.
- The thin-film panels are composed of non-crystalline silicon (amorphous) or other material as an example of copper indium gallium selenide or cadmium telluride. These panels are flexible, different from the previous types, and installed on a wide

range of various surfaces. They have the lowest efficiency and price. But they can generate energy even in light diffusion conditions (Mohandes, El-Chaar and Lamont, 2009).

As Shown in the MESIA (2014) report, the PV panel is integrated with other components to configure the solar system, which are the storage battery, controller, inverter, mounting structure and monitoring device. The PV cells convert the light to energy, while the storage battery stores the power generated by the PV panel, which is not used directly. The battery is expensive, and it needs to be substituted every few years. The controller is the device that promotes electricity to flow between panels and battery and restrains it from being overcharged. Further, the inverter is used to convert the DC current to AC current, which is required from most of the machines. The mounting structure gives support for the panels. Lastly, the monitoring device is used to monitor the solar system performance.

There are two classifications of PV panels off-grid system and grid-connected solar system. Off-grid is designed to be a self-sufficient model that is not related to the local grid. The generated energy is kept in a storage battery for later consumption as at night. On the other hand, a grid-connected solar system is designed to interconnect with the local grid. No need to use storage batteries in this system as well as cannot store the over energy, thus the devices receive the power directly and the rest of the electricity is fed into the local grid (MESIA, 2014).

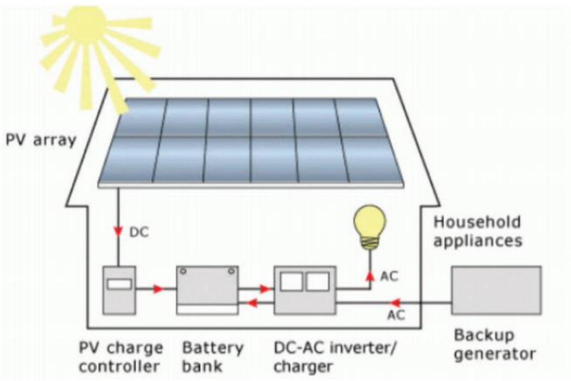


Figure 2.16: Off-Grid system source: MESIA, 2014

In MESIA (2014) study, the global market of solar is always variable. Recently the prices of solar systems are minimized, and solar manufacturing technologies are renewed in a wide range. Further, the demand for PV is increased by 30% per year over the last 20 years.

2.12 Summary

In this research, the conducted literature review introduces UAE's interest in establishing the principles and rules of sustainability in all country organizations. Since the UAE is one of the highest consumers of electricity per capita globally, the governments maximize their efforts to reduce the consumption rate and produce clean energy from renewable energy resources. The building sector is the most responsible for wasting energy, especially the residential sectors.

The literature review presents the UAE initiative to enhance the performance of the building by addressing several regulations and policies. However, the specialist and engineers in building construction still used the conventional systems to construct the building with meeting the minimum requirements of rules to provide low initial cost for the clients without concern on the building lifespan expanses.

Moreover, the reviews present the country's efforts to provide appropriate housing for its citizens with acceptable prices; therefore, most of these housing units constructed based on the traditional system of the building. The housing sector needs enhancement methods and strategies to upgrade its performance to be more efficient and sustainable.

The literature review introduces various passive design methods and technologies to improve the housing unit's energy efficiency. Moreover, it presents the photovoltaic panels technology that is used abundantly in UAE.

These refurbishment strategies will be used in the simulation chapter to modify the selected cases related to government housing organizations in terms of enhancing their energy consumption performance by taking into account the life cycle cost of the case study.

Chapter 3

Methodology

3- Methodology

3.1 Introduction

The purpose of each research is to evaluate problems that are related to a particular field systematically and comprehensively, aiming to characterize, predict, or clarify a phenomenon. Regardless of the research's purpose, it is essential to approach research in an organized way with a proper and scientifically approved methodology.

The appropriate selection of the method is critical when researching to ensure that the study's aim can be achieved and the results can be adequately assessed. This chapter will introduce an in-depth assessment of the research steps and procedures used to collect and analyze data regarding research objectives and questions. Each research step should use various methods, strategies, and tools to guarantee the results are valid. Moreover, it will cover the process of sampling techniques and data assessment methods. All these strategies and procedures will be addressed and justified crucially.

Furthermore, the chapter will present a review and evaluation for similar studies methodologies related to the research field, which either aims to develop over their outcomes or assess the same study subject from different views of work. Also, to evaluate their methodologies and strategies in other conditions to check if the same results will be extracted or not, which will lead to recognizing various factors that impact the research results. This step is vital to carry out the research because it contributes to saving time and efforts and directing the author to explore new knowledge instead of starting from scratch.

Previous studies demonstrated the diversity of methodologies used to carry out research specializing in sustainable, affordable housing design based on the studies' purposes.

3.2 Similar topics methodologies

Lack of awareness among construction sector workers of the significance of incorporating sustainability factors into developing affordable housing projects and the objection of some developers to the idea due to financial reasons. Without ignoring the intellectual development of the sustainable building technologies and strategies that could be used in enhancing the performance of these housing units led appear several studies concentrated on creating sustainable, affordable housing units and their positive aspects. The investigation of the previous studies related to sustainable and affordable housing topics demonstrated the diversity of methodologies used to achieve these research aims and objectives.

The investigation of sustainability in affordable housing was carried out either by a single methodology or the mixing methods. However, the most common methods were addressed literature review, survey, simulation and mixed approach.

3.2.1The literature reviews methodology

Regardless of the disciplines, the literature review is the initial process for any research where several previous studies were described and analyzed to address and assess the research area to establish the study aim and justify the study hypotheses and questions. However, the authors used it as the main method to conduct the research when they want to assess theory or evidence in a particular area or to check a specific theory's validity or accuracy. Consequently, this methodology is essential for any research topic, either as an individual method or as a support method for other methodologies (Snyder, 2019). According to Maier (2013), The process of conducting a literature review research starts with designing the study by identifying the research purposes and setting the research questions and topic concerns. Then doing the review by studying and exploring relevant issues or similar questions. After that, carry out the evaluation and analysis method of the most pertinent studies in regard to objectives, method of work and results and compare them to extract the outcomes listed in the results section. Concluding with addressing and explaining the findings that either meet or dissent the research objectives and purposes, as shown in Fig (3.1).

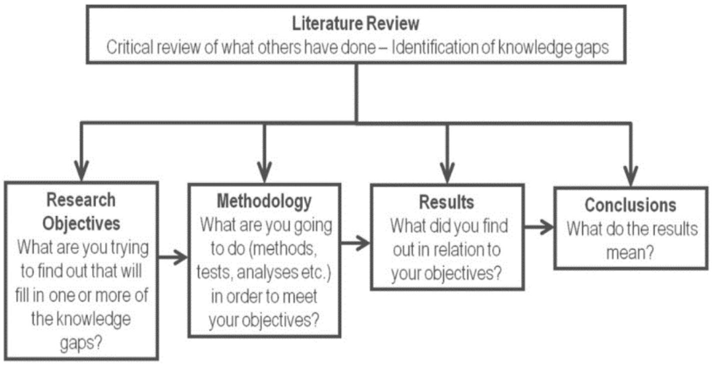


Figure 3.1: Conceptual illustration of literature review procedure source: Maier,

Several studies adopted a literature review methodology to conduct sustainable, affordable housing mainly to provide definitions and to address the challenges and factors that impact the integration of sustainability and affordability in housing development.

As in Syed Jamaludin, Mahayuddin and Hamid (2018) study, where they conduct an extensive literature review to explore the practices of the affordable and sustainable housing situation in the Malaysian construction industry. Starting with definitions of the main terms of the research as affordable housing, sustainable housing and the integration between them.

Also, they provided a review of sustainable, affordable statutes in developed and developing countries. Moreover, it presented a list of the critical challenges facing the implementation of sustainable, affordable housing in Malaysia, which is divided into four categories market, societal, professional and technological difficulties. Concluding with a list of recommendations to enhance the awareness and knowledge of developers about the importance of combining sustainable and affordable housing. In addition to upgrading the country regulations and rules to establish sustainable affordable housing practices.

The literature review provides a piece of deep and extensive knowledge and background in terms of the research area. It also helps the author establish the research framework and clarify the path to conduct the research properly. But implementing this study in some research areas is inefficient due to lack of availability of information or difficulty accessing the data. Some investigations also require more than a literature review to extract useful outcomes that serve the study area. This method consumes lots of time and effort.

3.2.2 Survey methodology

The methodology of the survey can be defined as the mean of collecting quantitative information about a specific topic from a large sample of the population to investigate their responses and reactions. Generally, it can be used to either collect opinions, measure satisfaction or assess the awareness level of the group of people. It could be conducted either as a web survey, personal interviews, mails survey and telephone surveys. This method is rarely found alone in sustainable, affordable housing studies (Dillman, Hox and Leeuw, n.d.).

Said et al., (2016) research adopted survey methodology of work, which aimed to investigate the best zone to construct sustainable, affordable housing units in Sabah state, Malaysia, through distributed questionnaires consisting of 26 criteria to inhabitants within the most popular and required six zones of the city. The questionnaire's purpose was to examine and elicit the opinions of respondents via evaluating their existing homes is related to the proposed standards that address sustainable housing affordability. The questionnaires' outcomes presented that all zones are suitable for sustainable, affordable housing projects with a slight disparity between them. This research could be used by property developers to find the appropriate locations to develop sustainable, affordable housing projects. Another study was conducted in Malaysia to explore the housing developers' insights on sustainable, affordable housing potential benefits. They used a cross-sectional hand delivery questionnaire survey, which including 23 sustainable, affordable housing benefits distributed among clients, developers and developer organizations. The survey results presented that the Malaysian housing industry isn't yet convinced of the importance of sustainable, affordable housing and its potential benefits. Therefore, the government needs to modify and upgrade its policies and regulations to support the combination of affordability and sustainability as well as decrease housing operation cost (Olanrewaju, Tan and Abdul-Aziz, 2018). However, survey methodology helps researchers collect data from a large sample of people and examine their opinions, awareness, reactions, etc., with a low amount of expenses compared with other methodologies. However, this method doesn't provide sufficient information on some topics, especially on a controversial topic—moreover, it lacks accuracy due to the different respondents' cultural and social backgrounds.

3.2.3 Simulation and computer modeling methodology

Many papers in the sustainable, affordable housing field rely on simulation methodology to investigate the research objectives and conduct the study with consideration of real-world parameters and conditions. Simulation methodology is used to evaluate the performance of the model or system that either existed or proposed. Starting the projects or studies with simulation tools, especially in science, engineering, video games and economics fields will help predict outcomes, examine various parameters and minimize the clashes before implementing the project in real life. The simulation could be used in various forms, either as equations, mathematical and computer software (Jaleesha and Ezhil, 2019). Generally, using computer simulation in sustainable, affordable housing field to measure various variables regards sustainability and assess factors that impact the life cycle cost.

Marzouk and Azab conducted their study through simulation methodology to develop a dynamic model in STELLA software. The developed model could clarify the interaction between systems of the building, costs and sustainable properties to assess the economic and environmental performance of low-income housing. The financial aspect is evaluated by life cycle cost, while the environmental performance of the material is determined by LEED credit that presented in five scenarios. The proposed evaluation outcomes revealed that eco-friendly materials recorded a better performance in terms of operational cost and LEED credit compared with conventional material (Marzouk and Azab, 2017).

Moreover, Alemi and Loge (2017) presented an affordable zero net energy prototype house developed by the UC Davis Solar Decathlon team in California, America, which aimed to provide comfort and better life quality for farmworkers that they can afford. The prototype house was developed at BEopt an energy modeling software and Microsoft Excel. The designers implemented several strategies and technologies to attain their goals. Such as implemented passive and active design strategies, used energy-efficient appliance, greywater heat recovery system and PV panels. Moreover, they adopted the in-line framing method used 10% less lumber than the conventional framing method. Both BEopt and Excel were used to investigate the energy performance of the prototype, which addressed a significant reduction in energy consumption compared with traditional homes.

Regardless of the simulation model function, the computer simulation is the best to predict the closest behaviors and reactions that could be happened in real life. It can investigate and solve complex cases and systems. Besides, this method can use a wide range of variables under controlled conditions, extending the research area. However, optimal outcomes and solutions are difficult to be produced by simulation approach according to unexpected circumstances. Also, it requires great caution in entering the data as it affects the validity and reliability of the simulation and sometimes simulation methodology-based studies demand significant expenses to use the software.

3.2.4 Mixed methodology

Several studies were conducted in sustainable, affordable housing based on mixed methods or multi-methodologies. Mainly mixed-method studies integrate into the same study quantitative and qualitative research or a series of processes in collecting data, investigating and evaluating variables. For example, in Ali and Alzu'bi (2017) analysis, they used several methods to carry out their study, which is drawing review, field survey, personal interviews and computer simulation. To explore the situation of various affordable housing projects in Jordan and develop an affordable and sustainable housing model. Reviewing the "as-built" drawings to collect the data regards building physical and operational characteristics. Both surveys and interviews were conducted with architects and decision-makers in the housing sector to obtain further information related to sustainable, affordable housing parameters that could be used in the hot and arid climate.

Furthermore, they used DesignBuilder simulation software to assess the energy consumption patterns of these housing and BRE Code Water Calculator to analyze the water efficiency. The outcomes data of these investigations and assessments were utilized to develop a new model that combined affordability and sustainability, which was later compared to these housing. The analysis demonstrated that the proposed model provided a considerable reduction in energy and water consumption.

Other studies conducted on the same topic combined literature review and survey methodologies as Chan and Adabre research. They run a study to address and categorize the critical success factors (CSC) required to bridge the gap between sustainable and affordable housing. Initiating a comprehensive review of the literature to identify the main (CSC) factors, followed by a questionnaire survey that sends to affordable housing experts. Consequently, it concluded with 21 (CSC) factors classified into six groups. This research finding could be used as a guide for housing developers and governments for establishing sustainable housing projects (Chan and Adabre, 2019). Researchers usually prefer to use mixed methodologies to enhance the validity and accuracy of study results, introduce a greater variety of views, could help synthesize and combine theories and some studies used mixed methods to compete between them. However, lack of experience in one of the methodologies could lead to consume more time and cost and increase the complexity of the research design (Ganiyu, 2016).

3.3 Methodology selection and software selection

It is quite evident that there are various methodologies used in the sustainable, affordable housing field with several variations between them. Nevertheless, the central method adopted in this research is a computer simulation, which will be supported by literature review and personal interview methods to achieve the aim and objectives of the study.

Initiating with literature review, which is a fundamental approach used to collect data regarding affordable and sustainable housing concepts and identify the parameters that impact energy efficiency. Followed by personal interviews with affordable housing organizations to gather case-studies information and engineering drawings. Moreover, other meetings will be conducted with architects, engineers and specialist to collect more data that serve the study. Computer simulation will be used as an investigation and validation tool for energy performance of the particular cases where will be implemented on IES-VE software. The economic performance of the housing will be evaluated through the life cycle cost, which will be discussed in detail later in another chapter. However, Excel software will be responsible for all numerical calculations.

3.4 Methodology justification

The appropriate and preferred method for investigating the impact of various passive design variables and the utilization of PV panels on affordable housing energy performance is computer simulation due to many factors.

A digital model will be developed through computer simulation, which imitates the case-study real situation and climatic conditions where various variables can be measured under a controlled environment during a short period. Thus, allow the study to experience several solutions, expand the research area and improve study examination flexibility. The controlled conditions enhance the efficiency of the investigation results and respect the time limit of conducting the study.

Moreover, most computer software available for students is either a free trial or low price so, computer simulation methodology will meet the research objectives with acceptable expenses for a student.

Both literature review and personal interviews are essential in this study to collect study required data, but the author can't adopt them to conduct the research as standalone methodology. They are not adequate to attain the study objectives and desires that were presented in the introduction chapter.

3.5 Software validation

There is various software available in the market that could be used to measure the buildings' energy performance and thermal comfort. However, this study will rely on Integrated Environmental Solutions- Virtual Environment (IES-VE) version 2019, where the computational models will be developed and investigated. IES-VE software has been extensively validated and its calculation and assessment methods meet the requirements of many international standards, for example, ASHRAE 55 and UK National Calculation Methodology (Mohammad and Shea, 2013). Furthermore, it has been implemented globally in several energy-efficient building projects and specialized researches in energy and environmental fields.

Daaboul, Ghali and Ghaddar (2017) conducted a study to investigate the use of mixed-mode ventilation and air conditioning as a substitute for energy saving for an office building in Lebanon by adopting IEV-VE software for simulation. They found out during the research that the energy consumption assessment done by the IES-VE computational model has an average 6% variation against the actual consumption of energy.

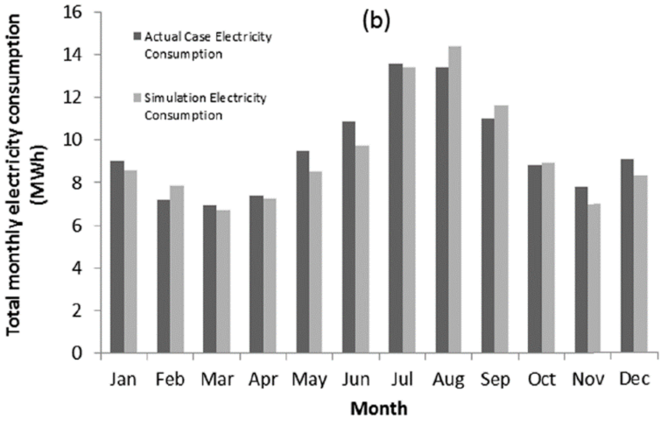
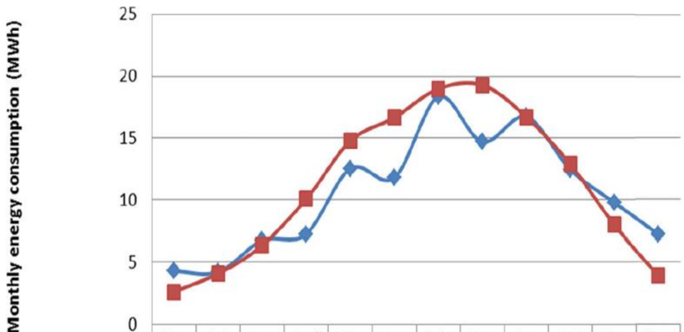


Figure 3.2: The actual energy consumption against the IES-VE model value
source: Daaboul, Ghali and Ghaddar, 2017

Another research carried- out by Abu-Hijleh et al. (2016) to assess the technical and economic benefits of retrofitting existing villa in UAE through IES-VE software. The study also presented the accuracy and validity of the software when compared to the predicted energy consumption with actual bills of the building. As shown in Fig (3.3), the variation between actual and IES-VE simulated energy consumption was slightly estimated by 6.5% over the year.



	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Actual (MWh)	4.29	4.22	6.74	7.24	12.56	11.82	18.34	14.71	16.74	12.49	9.8	7.22
IES (MWh)	2.63	4.1	6.33	10.07	14.78	16.67	18.97	19.28	16.7	12.92	7.99	3.93

Figure 3.3: actual energy and IES-VE simulated energy consumption
source: Abu-Hijleh et al., 2016

A study was conducted to evaluate the impact of shading elements on conserving the cooling energy when implemented in various facade orientations and different glazing configurations and thermal properties through IES-VE software, which resulted in proofing the effectivity of shading devices in reducing the cooling loads in a high-rise building in Malaysia. This study adopted IES-VE software for carrying out its simulation due to its high accuracy, where the statistical variation means values between the software and the measured data was intangible. (Lau, Salleh, Lim and Sulaiman, 2016).

Another study in Malaysia was conducted to evaluate the U-shape microclimate performance in a hospital through IES-VE, where the field measurements of air temperature compared with the IES-VE simulation results to check the calibration of the study base case. This proved the validity of the software, particularly between 10:00 am to 4:00 pm, as shown in the below figure (Almhafdy, Ibrahim, Ahmad and Yahya, 2013).

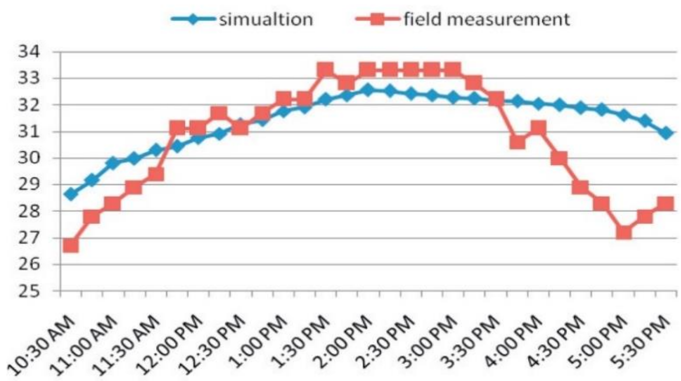


Figure 3.4: The calibration of the study model compared with field measurements records source: Almhafdy, Ibrahim, Ahmad and Yahya, 2013

IES-VE provides unique tools and technologies which allow architects and engineers to read, visualize and understand the results quickly. Moreover, the software offers a wide range of assessment applications that contribute to examining different design options, specifying the appropriate passive strategies and identifying suitable renewable energy technologies. Also, extracting conclusions on energy performance, level of thermal comfort and airflows according to different climatic regions and building functions with an eye towards various green rating regulations.

This study adopts IES-VE software to set up the selected base cases simulation models and evaluate their performance in terms of energy-saving. Moreover, it used to create the base cases developed models after implementing various passive design methods and renewable energy technologies, which will be later simulated to examine the energy consumption representation of each of them.

3.6 Research methodology

As mentioned before, the study aims to investigate the energy performance and the life cycle cost on existing affordable villas located in Dubai before and after using passive strategies and PV panels. As presented, the computer simulation method considered the most appropriate research methodology that complies with the study scope.

Initially, several element considerations related to the case-study were set. The concerns include the configuration, orientation, construction material, windows sizes and location, MEP systems and the surrounding environmental conditions. Each case-study model will be treated as a base case reference for assessing the cases' performance when various variables are applied. Different scenarios will be conducted, which include various passive design strategies and renewable energy techniques.

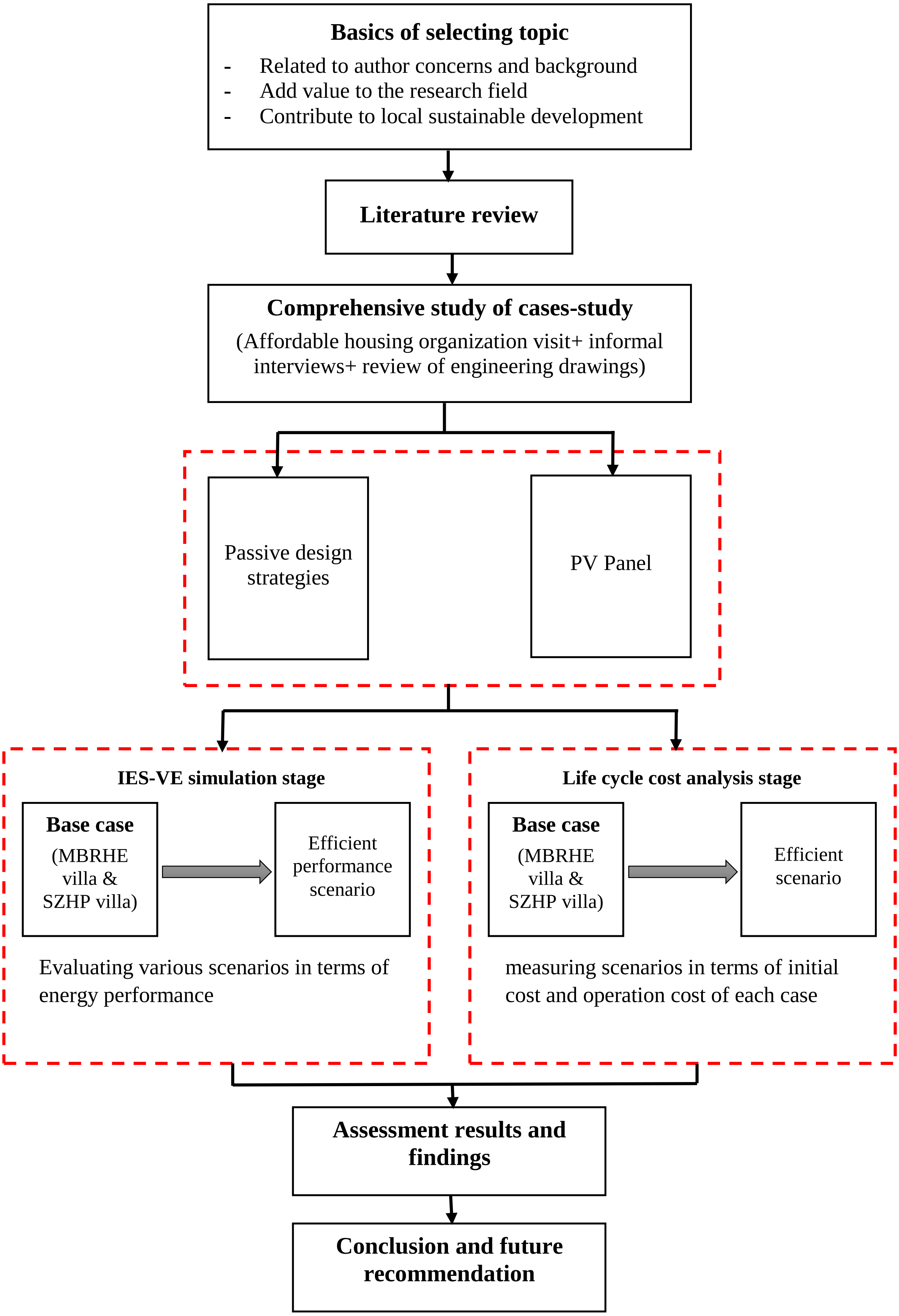
A comprehensive investigation will be implemented for each scenario in terms of energy performance and indoor thermal comfort, followed by life cycle cost analysis for each situation. The findings and outcomes of both assessments will be compared. The comparison processes will identify if the implantation of sustainable design measures and construction for affordable housing will enhance the efficiency of energy and life cycle cost.

3.7 Methodology limitation

Most of the researchers constrained either by research timeframe, budget or lack of resources and information. These limitations and restrictions impact the quality of the study results, which need to be avoided in future works. In this research, most of the restrictions are related to the time and poor access to the information.

- Difficulty accessing information from government departments regards case study, especially in terms of costs, due to privacy.
- Lack of support and cooperation of decision-makers and workers in the housing sector affected the information's accuracy.
- Due to time limitations, the assessment was limited to energy efficiency while other sustainable factors as water efficiency were marginalized.

3.8 Methodological diagram



3.9 Research cases-study

The research aims to enhance the energy performance of affordable housing located in the UAE. As mentioned in the literature review, the UAE government established several organizations at the federal and local levels that are aiming to offer appropriate housing to UAE citizens. One of the essential duties of these organizations to provide a suitable dwelling for low-income households. In this study, the targeted organizations are Mohammed Bin Rashid Housing Establishment (MBRHE) and Sheikh Zayed Housing Programme (SZHP).

3.9.1 Case study justification and selection criteria

Before providing an overview for each case study, it is essential to clarify the criteria and consideration of selecting the research base cases. The author considered when selected the cases several parameters, the first one, the cases should belong to the government organizations that aim to provide for UAE citizen appropriate housing units with either suitable prices or as free homes. Each case should be a private villa due to the citizens' preferences to living in private dwellings. Further, both cases need to share the same location, which in this study is Dubai. To ensure that both follow the same building regulations and share the same climate conditions. Also, they are having similar architectural features and structural systems.

A few differences between the two cases, such as the envelope construction materials vary between them, where the MHBRE case study meets the minimum requirements of building regulations in Dubai. Also, the total built-up area of the MBRHE villa wider than the SZHP villa and it is more expensive, which allows the author to expand the research investigation and provide various models to enhance their efficiency based on the villa's initial simulation model energy performance.

Furthermore, the residential communities that belong to the housing establishment are constructed in all UAE cities. As the UAE population continues to grow, these projects continue to be executed. Generally, these housing projects are replicated most of the time with similar villa design options, construction material, plot limit area, landscape design and type and costs of construction. Therefore, the enhancement of this project will be reflected widely in the country. Converting these cases-studies into prototypes that other developers can benefit from and comply with them will greatly impact the public and private level.

3.9.2 Overview of Dubai City

Dubai has had a substantial transformation over the past decades. In 2000, the city had around 862,387 people and the city at the beginning of prosperity. The current population of the city is 3.1 million, which predicted to be increased more over the next decade (Rakhshan, Friess and Tajerzadeh, 2013). The 2020 master plan of Dubai is expected to add around 24,000 residential buildings to the city; consequently, the energy demand will be increased.

The sustainability report presented that the residential sector was the largest consumer of energy, using 73.68% of the generated electricity in Dubai, followed by the commercial industry (Abu-Hijleh and Jaheen, 2019).

As mentioned before, in order to establish sustainability and improve the energy performance of the residential building in Dubai, it demonstrated several regulations and strategies such as green to enhance the building performance, public health, decreasing water, energy and material consumption, etc. Moreover, it encourages the developers to integrate sustainable parameters into their housing projects.

3.9.3 Overview of SZHP case-study

The first case study is located within Al Qouz second residential compound, executed by Sheikh Zayed Housing Programme in 2015 and completed in 2017. The site is located on Al Qouz-2 in Dubai near Al Khail Road and Mohammed Bin Rashid district. The compound includes 159 private-owned housing extended over 99,600 m^2. SZHP considered architectural diversity in creating the design of the housing units, which consists of four model styles are the Mediterranean, Islamic, Modern and Andalusian. Regardless of the model style, each villa build-up area is equal to 375.4 m^2 distributed over two floors with four bedrooms.

The project aimed to provide comfortable and appropriate homes for UAE households by implementing different sustainable design parameters that enhance the building performance, such as using green construction materials and efficient electrical appliances. Moreover, they are equipped with a solar water heating system located on the roof to provide around 75% of domestic hot water's household needs.

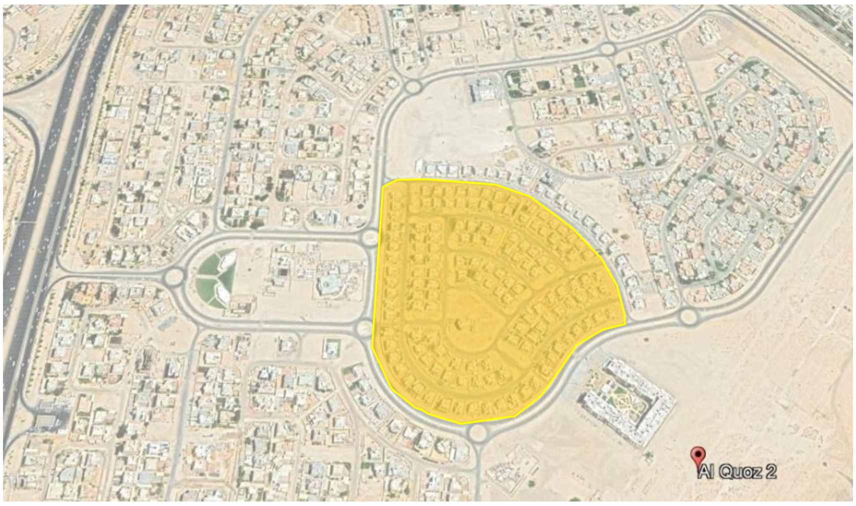


Figure 3.5: SZHP Al Qouz –2 project aerial view source: Google Earth, 2020

Figure 3.6: The four design options of Al Qouz-2 project source: Szhp.gov.ae, 2020

3.9.4 Overview of MBRHE case-study

Recently MBRHE launched the "Typical Villas" initiative for the citizen. The establishment provided five fixed typical design at different prices according to the size of each villa that designed to meet the household needs. This initiative targeted the grant category of UAE citizens who own lands, wherefore the MBRHE will be responsible for providing housing design, building construction supervision and material selection. And in order to ensure competitive prices, MBRHE cooperated with several contractors and suppliers.

The establishment provides two main exterior façades options are modern and classic styles. All villas types consist of two floors and the number of rooms varies from four to five. The design of the housing is based on the conventional construction system that is generally used in UAE.

Figure 3.7: the two design options of the Typical villa MBRHE initiative source: Establishment, 2020.

For this case study, the actual location is missing, so the author provides a proposed site in the same city as the previous case study, which will be in Al Warqa-4 in Dubai.

Figure 3.8: The proposed location of case-study 2 aerial view source: Google Earth, 2020

Both cases will be explained in detail in the next chapter regarding the construction materials, structural and HVAC system, etc.

3.9.5 Overview for the proposed developed models

As mentioned before, for each case study, various simulation models will be created. The author will adopt several passive and active design refurbishments. The below table (3.1) summarizes the enhancement parameters for the proposed scenarios for each case study. In general, in the first two scenarios, the scenarios were created based on passive cooling methods such as changing construction materials types and depths, installing shading elements, and using a green roof system. While in the rest scenarios, the author integrated the active design and cooling passives parameters to develop the models.

Generally, the author concentrates on the climate conditions of the selected case studies, which is, as mentioned before, hot and arid climate; therefore, all the passive design methods used in the simulation models are later suitable to the region. Furthermore, the number of sunshine hours in the UAE range between 10 to 14 hours so, the utilization of PV renewable technology will be implemented in some of the proposed scenarios. Moreover, the availability of construction material in the country takes into consideration and the ability to reuse and recycle them.

Table 3.1: Summary of the proposed scenarios that will be used in the simulation

<table>
<tr><th>case study</th><th>Scenarios</th><th colspan="2">Proposal enchantments parameter</th></tr>
<tr><td rowspan="5">SZHP case-study</td><td>Sc-1</td><td colspan="2">- Utilize horizontal and landscape shading devices
- Expand insulation layer thickness in the roof
- Use Argon gas in the windows cavity instead of air</td></tr>
<tr><td>Sc-2</td><td colspan="2">- Use thermal block caped with EPS insulation layer for the external wall rather than the current wall system
- Implement green roof system
- Change window air cavity thickness
- Distribute trees around the villa</td></tr>
<tr><td>Sc-3</td><td colspan="2">- Utilize extensive green roof
- Modify glazing elements property and thickness
- Change lighting system type
- Install horizontal shading elements in west and east direction</td></tr>
<tr><td rowspan="2">Sc-4</td><td colspan="2">- Upgrade roof slab insulation
- Use a green roof system
- Keep the same lighting system and horizontal shading devices that used in the previous scenario
- Use two options of wall elements and renewable energy technology</td></tr>
<tr><td>Option ‘A’
Reduce the current wall system of the villa and add a PIR insulation layer.
Use monocrystalline PV system</td><td>Option ‘B’
Use thermal blocks covered with PIR insulation
Use polycrystalline PV technology</td></tr>
<tr><td rowspan="5">MBRHE case-study</td><td>Sc-1</td><td colspan="2">- Expand wall thickness
- Change villa roof insulation layer thickness
- Increase air gape layer in the glazing elements</td></tr>
<tr><td>Sc-2</td><td colspan="2">- Change external wall material
- Upgrade the polyurethane insulation layer conductivity
- Provide shading elements in east, west and south elevation
- Use triple glazed window instead of the current system</td></tr>
<tr><td>Sc-3</td><td colspan="2">- Add PIR insulation layer over the external wall
- Change lighting system
- Enhance window properties and use UPVC frame
- Apply green roof system
- Distribute trees surrounding the villa</td></tr>
<tr><td>Sc-4</td><td colspan="2">- Use the same lighting system as the previous scenario
- Implement green roof system
- Modify window layers’ thickness and properties
- Install shading elements
- Change wall thickness and provide an insulation layer
- Apply monocrystalline PV system</td></tr>
<tr><td>Sc-5</td><td colspan="2">- Utilize the concept of courtyard
- Upgrade roof material
- Expand air cavity of the glazing elements
- Use the same lighting system implemented in the 3rd scenario
- Implementation of polycrystalline PV technology</td></tr>
</table>

Chapter 4

Model Set-Up

4- Model Set-Up

4.1 Introduction

As discussed earlier in chapter two, the United Arab Emirates provides several efforts to meet the challenges of climate change and energy issues under the international efforts' framework. Therefore, to attain this aim, several initiatives, strategies and regulations are established.

This study aligns with these aims and efforts to study the influence of the passive design strategies and renewable technologies on affordable housing communities' design to enhance energy performance and thermal comfort. The two cases-study that were selected in chapter three, where one of them within Mohammed Bin Rashid Housing Establishment project while the other one within Sheikh Zayed Housing Programme.

After carrying out the literature review and identifying the research methodology, this chapter will introduce the details of the implementation study methodology. Also, this research will also present the assessment parameters and various variable of simulation that affect the final research outcomes and finding. Furthermore, it will discuss the basis for selecting investigation variables and parameters.

The chapter will start with cases study detailed description of housing physical and operational characteristics, followed by conducting a validation process of the IES-VE software. Various scenarios will set for each case-study, which will be simulated through the software in terms of energy consumption and thermal comfort.

Both selected villas are located in Dubai; therefore, it is essential to identify the location's climatic conditions.

4.2 Dubai climatic condition

The Dubai climate data recorded from the Dubai International airport weather station is presented in table 4.1 below. Over the course of years from 1977 to 2019, the table indicates that the average highest temperature is recorded in July and August months, which is known as the peak summer season. In contrast, the lowest moderate temperature degrees were recorded in January and February months.

Moreover, Table 4.1 displays that the max. average temperature in August is 41.5 C°. However, the max. temperature is 48.8 C° while the average humidity is 52% and the average wind speed is 13.5 km/h. On the other hand, the min. average temperature is recorded in

January equals 14.7 C°. where the lowest degree equals 7.7 C°, the average humidity is 64% and the average wind velocity is 12 km/h.

Table 4.1: The average weather records from 1977 to 2019 in Dubai source: ncm.ae, 2020

	Temperature					Humidity				Wind			
Month	Max	Mean Max	Mean	Mean Min	Min	Mean Max	Mean	Mean Min	Rainfall	Mean	Max	Mean Max	Solar Radiation
January	31.8	24.3	19.5	14.7	7.7	81	64	45	15.1	12	59.3	22.3	3921.6
February	37.5	25.7	20.6	15.7	7.4	82	63	42	19.2	13.1	57.4	24.3	4668.5
March	41.3	28.7	23.1	18	11	81	60	38	22.5	13.6	59.3	25.5	5512
April	43.5	33.3	27.2	21.5	13.7	74	52	30	4.8	13.1	72.2	25.7	6318.8
May	47	37.8	31.3	25.2	15.7	70	48	26	0.4	13.7	63	25.9	6944.8
June	47.9	39.9	33.4	27.8	21.3	76	54	29	0	13.7	51.9	25.2	7033.1
July	48.5	41.3	35.3	30.5	24.1	74	53	31	0.8	13.6	66.7	25.5	6522.4
August	48.8	41.5	35.4	30.7	24	73	52	30	0	13.5	55.6	25.8	6278.6
September	45.1	39.2	33	28	22	79	58	31	0	12.4	40.7	24.7	5899.2
October	42.4	35.7	29.8	24.6	15	80	59	33	1.1	11.4	61.1	23.5	5163.8
November	38	30.7	25.4	20.3	10.8	78	60	38	4.8	11.2	61.1	22.3	4283.5
December	33.2	26.4	21.5	16.6	8.2	81	64	44	15.7	11.3	55.6	21.5	3870.2

As shown in Fig (4.1), the wind in Dubai flow from various directions with small variation regards wind speed. Most of the wind blowing from west and northwest.

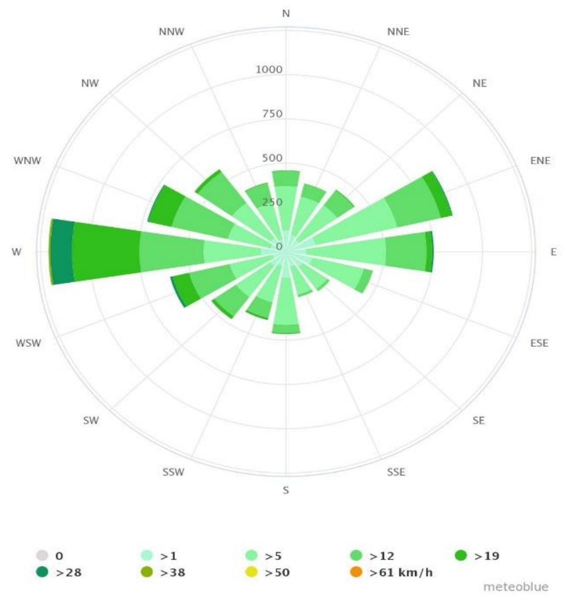


Figure 4.1: Dubai wind rose based on 30 years simulation source: weather et al., 2020

The solar radiation amount available in any location depends on the latitude and the number of sunlight hours. According to Fig (4.2), in the summer, the number of sunlight is around 13 hours per day, while the number of sunlight hours in winter is around 10 hours.

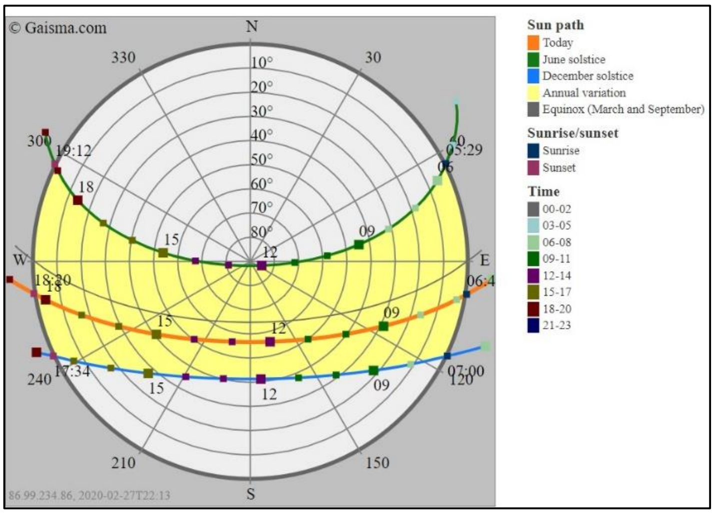


Figure 4.2: Dubai sun path source: Gaisma, 2020.

It is important to identify and address the selected cases study system and major components that directly or indirectly impact consumption of energy rate and thermal comfort level.

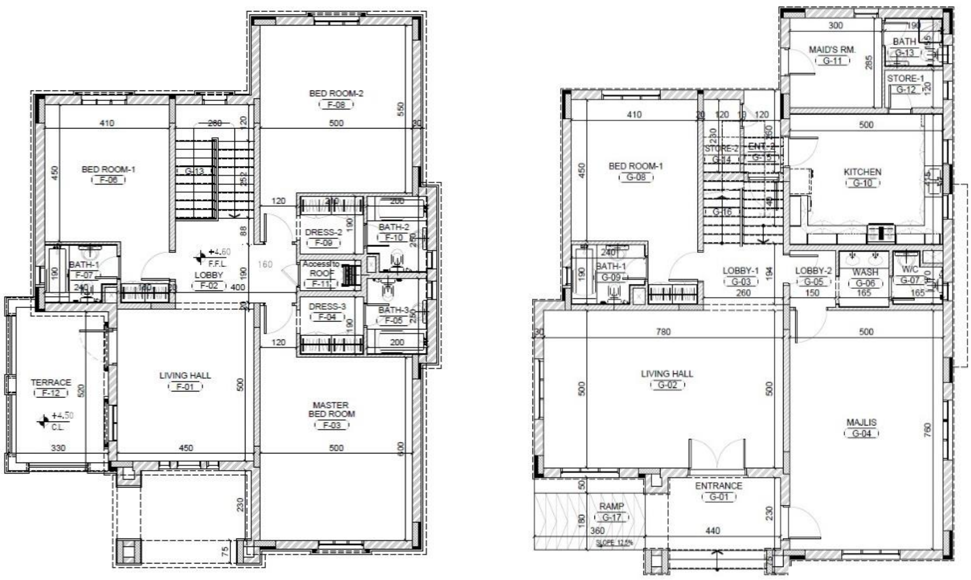
4.3 A close look at SZHP case-study

As mentioned in the previous chapter, the selected villa is located in Al Qouz second within the 159-housing compound project below Sheikh Zayed Housing Programme. They constructed four design options: The Mediterranean, Islamic, Modern and Andalusian.

Figure 4.3: SZHP case study site location source: Google Earth, 2020.

The design option of the selected villa is the Mediterranean, which consists of two floors. The total area of the plot is around 585 m² and the building's total area is 375 m², where; the rest of the property is used for a parking garage, garden, and water tank. The original drawings of the villa were analyzed, with main characteristics and information highlighted in Table 4.2.

Figure 4.4: Villa perspective view source: Szhp.gov.ae, 2020



1St Floor Ground Floor

Figure 4.5: Case study plans

4.3.1 SZHP surrounding

As we mentioned earlier, the chosen villa is located within a residential complex, where it is surrounded from two sides with sub-streets and open areas, while the other sides are adjacent to the (G+1) villas belonging to the complex.

Table 4.2: Information of SZHP Villa

SZHP Building characteristics	
Type of the building	Residential “Private Villa”
Location	Al Quoz 2 - Dubai
Completion year	2017
Occupancy	5 Adults and 2 children
Total Build-up area (m^2)	375.3 for (GF area = 202.6 m^2 and 1st area = 172.7 m^2)
Total height (m)	9.55
No. of floor	G+1
Use of the areas	Majlis, 2 living halls, 1 kitchen, 4 bedrooms, 1 maid room, 5 bathrooms, 1 toilet, 3 dress room and 2 stores
External wall elevation area (G+1st) External window area (G+1st) Total Glazing/ External wall %	417.135 m^2 52.135 m^2 12.5% < 40%
Construction system	Post lintel (column-beam) structural system

4.3.2 Vegetation and landscape

Each villa in the housing compound is provided with yards, divided into walkways, parking area and green area. The green zone's total area is equal to 136 m^2, which could be used to cultivate several types of plants such as date Palm and Damas tree.

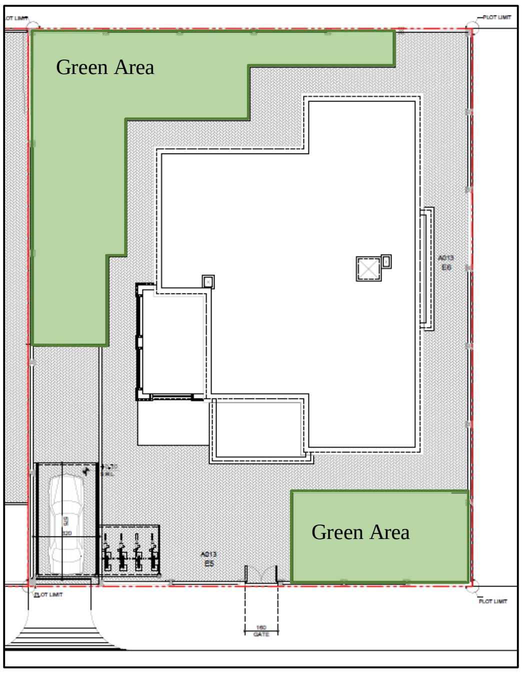


Figure 4.6: Setting layout plan

4.3.3 Construction material

The construction material plays an essential role in conducting this research, especially the material of roof and walls. After reviewing the architectural and structural drawings and the project documents, the main material for roof, walls, floors and glazing elements are presented in Table 4.3.

The villa structural system elements as foundation, columns, beams and slabs are made of reinforced concrete where the steel bars and concrete materials are embedded together to resist internal and external loads.

The villa's external walls were constructed by Autoclaved Aerated Concrete (AAC), which is a lightweight and permeable concrete. Generally, AAC blocks generated from sand or fly ash mixed with lime and cement (binding agent), aluminum powder (rising agent) and water. AAC block is characterized with its ability to thermal insulation and sound absorption (Ropelewski and Neufeld, 1999). The internal walls were made of solid and hollow block with different thickness. Both blocks are composed of concrete masonry but the difference between them is the solid block id fully concrete while the hollow block consist of hollow cores. The cores reduce weight and total cross-sectional area of block which is according to SZHP civil specification the two cores of the hollow block of them shouldn’t be more than 40% of the total cross-sectional area.

The roof design of the housing units adopts the combo roof system, which compromises waterproofing, thermal insulation and coating layers above the concrete slab, as shown in Fig (4.7).

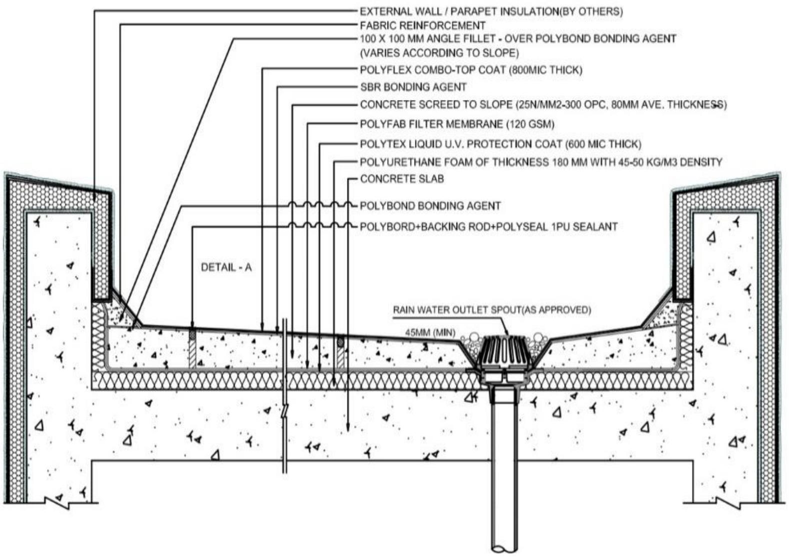


Figure 4.7: Combo roof section typical details source: Dubai Municipality, 2020

Table 4.3: SZHP construction material properties

Villa element	Material	Thickness (mm)	Total U-value (W/m² k)
Roof (Combo Roof)	Plaster layer	15	0.135
	Concrete slab	250	
	Polyurethane foam	170	
	Liquid coating acrylic base (Polytex)	0.6	
	Filter layer (Polyfab)	-	
	Concrete screed	80	
	SBR bonding agent	-	
	Top waterproofing coating	0.8	
External Wall	Plaster	15	0.317
	Autoclaved Aerated Concrete (AAC)	300	
	Plaster	15	
Internal wall	Plaster	15	-
	Solid blocks/ Hollow block	100/200	
	Plaster	15	
Ground Floor	Concrete slab Ground	200	2.475
	Concrete screed	70	
	Tiles	30	
1^{st} Floor	Plaster	15	2.34
	Concrete slab	250	
	Screed	70	
	Tiles	30	
Windows	UPVC frame with double glass layers separated with an air gap between them.	24 (6+12+6)	1.91

All wet zones as the villa's kitchen and toilets, were provided with 60x60 gypsum ceiling tiles with considering the minimum requirement of heights.

After reviewing the elevation drawings and main perspectives, the utilization of shading devices is not existing, except for the main entrance, which covered for aesthetic reasons. Also, the 1^{st}-floor openings are surrounded by a 15 mm projection frame.

4.3.4 Main electrical appliance in SZHP

The primary electrical appliances that consume energy in any residential building in UAE are air-conditioning (AC), lights and water heaters. The current cooling system implemented in the villa is the split air conditioner unit, practically the wall-mounted type. The system consists of the outdoor unit (condenser coil, compressor and ventilation fan) located in the roof, ceiling suspended unit (evaporator coil, filter and blower) and wall-mounted remote control. The minimum COP (coefficient of performance) of the current air conditioning unit is 3.8, equal to EER=13 (Energy efficiency ratio). Natural ventilation is responsible for supplying fresh air.

The current indoor lighting system used in the selected villa is made of fluorescent lamps where it available either as surface/ wall-mounted lamps or compact fluorescent (CFL). Also, they installed in the living room and majlis a chandelier point.

The domestic hot water system used in the villa is based on a solar water heating system. The villa solar hot water system complied with Dubai municipality requirements, where the system's total capacity provides around 75% of the inhabitants' needs. The system included two flat collectors, a 390-liter storage tank, and a 2.5 kw back up electrical heater. According to their calculation, the total daily hot water demand is 300 liters, which could consume 4882 kwh yearly of energy if the traditional system (electrical heater) is installed. Therefore, the solar energy contribution around 3600 while the rest is provided by the electrical heater.

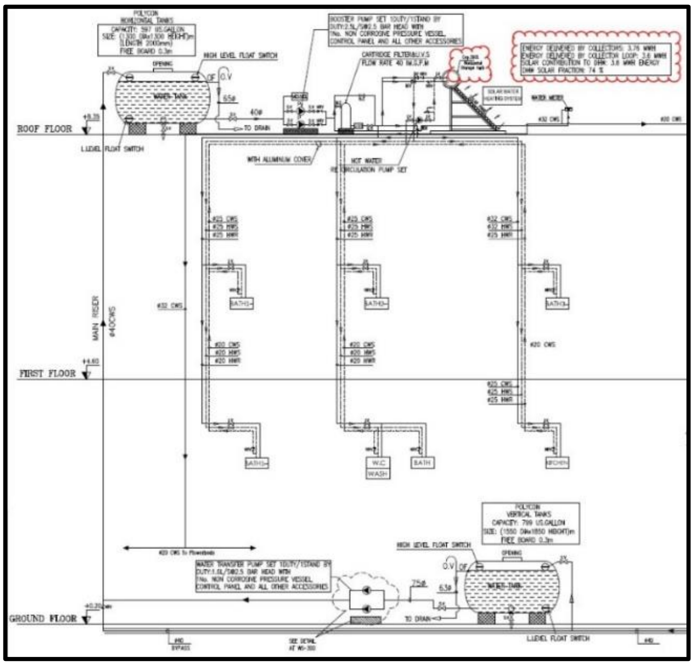


Figure 4.8: Solar hot water tank schematic diagram source: SZHP drawings

4.4 The validation of the first case study

In order to carry out the research properly, it is crucial to conduct a validation procedure where the software findings are compared against other resources. The validation step can ensure the capability of the software to run the simulation process and the accuracy of the study investigation results. As mentioned in chapter three, the selected software is IES-VE version 2019, where the villa will be built as per the architectural and MEP drawings, considering the location, villa configuration, construction material, and surrounding building, thermal and lighting profile. All the thermal properties assigned in the software have followed Dubai municipality's recommendations for materials and systems.

For this case study, the outcomes of the simulation will be compared with the energy consumption study conducted by SZHP engineers. According to their calculation, the total energy consumption of the villa during the year is 62,208 kWh.

4.4.1 Set-up the model in the software

The villa was modeled in the software, where all the envelope features were considered as shown in the perspectives and elevations drawings, such as doors and windows location and sizes and architecture shading elements. Moreover, the height and thickness of the walls and slabs were defined. The construction materials of the case study envelope were assigned as presented in Table 4.3. Furthermore, to attain more acceptable accuracy in predicting the energy performance of the villa, the author defined various parameters as orientation, internal loads, infiltrations, thermal and lighting profiles. As illustrated in Fig (4.10), the presence of the adjusted villas is considered.

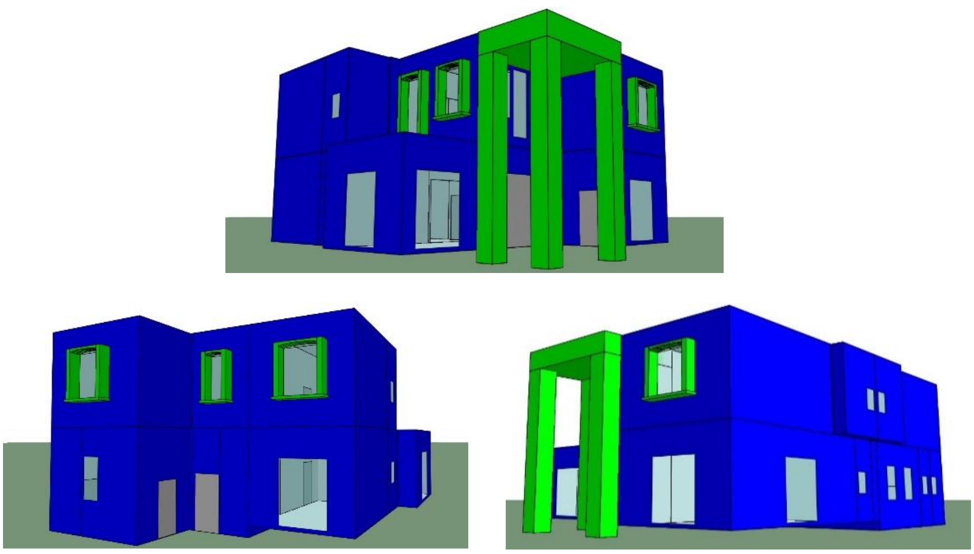


Figure 4.9: 1st Base case simulation model perspectives source: IES-VE software,

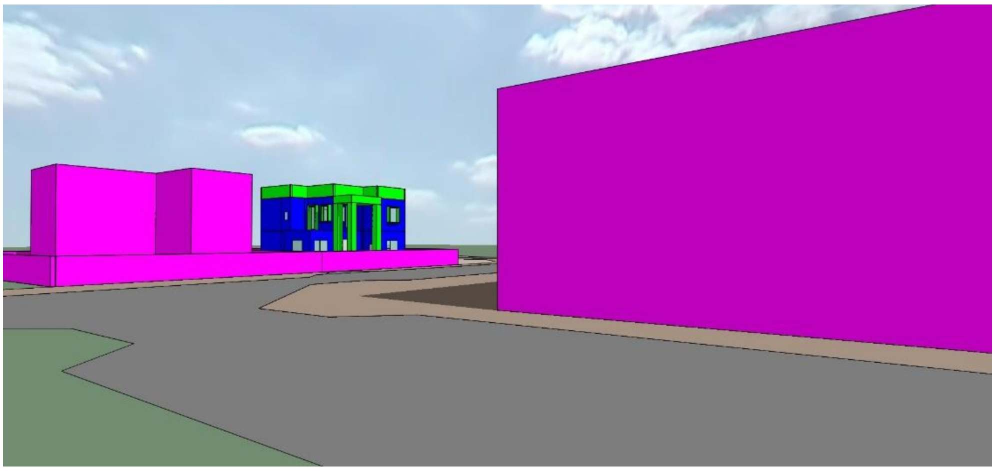


Figure 4.10: Perspective view of the case study with the adjust building source: IES-VE software, 2019

The study concentrates on the investigation of energy performance and thermal comfort of the villas before and after the modification; therefore, the climate conditions of the selected case study play a significant role in achieving reliable and accurate outcomes. Dubai city location and initial weather data are included in the IES-VE database, so the author defined it directly, as shown in Fig (4.11), followed by addressing the nearest climate data file where the list of surrounding cities was presented, to choose the nearest one. In this case study, Abu Dhabi weather file is the closet of Dubai. The obtained data involve latitude, longitude, temperature ranges, wind velocity and solar radiation.

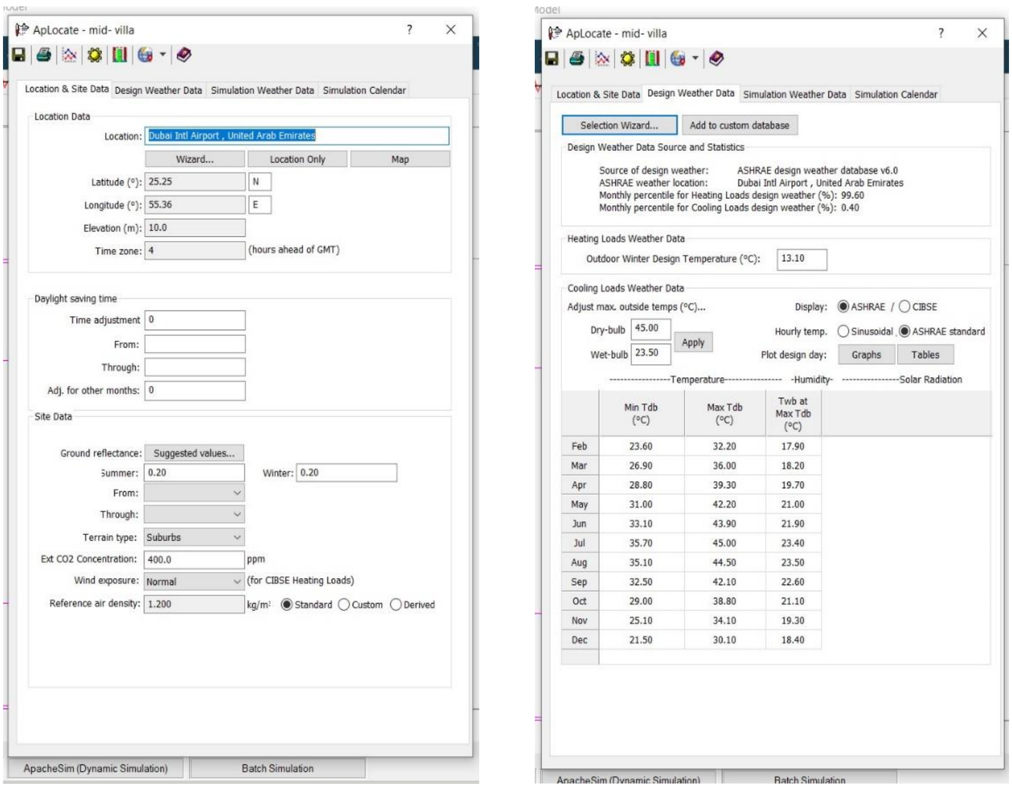


Figure 4.11: Location and weather data of the case study setup source: IES-VE software, 2019

The construction materials of the villa, including block works, concrete works and finishes works, considering their thermal properties, were assigned in the software as shown in Table 4.3.

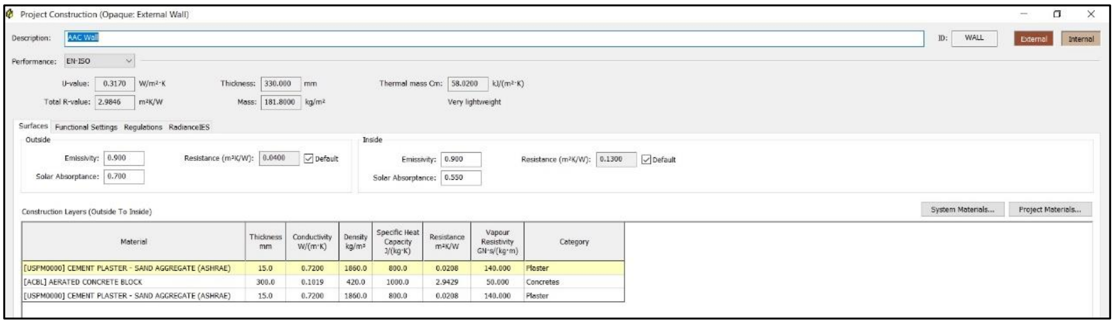


Figure 4.12: External wall (AAC Block) thermal properties source: IES-VE software, 2019

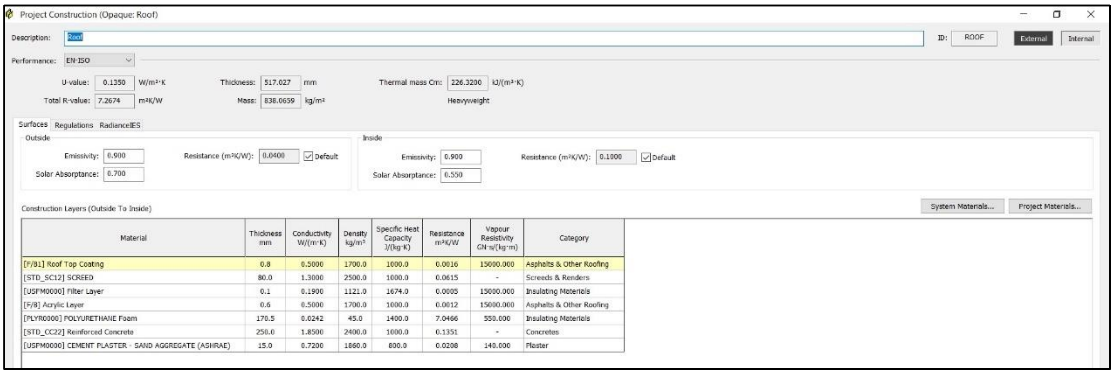


Figure 4.13: Combo roof thermal properties source: IES-VE software, 2019

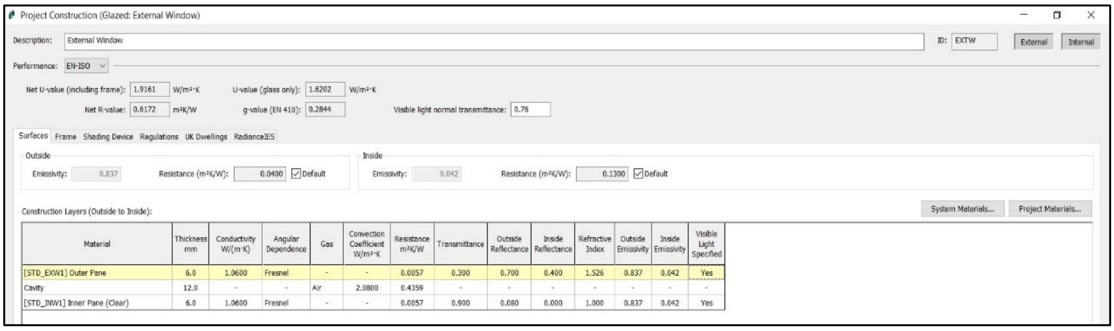


Figure 4.14: Double glazed properties source: IES-VE software, 2019

The inside heat must be extracted from the villa by the air conditioning system created from various resources, externals and internals—external heat gains produced from solar radiation, outdoor air and ambient temperature, where air enters the villa by infiltration and ventilation. While, internal heat gains generate due to the usual internal activities of the household and electrical devices.

Evolving the internal gains in the analysis will add more accuracy to the study. The three most effective sources of the heat gain defined in the project are the lighting, electrical devices, and housing occupants' presence. The below table presents the summary of the heat gains implemented in the simulation model of the villa, which was collected from several resources.

Table 4.4: Example of energy consumption of residential households' electrical appliances sources: ASHRAE handbook, 2017, Ruellan, Park and Bennacer, 2016 & Setlhaolo and Xia, 2015.

Electrical appliance	Power consumption (watts)	Duration (average)
Microwave	1200	30 mints daily
Dishwasher	1800	3 hours daily
Freezer	320	24 hours daily
Fridge	180	24 hours daily
Coffee maker	1000	30 mints daily
Stove	2000	4 hours daily
Vacuum cleaner	1200	3 hours daily
Washing machine	2000	3 hours daily
Laptop	50	4 hours daily
Computer + monitor	113	2 hours daily
TV	110	10 hours daily
Satellite + Set-top box	104	10 hours daily
Wi-Fi router	7	24 hours daily
Play station	200	5 hours on weekends
Clothes dryer	2000	3 hours daily
Water cooler	100	24 hours daily

Developing thermal and lighting profiles for the villa will enhance the result of the base case's efficiency and reliability. These profiles can be set daily, weekly and annually. For this villa, weekdays, weekend and annual profiles had been created in the IES-VE software for thermal and lighting systems as the followings:

A. Cooling system profile

In the morning hours, the villa will be occupied by housemaids from 8:00 am to 2:00 pm, while the rest of the day will be occupied by the whole household, as shown in Fig (4.15). On the weekend, the villa will be empty from the family from 1:00 pm to 7:00 pm, as displayed in Fig (4.16).

During winter months most of the of households in UAE rely on the natural ventilation for cooling, therefore the cooling system of the villa will be switched off from 15 of November to 15 of March as presented in Fig (4.17).

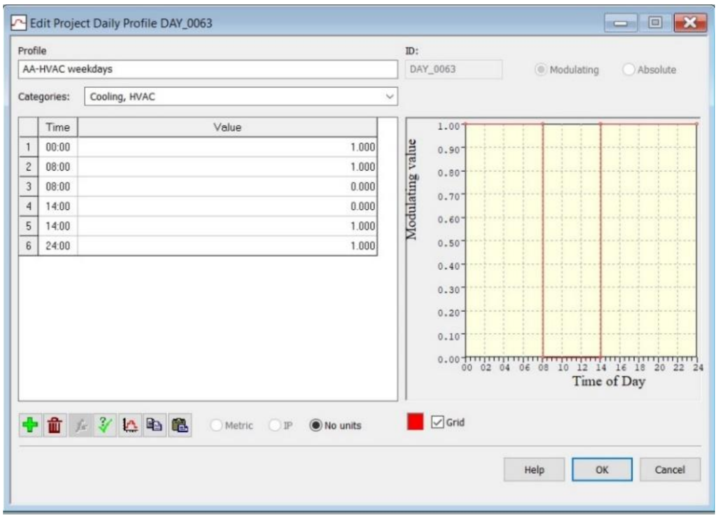


Figure 4.15: HVAC weekdays profile source: IES-VE software, 2019

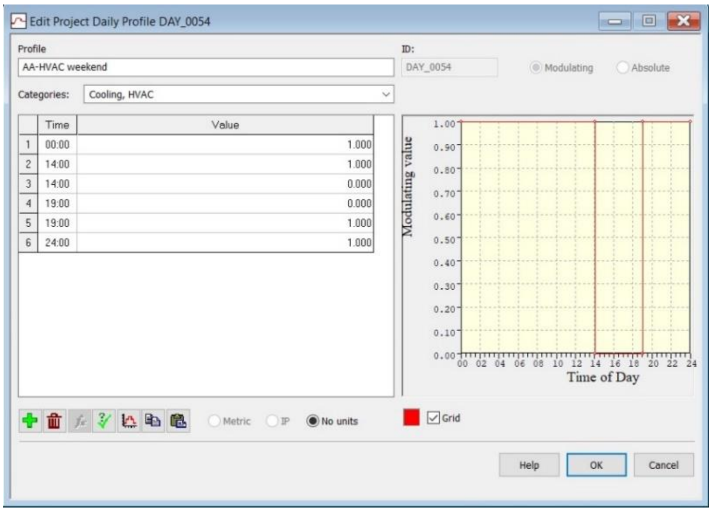


Figure 4.16: HVAC weekends profile source: IES-VE software, 2019

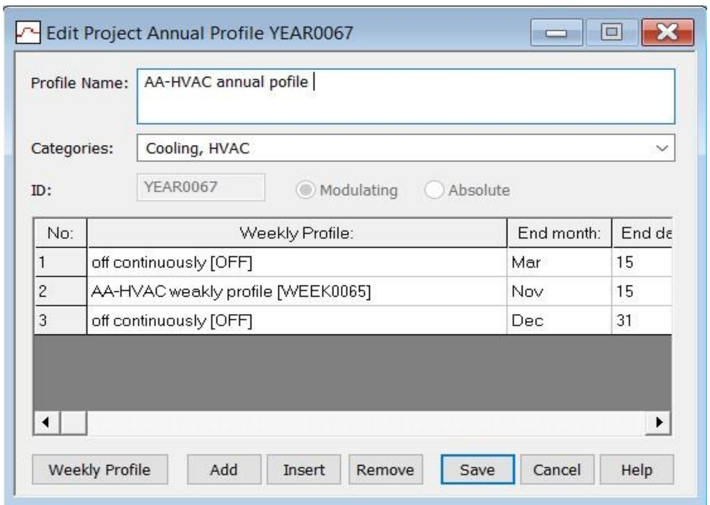


Figure 4.17: HVAC annual profile source: IES-VE software, 2019

B. Natural ventilation profile

On winter season the simulation model assume that the occupants of the villa will depend only on natural ventilation. Therefore, a window profile was created applied in the living rooms, bedrooms and kitchen. The window will be opened the whole day, but during afternoon the window will be closed. The rest of the year as mentioned before the villa will rely on the mechanical cooling system.

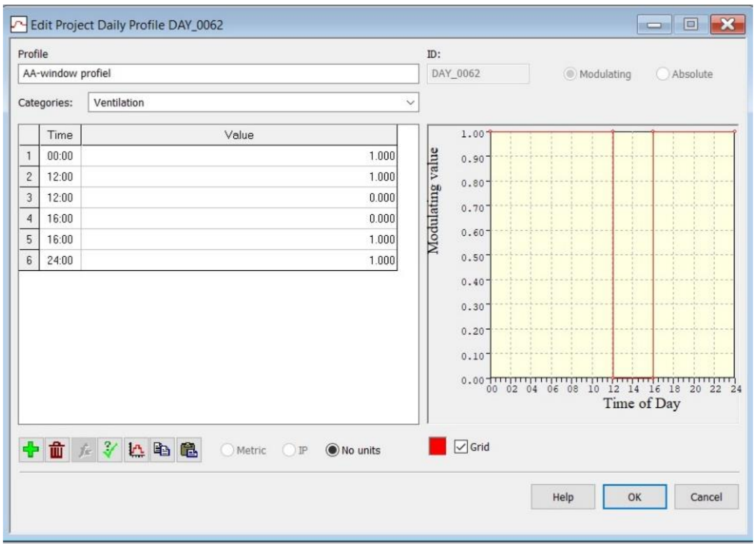


Figure 4.18: window daily profile source: IES-VE software, 2019

In this simulation model, the author assumed that the villa not air tight and there are a few leakedges in thre villa enevelope, so an infiltration rate was set in the software. Aaording to Abu-Tair, Fırat and Kinuthia (2018), the inflitration flow rate value equivalent to 0.25 ACH (air change per hour).

The cooling system temperature setpoints that used in the simulation model is 24°C for all the villa rooms, which is the recommended temperature for the body from DEWA. Moreover, the energy efficieny rate of the system was set as the mentioned before to be 13.

According to their AC drawings, all toilets and kitchen was provided with wall/mounted extract fan. A daily profile was set for all of them as shown in below table.

Table 4.5: Wall/mounted extract fan power consumption and daily work hours source: Clipsal, 2010

Function	Power consumption (Watts)	Duration (average)
Kitchen fan	40	5 hours daily
Toilets fan	30	3 hours daily

C. Internal lighting profile

During weekdays the villa required the artificial lighting mostly at night hours from 17:30 pm to 23:00 pm, the rest of the night hours the artificial lights will be turned off from 23:00 pm until 5:00 am when the household member prepare themselves for their works and schools and it will be turned off again at 7:00 am. On the weekends the lighting system has another profile, where the lamps will be turned on from 19:00 pm to 1:00 am, then it turned on again from 5:00 am to 6:00 am to do their religious duties. All the lighting lamps types were addressed in the simulation model as presented in lighting drawings.

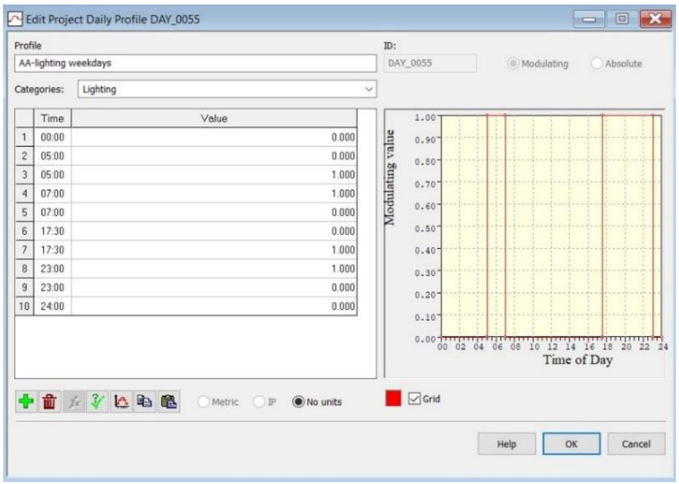


Figure 4.19: Lighting weekdays profile source: IES-VE software, 2019

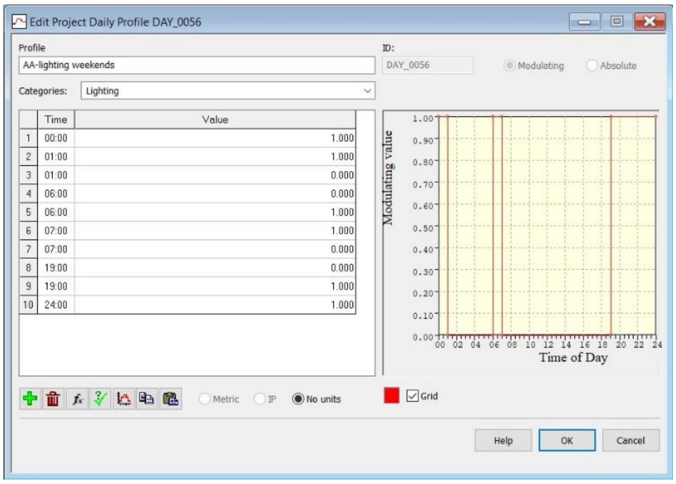


Figure 4.20: Lighting weekend profile source: IES-VE software, 2019

D. External lighting profile

The external lighting of the villa was also considered in the analysis of the base case. During the weekdays the external lighting switched on from 18:00 pm to 24:00 am, while during weekends the turned on from 19:00 pm to 2:00 am.

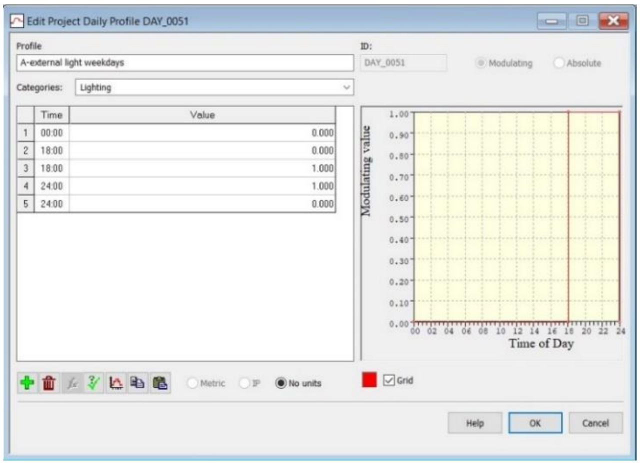


Figure 4.21: External lighting weekdays profile source: IES-VE software, 2019

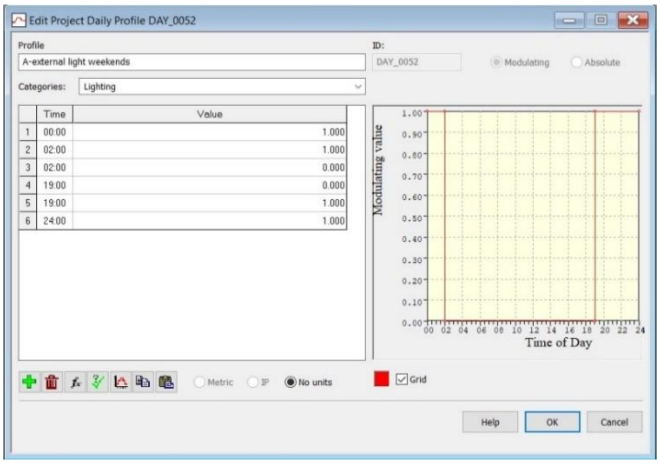


Figure 4.22: External lighting weekends profile source: IES-VE software, 2019

Although the main system of generating domestic hot water is the solar system, but it only generates 75% of the occupants' demands. Therefore, the system provided with 2.5 kw pack up electrical heater, which require around 1282 kw of electricity annually. Also, this amount of consumption considered in the simulation of the case study.

4.4.2 Validity of the simulation model

After setting all these parameters in the software to create the villa simulation model, an energy analysis was conducted to check the validity of the case.

Table 4.6: The electricity consumption of the simulation model source: IES-VE software, 2019

	Total electricity (MWh)
Date	mid- villa trial 10.aps
Jan 01-31	2.3172
Feb 01-28	2.0944
Mar 01-31	3.4521
Apr 01-30	5.0836
May 01-31	6.3932
Jun 01-30	6.9299
Jul 01-31	7.6541
Aug 01-31	7.7889
Sep 01-30	7.0553
Oct 01-31	6.0153
Nov 01-30	3.6355
Dec 01-31	2.3172
Summed total	60.7367

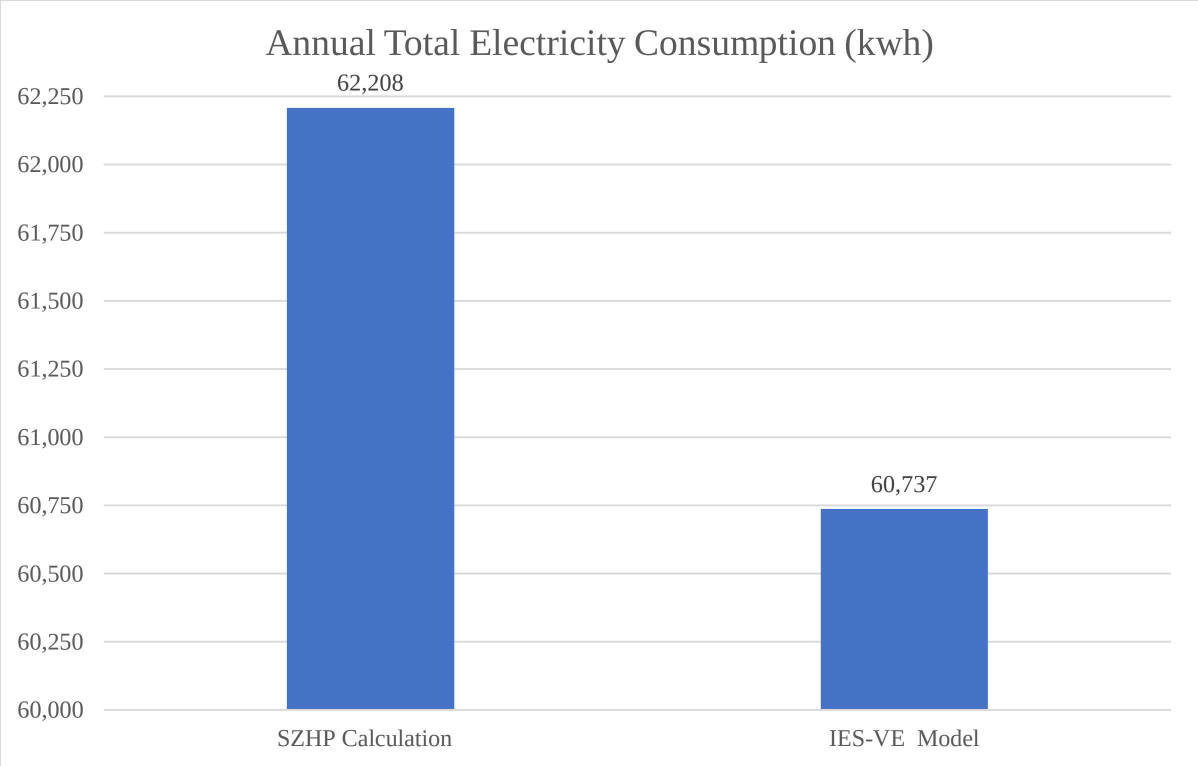


Figure 4.23: Calibration between IES-VE model and SZHP calculation in terms of annual total electricity consumption source: Author, 2020.

As shown in Fig (4.23) the differences between the simulation model and SZHP study equal to 1471 kwh which is around 2.36%. This variation percentage is acceptable as mentioned in methodology chapter in the validation of software section.

Unfortunately, the actual electricity consumption bills of this villa are missing which mean that the comparison has been conducted based on the calculation and study of SZHP engineers. Although having the actual electricity bills will support more the accuracy of the simulation model but based on this simulation the IES-VE software prove their ability to carry out the investigation of this research properly.

However, in the real life some factors could be changed during the year, depending on the household pattern and behavior such as AC temperature setpoints which could be vary in terms of level of comfort of the users. Also, the multiplicity and variation of electrical appliances that could be used in the villa. Furthermore, some families used the mechanical cooling system during winter season which will increase the electricity consumption.

Various scenarios will be developed to enhance the performance of the villa in terms of energy and thermal comfort, based on this base case. Therefore, for each scenario a simulation model in IES-VE software will be created in the next section.

4.5 1st case study scenarios simulation model set-up

In this section, the enhancement strategies will be established for the villa represented in different scenarios. The improvement methods adopt various passive design strategies and renewable energy technology. IES-VE software will assess each developed scenario simulation model regards of energy consumption and thermal comfort.

As presented in methodology chapter before, the retrofitting scenarios will be developed according to the cooling passive design strategies and PV panels. The design methods implemented in the first two scenarios were developed based only in the passive cooling strategies.

4.5.1 The 1st scenario

The retrofitting cooling practices used in this scenario as per the following enhancement:

- Providing shading elements (horizontal) in the west, east, and south elevation, also the terrace area was shaded.
- Cultivating trees in front of west and east windows.

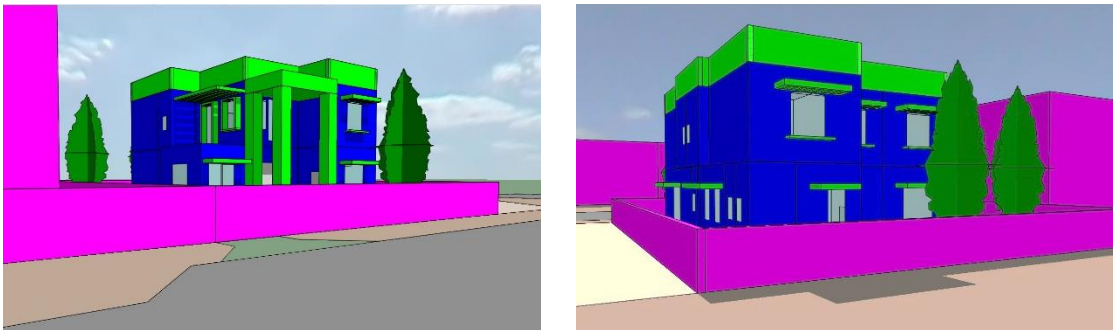


Figure 4.24: Perspective views of 1st scenario after adding the shading elements source: IES-VE software, 2019

- Following Estidama villa product database (1 pearl villa) for combo roof system, therefore the thickness of Polyurethane layer changed from 170.5 mm to 180 mm and thermal conductivity from 0.0242 to 0.0220 W/m.K.
- Changing the window filled cavity gas from air to argon.

Table 4.7: Scenario one material modification

Material	Thickness (mm)	Thermal conductivity (W/m.K)	U-value (W/m². K)
Polyurethane	180	0.0220	0.12 roof
Argon	12	1.4033	1.43 window with the frame

Estidama Villa Product Database (EVPD)
1 Pearl Villas

Insulation Products and Systems:
Roofs

Manufacturer Name	EVPD Reference	Insulation Product / System Type	Description of Wall / Floor / Roof make-up including insulation product and ancillaries *Ancillaries are all items provided 'by others' to make a viable construction & must be declared.* Items in brown represent products installed and/or provided by the Supplier Remaining items are to be specified in addition by the Contractor and are NOT provided by the listed supplier.	Manufacturer Construction Reference	Overall U-value including ancillaries (W/m^2K)
Roof Care CO. L.L.C	RFC-ROO-RER1-001	Combo Roofing System	1. 150mm Dense Reinforced Concrete roof slab, {density = 2400 kg/m3, thermal conductivity =1.9 W/mK} - (by others) 2. Roofcare insulated roofing system comprising : 155mm Spray applied Polyurethane Insulation (45-50 Kg/m3 density, thermal conductivity=0.022W/mK) Polytex- liquid elastomeric UV Protection coating(600 microns) (not relied upon in U-value calculation). Polyfab geotextile seperation layer(120gsm)(not relied upon in U value calculation) Screed concrete (to falls 1:120)(Average 80mm thick) (density=2500 Kg/m3, thermal conductivity=1.3 W/mK). Polyflex- Comboflex cementitious top coating (not relied upon U value calculation) Polyflex and Polytex act as vapour barriers.	RC-CR-001	0.14
Roof Care CO. L.L.C	RFC-ROO-RE2-003	Combo Roofing System	1. 150mm Dense Reinforced Concrete,roof slab {density =2400 kg/m3, thermal conductivity =1.9 W/mK} - (by others)(Roof Slab) 2. Roofcare insulated roofing system comprising : 180mm Spray applied Polyurethane (45-50 Kg/m3 density, thermal conductivity=0.022W/mK) Polytex- liquid elastomeric UV Protection coating(600 microns) (not relied upon in U-value calculation). Polyfab geotextile seperation layer(120gsm)(not relied upon in U value calculation) Screed concrete (to falls 1:120)(Average 80mm thick)(density=2500 Kg/m3, thermal conductivity=1.3 W/mK). Polyflex- Comboflex cementitious top coating (not relied upon U value calculation) Polyflex and Polytex act as vapour barriers.	RC-CR-003	0.12

Figure 4.25: Combo roof Estidama Description for villas source: DMT - Home, 2020

4.5.2 The 2nd scenario

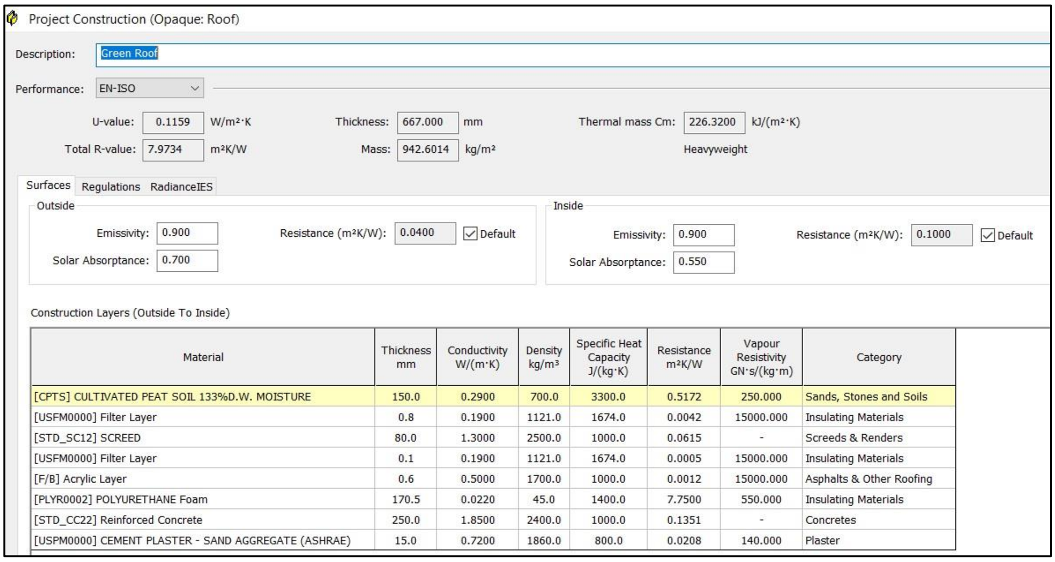
The second scenario was developed based in changing the external wall material and using green roof system as the following:

- Changing the 300mm AAC material to thermal block covered with insulation material and plasterboard as shown in the Table 4.8.

Table 4.8: Second Scenario proposed external wall configuration

Material	Thickness (mm)	Conductivity (W/m.K)	Total U-value ($W/m^2.K$)
Plaster	15 mm	0.72	0.234
Thermal Block (concrete + EPS + concrete)	200 mm	(0.51+0.0357+0.51) 1.056	
Expanded polystyrene (EPS)	70 mm	0.036	
Plasterboard	30 mm	0.16	

- As presented in Literature review, there were two type of green roof: the extensive and intensive type. In this scenario the extensive type was used because it cheaper and lighter than intensive green roof. 70% of roof area provided with green roof while the rest of the area used for solar water system and mechanical equipment. The total roof area = 159.1 m^2 therefore, the green roof area occupied 111.37 m^2.
- Expanding the width of double-glazed window gap thickness from 12mm to 16mm.


Project Construction (Opaque: Roof)

Description: Green Roof

Performance: EN-ISO

U-value: 0.1159 W/m²·K Thickness: 667.000 mm Thermal mass Cm: 226.3200 kJ/(m²·K)

Total R-value: 7.9734 m²K/W Mass: 942.6014 kg/m² Heavyweight

Surfaces Regulations RadianceIES

Outside — Emissivity: 0.900 Resistance (m²K/W): 0.0400 Default Solar Absorptance: 0.700

Inside — Emissivity: 0.900 Resistance (m²K/W): 0.1000 Default Solar Absorptance: 0.550

Construction Layers (Outside To Inside)

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[CPTS] CULTIVATED PEAT SOIL 133%D.W. MOISTURE	150.0	0.2900	700.0	3300.0	0.5172	250.000	Sands, Stones and Soils
[USFM0000] Filter Layer	0.8	0.1900	1121.0	1674.0	0.0042	15000.000	Insulating Materials
[STD_SC12] SCREED	80.0	1.3000	2500.0	1000.0	0.0615	-	Screeds & Renders
[USFM0000] Filter Layer	0.1	0.1900	1121.0	1674.0	0.0005	15000.000	Insulating Materials
[F/B] Acrylic Layer	0.6	0.5000	1700.0	1000.0	0.0012	15000.000	Asphalts & Other Roofing
[PLYR0002] POLYURETHANE Foam	170.5	0.0220	45.0	1400.0	7.7500	550.000	Insulating Materials
[STD_CC22] Reinforced Concrete	250.0	1.8500	2400.0	1000.0	0.1351	-	Concretes
[USPM0000] CEMENT PLASTER - SAND AGGREGATE (ASHRAE)	15.0	0.7200	1860.0	800.0	0.0208	140.000	Plaster

Figure 4.26: Green roof layers implanted in the villa roof source: IES-VE software, 2019

- Placing trees as shading technique in front of east and west windows elevations as shown in Fig (4.27)

Figure 4.27: Top view perspective
source: IES-VE software, 2019

4.5.3 The third scenario

the enhancement of the villa in the third scenario included the utilization in LED light, green roof and modification of glazing specification as presented in below:

- Same of the previous scenario the type of green roof is extensive with total implemented area equal of 50% of the of the total roof.
- Expanding the cavity space of the air gap between glazed layer. Also changing the specification of the outer pane as illustrated in Table (4.9). These data were collected from engineer worked in glazing field in Dubai through personal interview. The resulting U-value for the glass only = 1.373 W/m².K.

Table 4.9: Third scenario double glazed thermal property

Material	Thickness (mm)	Conductivity (W/m.K)	Transmittance	Outside ref.	Inside ref.
Outer pane	6	1.06	0.255	0.389	0.331
Air	16	-	-	-	-
Inner pane	6	1.06	0.9	0	0

- Using LED light lamp instead of compact fluorescent light inside the villa. In this scenario the author used an online calculator website to specify the required LED wattage to illuminate each room in the villa. Table 4.10 presents the calculations.

Table 4.10: Calculation of the requirement of LED in each room in the villa source: LED Lighting Requirement Calculator - Charlston Lights, 2020.

Room name	W x L x H	Required watts	LED opt. (cubical 9W)
Majlis	5 x 7.6 x 3.50	52	Nos. = 8
Living room	5 x 7.8 x 3.50	56	Nos. = 8
Bedroom-1	4.1 x 4.5 x 2.7	25	Nos. = 4
GF lobby	1.94 x 2.6 x 3.50	6	Nos. = 1
Kitchen	4.15 x 5 x 3.50	38	Nos. = 6
Maid room	2.85 x 3 x 3.50	11	Nos. = 2
M. bedroom	5 x 4.5 x 3.50	31	Nos. = 6
1st F. Bedroom-1	4.1 x 4.5 x 3.50	25	Nos. = 4
Bedroom-2	5 x 5.5 x 3.50	38	Nos. = 6
Living Hall	4.50 x 5 x 3.50	31	Nos. = 5
1st F. lobby	2.6 x 6.7 x 3.50	24	Nos. = 4
Toilets, baths and store	Vary	From 3 to 6	Nos. = 1

- Providing horizontal shading elements in east and west elevation.

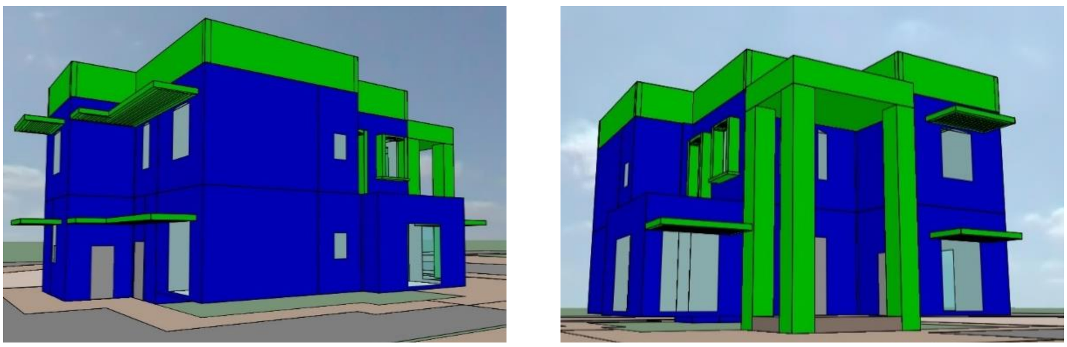


Figure 4.28: Third scenario west and east shading element source: IES-VE software, 2019

4.5.4 The fourth scenario

In this scenario two options of external wall and PV technology will be introduced to check their impacts on the housing energy performance. The common improvement elements for both options utilized as the following:

- Upgrading the roof slab insulation material as Estidam requirement for combo roof. as shown in below table.

Table 4.11: 4th scenario roof layers modification

Material	Thickness (mm)	Conductivity (W/m.K)	U-value (W/m².K)
Top coating	0.8	-	0.1171
Screed	80	1.3	
Filter layer	-	-	
Acrylic layer	-	-	
Polyurethane foam	180	0.022	
Reinforced concrete	250	1.85	
Plaster	15	0.72	

- Applying green roof system over 30% of the roof area. Therefore, the total U-value of the combination of green roof system with combo roof equal to 0.11W/m².K.
- Implementing the same window type and property in the 3rd scenario, which presented in Table 4.9.
- Replacing the internal current lighting system from CFL as third scenario to LED lamp as shown in Table 4.10.
- Using shading element such as horizontal shading and trees for both west and east elevation and covering the terrace with pergola as shown in Fig (4.29).

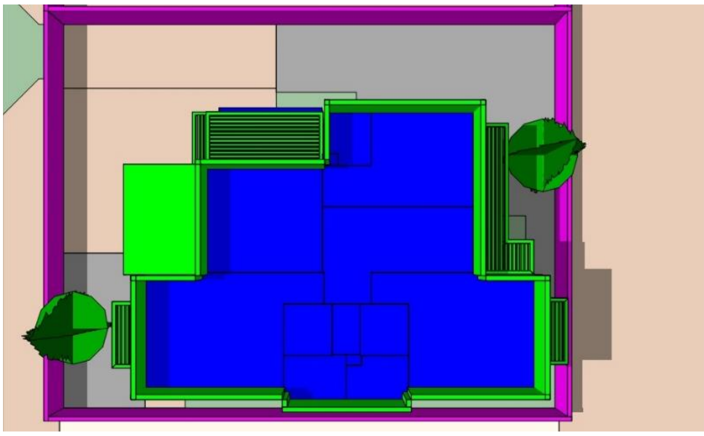


Figure 4.29: Top view of the 4th scenario source: IES-VE software, 2019

- External wall option ‘A’: In this option the external wall made of AAC block and polyisocyanurate (PIR) insulation material layer as shown in Table 4.12.

Table 4.12: The 4th scenario option ‘A’ external wall layer

Material	Thickness (mm)	Conductivity (W/m.K)	U- value (W/m².K)
Plaster	15	0.72	
AAC block	200	0.109	
PIR	50	0.025	0.241
Plasterboard	20	0.16	

- External wall option ‘B’: The external wall in this option comprised of thermal block with polyisocyanurate (PIR). Table 4.13 introduce the wall construction layers.

Table 4.13: The 4th scenario option ‘B’ external wall layer

Material	Thickness (mm)	Conductivity (W/m.K)	U- value (W/m².K)
Plaster	15	0.72	
Thermal block concrete + EPS + concrete	200 (70+60+70)	(0.51+0.0357+0.51)	0.234
PIR	50	0.025	
Plasterboard	20	0.16	

As presented in literature review chapter there were three main PV panel technology could be installed in the housing. The author will assess two technology of PV for this villa which are the monocrystalline and polycrystalline. For both technologies, the selected orientation and tilt angle are the same. According to Regulation and Supervision Bureau (2017), the best orientation of PV panels to face the south direction and the inclination angle equivalent to 24° to obtain the maximum efficiency. The proposed occupied area of the PV 50% of the roof area which equal to 85 m².

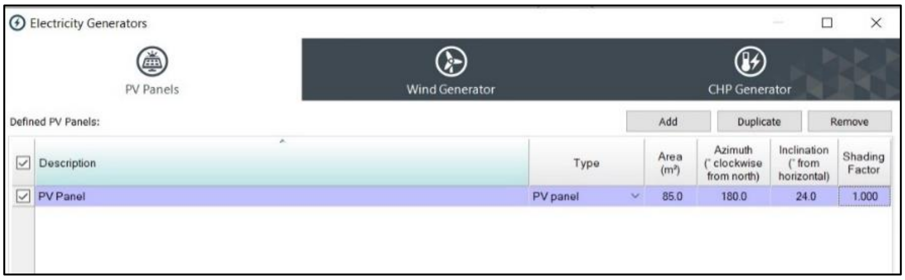
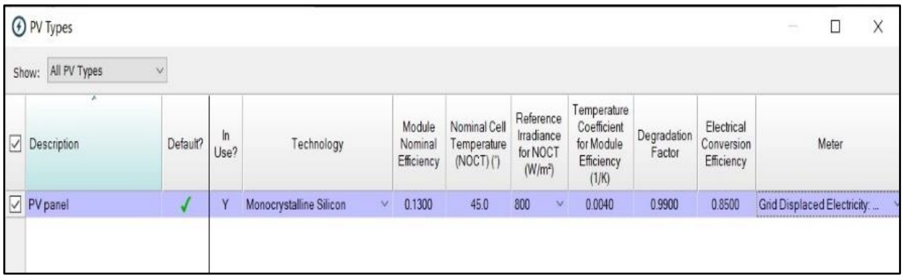


Figure 4.30: PV panel installation details source: IES-VE software, 2019

- PV option ‘A’: The monocrystalline PV technology.

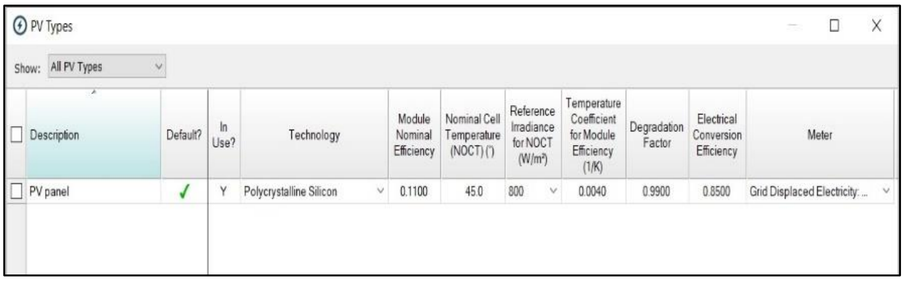

PV Types

Show: All PV Types

Description	Default?	In Use?	Technology	Module Nominal Efficiency	Nominal Cell Temperature (NOCT) (°)	Reference Irradiance for NOCT (W/m²)	Temperature Coefficient for Module Efficiency (1/K)	Degradation Factor	Electrical Conversion Efficiency	Meter
PV panel	✓	Y	Monocrystalline Silicon	0.1300	45.0	800	0.0040	0.9900	0.8500	Grid Displaced Electricity: ...

Figure 4.31: Monocrystalline PV panel property source: IES-VE software, 2019

- PV option ‘B’: The polycrystalline PV technology.


PV Types

Show: All PV Types

Description	Default?	In Use?	Technology	Module Nominal Efficiency	Nominal Cell Temperature (NOCT) (°)	Reference Irradiance for NOCT (W/m²)	Temperature Coefficient for Module Efficiency (1/K)	Degradation Factor	Electrical Conversion Efficiency	Meter
PV panel	✓	Y	Polycrystalline Silicon	0.1100	45.0	800	0.0040	0.9900	0.8500	Grid Displaced Electricity: ...

Figure 4.32: Polycrystalline PV panel property source: IES-VE software, 2019

All these scenarios were analyzed in terms of energy consumption and thermal comfort which all of them in the next chapter will be assessed regards their costs. The same configuration and process will be made for MBRHE case study in the next section.

4.6 A close look at MBRHE case-study

As presented, in methodology chapter, the second selected case study belong to Mohammed Bin Rashid Housing Establishment Typical Villas project. The idea of this project is to allow citizen to own homes with affordable prices.

Five design options were provided with different sizes and exterior design perspective. The perspective design option of the selected villa is the modern style with total build up area 443.24 m². The total plot area of the any option is vary from site to other because it depends on the area of land owned by the client. According to their design the rest of any plot consist of parking area, walk paving and agricultural area.

The villa characteristics summarized in below Table 4.14. after assessing the project architectural, structural and MEP drawing and documents. The proposed location of the case study will be in Al Warqa-4, near Tripoli and Nouakchott streets.

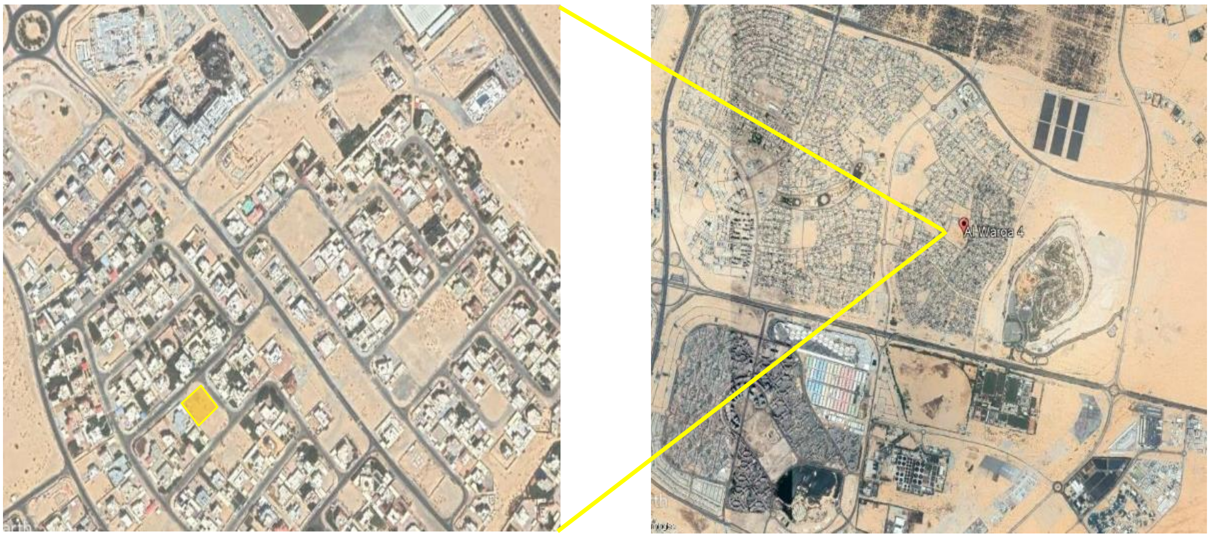


Figure 4.33: MBRHE case study site location source: Google Earth, 2020.

Figure 4.34: The selected case study perspective view source: MBRHE

Figure 4.35: The selected case study plans source: MBRHE

Table 4.14: Information of MBRHE Villa

MBRHE Building characteristics	
Type of the building	Residential “Private Villa”
Location	Al Warqa 4 - Dubai
Occupancy	4 Adults and 4 children
Total Build-up area (m²)	443.25 for (GF area= 210.83 m² and 1st area= 232.42 m²)
Total height (m)	9.30
No. of floor	G+1
Use of the areas	Majlis, Guest room, 1 kitchen, 1 Sala, 1 Living & study room, 1 Maid room, 1 laundry, 1 Store, 4 Bedrooms, 4 Dress, 1 Family living and 7 Bathes.
External elevation area (G+1st) External window area (G+1st) Total Glazing/ External wall %	496.02 m² 59.91 m² 12.08% < 40%
Construction system	Post lintel (column-beam) structural system

4.6.1 MBRHE villa surrounding

As shown in Fig (4.33), the case-study proposed location surrounded by G+1 villa from three sides, one of them adjacent to it while the others located on the opposite side of the adjacent streets. Moreover, the backside of the site is open.

4.6.2 Vegetation and landscape

Like the SZHP case study, the architecture drawing of MBRHE presented that the villa is surrounded by a wide landscape area that will fill with natural soil.

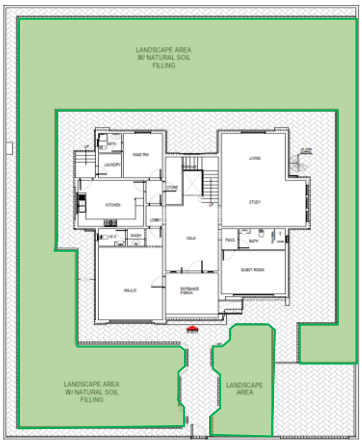


Figure 4.36: MBRHE setting out plan

4.6.3 Construction material

Mostly in Dubai, the housing sector's construction materials are the same; therefore, by looking into the architectural and structural drawings and construction documents, the MBRHE case study shared mostly the same construction materials but with different thickness or utilized other material as presented in Table 4.15. Regardless of the type of construction materials implemented, both cases study must comply with the building's local authorities' regulations and rules.

A. External Walls, Roofs, and Floors:

Building elements forming the external walls, roofs, and floors (where one side of the floor is exposed to ambient conditions) must have an average thermal transmittance (U Value) which does not exceed the following values:

Roof	U= 0.3 W/m²K
External Wall	U= 0.57 W/m²K

Figure 4.37: Dubai municipality maximum regulation of U-value for external walls and roof

B. Glazed Elements - Fenestration:

1. If the total area of external walls that let in light is forty per cent (40%) or less of the external wall area, then the glazing elements must meet the following performance criteria:

Thermal Transmittance (Summer U value)	U= 2.1 W/m²K (max)
Shading Coefficient (SC)	0.4 (max)
Light Transmittance	0.25 (min)

Figure 4.38: Dubai municipality glazing regulation source: Dubai Municipality, 2020

By looking into the villa's structural drawing, the reinforced concrete is the standard material used in designing the estate's structural elements. As discussed with MBRHE engineers, the villa's external wall is made of a thermal block wall covered with plasters layer from inside and outside, where the exterior face is coated with a light reflective value higher than 75%. At the same time, the internal wall is made of solid and hollow blocks, same as the previous case study.

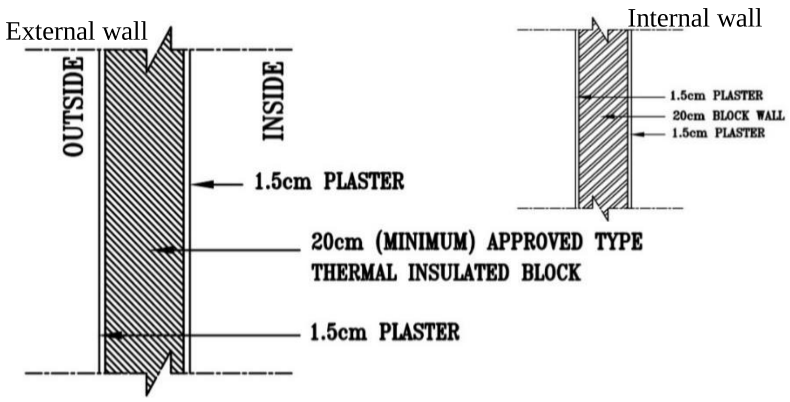


Figure 4.39: Typical wall section source: Dubai Municipality, 2020

The thermal blocks are composed of an insulation layer that is located between two compressed concrete layers. The insulation layer that used in the villa block is polystyrene, with 60 mm thickness.

The combo roof system was also implemented in this case study but with a lower thickness of polyurethane insulation layer than the SZHP case study.

The double-glass window is the preferable window used in Dubai. It is part of the city regulations. It also installed it in all villa glazing elements but different thickness compared with the previous case study. For the frame, they used Aluminum material.

Similar to the SZHP villa, all wet zones are provided with a 60x60 gypsum board ceiling, located beneath the 1st and roof concrete slab, where the height of the ceiling is equal to 2.7m from the finishing material level. As shown in Fig (4.34), the architectural features of the modern style contribute a shading for the main entrance glazing elements.

Table 4.15: MBRHE construction material properties

Villa element	Material	Thickness (mm)	Total U-value (W/m^2 k)
Roof (Combo Roof)	Plaster layer Concrete slab Polyurethane foam Liquid coating (Polytex) Filter layer (Polyfab) Concrete screed SBR bonding agent Top waterproofing coating	15 200 155 0.6 - 80 - 0.8	0.148
External Wall	Plaster Thermal concrete block Plaster	15 200 15	0.46
Internal wall	Plaster Solid blocks/ Hollow block Plaster	15 100/200 15	-
Ground Floor	Concrete slab Ground Concrete screed Tiles	100 70 30	2.98

1^{st} Floor	Plaster Concrete slab Screed Tiles	15 200 70 30	2.5
Windows	Aluminum frame with double glass layers separated with an air gap between them.	28 (8+12+8)	1.91

4.6.4 Main electrical appliance in MBRHE

The split unit air conditioning is the cooling system of the villa. According to their HVAC calculation, the maximum energy efficiency ratio of the unit = 8, which equivalents to 2.35 COP.

The lighting system drawings showed that the villa used two types of lightings the compact fluorescents lamp and LED light bulb (light emitting diode). The efficiency and the lifetime span of LED light is higher than incandescent and CFL. LED lamps can decrease the electricity consumption by 20% of the villa produced by lighting system.

Further, MBRH establishment installed solar collectors in the villa roof with 400-liter storage tank capacity, connected with two (2 kw) back up the electric heater.

4.7 The validation of the second case study

For this case study, a validation process will be executed to ensure the validity and accuracy of the simulation predicted results. The outcomes of this simulation model will be compared with actual DEWA electricity bills gathered from other house owners who lived in the MBRHE villa project located in Al-Qouz. These houses shared the same number of rooms and construction materials of the selected villa.

The bills gathered for two months, June and July, from two villas. The author will take the average bills for each month as shown in Table 4.16.


Green Bill
Tax Invoice
Invoice: 100360470154
Issue Date: 30/06/2019
Month: June 2019
Period: 23/05/2019 to 23/06/2019
DEWA VAT No.: 100027620200003
Electricity
Kilowatt Hours(kWh)
6,276

Green Bill
Tax Invoice
Invoice: 100098689815
Issue Date: 24/06/2019
Month: June 2019
Period: 19/05/2019 to 18/06/2019
DEWA VAT No.: 100027620200003
Electricity
Kilowatt Hours(kWh)
9,600
(Current reading - Previous reading) x MF

Figure 4.40: Part of DEWA bills presents the electricity consumption during June
source: Owners of the villas

Figure 4.41: Part of DEWA bills presents the electricity consumption during July
source: Owners of the villas

Table 4.16: The average electricity consumption during June and July

Month	Average electricity consumption
June	7938 kWh
July	8174.5 kWh

4.7.1 Set-up the model in the software

Same as the previous case, the villa will be modeled in the software with considering architecture features and structural and MEP measurements. Further, the zones distribution, boundary wall surrounding the building and openings locations and sizes are shown in the below figures.

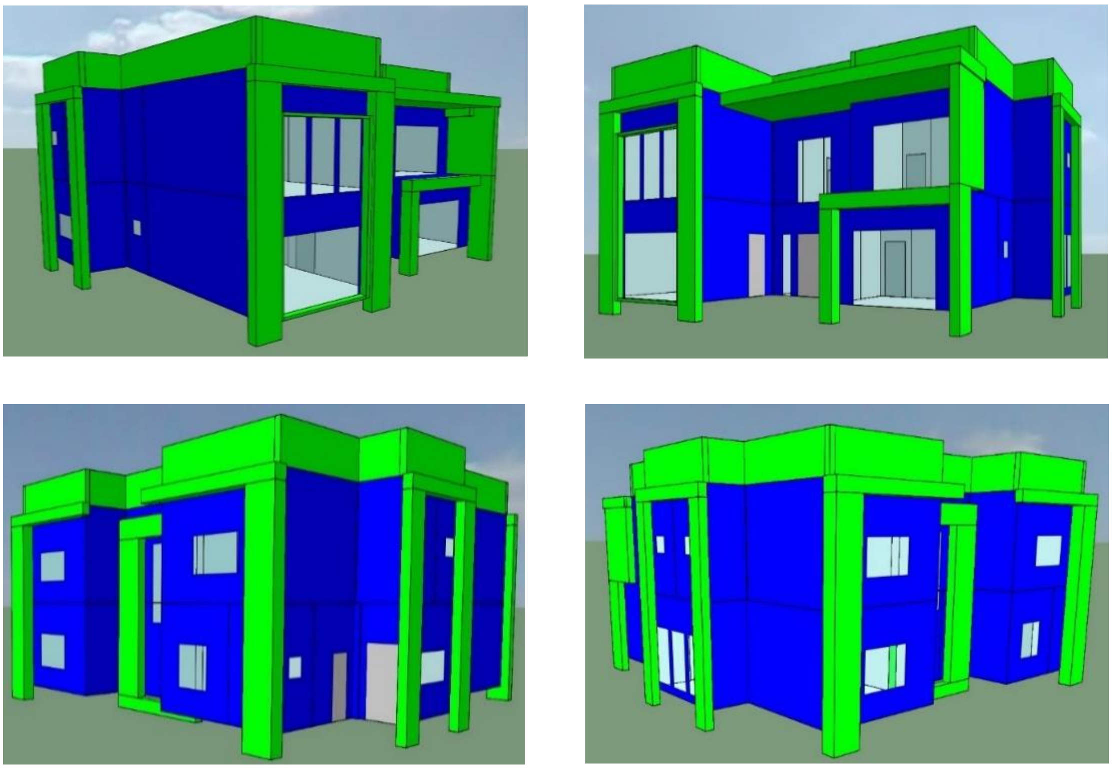
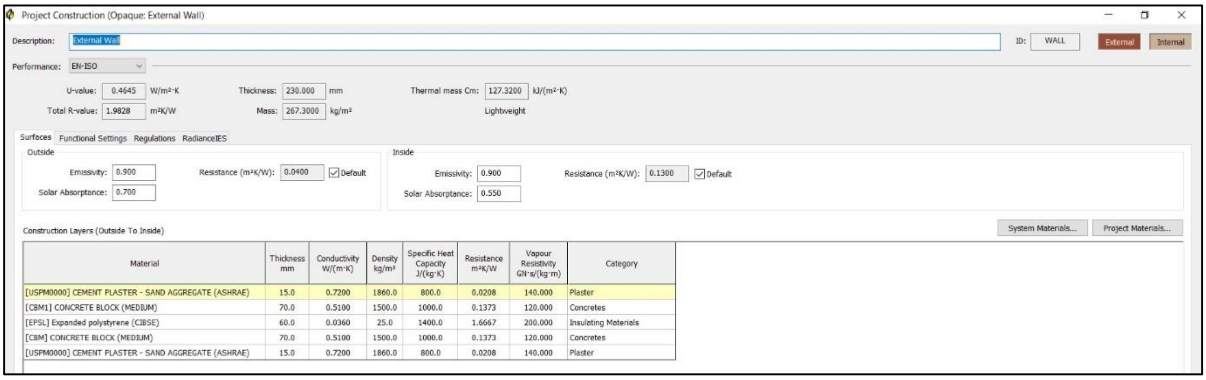


Figure 4.42: 2nd Base case simulation model different perspective views
source: IES-VE software, 2019

Figure 4.43: Perspective view of the 2nd case study with the adjust building source: IES-VE software, 2019

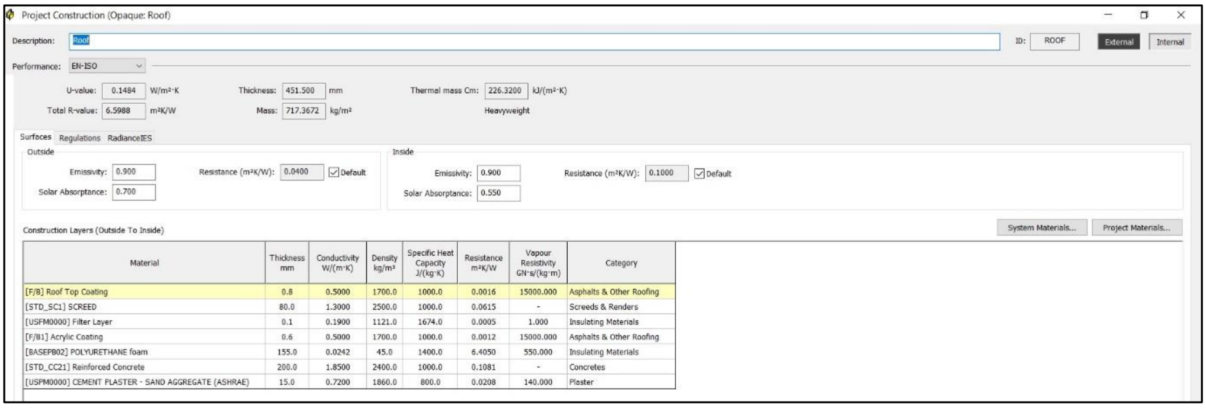
The MBRHE villa proposed site located in Dubai, therefore the same location and weather data as represented in Fig (4.11)

As mentioned before, the housing envelope construction material varies in comparison with the previous case study, either in material type or thickness. Similar to the SZHP simulation model, the envelope material of the selected villa was assigned as discussed with MBRHE engineers and presented in architectural drawings in the simulation model.



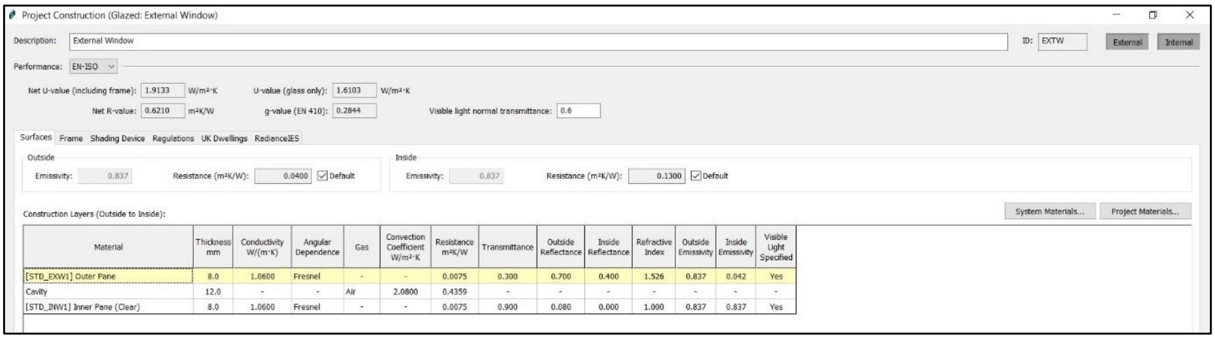
Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[USPM0000] CEMENT PLASTER - SAND AGGREGATE (ASHRAE)	15.0	0.7200	1860.0	800.0	0.0208	140.000	Plaster
[CBM1] CONCRETE BLOCK (MEDIUM)	70.0	0.5100	1500.0	1000.0	0.1373	120.000	Concretes
[EPSL] Expanded polystyrene (CIBSE)	60.0	0.0360	25.0	1400.0	1.6667	200.000	Insulating Materials
[CBM] CONCRETE BLOCK (MEDIUM)	70.0	0.5100	1500.0	1000.0	0.1373	120.000	Concretes
[USPM0000] CEMENT PLASTER - SAND AGGREGATE (ASHRAE)	15.0	0.7200	1860.0	800.0	0.0208	140.000	Plaster

Figure 4.44: External wall (Thermal Block) thermal properties source: IES-VE software, 2019



Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[F/B] Roof Top Coating	0.8	0.5000	1700.0	1000.0	0.0016	15000.000	Asphalts & Other Roofing
[STD_SC1] SCREED	80.0	1.3000	2500.0	1000.0	0.0615	-	Screeds & Renders
[USFM0000] Filter Layer	0.1	0.1900	1121.0	1674.0	0.0005	1.000	Insulating Materials
[F/B1] Acrylic Coating	0.6	0.5000	1700.0	1000.0	0.0012	15000.000	Asphalts & Other Roofing
[BASEPB02] POLYURETHANE foam	155.0	0.0242	45.0	1400.0	6.4050	550.000	Insulating Materials
[STD_CC21] Reinforced Concrete	200.0	1.8500	2400.0	1000.0	0.1081	-	Concretes
[USPM0000] CEMENT PLASTER - SAND AGGREGATE (ASHRAE)	15.0	0.7200	1860.0	800.0	0.0208	140.000	Plaster

Figure 4.46: Combo roof thermal properties source: IES-VE software, 2019



Material	Thickness mm	Conductivity W/(m·K)	Angular Dependence	Gas	Convection Coefficient W/m²·K	Resistance m²K/W	Transmittance	Outside Reflectance	Inside Reflectance	Refractive Index	Outside Emissivity	Inside Emissivity	Visible Light Specified
[STD_EXW1] Outer Pane	8.0	1.0600	Fresnel	-	-	0.0075	0.300	0.700	0.400	1.526	0.837	0.042	Yes
Cavity	12.0	-	-	Air	2.0800	0.4359	-	-	-	-	-	-	-
[STD_INW1] Inner Pane (Clear)	8.0	1.0600	Fresnel	-	-	0.0075	0.900	0.080	0.000	1.000	0.837	0.837	Yes

Figure 4.47: Double Glazed window property source: IES-VE software, 2019

The internal gains of electrical equipment and household activities were also defined in this case study. The same electrical appliances presented in Table 4.4 were assigned in the software to conduct more accurate predicted results.

The cooling system profiles, natural ventilation, and lighting system were also created in the simulation model. In this model, the family lifestyle is different than the 1st case study as mentioned below:

A) Cooling system profile

The cooling system profile in the villa was divided into several scenarios: the ground floor profile and 1st floor profile and majlis profile. The author assumed that part of the family would stay at the villa during the working days; therefore, the air conditioning units on the ground floor will be switched on from 5:00 am to 11:00 pm and switched off at night hours except for the majlis and guest room. The cooling system units on the 1st floor will be turned off from 8:00 am to 1:00 pm and turned on the rest of the day.

Majlis and guest room air conditioning units will be run only four hours during the weekdays from 6:00 pm to 10:00 pm. All the villa zones share the same weekend profile where the household leaves the villa from 2:00 pm to 7:00 pm. Consequently, the cooling system will be turned off during this time.

The annual profile of this case study will be similar to the previous case. From 15 November to 15 March, the cooling and ventilation system is based only on natural ventilation during the winter months.

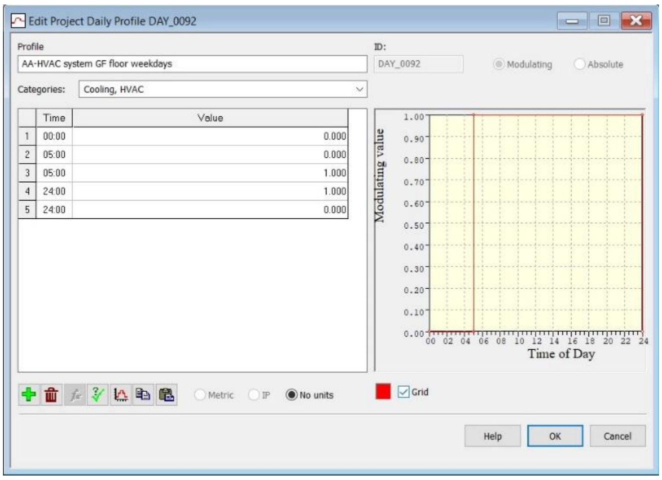


Figure 4.47: HVAC weekdays ground floor profile
source: IES-VE software, 2019

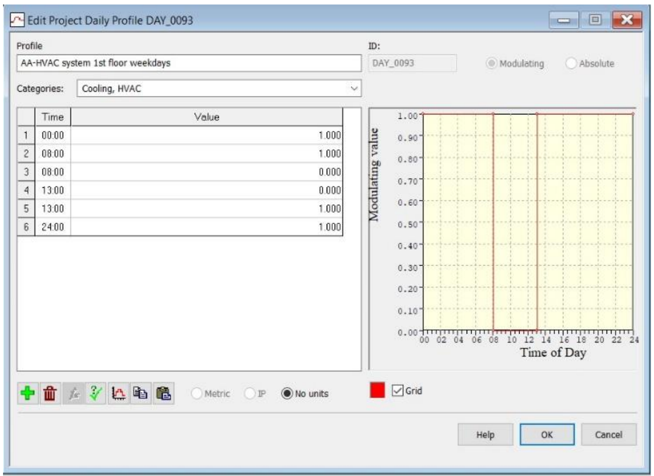


Figure 4.48: HVAC weekdays first floor profile
source: IES-VE software, 2019

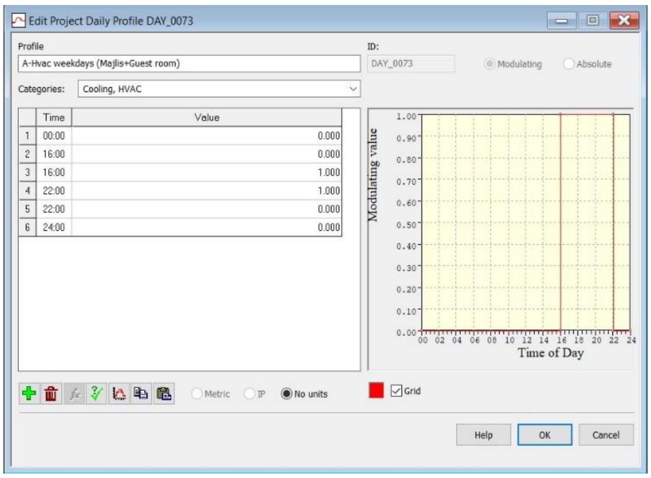


Figure 4.49: HVAC weekdays majlis and guest room profile
source: IES-VE software, 2019

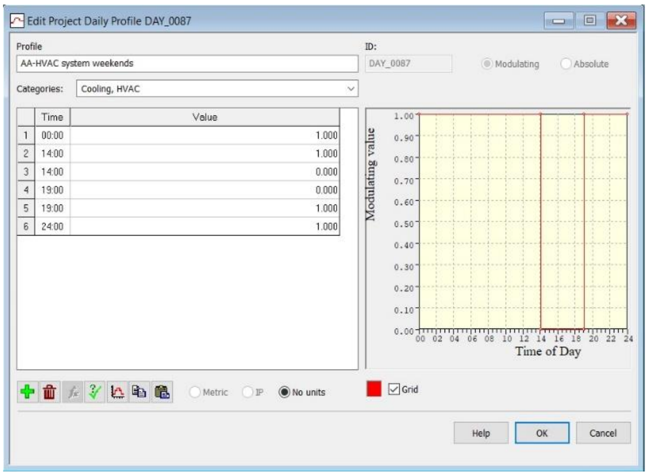


Figure 4.50: HVAC weekends profile
source: IES-VE software, 2019

B) Natural ventilation profile

Same as the SZHP case study, the villa windows will be open during winter days and only closed from 12:00 pm to 4:00 pm. Furthermore, the infiltration flow rate was considered in this simulation model and is equal to 0.25 ACH. There was two temperature air conditioning set point used in this villa. Only the Sala and kitchen area setpoint equal to 23°C while the setpoint value for the rest of the villa equivalent to 24°C. The energy efficiency rate (EER) of the model cooling system was set on eight, as shown in their drawings.

According to their AC drawings, all toilets and kitchen was provided with a wall/mounted extract fan. A daily profile was defined as presented in the previous case study Table 4.5. In this case study also, the energy consumption generated by the backup electrical heater system for hot water is neglected, which means the household domestic hot water demand relies only on the solar water system.

C) Internal lighting system

The simulation model of this case study internal lighting system imitated the previous model's internal lighting system in both weekday and weekend profiles. The lighting turned on via weekdays from 5:00 am to 7:00 am and from 5:30 pm to 11:00 pm. On the weekend, the artificial lighting turned on from 5:00 am to 6:00 am and from 7:00 pm to 1:00 am, as shown in Fig (4.19 & 4.20).

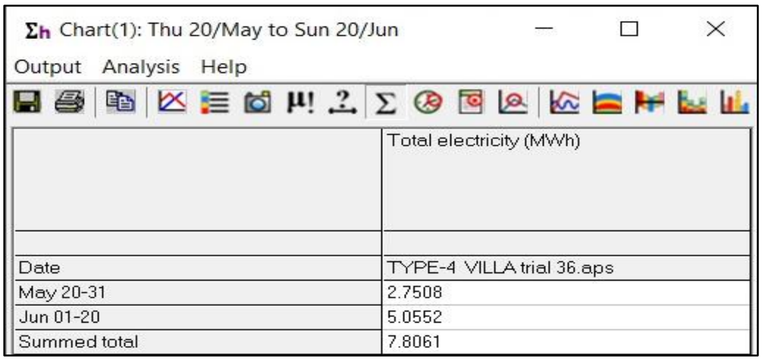
D) External lighting profile

Also, this villa's external lighting system had the same weekdays and weekends profiles of the SZHP case study. As presented in Fig (4.21 & 4.22), weekdays profile lighting switched on from 6:00 pm to 24:00 am, and the weekend's profile run from 7:00 pm to 2:00 am.

4.7.2 Validity of the simulation model

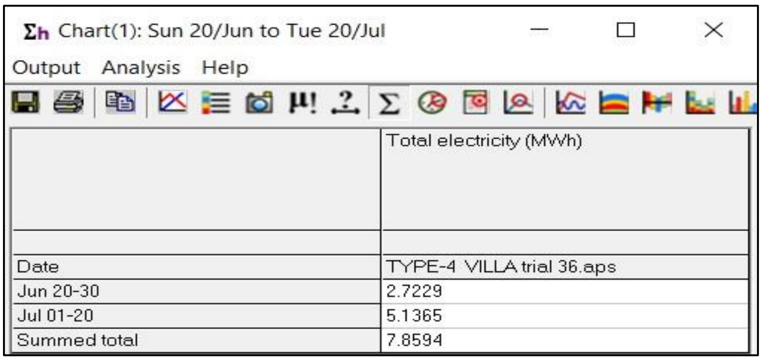
After assigning the factors that affect electricity consumption in the IES-VE software, an assessment of the electricity consumption was carried out to the model accuracy of this case study computational model. Two analyses were conducted in a different period to ensure the simulation's accuracy compared with DEWA actual bills. The 1st analysis from 20 of May to 20 of June and the 2nd analysis from 20 of June to 20 of July.

Table 4.17: The electricity consumption of the simulation model from 20/5 to 20/6 source: IES-VE software, 2019



	Total electricity (MWh)
Date	TYPE-4 VILLA trial 36.aps
May 20-31	2.7508
Jun 01-20	5.0552
Summed total	7.8061

Table 4.18: The electricity consumption of the simulation model from 20/6 to 20/7 source: IES-VE software, 2019



	Total electricity (MWh)
Date	TYPE-4 VILLA trial 36.aps
Jun 20-30	2.7229
Jul 01-20	5.1365
Summed total	7.8594

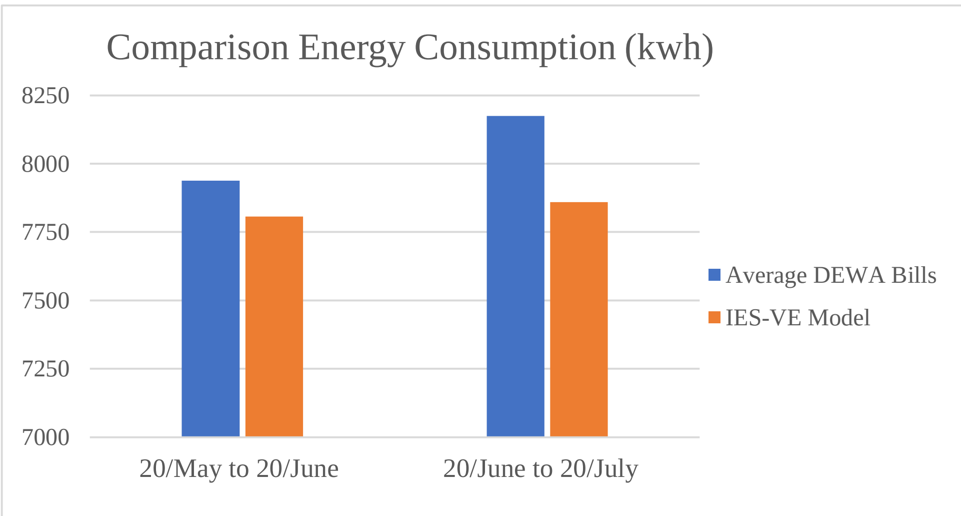


Figure 4.51: Calibration between IES-VE model and DEWA Bills in terms of two months electricity consumption source: Author, 2020

As presented in Fig (4.51), the variation between the IES-VE model and DEWA Bills is 131.9 kWh from May to June, which is estimated at 1.66%. While from June to July, the energy consumption difference equals 315.1 kWh, which is around 3.85%.

Although having the electricity consumption of all months will enhance the accuracy and reliability of the simulation, these percentage of errors are acceptable to develop scenarios based on this computational model and to conduct the research on the right track.

4.8 2nd case study scenarios simulation model set-up

Similar to the 1st case study, various scenarios will be developed to enhance the villa's energy performance and thermal comfort. Each of these scenarios will be analyzed through IES-VE software as the base case in terms of electricity consumption and thermal comfort, which will be followed later by a comparison process to identify the optimum scenarios for each case study.

4.8.1 The 1st scenario

The first scenario was constructed to upgrade the construction material by changing the layers' thickness for the external wall, roof and windows. As per the following:

- Expanding the wall's total thickness from 200mm in the base case to 250mm, as shown in Table 4.19. Thermal block property collected from Hussain Mohd. Abbas block factory LCC.

Table 4.19: 250mm thermal block for external wall

Material	Thickness (mm)	Conductivity (W/m.K)	U- value (W/m².K)
Plaster	15	0.72	0.28
Concrete EPS Concrete	70 110 70	0.51 0.0357 0.51	
Plaster	15	0.72	

- Changing the thickness of the combo roof insulation material (polyurethane foam) to be like the SZHP combo roof system (base case) as presented in Table 4.20.

Table 4.20: 1st scenario combo roof system

Material	Thickness (mm)	Conductivity (W/m.K)	U- value (W/m².K)
Top coating	0.8	-	0.124
Screed	80	1.3	
Filter layer	0.1	-	
Acrylic coating	0.6	-	
polyurethane foam	170	0.022	
Reinforced concrete	200	1.85	
Plaster	15	0.72	

- The external window layers were modified as shown in the below table instead of the villa's current glazed system.

Table 4.21: 1st scenario glazing elements

Material	Thickness (mm)	Conductivity (W/m.K)	U- value (W/m².K)
Outer pane	6	1.06	1.723
Air	16	-	
Inner pane	6	1.06	

4.8.2 The 2nd scenario

The second scenario's enhancement is based on retrofitting the external wall and the glazing system—also, the utilization of shading elements and landscape shades.

- Replacing 200mm thermal block with 250mm AAC block as presented in Table 4.22.
- Upgrading the polyurethane foam conductivity to be 0.022 W/m.K instead of 0.0242 W/m.K.

Table 4.22: AAC block thermal property in 2nd scenario

Material	Thickness (mm)	Conductivity (W/m.K)	U- value (W/m².K)
Plaster	15	0.72	0.4025
AAC block	250	0.11	
Plaster	15	0.72	

- Covering all west, east and south window elevations with horizontal shading elements. Moreover, placed trees in front of both the west and east sides.

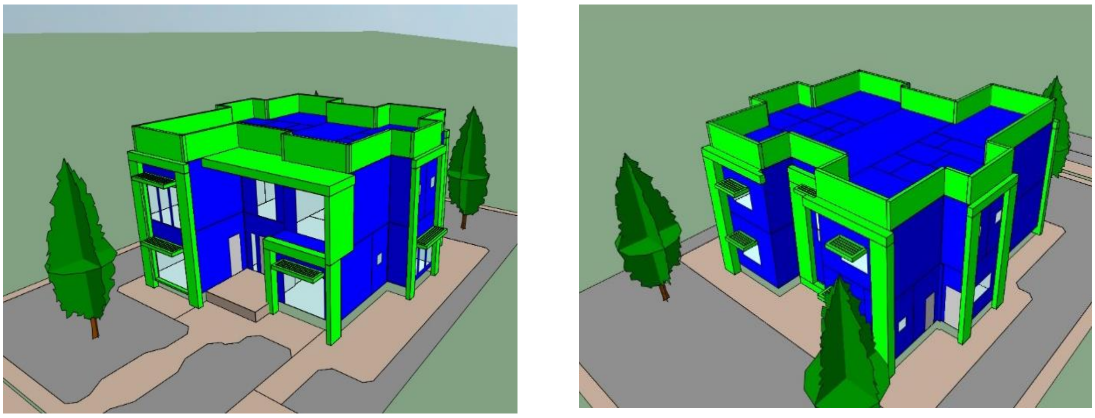


Figure 4.52: The implementation of shading elements source: IES-software, 2019

- A triple glazed window was used in this scenario rather than the doubled glazed as presented in Table 4.23.

Table 4.23: Triple Glazed window property

Material	Thickness (mm)	Conductivity (W/m.K)	U- value (W/m².K)
Outer pane	6	1.06	1.63
Air	12	-	
Pane	6	1.06	
Air	12	-	
Inner pane	6	1.06	

4.8.3 The third scenario

In this scenario, the author replaced the CFL lamp with LED, modified the property of the glass and external wall, like the following:

- In this scenario, the external wall thermal block remained the same as the base case, but it provided insulation material (PIR) covered with plasterboard, as shown in Table 4.13.
- LED lamps were installed inside the villa instead of the current system of light where the requirement of wattage calculated similarly to the third scenario in the previous case-study as presented in Table 4.24.

Table 4.24: Calculation of the requirement of LED in each room in the MBRHE villa source: LED Lighting Requirement Calculator - Charlston Lights, 2020.

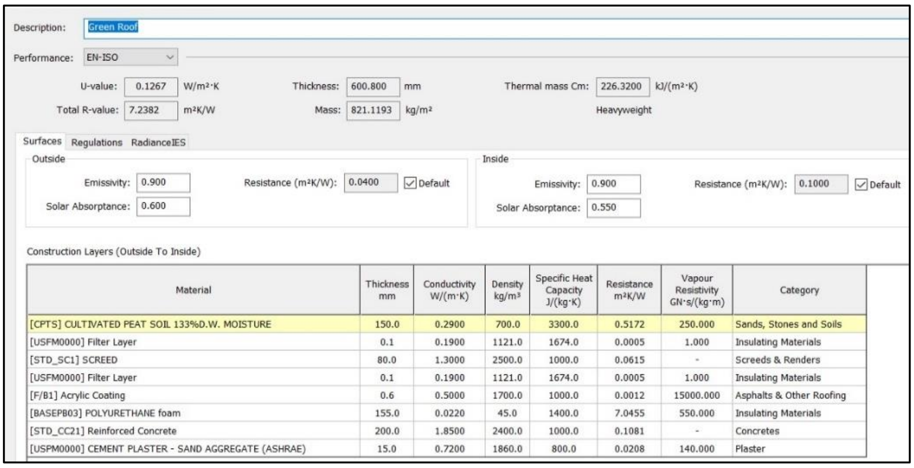
Room name	W x L x H Meter	Required watts	LED option (Nos. x watts)
Majlis	4.7 x 6.3 x 3.3	40	4 x12
Guest Room	3.75 x 4.7 x 3.3	24	2 x 12
Sala	3.9 x 5.65 x3.3	30	3 x 12
Kitchen	4 x 4.8 x 2.7	35	4 x 12
Maid room	2.9 x 3.85 x 3.3	15	2 x 12
Store	1.2 x 4.1 x 3.3	4	1 x 9
Living & study room	4 x 6.2 x 3.3	63	6 x 12
Family living	3.9 x 9.85 x 3.3	53	5 x 12
M. bedroom	4.8 x 6.3 x 3.3	41	4 x 12
Bedroom-1 & 2	3.95 x 4.7 x 3.3	25	4 x 9
Bedroom 3	4.5 x 4.7 x 3.3	29	4 x 9
Toilets	Vary	From 4 to 9	1 x 12
Dress	Vary	From 5 to 7	1 x 9

- Also, in the modification of the glazed system of the scenario, the thickness of the glazed elements kept the same as the current system, while the thermal properties were upgraded. It was also replacing the aluminum frame with the UPVC frame.

Table 4.25: 4th scenario glazed system property

Material	Thickness (mm)	Conductivity (W/m.K)	Transmittance	Outside ref.	Inside ref.	U-value of glass only
Outer pane	8	1.06	0.255	0.389	0.331	1.61 W/m².K
Air	12	-	-	-	-	
Inner pane	8	1.06	0.9	0	0	

- The green roof system was implemented over the combo roof with respect to the materials layer's thickness. The green roof covered around 60% of the roof area, which is equal to 114 m². Fig (4.53) presents the layers of the proposed green roof.



Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[CPTS] CULTIVATED PEAT SOIL 133%D.W. MOISTURE	150.0	0.2900	700.0	3300.0	0.5172	250.000	Sands, Stones and Soils
[USFM0000] Filter Layer	0.1	0.1900	1121.0	1674.0	0.0005	1.000	Insulating Materials
[STD_SC1] SCREED	80.0	1.3000	2500.0	1000.0	0.0615	-	Screeds & Renders
[USFM0000] Filter Layer	0.1	0.1900	1121.0	1674.0	0.0005	1.000	Insulating Materials
[F/B1] Acrylic Coating	0.6	0.5000	1700.0	1000.0	0.0012	15000.000	Asphalts & Other Roofing
[BASEPB03] POLYURETHANE foam	155.0	0.0220	45.0	1400.0	7.0455	550.000	Insulating Materials
[STD_CC21] Reinforced Concrete	200.0	1.8500	2400.0	1000.0	0.1081	-	Concretes
[USPM0000] CEMENT PLASTER - SAND AGGREGATE (ASHRAE)	15.0	0.7200	1860.0	800.0	0.0208	140.000	Plaster

Figure 4.53: 4th scenario roof system layers source: IES-VE software, 2019

- Distributing trees to establish shadows over the west, east and south elevations as illustrated in Fig (4.54).

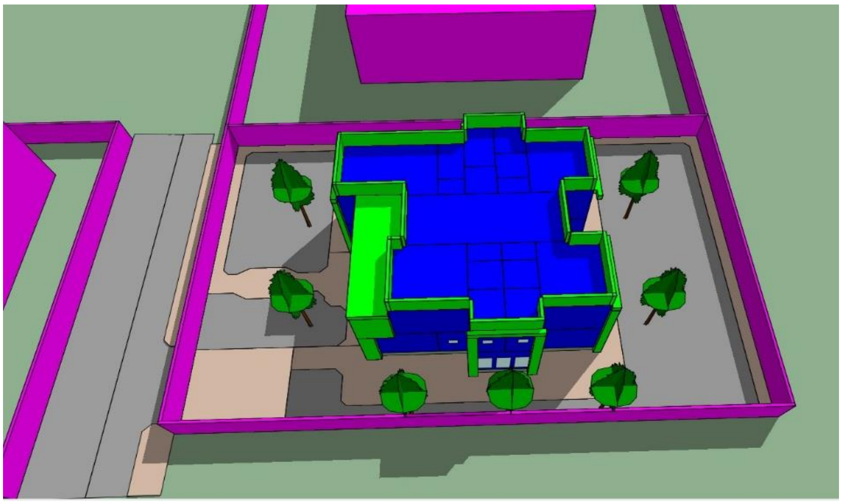


Figure 4.54: Top view of the villa in scenario 3 source: IES-VE software, 2019

4.8.4 The fourth scenario

This scenario presented the utilization of PV panel technology and a refurbishment of construction envelope material as mentioned below:

- As proposed in the 3rd scenario, the utilization of LED lamps instead of CFL where it is listed in Table 4.24.
- The green roof system also applied over the combo roof, but here the green roof occupied 70 m².
- The double-glazed window properties were modified, as illustrated in Table 4.25, but with different layer thickness. The cavity gas used in this scenario is the argon and the aluminum frame replaced with UPVC as shown in Table 4.26.

Table 4.26: 4th scenario double glazed layers

Material	Thickness (mm)	Conductivity (W/m.K)	U- value (W/m².K)
Outer pane	6	1.06	1.31
Argon	16	-	
Inner pane	6	1.06	

- Horizontal shading devices were installed on the east elevation and like the third scenario, trees were located near the east, west and south sides.

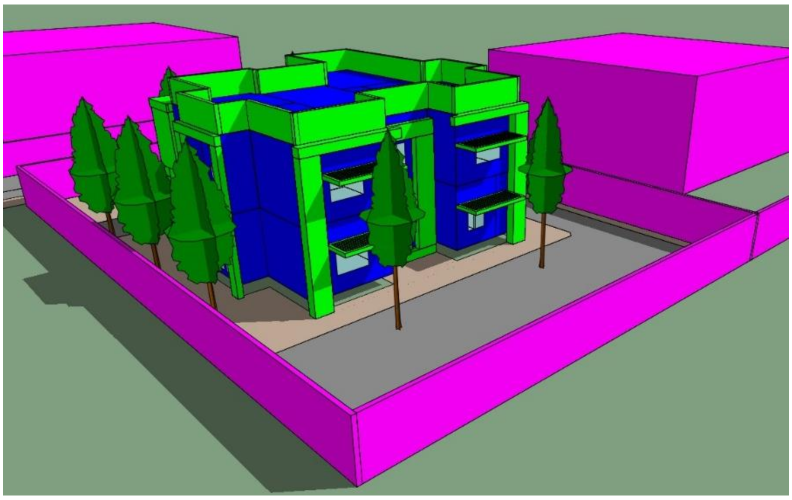


Figure 4.55: East elevation shading element source: IES-VE software, 2019

- The external villa wall is made of 250mm thermal block combined with insulation material shown in below Table.

Table 4.27: The 4th scenario for MBRHE external wall layer

Material	Thickness (mm)	Conductivity (W/m.K)	U- value (W/m².K)
Plaster	15	0.72	0.234
Thermal block concrete + EPS + concrete	250 (70+110+70)	(0.51+0.0357+0.51)	
EPS	50	0.025	
Plasterboard	20	0.16	

- In this scenario, the proposed selected PV technology is monocrystalline. The proposed area where the PV panels were installed equal to 70 m² (35% of roof area) and as mentioned before, the best orientation of it is the south and the inclination angle set up in the software is 24°.

4.8.5 The fifth scenario

This scenario developed based on the influence of the courtyard. The author redesigned the plans of the MBRHP villa to place the courtyard in the proper location. The yard is placed in the center of the villa plan where the sala on the ground floor and living family on the 1st floor are located. The updated zones are highlighted as presented in Fig (4.56 & 4.57).

Regarding the modification of the plans, on the ground floor, the guest room was replaced with the entrance and family toilet, while the sala area was reduced because of the courtyard. The rest of the ground floor rooms remained the same.

On the first floor, all room distribution remained the same as the current villa plan except the family living room, which was replaced with the courtyard.

The current The updated

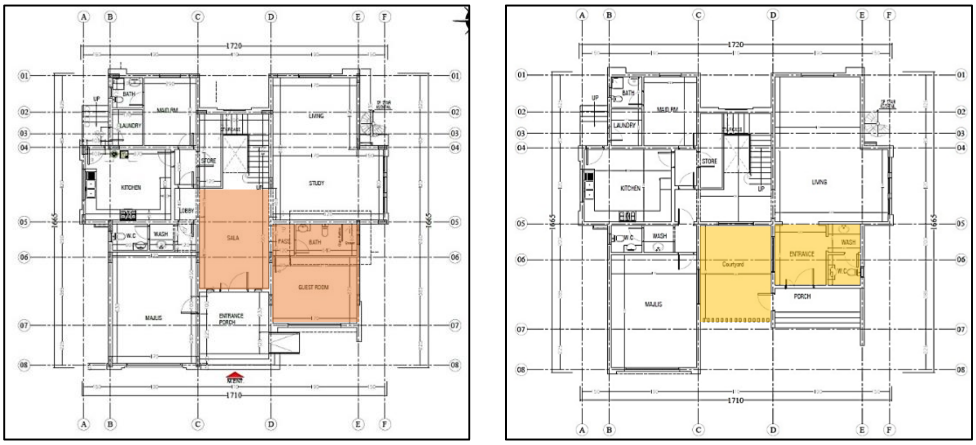


Figure 4.56: The modified zone in the current and updated ground floor plan.

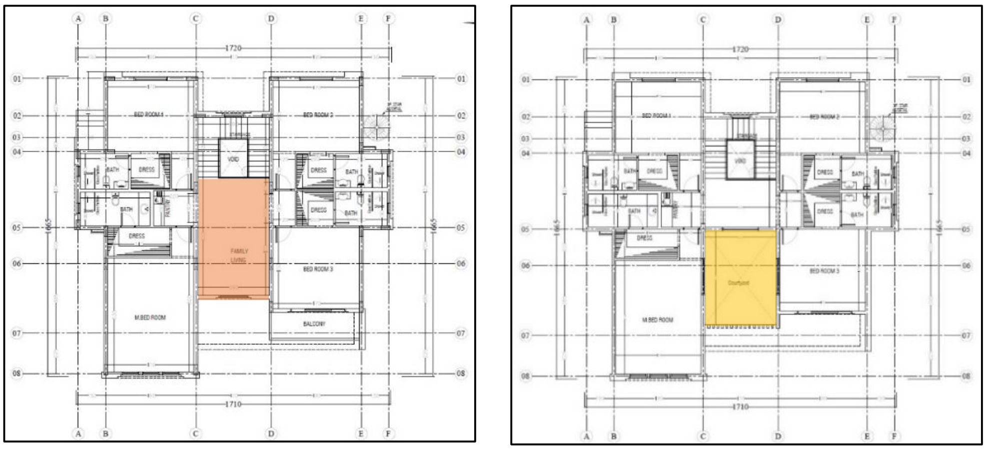


Figure 4.57: The modified zone in the current and updated first floor plan.

The total built up area of the new plans equals 426.2 m², which is less by 17 m² in comparison with the current villa total area. The proposed courtyard was covered by GRP (glass reinforced plastic) pergola from the front and topsides.

Figure 4.58: The 5th scenario proposed courtyard design

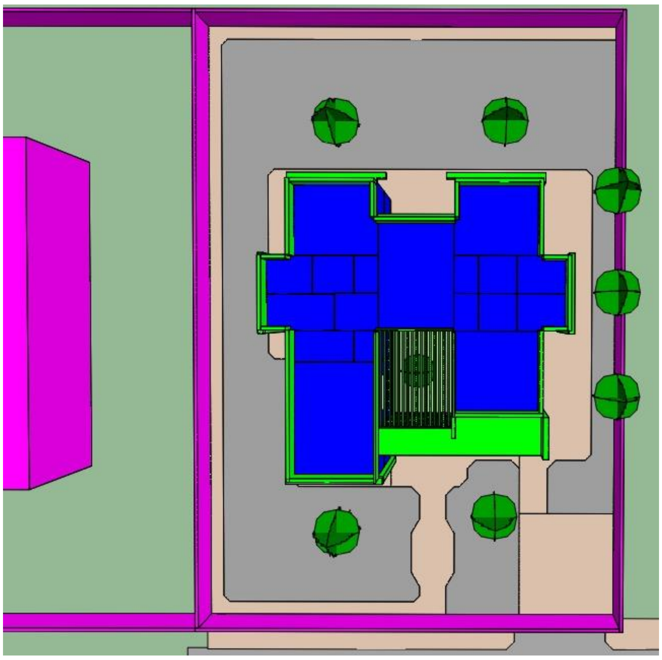


Figure 4.59: 5th scenario top view source: IES-VE software, 2019

Besides utilizing the courtyard, other passive and active design strategies are used in this scenario, as mentioned below.

- The selected thickness of this scenario external wall is 250mm, as presented in Table 4.19.
- In addition, the combo roof insulation thickness and the property changed as mentioned in Estidama specification of the combo roof and
- the glazing elements identified as the below table and frame of them made of UPVC material

Table 4.28: Double glazed construction material

Material	Thickness (mm)	Conductivity (W/m.K)	U- value (W/m².K)
Outer pane	6	1.06	1.52
Air	16	-	
Inner pane	6	1.06	

- The lighting system in the scenario utilized LED lamps as presented in the 3rd scenario but with different quantities in few rooms due to the reduction of their areas, as explained in the below table.
- The roof is occupied with PV panels type polycrystalline, covering around 60% of the roof area around 108 m².

Table 4.29: Calculation of the requirement of LED in each room in the MBRHE villa 5th scenario source: LED Lighting Requirement Calculator - Charlston Lights, 2020.

Room name	W x L x H Meter	Required watts	LED option (Nos. x watts)
GF stair area	2.1 x 3.9 x 3.3	11	2 x 9
Entrance	2.8 x 3.3 x 3.3	12	2 x 9
FF stair area	3.9 x 6 x3.3	32	3 x 12

The simulation models for each selected case study and its alternative enhancement scenarios were build-up in IES-VE software, assessed energy consumption and thermal comfort. The conducted data of this stage will be used in the next chapter to calculate the life cycle cost of them. In the next step, these results will be analyzed to determine the appropriate seriousness in terms of energy performance and life cycle cost.

Chapter 5

Life Cycle Cost Analysis

5- Life Cycle Cost Analysis

5.1 Introduction

In a building lifetime, the main two factors with significant impacts are the building's life cycle cost (LCC) and environmental effects, where both can be evaluated by the life cycle assessment (LCA) and the life cycle costing analysis (LCCA). This chapter aims to introduce a methodology of assessing the performance of the housing life cycle cost before and after implementing energy-efficient parameters. The analysis of life cycle cost will be conducted for the selected villas and the developed scenarios. The chapter will start with an explanation and identification of the life cycle cost concept, method of work and its related terms.

5.2 Definitions

The life cycle assessment approach is more relevant to environmental aspects, which supports in the elect the appropriate construction methods, production processes and structural materials. In addition, LCA plays an essential role in minimizing the life cycle emission (LCE) and by performing it in the building's design (Mostavi, Asadi and Boussaa, 2017).

Furthermore, the cost of executing the building and building lifetime cost are evaluated by the life cycle costing analysis (LCCA) approach. LCCA methodology assists project engineers and managers in developing cost-effective and value engineering methods while implementing the building design. It’s crucial to analysis the cost of building lifecycle to make design decisions if it’s worth it to invest or not in improving the energy performance of the building (Ahmed, 2016).

Life cycle cost analysis is a financial and commercial technique that is applied to study and assess the costs of building lifecycle that helps accountant, cost analyst, project engineers and managers in decision-making for the long-term of the project. The types of building costs include construction cost, structural cost, design cost, maintenance and operational costs. The purpose of applying the LCCA is to assist in predicting the cost of the building and to develop alternative optimum designs that own the same building functions and specifications but result in providing the minimum life cycle cost (Mostavi, Asadi and Boussaa, 2017).

In this research, the life cycle cost of a building will be defined and implemented to decide if the applied efficient energy strategies and modifications on the selected villas will identify an efficient outcome for the lifetime of the project and to provide the cost payback period.

Moreover, the process, advantages, applications and case studies of life cycle cost and its analysis will be discussed briefly.

5.3 Life cycle cost (LCC) concept of work.

The process of building life cycle cost is divided into three main sub-categories, which are capital or initial cost, operation and maintenance cost, and demolition cost, as presented in Fig (5.1).

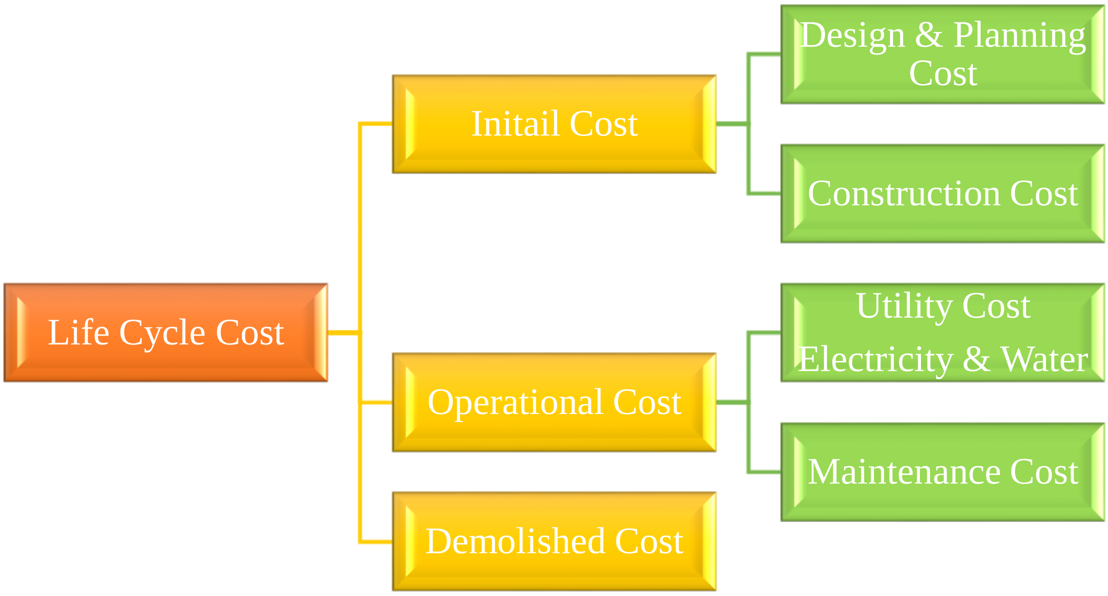


Figure 5.1: Organizational chart of life cycle cost

The initial cost includes building design, planning and construction costs. The building project design, planning and construction are considered as the primary steps of executing a building where it expends 30% to 50% from the project lifetime. The design cost is conducted in conceptual design and detailed design phases, while the project planning cost contains the estimated construction cost and the predicted payback period for the investment, which is also called the feasibility study of a project. Also, construction cost that illustrates precise and real facts of the accurate building costs that carried out from project execution, testing and commissioning (Robati, McCarthy and Kokogiannakis, 2018).

Both project design and planning stages have a significant amount of uncertainty. That's led to implementing comprehensive life cycle cost analysis, which in return minimize the cost, reduce the project risks and enhance the performance of the project. Due to the diversity of building designs and plans, LCCA supports end users, clients, and designers to select the preferable building and compile building rules and regulations for specific requirements.

Moving forward, the operation and maintenance costs are the second categories of building cost, which consumes 50% to 80% from the project life cycle. It consists of operating, labor cost, energy cost, transportation cost, spare parts and maintenance costs. The operation and maintenance costs are associated with the building use-stage.

The third category is demolition cost, which is configured at the termination phase of the project. This phase arises due to a failure of the building after a long time or expensive maintenance; therefore, the cost is related to laborers who are demolishing the building (Ahmed, 2016).

5.4 Advantages of LCCA

As mentioned previously, applying LCCA has several benefits for the lifetime of the project or building and at different stages. At the design phase, LCCA provides designers with clear results of economic position for the project where they have the flexibility to alternate design aspects in order to minimize the cost of the project. In addition, at the planning and construction phases of a building, LCCA gives the purchasers, project engineers and project managers an exact figure of materials, structure, labor and overhead costs in which they perform value engineering along with accomplishing the project requirements. Moreover, at maintenance and operation phases, the LCCA is used to observe the energy consumption of a building to improve the functionality of building equipment to increase the energy-saving and promote building performance, reduce maintenance and decrease the overall cost. It can be summarized that LCCA has a major role in assisting project stakeholders in making financial and economic decisions (Kale, Joshi and Menon, 2016).

5.5 LCCA case study

Since the life cycle cost of building has an impact on resulting a successful project or a failure one, thus the analysis of life cycle cost had been implemented into diverse engineering projects. A case study was performed in Tunisia for measuring the life cycle cost of the residential building that combined cool coating and thermal installation in the roof where the LCCA used to obtain the net saving value, payback period and efficiency of the project. LCCA was conducted to observe the impact of adding cool coating and thermal installation on the environment and economic aspects (Saafi and Daouas, 2018).

Furthermore, another case study was created on assessing the as-built performance of an existing building in Toronto where LCCA was applied to test the modified design of the house in order to decide whether it's worthy of retrofitting a building. The modified design included an enhanced energy model for the house, which will lead to save the energy, increase efficiency and reduce utility bills. The purpose of implementing LCCA in this study is to provide the saving of cost during the lifetime of the house and to support decision makers that investment is profitable based on the payback period and cost reduction (Tokarik and Richman, 2016).

5.6 Life cycle cost research methodology and software

After addressing the research aim, objectives and scope of work in the introduction chapter and identifying the selected base casas (SZHP & MBRHE) in terms of location, construction material, MEP systems, etc., besides developing the alternative housing scenarios in the previous chapter, which including the enhancement of insulation materials, glazing system, external walls, etc. In this section, an assessment method will be conducted to calculate the life cycle cost (LCC) of each villa and its emerged scenarios.

The initial cost comprises all costs required in the design and construction phases of the building. In this research, the initial cost data for each villa was collected from their organization, which is in the first case from Sheikh Zayed Housing Programme and the second case from Mohammed Bin Rashid Housing Establishment.

The operation cost is related to any cost needs to operate the building properly. In this study, the operation cost will concentrate on the electricity consumption cost and maintenance cost, while the water consumption cost will be ignored because the study investigation focused on the energy performance for the villas and their options.

Unfortunately, the demolition cost of the building will be ignored in the analysis of the life cycle cost due to the lack of data and information availability. The two cases shared almost the same height and total built-up area; therefore, neglecting the demolition cost doesn't have a major impact on the analysis's overall outcomes.

Before starting the calculation of the life cycle cost of the villas and their options, the author presents the method of calculating the electricity and maintenance cost.

- The maintenance cost

After conducting interviews with construction sector specialists, the average lifespan of the housing units in UAE extends from 25 to 40 years, where during this period, the building will require maintenance, which includes mechanical, electrical and civil maintenance.

Generally, some maintenance work needs an annual refurbishment as air conditioning gas and devastating lamps. While other need to be replaced every five years, such as the compressor of the AC system and external building paints. Moreover, pumps and sanitation service demand to be changed every ten years.

Collecting these costs is complicated due to the diversity of equipment options and brands in the market, also the variation of their prices over the housing lifespan period. Therefore, engineers developed a maintenance cost estimation method, which will calculate it as a percentage of the building's initial cost, that is vary based on the building age. The author will calculate the maintenance cost based on this method, as presented in Table 5.1.

Table 5.1: The method of calculating maintenance cost of the building source: collected from various consultants and developers, engineers and specialists

Maintenance of building					
Year	1st year	1 to 5	5 to 10	10 to 15	Above
Percentage of initial cost	0%	3%	7%	10%	10% every three years

- The electricity cost

The cost of electricity in Dubai depends on the slab tariff system of consumption, which is implemented by DEWA (Dubai Electricity and Water Authority) since 2008 and revised in 2011. The cost of electricity subsidies the electricity consumption into four categories based on the electrical consumption rate, where each category has a different electrical tariff. The electrical tariff cost varies in terms of building type and nationality.

The electrical consumption cost is calculated based on the national residential electrical slab tariff, as shown in Table (5.2). Since 2011, the slab electricity tariff hasn’t changed, but in the first of 2018, the value-added tax was implemented in the electrical and water bills, equivalent to 5% of the total electricity bill.

Furthermore, in March 2020, DEWA added a fuel surcharge on the bill, which is equal to 0.065% AED/kWh (DEWA, 2020). The 5% VAT is applicable for the next five years from the issued date of the VAT, where the percentage of it might be changed after the five years (Government.ae, 2020). Therefore, the author will assume that the current electricity consumption prices won't change in the future and will use these costs in the analysis of LCC electricity consumption of the selected villas and their scenarios.

Table 5.2: DEWA electrical slab tariff, source: DEWA bills

Electrical slab tariff for (UAE Nationals)	
Residential monthly consumption	Slab Tariff
0 to 2000 kWh	0.075 AED
2001 to 4000 kWh	0.09 AED
4001 to 6000 kWh	0.105 AED
6000 kWh and Above	0.125 AED

As mentioned before, the life cycle cost analysis will conduct through Microsoft Excel, where the number of tables will be prepared for each case study and scenario. Each table will be divided into three groups: the initial cost, maintenance cost and electricity cost, where all of them will be calculated to find out the LCC.

5.7 Life cycle cost analysis

This section will introduce the analysis of the LCC for each case study and its developed scenarios. Before presenting the analysis, few factors need to be indicated in this research. 1st one that the estimated lifespan period of the selected housing is 35 years. Moreover, the energy consumption will collect from the IES-VE simulation where the selected villas and options set-up. The author will also consider the fuel surcharge issued in January 2020 instead of March 2020, so it won't include in the electricity consumption cost calculation before 2020.

5.8 SZHP case study LCC analysis

- The SZHP case study's initial cost was collected from the establishment engineers, which is equal to 1,240,000 AED.
- The maintenance cost calculated as the following table:

Table 5.3: Total maintenance cost of SZHP villa

Maintenance Cost		
Initial cost (AED) =		1,240,000
Lifespan period	Percentage of the initial cost	Cost (AED)
1st year	0	0
From 1 to 6 years	3.0%	37,200
From 6 to 11 years	5% to 7%	86,800
From 11 to 16 years	10.0%	124,000
From 16 to 35 years	10% each 3 years	785,333.3
Total maintenance cost		**1,033,333.3**

- The electricity cost

As mentioned in chapter four, this villa construction was completed in 2017. Therefore, two calculations of electricity will be developed, the 1st one from 2018 to 2020 (before the fuel surcharge issued) and the 2nd one from 2020 to 2053. A yearly table will also be created for the electricity consumption cost, as presented in the below tables.

Table 5.4: Monthly cost of electricity consumption in 2018 & 2020

cost of electricity consumption in 2018			In 2020
Month	Energy consumption (kWh)	Cost per month (AED)	Cost per month (AED)
January	2317.2	178.55	345.62
February	2094.4	158.50	309.36
March	3452.1	280.69	530.33
April	5083.6	443.78	812.92
May	6393.2	589.15	1054.94
June	6929.9	656.24	1162.02
July	7654.1	746.76	1306.49
August	7788.9	763.61	1333.39
September	7055.3	671.91	1187.03
October	6015.3	541.91	979.55
November	3635.5	297.20	560.18
December	2317.2	178.55	345.62

Table 5.5: Total year electricity consumption cost

Yearly consumption cost of electricity (AED)	
Total cost 2018	5,782.18
Total cost from 2018 to 2020	11,564.37
Total cost 2020	9,927.46
Total cost from 2020 to 2053	327,606.29
Total	**339,170.66**

- Table 5.6 presented the life cycle cost of the SZHP case study

Table 5.6: LCC cost of SZHP

Category	Costs (AED)
Initial cost	1,240,000
Operation cost	Maintenance cost = 1,033,333.3 Electricity cost = 339,170.66
Total cost	**2,612,503.993**

Before introducing the LCC cost of developed scenarios, it is essential to present the material schedule cost, as illustrated below. The actual cost of materials varies from one supplier to another due to their percentage of margin. Thus, the applied cost in the below tables are the average of suppliers' cost collected while interviewing them.

- Blocks cost

Table 5.7: AAC block cost AED/m

AAC Block thickness (mm)	Cost (AED)/m³
600 x 250 x 200	150
600 x 250 x 250	150
600 x 250 x 300	160

Table 5.8: Thermal insulated block cost AED/m³

Thermal insulated block thickness (mm)	Cost (AED)/m³
400 x 200 x 200	250
400 x 200 x 250	270

- Shading devices: Window shading elements made of GRP (Glass reinforced plastic) which cost 500 AED/m³
- Plasterboard: Cost of plasterboard equal to 15 AED/m² and plaster 7 AED/m².
- Insulation

Table 5.9: Different insulation cost/m²

Type of insulation	Thickness (mm)	Cost (AED)/m²
EPS (1)	50	16
EPS (2)	70	24
PIR	50	40

- Combo roof system cost

Table 5.10: combo roof cost with different polyurethane insulation thickness

Thickness of polyurethane (mm)	Cost (AED)/m²
155	160
170	175
180	185

- Green roof cost: The green roof cost is 100/m² in addition to the current roof cost.
- 1st case study window type cost (Average)

Table 5.11: 1st case study proposed window type cost

Window type (mm)	Type of gas	Type of Frame	U-value W/m².K	Cost AED/m²
Current (6+12+6)	Air	UPVC	1.916	400
Type-1 (6+12+6)	Argon	UPVC	1.43	430
Type-2 (6+16+6)	Air	UPVC	1.52	410
Type-3 (6+16+6)	Air	UPVC	1.52	420

5.8.1 1st scenario LCC

As presented in the previous chapter, the 1st scenario included several modifications that could change the cost of the initial cost of the current villa. Therefore, the additional costs of the initial cost as the following:

- Shading devices (GRP)

Table 5.12: 1st scenario shading element cost

Type	Volume (m^3)	Quantity	cost (AED)	Total cost
Window pergola	0.266	10	1330	1860
Terrace pergola	1.06	1	530	

- 180 mm thick combo roof insulation

Table 5.13: 1st scenario roof cost

Roof	Area (m^2)	cost AED	Cost difference (AED)
Current roof	159.1	27,842.5	1591
Polyurethane 180 mm	159.1	29,433.5	

- Glazing system

Table 5.14: 1st scenario window cost

Window type	Area (m^2)	cost AED	Cost difference (AED)
Current type	52.135	20,854	1564
Type-1	52.135	22,418	

- 1st scenario initial cost: After calculating the additional costs gained due to implementing passive design strategies.

Table 5.15: 1st scenario total cost

Initial cost	AED
Current cost	1,240,000
Additional cost	5,015
Total cost	**1,245,015**

- 1st scenario maintenance cost

Table 5.16: 1st scenario maintenance cost

Maintenance Cost		
Initial cost (AED) =		1,245,015
Lifespan period	Percentage of the initial cost	Cost (AED)
1st year	0	0
From 1 to 6 years	3.0%	37350.5

From 6 to 11 years	5% to 7%	87151.1
From 11 to 16 years	10.0%	124501.5
From 16 to 35 years	10% each 3 years	788509.5
Total maintenance cost		**1,037,512.5**

- 1st scenario electricity cost

Table 5.17: 1st scenario monthly cost of electricity consumption in 2018 & 2020

cost of electricity consumption in 2018			In 2020
Month	Energy consumption (kWh)	Cost per month (AED)	Cost per month (AED)
January	2317.2	187.48	345.62
February	2094.4	166.42	309.36
March	3385.6	288.44	519.51
April	4938.4	449.96	787.00
May	6212.1	594.84	1018.81
June	6734.1	663.35	1122.95
July	7427.3	754.33	1261.25
August	7565.1	772.42	1288.74
September	6824.6	675.23	1141.01
October	5839.5	549.30	947.85
November	3580.2	306.83	551.18
December	2317.2	187.48	345.62

Table 5.18: 1st scenario yearly electricity consumption

Yearly consumption cost of electricity (AED)	
Total cost 2018	5,596.07
Total cost from 2018 to 2020	11,192.15
Total cost 2020	9,638.91
Total cost from 2020 to 2053	318,084.02
Total	**329,276.17**

- Table 5.19 presented the life cycle cost of 1st scenario

Table 5.19: LCC cost of 1st scenario

Category	Costs (AED)
Initial cost	1,245,015
Operation cost	Maintenance cost = 1,037,512.5 Electricity cost = 329,276.17
Total cost	**2,611,803.67**

5.8.2 2nd scenario LCC

The additional cost of the 2nd scenario retrofitting passive strategies, as illustrated below:

- Wall with 200mm thermal block + 70 EPS

Table 5.20: 2nd scenario wall cost

Wall	Type	Area (m^2)	Volume (m^3)	cost AED	Cost difference (AED)
Current wall	AAC	380	114.14	18,262.4	12,897.6
	Plaster			2660	
2nd scenario wall	Thermal	380	76	19,000	
	EPS			9,120	
	Plasterboard			5,700	

- 70% Green roof

Table 5.21: Cost 70% of green roof

Roof area	Percentage Area	Cost (AED)
159.1	70%	11,137

- Glazing system

Table 5.22: 2nd scenario glazing system cost

Window type	Area (m^2)	cost AED	Cost difference (AED)
Current type	52.135	20,854	521.35
Type-2	52.135	21,375.35	

- 2nd scenario initial cost

Table 5.23: 2nd scenario initial costs

Initial cost	AED
Current cost	1,240,000
Additional cost	24,555.95
Total cost	**1,264,555.95**

- 2nd scenario maintenance cost

Table 5.24: 2nd scenario maintenance cost

Maintenance Cost		
Initial cost (AED) =		1,264,555.95
Lifespan period	Percentage of the initial cost	Cost (AED)
1st year	0	0.0
From 1 to 6 years	3.0%	37,936.7
From 6 to 11 years	5% to 7%	88,518.9
From 11 to 16 years	10.0%	126,455.6
From 16 to 35 years	10% each 3 years	800,885.4
Total maintenance cost		**1,053,796.6**

- 2nd scenario electricity cost

Table 5.25: 2nd scenario cost of electricity consumption in 2018 & 2020

cost of electricity consumption in 2018			In 2020
Month	Energy consumption (kWh)	Cost per month (AED)	Cost per month (AED)
January	2317.2	187.48	345.62
February	2094.4	166.42	309.36
March	3402	289.99	522.18
April	4948.9	451.12	788.88
May	6183.4	591.07	1013.09
June	6681.8	656.49	1112.52
July	7357	745.11	1247.22
August	7495	763.22	1274.75

September	6786.7	670.25	1133.45
October	5838.1	549.15	947.60
November	3587.6	307.53	552.38
December	2317.2	187.48	345.62

Table 5.26: 2nd scenario yearly electricity consumption

Yearly consumption cost of electricity (AED)	
Total cost 2018	5,565.29
Total cost from 2018 to 2020	11,130.58
Total cost 2020	9,592.68
Total cost from 2020 to 2053	316,558.35
Total	**327,688.93**

- Table 5.27 presented the life cycle cost of 2nd scenario

Table 5.27: 2nd scenario LCC cost

Category	Costs (AED)
Initial cost	1,264,555.95
Operation cost	Maintenance cost = 1,053,796.6 Electricity cost = 327,688.93
Total cost	**2,646,041.51**

5.8.3 3rd scenario LCC cost

The 3rd scenario proposed energy performance enhancement strategies cost as the following:

- 50% Green roof

Table 5.28: Cost of 50% green roof

Roof area	Percentage Area	Cost (AED)
159.1	50%	7,955

- Glazing system

Table 5.29: 3rd scenario glazing system cost

Window type	Area (m^2)	cost AED	Cost difference (AED)
Current type	52.135	20,854	1,042.7
Type-3	52.135	21,896.7	

- Lighting system

According to engineers related to lighting consultants, the average cost of a compact fluorescent lamp equivalent to 50% of an LED lamp, but the LED lighting and lifespan period's efficiency is better than CFL. As presented in the previous chapter, the LED lamp used equally to 9 watts in the villa with various quantities based on the room dimensions. The cost of a compact fluorescent lamp is an estimated cost.

Table 5.30: 3rd scenario lighting system cost

Type of lamp	Quantity	Cost of 1 lamp (AED)	Total cost (AED)	Cost difference (AED)
9 Watts LED	62	8	496	248
CFL (current)	50% of LED cost therefore it = 248 AED			

- Shading devices made of (GRP) on west and east elevations.

Table 5.31: 3rd scenario shading element cost

Type	Volume (m^3)	Quantity	cost (AED)	Total cost
L-shape pergola	0.844	2	844	1509
Window pergola	0.266	5	665	

- 3rd scenario initial cost

Table 5.32: 3rd scenario initial cost

Initial cost	AED
Current cost	1,240,000
Additional cost	10,754.7
Total cost	**1,250,754.70**

- 3rd scenario maintenance cost

Table 5.33: 3rd scenario maintenance cost

Maintenance Cost		
Initial cost (AED) =		1,250,754.70
Lifespan period	Percentage of the initial cost	Cost (AED)
1st year	0	0.0
From 1 to 6 years	3.0%	37,522.6
From 6 to 11 years	5% to 7%	87,552.8
From 11 to 16 years	10.0%	125,075.5
From 16 to 35 years	10% each 3 years	792,144.6
Total maintenance cost		**1,042,295.6**

- 3rd scenario electricity cost

Table 5.34: 3rd scenario cost of electricity consumption in 2018 & 2020

cost of electricity consumption in 2018			In 2020
Month	Energy consumption (kWh)	Cost per month (AED)	Cost per month (AED)
January	2025.7	159.93	298.18
February	1832.5	144.31	269.38
March	3069.5	258.57	468.06
April	4610.2	413.77	728.42
May	5879.1	553.67	954.92
June	6416.7	621.69	1059.63
July	7107.3	712.33	1197.41
August	7259.6	732.32	1227.79
September	6520.1	635.26	1080.26
October	5494.5	511.27	886.27
November	3267.3	277.26	500.25
December	2025.7	159.93	298.18

Table 5.35: 3rd scenario yearly electricity consumption

Yearly consumption cost of electricity (AED)	
Total cost 2018	5,180.32
Total cost from 2018 to 2020	10,360.64
Total cost 2020	8,968.75
Total cost from 2020 to 2053	295,968.87
Total	**306,329.50**

- Table 5.36 presented the life cycle cost of 3rd scenario

Table 5.36: 3rd scenario LCC cost

Category	Costs (AED)
Initial cost	1,250,754.70
Operation cost	Maintenance cost = 1,042,295.6 Electricity cost = 306,329.50
Total cost	**2,599,379.78**

5.8.4 4th scenario LCC cost

In chapter four, the scenario is divided into two options of different wall types and PV technology. But there were common strategies between them. Initially assessing the cost of the common strategies as presented below:

- 180mm thick combo roof insulation

The difference enhancement cost of the developed slab equal to 1591 AED (upgraded to polyurethane thickness), as shown in Table 5.13.

- This scenario's proposed glazing system is the same as the 3rd scenario; therefore, the difference of cost between the current villa and this scenario is equal to 1,042.7 as presented in Table 5.29.
- 30% Green roof cost

Table 5.37: Cost of 30% green roof

Roof area	Percentage Area	Cost (AED)
159.1	30%	4,773

- Lighting system

The lighting system's cost in this scenario is similar to the previous one, as presented in Table 5.30.

- Shading devices made of (GRP) on west and east elevations.

Table 5.38: 4th scenarios shading element cost

Type	Volume (m^3)	Quantity	cost (AED)	Total cost
Terrace pergola	1.06	1	530	2,039
L-shape pergola	0.844	2	844	
Window pergola	0.266	5	665	

- 4th Scenario option ‘A’ external wall cost

Table 5.39: 4th scenario wall option ‘A’

Wall	Type	Area (m^2)	Volume (m^3)	cost AED	Cost difference (AED)
Current wall	AAC	380	114.14	18,262.4	11,377.6
	Plaster			2660	
Option ‘A’ wall	AAC	380	76	11,400	
	PIR			15,200	
	Plasterboard			5,700	

- 4th Scenario option ‘A’ PV panel cost: Monocrystalline technology

The data of PV calculation was collected from the PV service provider and electrical engineer through interviews. The selected output power for the monocrystalline 330 watts and the average cost of PV watts = 1.9 USD/watts (6.973 AED/watts). According to IES-VE, the maximum production of clean energy in May equals 1680.7 kWh. Therefore, the calculation of PV panel cost, as shown in below Table.

Table 5.40: Single PV panels cost option ‘A’

PV panel calculation	
Required KW/day/hour	2.26 kW (2260 watts)
Number of panels	7 panels
Cost of panel (AED)	16,107.63

- PV system component cost

Table 5.41: Total cost of PV system option 'A'

Cost of component	Average cost (AED)
PV panels	16,107.6
Controller	2220
Battery	9,200
Mounting structures	3300
Invertor	1410
Combiner box	2500
Wiring	1670
Installation	6000
Total cost	42,407.6

- 4^{th} Scenario option 'B' external wall cost

Table 5.42: 4^{th} scenario wall option 'B'

Wall	Type	Area (m^2)	Volume (m^3)	cost AED	Cost difference (AED)
Current wall	AAC	380	114.14	18,262.4	18,977.6
	Plaster			2660	
Option 'B' wall	Thermal	380	76	19,000	
	PIR			15,200	
	Plasterboard			5,700	

- 4^{th} Scenario option 'B' PV panel cost: Polycrystalline technology

The author considers the same panel outputs as in option 'A'. Polycrystalline has a lower efficiency than monocrystalline thus, the average cost of PV watts = 1.6 USD/watts. The maximum output power of the PV model simulation is 1,422.1 kWh in May. The calculation of this option is presented in Table 5.43.

Table 5.43: Single PV panels cost option 'B'

PV panel calculation	
Required KW/day/hour	1.9 kW (1900 watts)
Number of panels	6 panels
Cost of panel (AED)	11,626.6

- PV kit cost

Table 5.44: Total cost of PV system option 'A'

Cost of component	Average cost (AED)
PV panels	11,626.6
Controller	2220
Battery	9200
Mounting structures	2830
Invertor	1410
Combiner box	2500
Wiring	1500
Installation	5200
Total cost	36,486.6

- 4th scenario initial cost option 'A'

Table 5.45: 4th scenario opt. 'A' initial cost

Initial cost	AED
Current cost	1,240,000
Additional cost	63,478.9
Total cost	**1,303,478.90**

- 4^{th} scenario maintenance cost option ‘A’

Table 5.46: 4^{th} scenario opt. ‘A’ maintenance cost

Maintenance Cost		
Initial cost (AED) =		1,303,478.90
Lifespan period	Percentage of the initial cost	Cost (AED)
1st year	0	0.0
From 1 to 6 years	3.0%	39,104.4
From 6 to 11 years	5% to 7%	91,243.5
From 11 to 16 years	10.0%	130,347.9
From 16 to 35 years	10% each 3 years	825,536.6
Total maintenance cost		1,086,232.4

- 4^{th} scenario opt. ‘A’ electricity cost

Table 5.47: 4^{th} scenario opt. ‘A’ cost of electricity consumption in 2018 & 2020

cost of electricity consumption in 2018				In 2020
Month	Energy consumption (kWh)	PV panel power output (kWh)	Cost per month (AED)	Cost per month (AED)
January	2025.7	-1389.4	50.11	93.54
February	1832.5	-1462.4	29.15	54.40
March	3055	-1494.6	122.88	229.38
April	4540.7	-1522	253.77	459.79
May	5757.7	-1680.7	354.99	633.24
June	6268.6	-1589.9	421.33	740.65
July	6935.1	-1593.6	494.40	858.96
August	7074	-1637.5	504.87	875.92
September	6369.8	-1601	431.26	756.73
October	5399.8	-1602.4	327.35	586.53
November	3242.8	-1387.1	146.14	272.79
December	2025.7	-1309.7	56.39	105.25

Table 5.48: 4th scenario opt. 'A' yearly electricity consumption

Yearly consumption cost of electricity (AED)	
Total cost 2018	3,192.63
Total cost from 2018 to 2020	6,385.26
Total cost 2020	5,667.18
Total cost from 2020 to 2053	187,016.81
Total	**193,402.07**

- Table 5.49. illustrated the life cycle cost of the 4th scenario opt. 'A'.

Table 5.49: 4th scenario opt. 'A' LCC cost

Category	Costs (AED)
Initial cost	1,303,478.90
Operation cost	Maintenance cost = 1,086,232.4 Electricity cost = 193,402.07
Total cost	**2,583,113.39**

- 4th scenario initial cost option 'B'

Table 5.50: 4th scenario opt. 'B' initial cost

Initial cost	AED
Current cost	1,240,000
Additional cost	65,157.9
Total cost	**1,305,157.90**

- 4th scenario maintenance cost option 'B'

Table 5.51: 4th scenario opt. 'B' maintenance cost

Maintenance Cost		
Initial cost (AED) =		1,305,157.90
Lifespan period	Percentage of the initial cost	Cost (AED)
1st year	0	0.0
From 1 to 6 years	3.0%	39,154.7
From 6 to 11 years	5% to 7%	91,361.1

From 11 to 16 years	10.0%	130,515.8
From 16 to 35 years	10% each 3 years	826,600.0
Total maintenance cost		**1,087,631.6**

- 4^{th} scenario opt. 'B' electricity cost

Table 5.52: 4^{th} scenario opt. 'B' cost of electricity consumption in 2018 & 2020

cost of electricity consumption in 2018				In 2020
Month	Energy consumption (kWh)	PV panel power output (kWh)	Cost per month (AED)	Cost per month (AED)
January	2025.7	-1175.6	66.95	124.96
February	1832.5	-1237.4	46.86	87.48
March	3049.3	-1264.7	140.54	262.34
April	4534.9	-1287.8	275.35	496.97
May	5746.1	-1422.1	382.22	677.33
June	6259.4	-1345.3	447.28	782.67
July	6922.2	-1348.4	520.01	900.42
August	7064.8	-1385.6	531.63	919.24
September	6361.7	-1354.7	457.52	799.25
October	5395.7	-1355.8	350.90	626.62
November	3242.3	-1173.7	163.98	305.16
December	2025.7	-1108.2	72.25	134.87

Table 5.53: 4^{th} scenario opt. 'B' yearly electricity consumption

Yearly consumption cost of electricity (AED)	
Total cost 2018	3,455.50
Total cost from 2018 to 2020	6,911.00
Total cost 2020	6,117.32
Total cost from 2020 to 2053	201,871.44
Total	**208,782.43**

- Table 5.54. presented the life cycle cost of the 4th scenario opt. ‘B’.

Table 5.54: 4th scenario opt. ‘B’ LCC cost

Category	Costs (AED)
Initial cost	1,305,157.90
Operation cost	Maintenance cost = 1,087,631.6 Electricity cost = 208,782.43
Total cost	**2,601,571.91**

5.9 MBRHE case study LCC cost

The author assumed that the villa was completed in 2018, same as the previous case study and its lifespan period is 35 years. Therefore, the calculation of this villa will be as the following:

- The initial cost of the MBRHE villa is 1,305,000 AED, which their engineers provided.
- The maintenance cost calculated as the following table:

Table 5.55: Total maintenance cost of MBRHE villa

Maintenance Cost		
Initial cost (AED) =		1,305,000
Lifespan period	Percentage of the initial cost	Cost (AED)
1st year	0	0.0
From 1 to 6 years	3.0%	39,150.0
From 6 to 11 years	5% to 7%	91,350.0
From 11 to 16 years	10.0%	130,500.0
From 16 to 35 years	10% each 3 years	826,500.0
Total maintenance cost		**1,087,500.0**

- The electricity cost

As presented in the previous case study calculation, the electricity consumption calculation will be divided into periods before fuel surcharge issued (before 2020) and after fuel surcharge (from 2020).

Table 5.56: Monthly cost of electricity consumption in 2018 & 2020

cost of electricity consumption in 2018			In 2020
Month	Energy consumption (kWh)	Cost per month (AED)	Cost per month (AED)
January	3204.4	271.32	490.02
February	2863.5	239.10	434.53
March	4204.9	369.09	656.07
April	5821.6	547.33	944.66
May	7161.1	719.39	1208.14
June	7531	767.94	1281.93
July	8246.7	861.88	1424.72
August	8340.8	874.23	1443.49
September	7476.2	760.75	1271.00
October	6662.4	653.94	1108.65
November	4298	379.35	672.69
December	3175	268.54	485.23

Table 5.57: Total year electricity consumption cost

Yearly consumption cost of electricity (AED)	
Total cost 2018	6,712.87
Total cost from 2018 to 2020	13,425.74
Total cost 2020	11,421.14
Total cost from 2020 to 2053	376,897.49
Total	**390,323.23**

- Table 5.58 presented the life cycle cost of the MBRHE case study.

Table 5.58: LCC cost of MBRHE

Category	Costs (AED)
Initial cost	1,305,000
Operation cost	Maintenance cost = 1,087,500.0 Electricity cost = 390,323.23
Total cost	**2,782,823.23**

The types of construction materials used in these simulation models were almost the same as the previous case study, with only a few differences in the window types.

- 2nd case study window type cost (Average)

Table 5.59: 2nd scenario window type cost

Window type (mm)	Type of gas	Type of Frame	U-value W/m².K	Cost AED/m²
Current (8+12+8)	Air	Aluminum	1.913	610
Type-1 (6+16+6)	Air	Aluminum	1.72	620
Type-2 (6+12+6+12+6)	Air	Aluminum	1.60	800
Type-3 (8+12+8)	Air	UPVC	1.71	420
Type-4 (6+16+6)	Argon	UPVC	1.31	450

5.9.1 1st scenario LCC analysis

The proposed improvement strategies could increase the cost of the initial cost; therefore, the strategies cost presented as the following:

- The thickness of the external wall increased, as shown in the previous chapter.

Table 5.60: 1st scenario wall cost

Wall	Type	Area (m²)	Volume (m³)	cost AED	Cost difference (AED)
Current wall	200mm thermal	429.5	85.9	21,475	7,516.25
1st scenario	250mm thermal	429.5	107.375	28,991.25	

- 170mm thick combo roof insulation

Table 5.61: 1st scenario roof cost

Roof	Area (m²)	cost AED	Cost difference (AED)
Current roof	200	32,000	3000
Polyurethane 170 mm	200	35,000	

- External window

Table 5.62: 1st scenario external window cost

Window type	Area (m²)	cost AED	Cost difference (AED)
Current type	59.91	36,545.1	599.1
Type-1	59.91	37,144.2	

- 1st scenario initial cost

Table 5.63: 1st scenario initial cost

Initial cost	AED
Current cost	1,305,000
Additional cost	11,115.35
Total cost	**1,316,115**

- 1st scenario maintenance cost

Table 5.64: 1st scenario maintenance cost

Maintenance Cost		
Initial cost (AED) =		1,316,115
Lifespan period	Percentage of the initial cost	Cost (AED)
1st year	0	0.0
From 1 to 6 years	3.0%	39483.5
From 6 to 11 years	5% to 7%	92128.1
From 11 to 16 years	10.0%	131611.5
From 16 to 35 years	10% each 3 years	833539.7
Total maintenance cost		**1,096,762.8**

- 1st scenario electricity cost

Table 5.65: 1st scenario cost of electricity consumption in 2018 & 2020

cost of electricity consumption in 2018			In 2020
Month	Energy consumption (kWh)	Cost per month (AED)	Cost per month (AED)
January	3204.4	271.32	490.02
February	2863.5	239.10	434.53
March	4170.1	365.25	649.86
April	5689.6	532.78	921.09
May	6895.5	684.53	1155.15
June	7203.8	725.00	1216.66
July	7861.8	811.36	1347.93
August	7940.7	821.72	1363.67
September	7153.3	718.37	1206.58
October	6456.7	626.94	1067.61
November	4246	373.62	663.41
December	3175	268.54	485.23

Table 5.66: 1st scenario yearly electricity consumption

Yearly consumption cost of electricity (AED)	
Total cost 2018	6,438.53
Total cost from 2018 to 2020	12,877.06
Total cost 2020	11,001.75
Total cost from 2020 to 2053	363,057.87
Total	**375,934.93**

- Table 5.67 presented the life cycle cost of 1st scenario

Table 5.67: 1st scenario LCC cost

Category	Costs (AED)
Initial cost	1,316,115
Operation cost	Maintenance cost = 1,096,762.8 Electricity cost = 375,934.93
Total cost	**2,788,813.07**

5.9.2 2nd scenario LCC analysis

The retrofitting of this scenario focused on the upgrading of the envelope materials of the case.

- The current external wall block material (200mm thermal) was replaced with the AAC block (250mm), calculating the new wall as shown below.

Table 5.68: 2nd scenario wall cost

Wall	Type	Area (m^2)	Volume (m^3)	cost AED	Cost difference (AED)
Current wall	Thermal	429.5	85.9	21,475	-5,368
2nd scenario	AAC	429.5	107.375	16,106.25	

- Shading devices made of (GRP) on south, west and east elevations.

Table 5.69: 2nd scenarios shading element cost

Type	Volume (m^3)	Quantity	cost (AED)	Total cost
Front side	0.362	3	543	1,337
Back side	0.24	5	600	
South side	0.388	1	194	

- External window

Table 5.70: 2nd scenario external window cost

Window type	Area (m^2)	cost AED	Cost difference (AED)
Current type	59.91	36,545.1	11,382.9
Type-2	59.91	47,928	

- 2nd scenario initial cost

Table 5.71: 2nd scenario initial cost

Initial cost	AED
Current cost	1,305,000
Additional cost	7351.9
Total cost	**1,312,351.90**

- 2nd scenario maintenance cost

Table 5.72: 2nd scenario maintenance cost

Maintenance Cost		
Initial cost (AED) =		1,312,351.90
Lifespan period	Percentage of the initial cost	Cost (AED)
1st year	0	0.0
From 1 to 6 years	3.0%	3,9370.6
From 6 to 11 years	5% to 7%	91,864.6
From 11 to 16 years	10.0%	131,235.2
From 16 to 35 years	10% each 3 years	831,156.2
Total maintenance cost		**1,093,626.6**

- 2nd scenario electricity cost

Table 5.73: 2nd scenario cost of electricity consumption in 2018 & 2020

cost of electricity consumption in 2018			In 2020
Month	Energy consumption (kWh)	Cost per month (AED)	Cost per month (AED)
January	3180.6	269.07	486.14
February	2840.9	236.97	430.86
March	4156.1	363.71	647.36
April	5714.6	535.53	925.56
May	6973.9	694.82	1170.79
June	7314.2	739.49	1238.68
July	8004.2	830.05	1376.34
August	8094.1	841.85	1394.27

September	7279.3	734.91	1231.72
October	6529.4	636.48	1082.12
November	4242.3	373.21	662.75
December	3150.1	266.18	481.18

Table 5.74: 2nd scenario yearly electricity consumption

Yearly consumption cost of electricity (AED)	
Total cost 2018	6,522.28
Total cost from 2018 to 2020	13,044.56
Total cost 2020	11,127.77
Total cost from 2020 to 2053	367,216.44
Total	**380,261.00**

- Table 5.75 presented the life cycle cost of 3rd scenario

Table 5.75: 2nd scenario LCC cost

Category	Costs (AED)
Initial cost	1,312,351.90
Operation cost	Maintenance cost = 1,093,626.6 Electricity cost = 380,261.00
Total cost	**2,786,239.48**

5.9.3 3rd scenario LCC analysis

In this scenario, enhancement included the active design method beside the passive design strategies.

- The current external wall covered with insulation material (PIR) with 50mm thickness

Table 5.76: 3rd scenario external wall cost

Wall	Type	Area (m^2)	Volume (m^3)	cost AED	Cost difference (AED)
Current wall	Thermal	429.5	85.9	21,475	17,180
3rd scenario	Thermal	429.5	85.9	21,475	
	PIR			17,180	

- External window cost

Table 5.77: 3rd scenario external window

Window type	Area (m²)	cost AED	Cost difference (AED)
Current type	59.91	36,545.1	-11,382.9
Type-3	59.91	25,162.2	

- 60% green roof

Table 5.78: Cost of 60% green roof

Roof area	Percentage Area	Cost (AED)
200	60%	12,000

- Lighting system

Same of the 3rd scenario in the previous case study, the cost of CFL is half of the cost of LED, therefore the calculation of the new lighting system presented in Table 5.79

Table 5.79: 3rd scenario lighting system cost

Type of lamp	Quantity	Cost of 1 lamp (AED)	Total cost (AED)	Cost difference (AED)
9 Watts LED	13	8	104	322
12 Watts LED	45	12	540	
CFL (current)	50% of LED cost therefore it = 322 AED			

- 3rd scenario initial cost

Table 5.80: 3rd scenario initial cost

Initial cost	AED
Current cost	1,305,000
Additional cost	18,119.1
Total cost	**1,323,119.10**

- 3rd scenario maintenance cost

Table 5.81: 3rd scenario maintenance cost

Maintenance Cost		
Initial cost (AED) =		1,323,119.10
Lifespan period	Percentage of the initial cost	Cost (AED)
1st year	0	0.0
From 1 to 6 years	3.0%	39,693.6
From 6 to 11 years	5% to 7%	92,618.3
From 11 to 16 years	10.0%	132,311.9
From 16 to 35 years	10% each 3 years	837,975.4
Total maintenance cost		**1,102,599.3**

- 3rd scenario electricity cost

Table 5.82: 3rd scenario cost of electricity consumption in 2018 & 2020

cost of electricity consumption in 2018			In 2020
Month	Energy consumption (kWh)	Cost per month (AED)	Cost per month (AED)
January	2673.6	221.16	403.63
February	2384.1	193.80	356.51
March	3469.2	296.34	533.11
April	4878.5	443.35	776.31
May	6003.4	567.45	977.18
June	6333.5	610.77	1043.03
July	6947.1	691.31	1165.45
August	7030.6	702.27	1182.10
September	6291.8	605.30	1034.71
October	5604.3	523.37	905.87
November	3589.3	307.69	552.66
December	2643.9	218.35	398.79

Table 5.83: 3rd scenario yearly electricity consumption

Yearly consumption cost of electricity (AED)	
Total cost 2018	5,381.15
Total cost from 2018 to 2020	10,762.30
Total cost 2020	9,329.36
Total cost from 2020 to 2053	307,868.97
Total	**318,631.27**

- Table 5.84 presented the life cycle cost of 3rd scenario

Table 5.84: 3rd scenario LCC cost

Category	Costs (AED)
Initial cost	1,323,119.10
Operation cost	Maintenance cost = 1,102,599.3 Electricity cost = 318,631.27
Total cost	**2,732,047.85**

5.9.4 4th scenario LCC analysis

The simulation model consists of several technologies integrated with the utilization of renewable energy technology.

- External wall cost changed due to the change of the current wall block size where the 250mm thermal block supported by EPS insulation material.

Table 5.85: 4th scenario external wall cost

Wall	Type	Area (m²)	Volume (m³)	cost AED	Cost difference (AED)
Current wall	200mm Thermal	429.5	85.9	21,475	17,824.25
3rd scenario	250mm Thermal	429.5	107.375	28,991.25	
	EPS			10,308	

- 35% of Green roof

Table 5.86: 4th scenario 35% green roof cost

Roof area	Percentage Area	Cost (AED)
200	35%	7,000

- External window cost

Table 5.87: 4th scenario window cost

Window type	Area (m²)	cost AED	Cost difference (AED)
Current type	59.91	36,545.1	-9,585.6
Type-4	59.91	26,959.5	

- Shading devices made of (GRP) on east elevations.

Table 5.88: 4th scenarios shading element cost

Type	Volume (m³)	Quantity	Total cost
East elevation	0.24	5	600

- In this case, the lighting system follows the same system in the previous scenario, which is developed based on LED lamps. The cost of them is equal to 322 AED.
- 4th Monocrystalline technology PV panel cost

The calculation consideration of the PV system is the same in SZHP 4th scenario option 'A' as the cost of PV watts equal to 6.973 AED/watts and the panel's output power is 330 watts. The occupied area of PV panels is 70 m². IES-VE simulation model presented the peak production of the proposed system in August (1384.1 kWh). The calculation of PV system cost, as illustrated below.

Table 5.89: PV panel cost

PV panel calculation	
Required KW/day/hour	1.86 kW (1860 watts)
Number of panels	6 panels
Cost of panel (AED)	13,806.5

- PV system component cost

Table 5.90: Total cost of PV system

Cost of component	Average cost (AED)
PV panels	13,806.5
Controller	2220
Battery	9,200
Mounting structures	2,850
Invertor	1,410
Combiner box	2,500
Wiring	1,500
Installation	5,200
Total cost	38,686.5

- 4th scenario initial cost

Table 5.91: 4th scenario initial cost

Initial cost	AED
Current cost	1,305,000
Additional cost	54,847.15
Total cost	**1,359,847.15**

- 4th scenario maintenance cost

Table 5.92: 4th scenario maintenance cost

Maintenance Cost		
Initial cost (AED) =		1,359,847.15
Lifespan period	Percentage of the initial cost	Cost (AED)
1st year	0	0.0
From 1 to 6 years	3.0%	40,795.4
From 6 to 11 years	5% to 7%	95,189.3
From 11 to 16 years	10.0%	135,984.7
From 16 to 35 years	10% each 3 years	861,236.5
Total maintenance cost		**1,133,206.0**

- 4th scenario electricity cost

Table 5.93: 4th scenario cost of electricity consumption in 2018 & 2020

cost of electricity consumption in 2018				In 2020
Month	Energy consumption (kWh)	PV panel power output (kWh)	Cost per month (AED)	Cost per month (AED)
January	2673.6	-1144.2	120.44	224.82
February	2384.1	-1204.3	92.91	173.43
March	3441.9	-1230.9	177.44	328.34
April	4807.1	-1253.4	304.32	546.86
May	5887	-1384.1	401.94	709.27
June	6197.6	-1309.4	444.42	778.04
July	6786.8	-1312.4	509.05	882.68
August	6856.5	-1348.5	512.76	888.68
September	6143.1	-1318.5	437.41	766.69
October	5497.5	-1319.6	366.11	651.26
November	3558.5	-1142.3	196.83	361.74
December	2643.9	-1078.6	123.27	230.10

Table 5.94: 4th scenario yearly electricity consumption

Yearly consumption cost of electricity (AED)	
Total cost 2018	3,686.92
Total cost from 2018 to 2020	7,373.83
Total cost 2020	6,541.91
Total cost from 2020 to 2053	215,883.00
Total	**223,256.83**

- Table 5.95 introduced the life cycle cost of 4th scenario

Table 5.95: 4th scenario LCC cost

Category	Costs (AED)
Initial cost	1,359,847.15
Operation cost	Maintenance cost = 1,133,206.0 Electricity cost = 223,256.83
Total cost	**2,716,309.94**

5.9.5 5th scenario LCC analysis

This scenario simulation model was developed based on the impact of the courtyard. As mentioned in the previous chapter, the implementation of the courtyard reduces the villa area, thus reducing the initial cost of the current system.

- The external wall material if the scenario is 250 mm thermal block, double glazed window with 16mm air gap, the same type of roof with 180mm thickness insulation and the lighting system of the villa utilize the LED lamps. Therefore, the initial cost of the building is approximately equal to 1,270,800 AED.
- Also, in this scenario, the author proposed the utilization of PV panels (polycrystalline type), which covered 60% of the roof area. As mentioned in option 'B' the 4th scenario, the average cost of panel watts equals 1.6 USD/watts. The below tables illustrated the PV cost.

Table 5.96: PV panels cost

PV panel calculation	
Required KW/day/hour	2.43 kW (2430 watts)
Number of panels	8 panels
Cost of panel (AED)	15,502.1

- PV kit cost

Table 5.97: Total cost of PV system

Cost of component	Average cost (AED)
PV panels	15,502.1
Controller	2220
Battery	9200
Mounting structures	3775
Invertor	1410
Combiner box	2500
Wiring	2000
Installation	6950
Total cost	43,557.1

- 5th scenario initial cost

Table 5.98: 5th scenario initial cost

Initial cost	AED
Current cost	1,270,800
Additional cost	43,557.10
Total cost	**1,314,357.10**

- 5th scenario maintenance cost

Table 5.99: 5th scenario maintenance cost

Maintenance Cost		
Initial cost (AED) =		1,314,357.10
Lifespan period	Percentage of the initial cost	Cost (AED)
1st year	0	0.0
From 1 to 6 years	3.0%	39430.7
From 6 to 11 years	5% to 7%	92005.0
From 11 to 16 years	10.0%	131435.7
From 16 to 35 years	10% each 3 years	832426.2
Total maintenance cost		**1,095,297.6**

- 5th scenario electricity cost

Table 5.100: 5th scenario cost of electricity consumption in 2018 & 2020

cost of electricity consumption in 2018				In 2020
Month	Energy consumption (kWh)	PV panel power output (kWh)	Cost per month (AED)	Cost per month (AED)
January	2474.6	-1493.8	77.24	144.18
February	2589.2	-1572.2	80.09	149.50
March	3539.6	-1606.9	152.20	284.11
April	4686.1	-1636.3	256.71	464.85
May	5860	-1807.0	352.34	628.96
June	6213.1	-1709.3	402.04	709.43
July	6782.8	-1713.3	464.41	810.41
August	6934	-1760.5	475.88	828.97
September	6173.1	-1721.2	396.32	700.16
October	5403.8	-1722.7	316.36	567.60
November	3970.7	-1491.3	202.80	372.02
December	2517.2	-1408.1	87.34	163.04

Table 5.101: 5th scenario yearly electricity consumption

Yearly consumption cost of electricity (AED)	
Total cost 2018	3,263.74
Total cost from 2018 to 2020	6,527.48
Total cost 2020	5,823.23
Total cost from 2020 to 2053	192,166.46
Total	**198,693.94**

- Table 5.102 introduced the life cycle cost of 5th scenario

Table 5.102: 5th scenario LCC cost

Category	Costs (AED)
Initial cost	1,314,357.10
Operation cost	Maintenance cost = 1,095,297.6 Electricity cost = 198,693.94
Total cost	**2,608,348.62**

The simulation models created in the previous chapter were exposed to life cycle cost analysis. All the outcomes and findings in this chapter and the last chapter will in the next chapter be assessed and compared to figure out the most effective models regarding energy consumption and life cycle cost.

Chapter 6

Results and Findings

6- Results and Finding

6.1 Introduction

By the end of the computer simulation models and LCC analysis, the results were collected to identify the optimum energy performance and cost-effective scenarios. This chapter will present the results produced by IES-VE software simulation models and the analysis of LCC in the previous chapters, followed by a discussion of the most appropriate scenarios for each selected case study in terms of energy consumption and life cycle cost.

The first section starting with the results for the energy consumption of each alternative scenario, is related to the base cases to understand the impact of the enhancement strategies on the energy performance of the building. The second section will introduce the LCC analysis findings for the scenarios and compare them with base cases to find the impact of the developed alternative models in the life cycle cost. It is concluded by a comprehensive comparative study between both section results to conduct the optimum models regarding the energy and LCC effectiveness.

This chapter aims to respond to the main question of the study as well as to attain the objectives of the research, which were defined earlier in the introduction chapter, to carry out recommendations and guidelines for affordable housing establishments.

6.2 Energy consumption results

The section will provide the results of each selected villa and its scenarios, which were created in chapter ‘4’. Each scenario will be compared with the base case to assess the influence of the passive design strategies and renewable energy technology. Starting with the SZHP case study and its enhancement scenarios in the same order of the previous chapter and MBEHE, respectively.

6.3 1st base case results (SZHP)

The base case's simulation model was set up as the current conditions of the villa, as mentioned in the fourth chapter. The outcomes of the simulation present almost an actual average electricity consumption for local households. Table 6.1 illustrated the electricity consumption results per month for the case study.

Table 6.1: SZHP villa energy consumption

Month	Electricity consumption kWh
January	2,317.2
February	2,094.4
March	3,452.1
April	5,083.6
May	6,393.2
June	6,929.9
July	7,654.1
August	7,788.9
September	7,055.3
October	6,015.3
November	3,635.5
December	2,317.2
Total	60,736.7

6.3.1 1st scenario results

The enhancement of this scenario concentrated on the construction materials of the roof and glazing elements of the villa combined with the effect of the shading elements implemented on the west and east façade. The below Fig. (6.1) shows the electricity consumption outcomes of the 1st scenario, which is slightly better than the base case performance, especially in the summer season, where it recorded in September the best reduction, which is around 230 kWh. While in the winter, the energy consumption of the scenario almost the same as the base case, particularly in the December, January and February months.

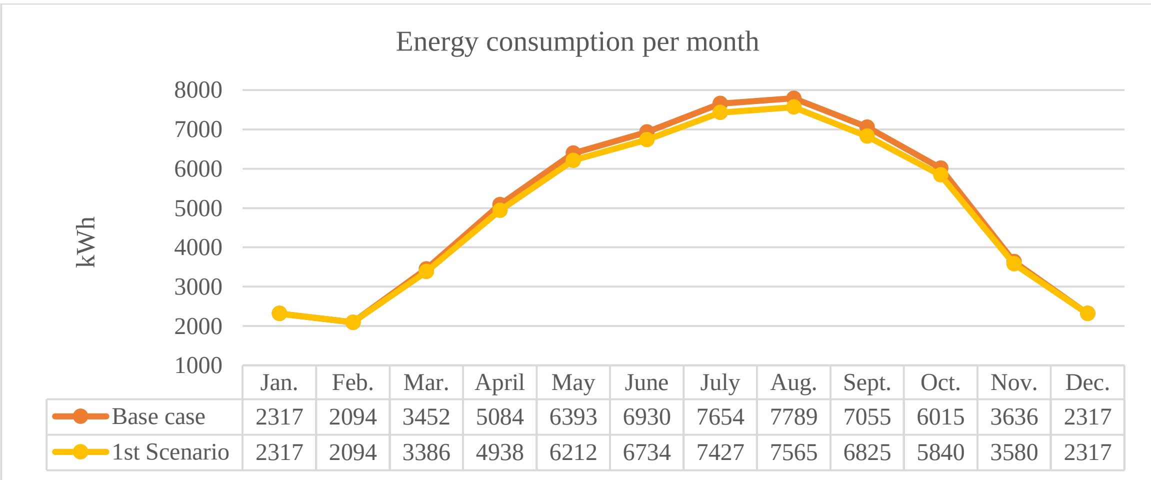
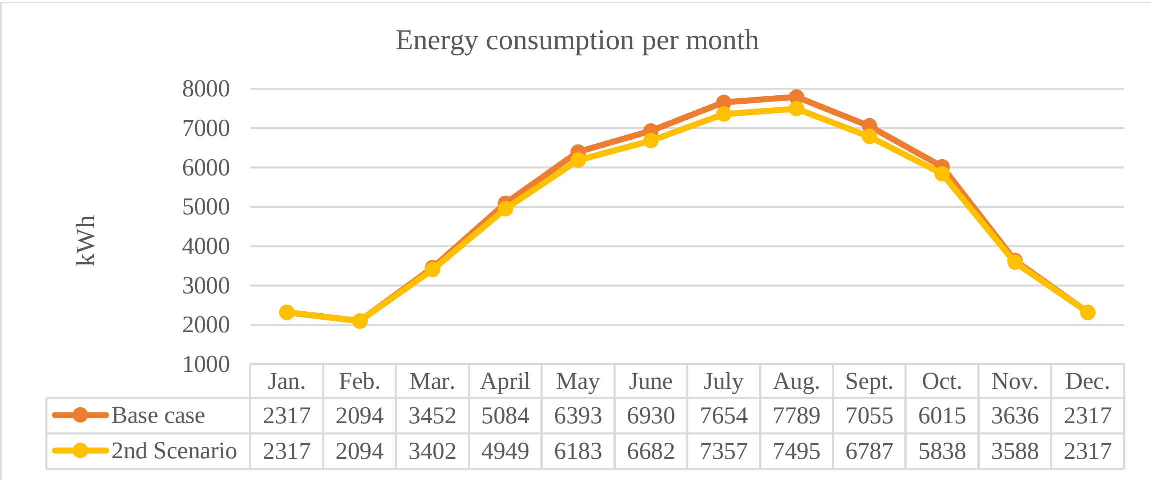


Figure 6.1: The energy consumption of the 1st scenario compared to the SZHP current base case consumption

6.3.2 2nd scenario results

Also, the 2nd scenario design strategies focused on the passive design strategies that enhance the envelope materials' thermal property, as shown in the previous chapter and the utilization of the extensive green roof system. Figure (6.2) illustrates the results of the 2nd scenario energy performance, which also has a minor variation in comparison with the base case. In the summer season, this scenario provides little improvement, but in the winter months, the scenario's result hasn't recorded any improvement in the energy performance.

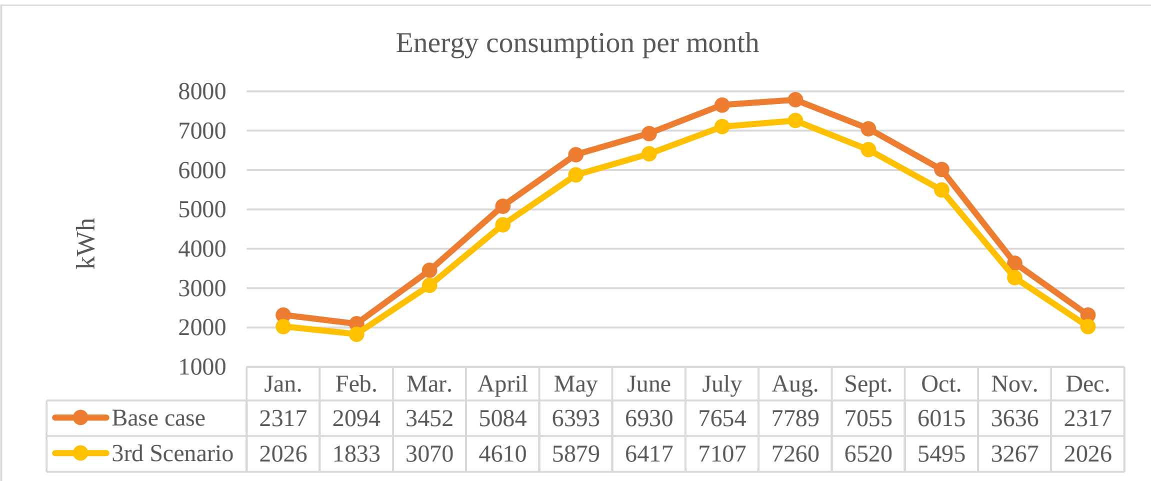


	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Base case	2317	2094	3452	5084	6393	6930	7654	7789	7055	6015	3636	2317
2nd Scenario	2317	2094	3402	4949	6183	6682	7357	7495	6787	5838	3588	2317

Figure 6.2: The energy consumption of the 2nd scenario compared to the SZHP current base case consumption

6.3.3 3rd scenario results

The scenario considers the upgrading of the active system, particularly the villa's lighting system, besides the passive design methods. LED lamps had a significant impact on the villa electricity consumption in cooperation with the enhancement of the window glass thermal properties.



	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Base case	2317	2094	3452	5084	6393	6930	7654	7789	7055	6015	3636	2317
3rd Scenario	2026	1833	3070	4610	5879	6417	7107	7260	6520	5495	3267	2026

Figure 6.3: The energy consumption of the 3rd scenario in contrast to the SZHP current base case consumption

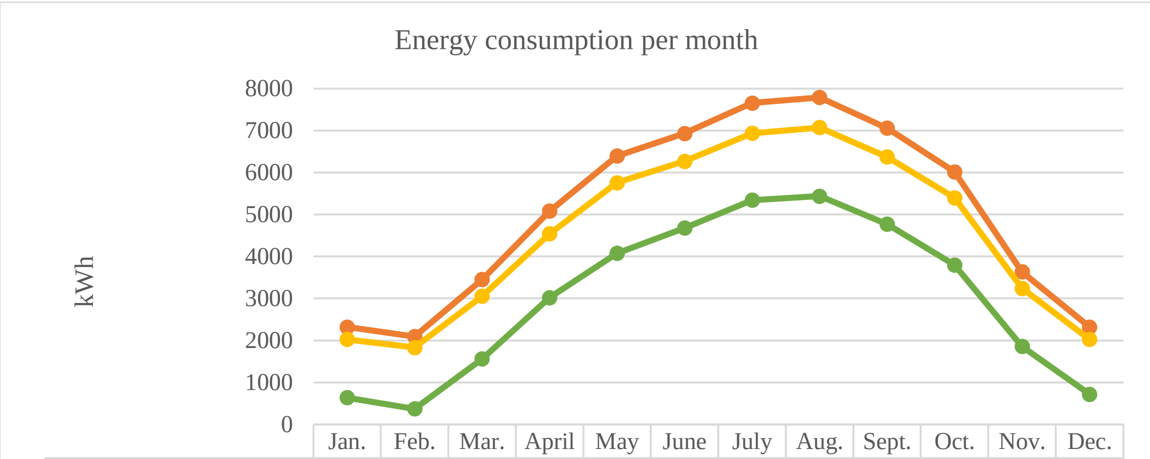
This scenario records a better representation regards the energy consumption compared with the base case and previous scenarios. In July, the model provides its best energy performance, while the lower consumption rate occurred in February. As presented in Fig (6.3) of the third scenario, the range of electricity consumption reduction is between 300 kWh to 530 kWh among months against the current consumption.

6.3.4 4th scenario results

As introduced in chapter ‘4’, the retrofitting strategies of this scenario split into two options in terms of external wall construction composition and PV technology type. However, there were between them some common enhancement parameters as the roof type, window glazing system, shading elements and LED lighting system.

- **4th scenario option ‘A’**

This option comprises monocrystalline PV technology covered 85m² of the roof area and AAC block integrated with PIR insulation material.



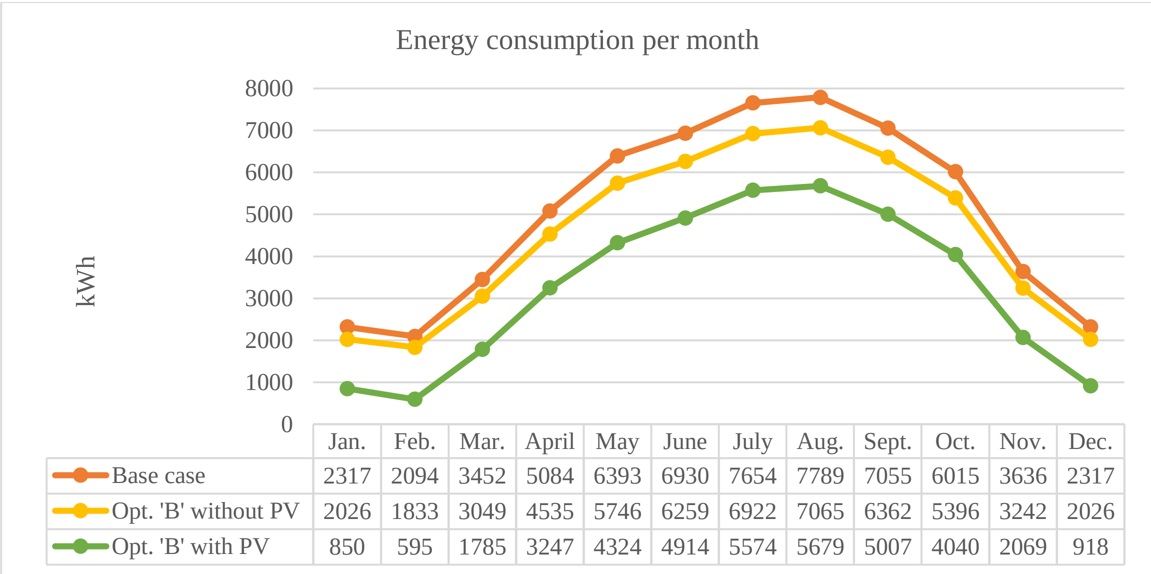
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Base case	2317	2094	3452	5084	6393	6930	7654	7789	7055	6015	3636	2317
Opt. 'A' without PV	2026	1833	3055	4541	5758	6269	6935	7074	6370	5400	3243	2026
Opt.'A' with PV	636	370	1560	3019	4077	4679	5342	5437	4769	3797	1856	716

Figure 6.4: The energy consumption of the 4th scenario opt. ‘A’ with & without PV technology against the SZHP current base case consumption

Fig. (6.4) shows the impact of option ‘A’ without the implementation of PV technology and with it. However, the option ‘A’ model retrofitting strategies play an essential role in improving the energy performance of the case study, which reduces the energy used in the hottest months by 700 kWh and 300 kWh in the coldest months. The interfere of monocrystalline PV panels technology provides a vital enhancement in decreasing electricity consumption. Therefore, the model reduction range increased to be ranged from 1700 kWh to 2350 kWh in winter months and summer months, respectively.

- **4th scenario option 'B'**

The option adopts polycrystalline PV panel technology and thermal block covered with PIR material for the external wall construction material. As presented in the below figure, in contrast with the base case, this option without PV system introduces an excellent energy performance through the year, which has a slight improvement compared with opt.'A' without the PV panels for the villa energy performance. However, the monocrystalline panels contribute more to mitigate dependence on electricity produced from fossil fuel than the polycrystalline PV system. The polycrystalline PV panels in this option also decrease the consumption of energy for the household, which consequently reduces the value of the electrical bills.



	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Base case	2317	2094	3452	5084	6393	6930	7654	7789	7055	6015	3636	2317
Opt. 'B' without PV	2026	1833	3049	4535	5746	6259	6922	7065	6362	5396	3242	2026
Opt. 'B' with PV	850	595	1785	3247	4324	4914	5574	5679	5007	4040	2069	918

Figure 6.5: The energy consumption of the 4th scenario opt. 'B' with & without PV technology against the SZHP current base case consumption

The highest energy reduction rate of the scenario recorded in August equivalent to 2110 kWh and December month presented the lowest rate of energy consumption.

6.5 SZHP energy consumption results comparison

A comprehensive comparison will be conducted in terms of total energy consumption for one year in order to assess the developed models' efficacy regarding energy consumption. As presented in Fig. (6.6), all the enhancement scenarios provide a better energy performance against the base case performance at various rates. The fourth scenario introduced the best efficient energy performance in both options where the PV panels technology used, especially option 'A', which had the best performance in enhancing the housing performance regards energy consumption, as illustrated before. The first two scenarios have a minor impact on reducing electricity use compared with the rest of the models. The third scenario also provides an excellent representation of consuming electricity, which decreases the total consumption by 5.0 MWh in contrast to the current situation of the villa. Generally, the most efficient strategies that significantly influence the building energy performance are the glass property, LED lighting system, and the utilization of PV panels. Regarding the energy consumption, the ideal scenarios for the are both options of the 4th scenario. SZHP unit introduces a good performance regards the energy due to their concentration on using appropriate construction materials with a proper thickness, which require few modifications to improve their energy performance.

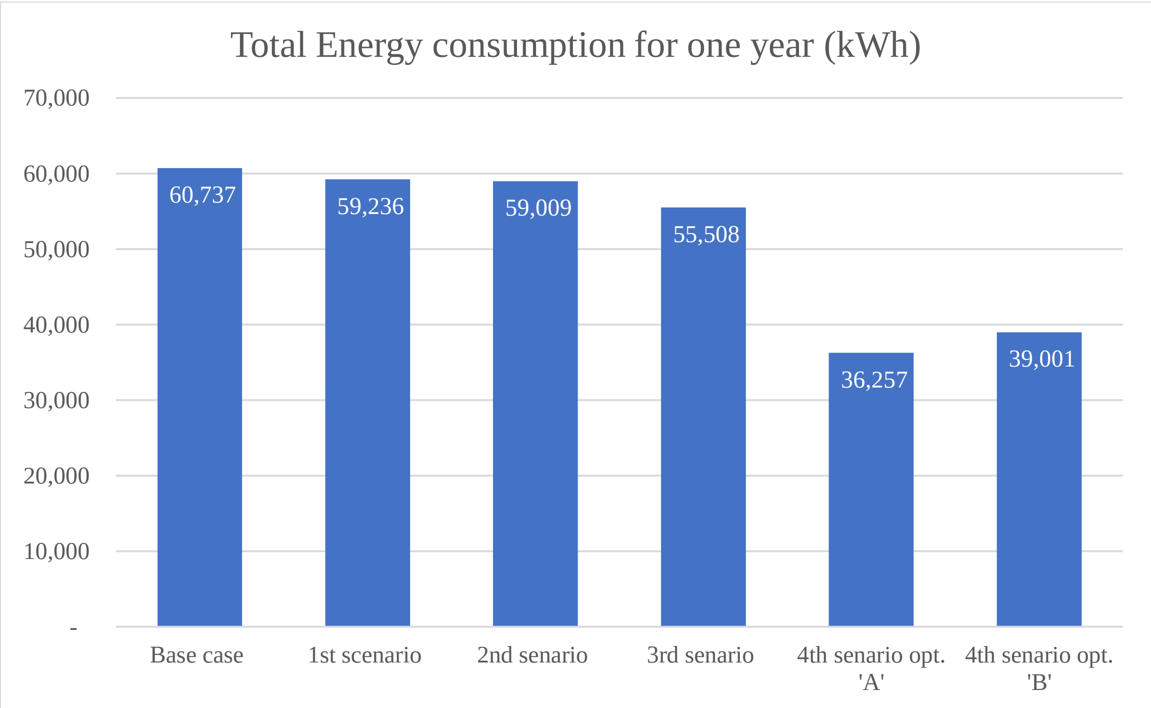


Figure 6.6: Total energy consumption of the SZHP base case and its developed scenarios for one year

6.6 2nd base case results (MBRHE)

This case study's simulation model was installed in IES-VE software as illustrated in their architecture and MEP drawings. The electricity consumed by the model, as shown in the below table.

Table 6.2: MBRHE villa energy consumption

Month	Electricity consumption kWh
January	3,204.4
February	2,863.5
March	4,204.9
April	5,821.6
May	7,161.1
June	7,53.0
July	8,246.7
August	8,340.8
September	7,476.2
October	6,662.4
November	4,298.0
December	3,175.0
Total	68,985.6

6.6.1 1st scenario results

As presented in chapter '4', the developed simulation model comprised several improvement refurbishments focused on the construction materials of the villa. Figure (6.7) shows progress in minimizing the consumption of electricity for the 1st scenario, especially in the hottest months where in August the reduction rate of the electricity = 400 kWh compared to the base case, while in the coldest days, the energy performance is almost the same in January, February and December.

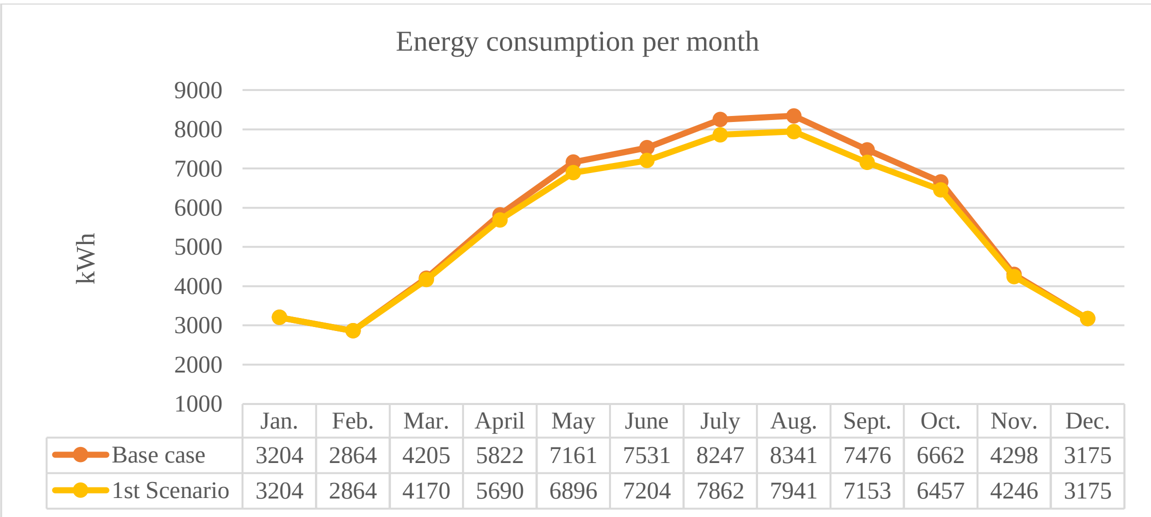
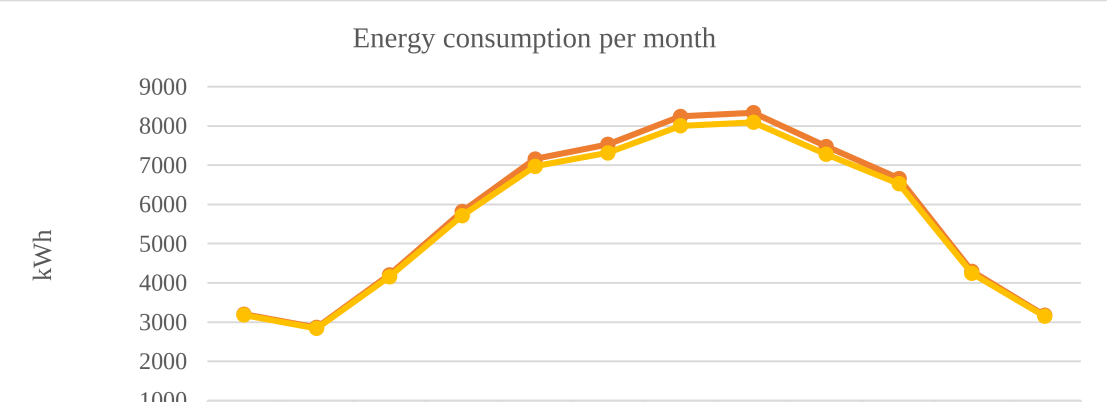


Figure 6.7: The energy consumption of the 1st scenario compared to the MBRHE current base case consumption

6.6.2 2nd scenario results

This scenario employed the AAC blocks for the external wall and triple glazed window to improve the thermal property of the building and installed horizontal shading elements over south, west and east elevation. As illustrated in the below figure, the modifications of this scenario have a minor amelioration in terms of electricity consumption. The maximum electricity reduction in August is almost equivalent to 240 kWh, while in the rest of the months, the dropping of electricity almost intangible.

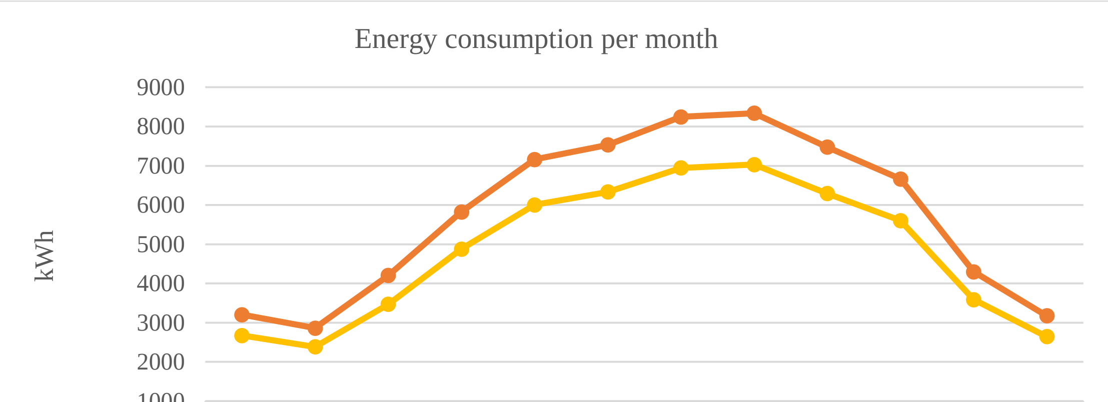


	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Base case	3204	2864	4205	5822	7161	7531	8247	8341	7476	6662	4298	3175
2nd Scenario	3181	2841	4156	5715	6974	7314	8004	8094	7279	6529	4242	3150

Figure 6.8: The energy consumption of the 2nd scenario compared to the MBRHE current base case consumption

6.6.3 3rd scenario results

The proposed retrofitting strategies in this scenario included the utilization of the green roof system and the insulation material over the external wall, as well as improving the properties of the glass and the frame of the windows.



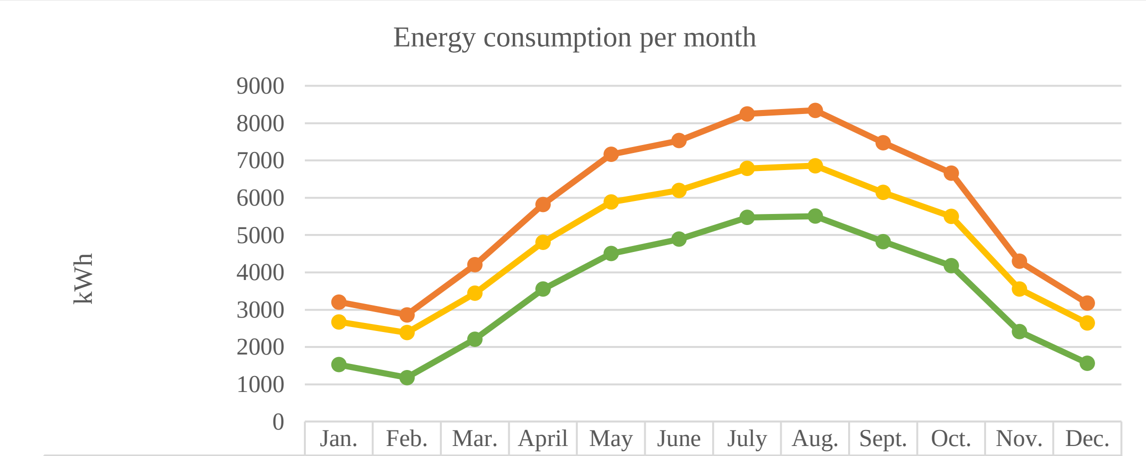
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Base case	3204	2864	4205	5822	7161	7531	8247	8341	7476	6662	4298	3175
3rd Scenario	2674	2384	3469	4879	6003	6334	6947	7031	6292	5604	3589	2644

Figure 6.9: The energy consumption of the 3rd scenario against MBRHE current base case consumption

Moreover, the installation of LED lights within the building spaces instead of CFL lamps. As illustrated in the above figure, this scenario provides an excellent performance regarding the consumption of energy. The mitigation of electricity in this scenario ranged from 450 kWh in winter to 1300 kWh in summer compared to the base case electricity consumption. The best electricity reduction observed in both the August and July months, on the other hand, February presented the lowest energy performance.

6.6.4 4th scenario results

This scenario was developed based on integrating the passive design strategies and renewable energy technology, particularly the monocrystalline system, which covers 35% of the roof area. The passive design strategies included the modification of the construction material external walls and windows, implementation of green roof system and shading elements as trees and horizontal pergolas.



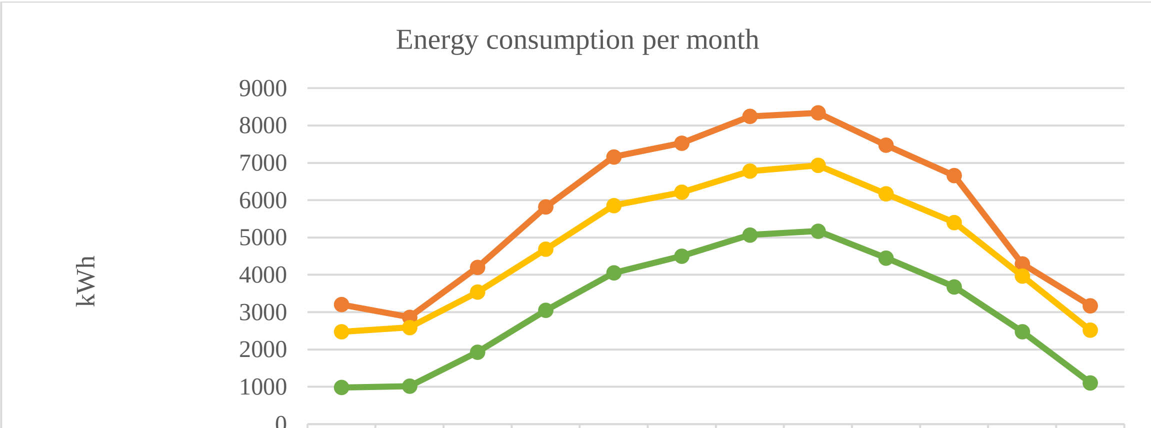
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Base case	3204	2864	4205	5822	7161	7531	8247	8341	7476	6662	4298	3175
4th Sc. without PV	2674	2384	3442	4807	5887	6198	6787	6857	6143	5498	3559	2644
4th Sc. with PV	1529	1180	2211	3554	4503	4888	5474	5508	4825	4178	2416	1565

Figure 6.10: The energy consumption of the 4th scenario with & without PV technology against the MBRHE current base case consumption

Fig (6.10) represents the villa's electricity consumption after implementing 4th scenario refurbishment strategies, which provide excellent performance in respect of energy consumption. PV panels play an essential role in minimizing the dependence on fossil fuel electricity production. Nevertheless, the scenario without the utilization of PV panels introduces an enhancement of the villa energy efficiency where the electricity reduced by 1485 kWh in August and in February by 480 kWh (the lowest and the highest months' energy consumption) in contrast with current villa performance.

6.6.5 5th scenario results

This scenario developed based on the impact of the courtyard, where it was placed in the middle of the villa as presented in chapter '4'. Moreover, other retrofitting methods implemented in the scenario targeted the case study envelope's construction material and the lighting system where LED lamps were installed. A polycrystalline PV system was proposed in the simulation model, which occupied 60% of the roof area.



	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Base case	3204	2864	4205	5822	7161	7531	8247	8341	7476	6662	4298	3175
5th Sc. without PV	2475	2589	3540	4686	5860	6213	6783	6934	6173	5404	3971	2517
5th Sc. with PV	981	1017	1933	3050	4053	4504	5070	5174	4452	3681	2479	1109

Figure 6.11: The energy consumption of the 5th scenario with & without PV technology compared to the MBRHE current base case consumption

As shown in the above figure, the courtyard scenario has a significant improvement in decreasing electricity consumption without the interference of the PV system, which records more than 1400 kWh lowering in electricity in August compared to the base case. As mentioned before, PV panels technology has the most significant impact in reducing energy due to its ability to produce energy. Therefore, the system boosts the housing efficiency regarding energy performance.

6.7 MBRHE energy consumption results comparison

Similar to the previous case study, inclusive comparison conduct focused on the total energy consumption of each scenario through one year to figure out the optimum scenario performance in terms of energy.

Fig. (6.12) presents the total energy consumption for the options for one year. Which illustrated the impact of the scenarios positively in decreasing the utilization of electricity compared with the base case, but the 2nd scenario records the lowest achievement where only

1500 kWh electricity reduced, followed by the 1st scenario, which enhances the energy efficiency of the villa slightly.

While the best performance attained by the 5th scenario where the courtyard integrated with polycrystalline PV technology integrated. The fourth scenario also presents an excellent representation regarding energy. The third scenario has an average performance in contrast with the 4th and 5th scenarios, but it minimized the total electricity consumption by more than 10MWh. Therefore, the optimum models of MBRHE are the 5th and 4th scenarios with respect to the consumption of energy. MBRHE villa needs several enhancements strategies to upgrade its energy performance, where the construction materials used in designing the villa meet the minimum regulations of the Dubai building authorities.

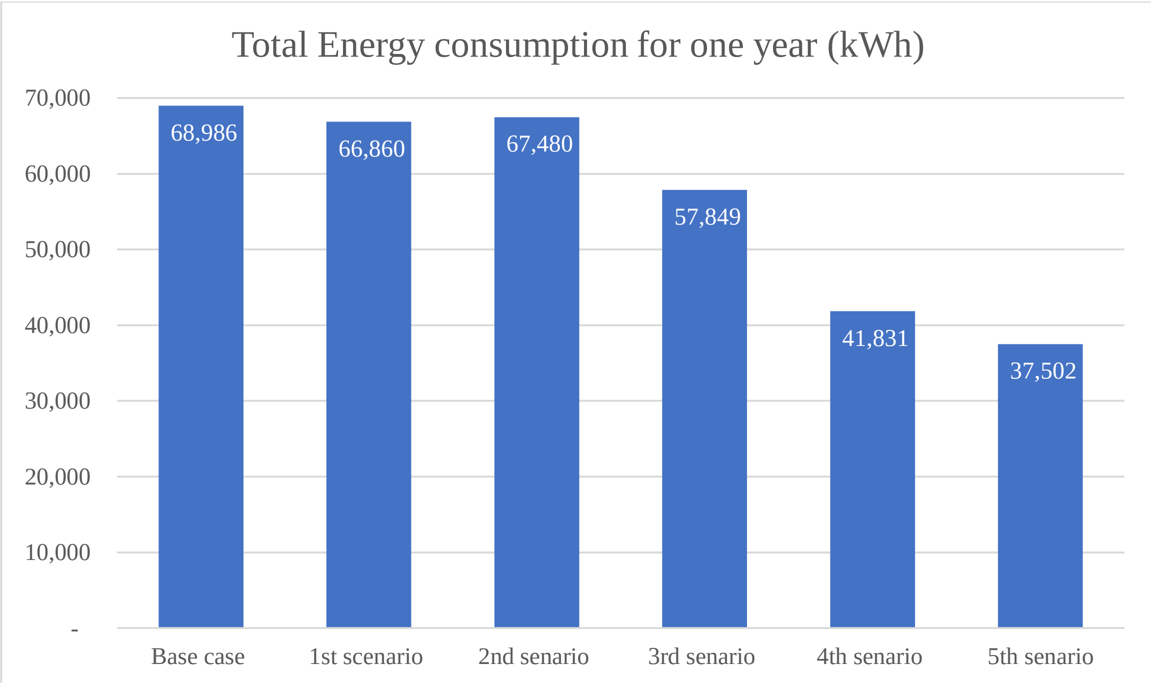


Figure 6.12: Total energy consumption of the MBRHE base case and its developed scenarios for one year

The IES-VE simulation model results were introduced and analyzed concerning the performance of the energy. The models were developed based on various passive design strategies and PV panel technologies. The intervention of these refurbishments will increase the units' initial cost; therefore, an analysis of the life cycle cost of each proposed scenario was conducted in chapter five, which needs to present their results in the next section.

6.8 LCC analysis results

The LCC study for the cases study and their emerged scenarios were carried out in the previous chapter, which includes the initial cost and operational cost. The results of each model will be presented in comparison with the base case to evaluate the impact of the improvement methods on the life cycle cost of the selected villas. As mentioned before, the predicted lifespan period of the villa is 35 years. The water consumption cost and demolish cost will be neglected in the LCC analysis.

6.9 1st base case LCC analysis result (SZHP)

The LCC analysis results of the 1st base case presented in chapter five are illustrated in the below figure. Figure (6.13) shows the main cost groups of the LCC cost. As mentioned before, the maintenance cost and the electricity consumption cost represent the operation cost, which is the summation of them higher than the case study's initial price.

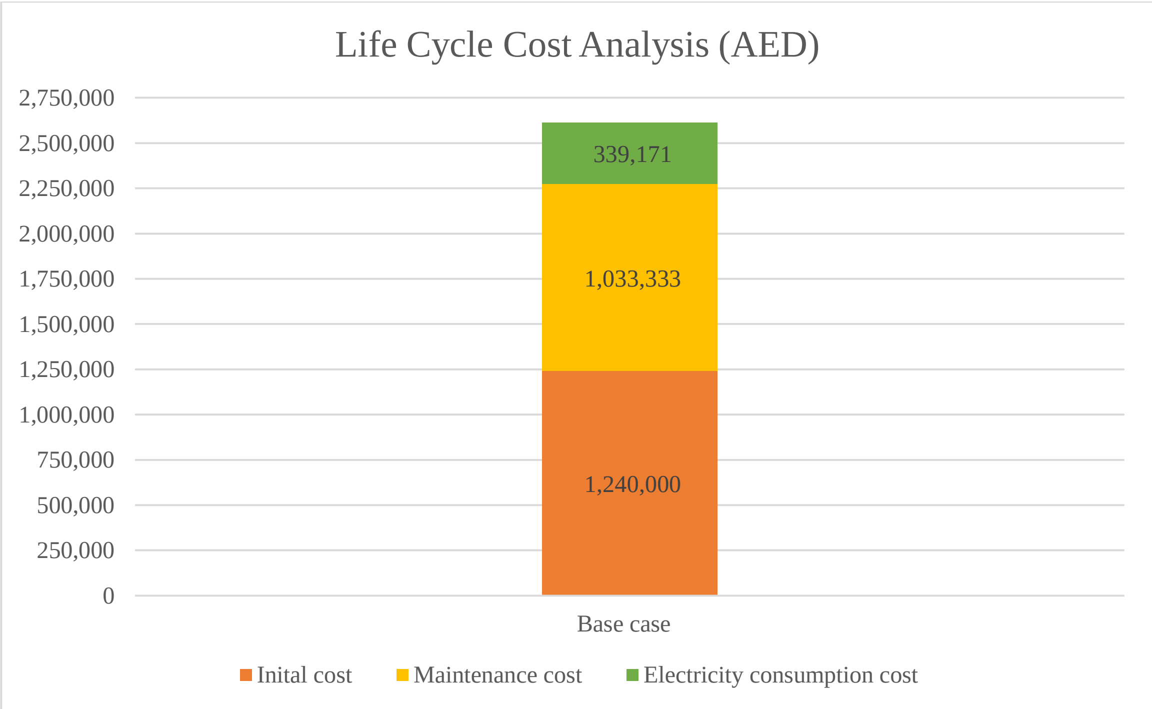


Figure 6.13: The life cycle cost analysis of the SZHP base case

6.9.1 1st scenario LCC results

The enhancement strategies cost of the 1st scenario is presented in Fig. (6.14). The initial and maintenance price of the 1st scenario higher than the base case, while the cost of electricity bills is lower than the base case consumption. The 1st scenario enhancements introduce slight differences in total LCC compared with the base case, equal to 700 AED. Thus, these strategies optimize the LCC of the case study slightly.

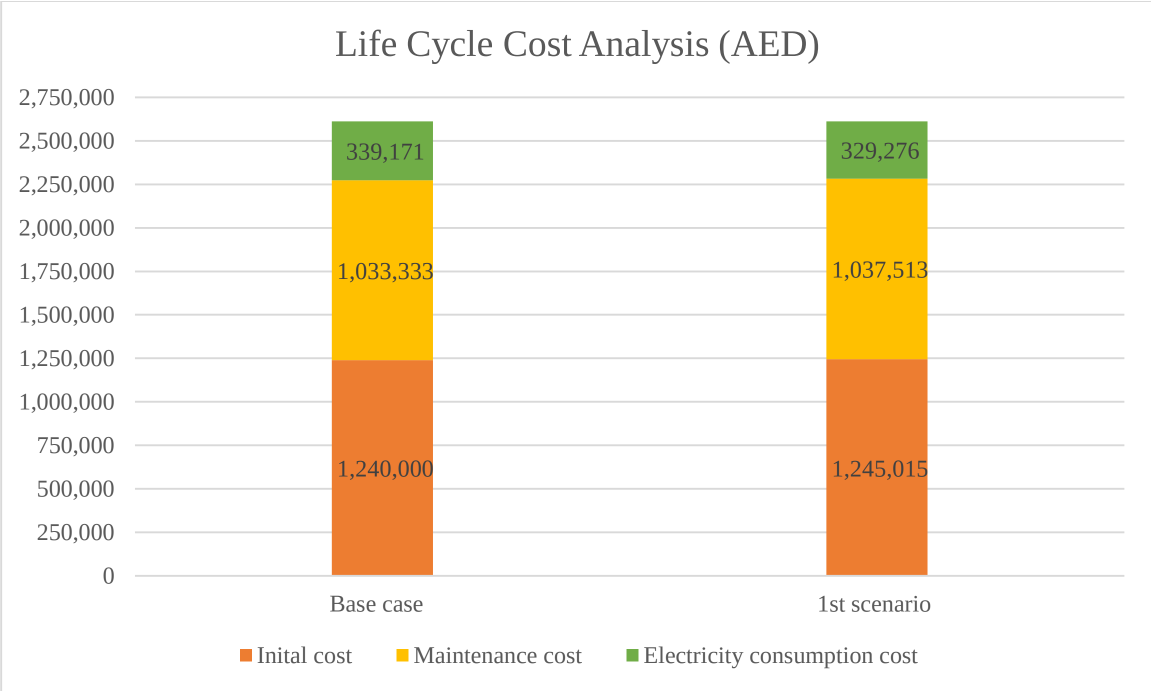


Figure 6.14: The life cycle cost analysis of 1st scenario compared to the SZHP base case

6.9.2 2nd scenario LCC results

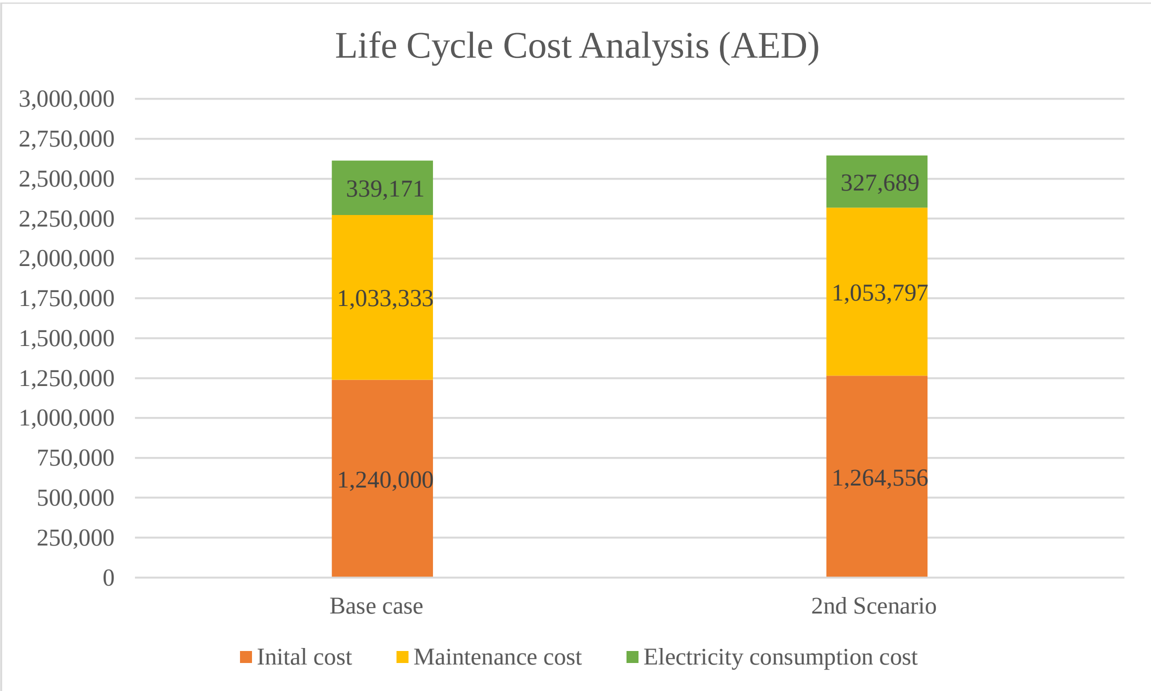


Figure 6.15: The life cycle cost analysis of 2nd scenario compared to the SZHP base case

As presented in the figure, although the electricity consumption cost of the scenario is lower than the base case by around 11,500 AED, both the initial and maintenance cost has increased dramatically by more than 20 thousand, which negatively affects the scenario performance in terms of LCC.

6.9.3 3rd scenario LCC results

The increase in the cost for maintenance and initial cost in this scenario, which approximately estimated by 19,000 AED, offset by a decrease in the energy consumption cost through the building lifespan period equaled to 32,800 AED, which resulted in a reduction in the life cycle cost of the 3rd scenario proposed model as presented in the Fig (6.16). The refurbishment strategies implemented in the base case have a significant impact on the LCC cost of the villa.

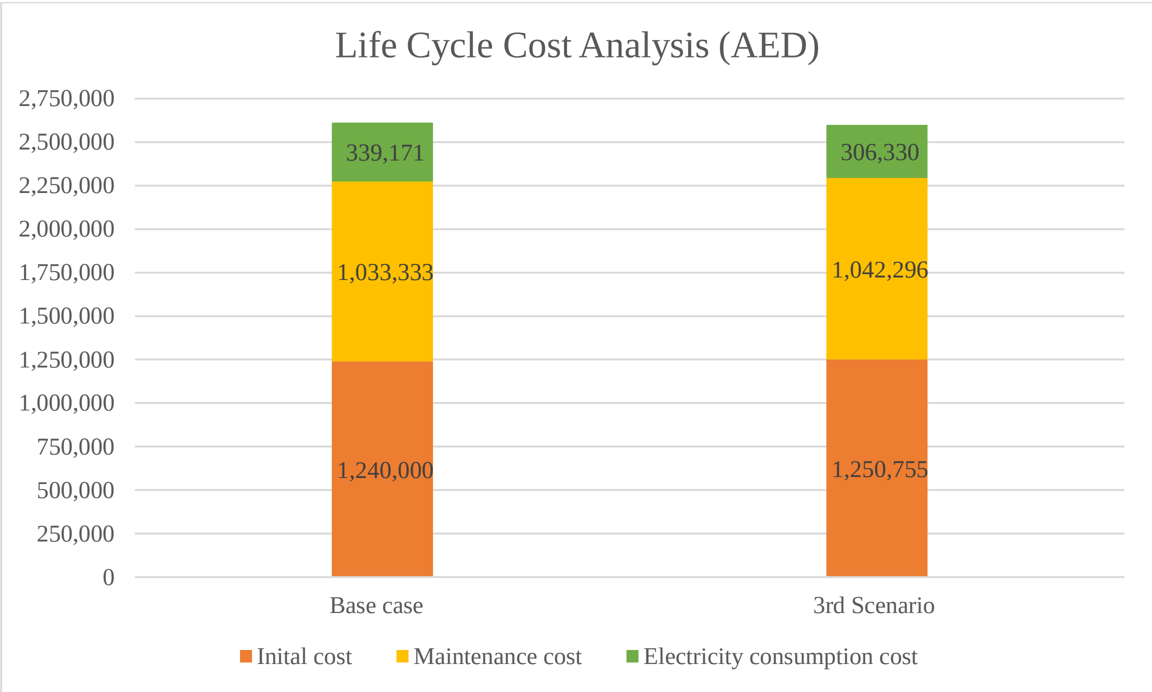


Figure 6.16: The life cycle cost analysis of 3rd scenario against the SZHP base case

6.9.4 4th scenario LCC results

As introduced before, this scenario divided into two options, LCC analysis conducted for both of them as the following:

- 4th scenario option 'A' LCC

As shown in the below figure, there is a significant increase in the initial cost of the villa by around 64 thousand dues to the installation of PV system technology, as well as in the maintenance cost of the scenario.

As the PV panels maximize the initial value, it also has a high impact in minimizing the electricity cost of the proposed model with more than 145 thousand. Thus, the refurbishment methods enhance the total life cycle cost of the villa during its lifespan period.

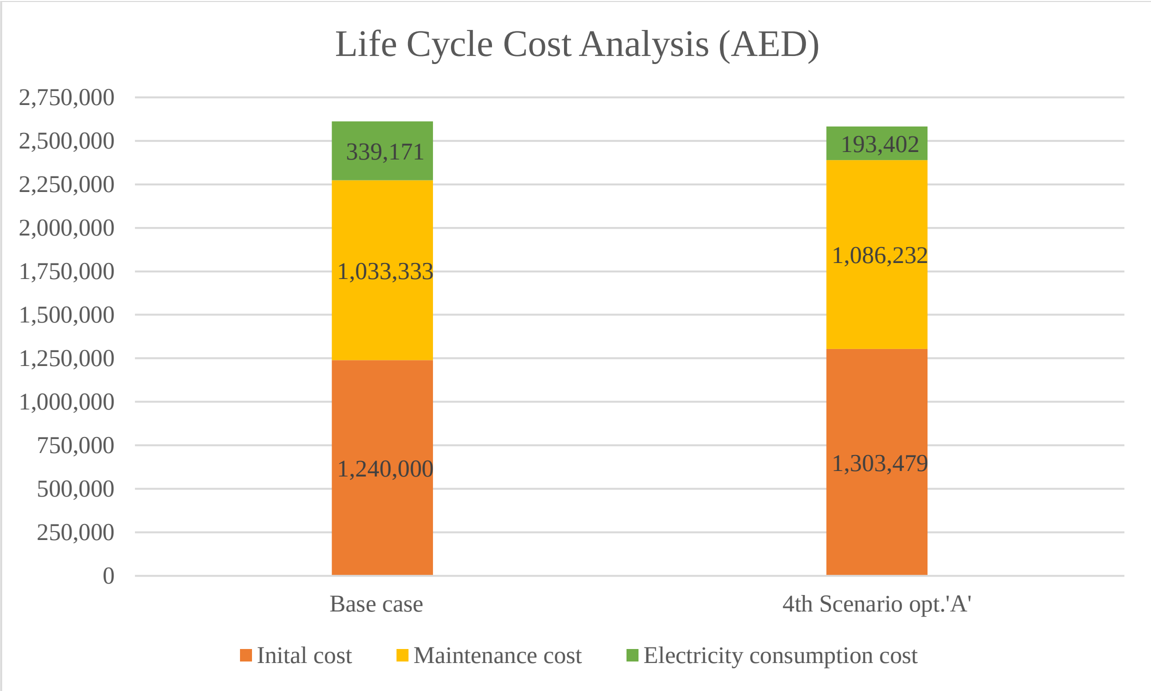


Figure 6.17: The life cycle cost analysis of 4th scenario option 'A' against the SZHP base case

- 4th scenario option 'B' LCC

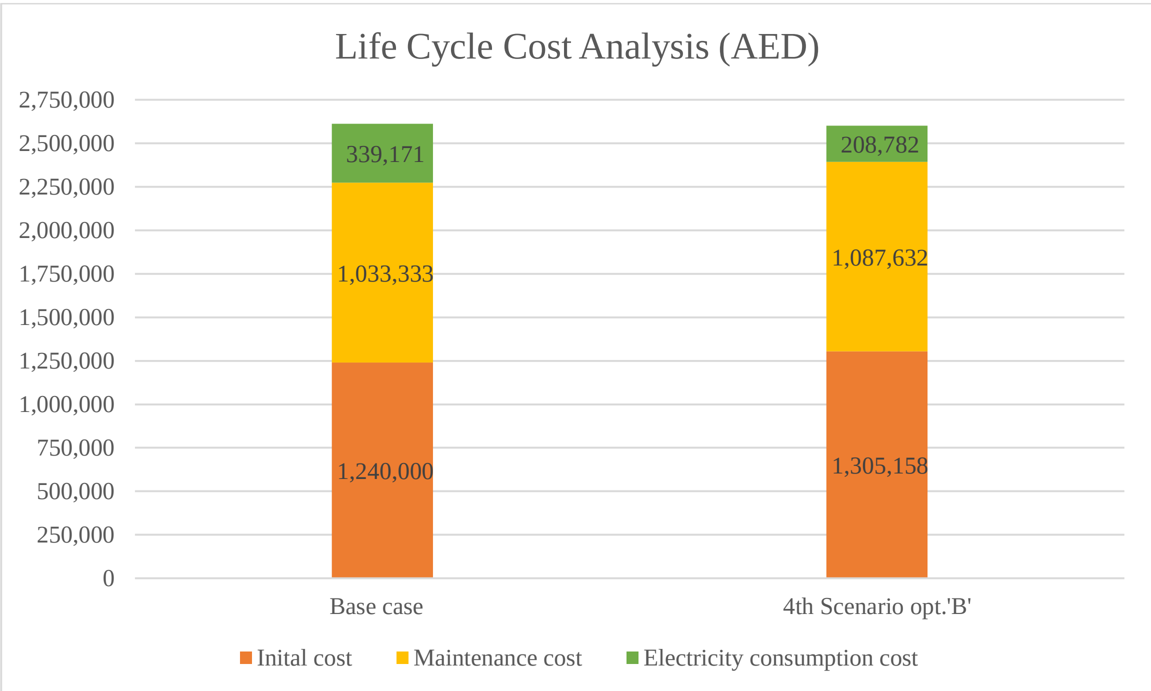


Figure 6.18: The life cycle cost analysis of 4th scenario option 'B' against the SZHP base case

This option of the scenario has increased both initial and maintenance costs by 65,000 and 54,000 AED, respectively, more than the base case, while the electricity bills cost has a reduction of around 130 thousand AED. But in comparison with option 'A' it has a lower rate of decline. PV panels with the other enhancement strategies have increased the base case's initial cost, which affects the servicing fee consequently because it was calculated based on the initial cost, as illustrated in Fig (6.18). The type of PV technology and its occupied area impact reducing the electricity bills cost and raising the other expenses; therefore, the owner has various prices to select between them.

6.10 SZHP LCC analysis results comparison

Figure (6.19) shows the total life cycle cost of the base case and its scenarios. The developed models positively contrast with the base case, except the 2nd scenario where the total LCC is higher than the base case. The best model in reducing the LCC is option ‘A’ from the 4th scenario, where the amount of reduction equivalent to 29.4 thousand. The third scenario also introduces an appropriate decrease in the life cycle cost of the building against the other scenarios and the base case. The 1st scenario modification has a minor influence on the LCC of the building. The fourth scenario of option ‘B’ has a moderate impact on lowering the LCC cost. In terms of LCC, the preferable model is option ‘A’ from the 4th and 3rd scenarios.

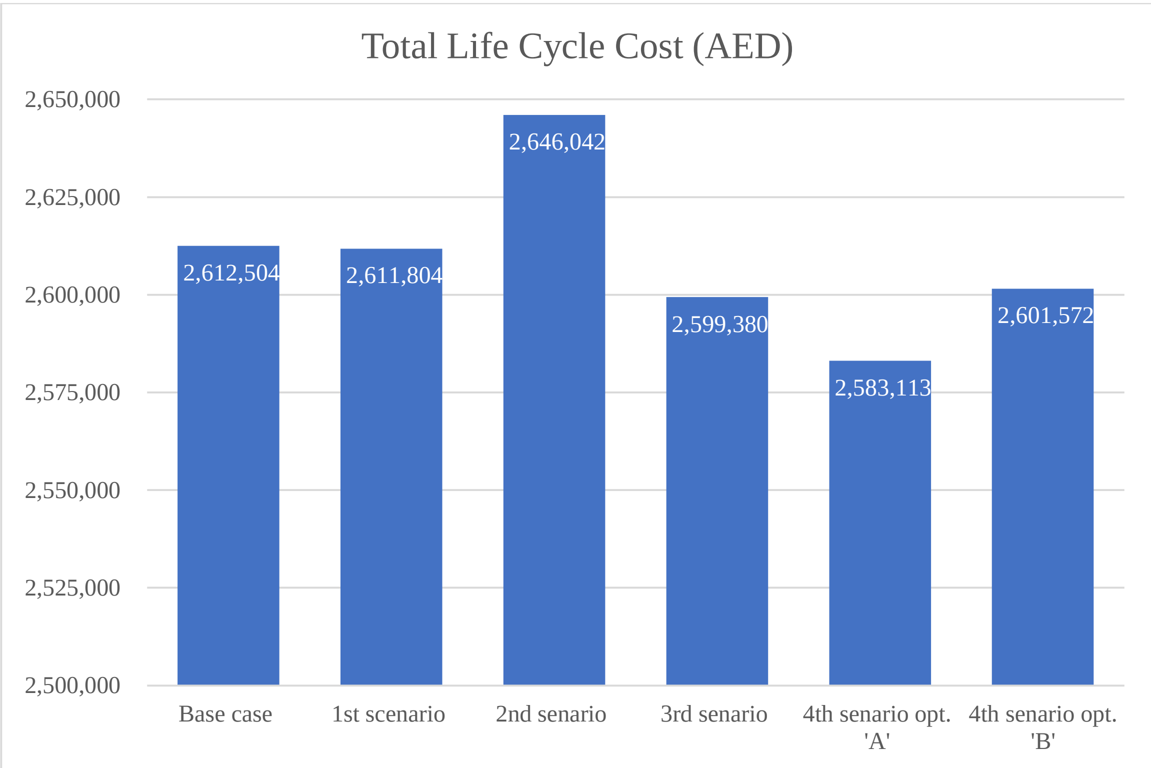


Figure 6.19: LCC analysis of the SZHP base case and its developed scenarios for 35 years

6.11 2nd base case LCC analysis results (MBRHE)

Similar to SZHP, the LCC analysis results in the previous chapter are presented in Fig (6.20). The figure shows that the classification categories of the LCC analysis of MBRHE villa over 35 years. Although the initial cost of the base case is high, the operation cost is higher (the summation of maintenance and electrical cost).

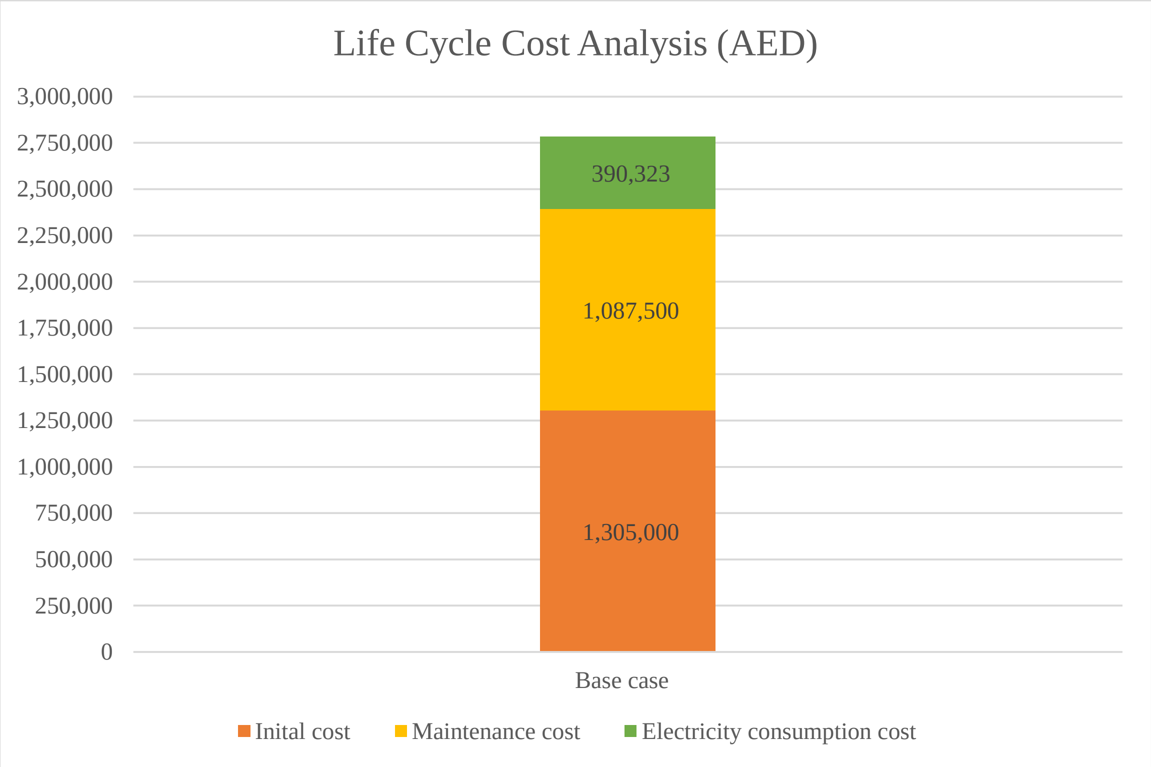


Figure 6.20: The life cycle cost analysis of the MBRHP base case

6.11.1 1st scenario LCC results

Several modifications are applied in the MBRHE base to improve its energy performance, which impacts its life cycle cost. The LCC cost results of the villa after applied the 1st scenario enhancement methods illustrated in Fig (6.21).

It illustrated that there are increases in initial and servicing costs by 11 and 9 thousand AED respectively, in contrast with the costs of the current villa LCC. While the electricity consumption cost decreased by around 14 thousand AED. This reduction in the electricity cost isn’t enough to cover the inflation in the initial and maintenance costs.

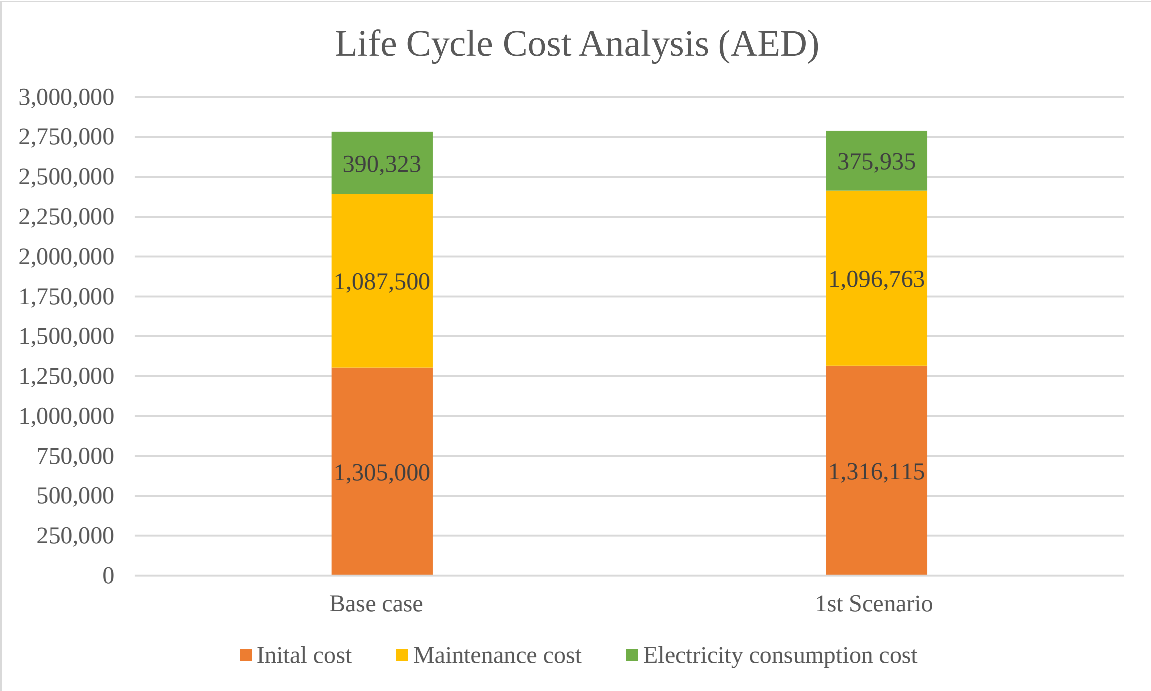


Figure 6.21: The life cycle cost analysis of 1st scenario against the MBRHE base case

6.11.2 2nd scenario LCC results

Figure (6.22) presented the LCC cost of the 2nd scenario refurbishment strategies, where the electricity cost minimized slightly against the real consumption cost. But this scenario raises the other LCC categories cost with a total amount of 13.48 thousand. Resulting in increasing the total scenario LCC cost.

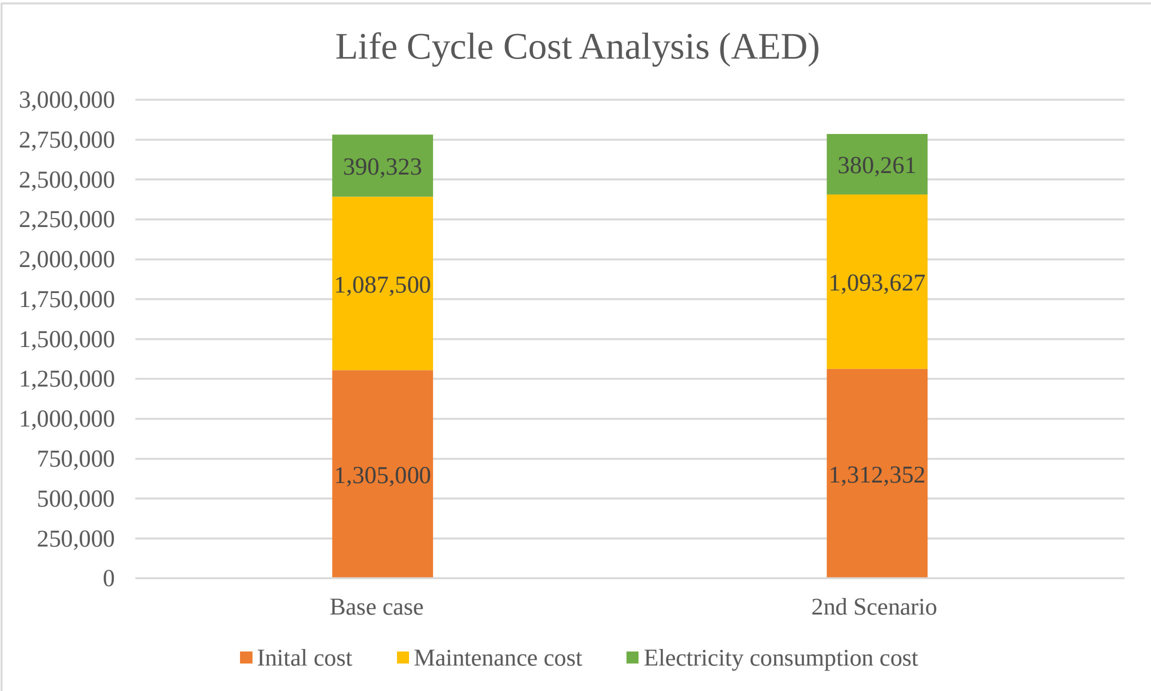


Figure 6.22: The life cycle cost analysis of 2nd scenario against the MBRHE base case

6.11.3 3rd scenario LCC results

The energy retrofitting strategies implemented in the 3rd scenario resulted in a significant reduction in electricity consumption in contrast with the base case, even if the initial and maintenance costs increase. The decline of the electricity cost covers more than the inflation in the initial and servicing costs with a balanced amount of 29.6 thousand AED. This means that the enhancement strategies used 3rd scenario greatly impact the housing unit performance regarding the energy and lie cycle cost.

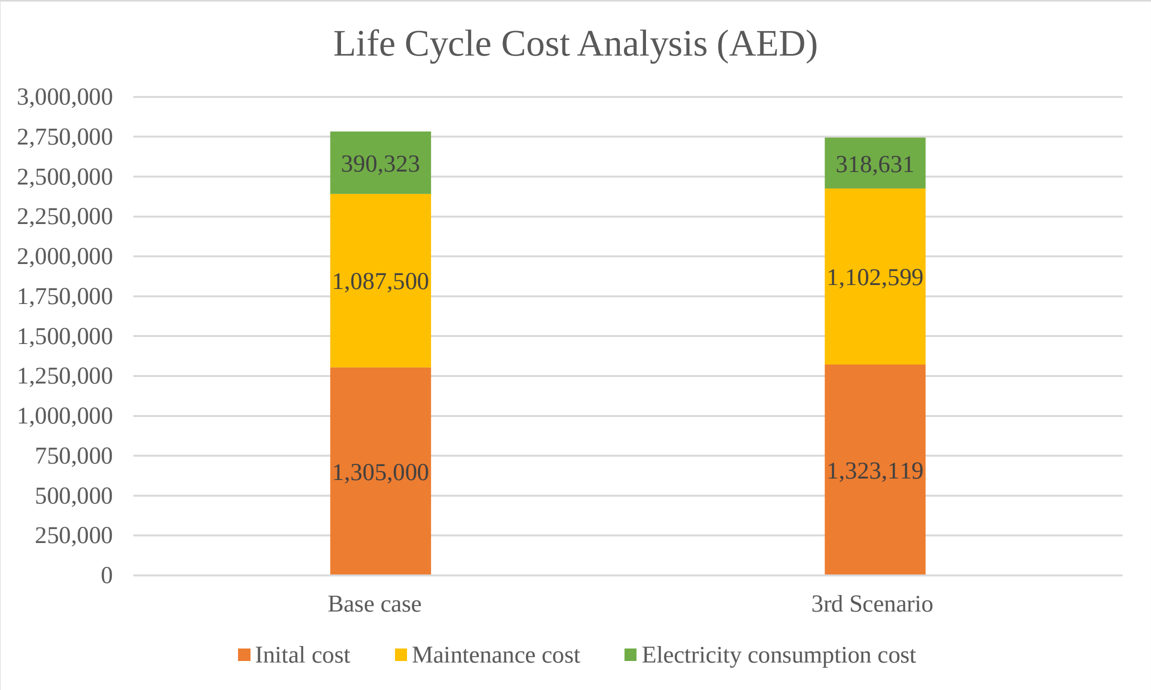


Figure 6.23: The life cycle cost analysis of 3rd scenario against the MBRHE base case

6.11.4 4th scenario LCC results

The below figure represents the life cycle cost of the enhancement strategies in the 4th scenario simulation model. The PV technology is integrated with other passive design methods to upgrade the base case's energy performance. A massive decline in the electricity consumption cost is introduced in the figure (6.24). While the initial and maintenance expenses increased dramatically, however, the reduction amount of this model is larger than the increases in the other LCC group costs, where it is approximately equivalent to 167.1 thousand AED. Although these strategies raise the initial cost of the building, they reduce the housing expenses over the villa lifespan period.

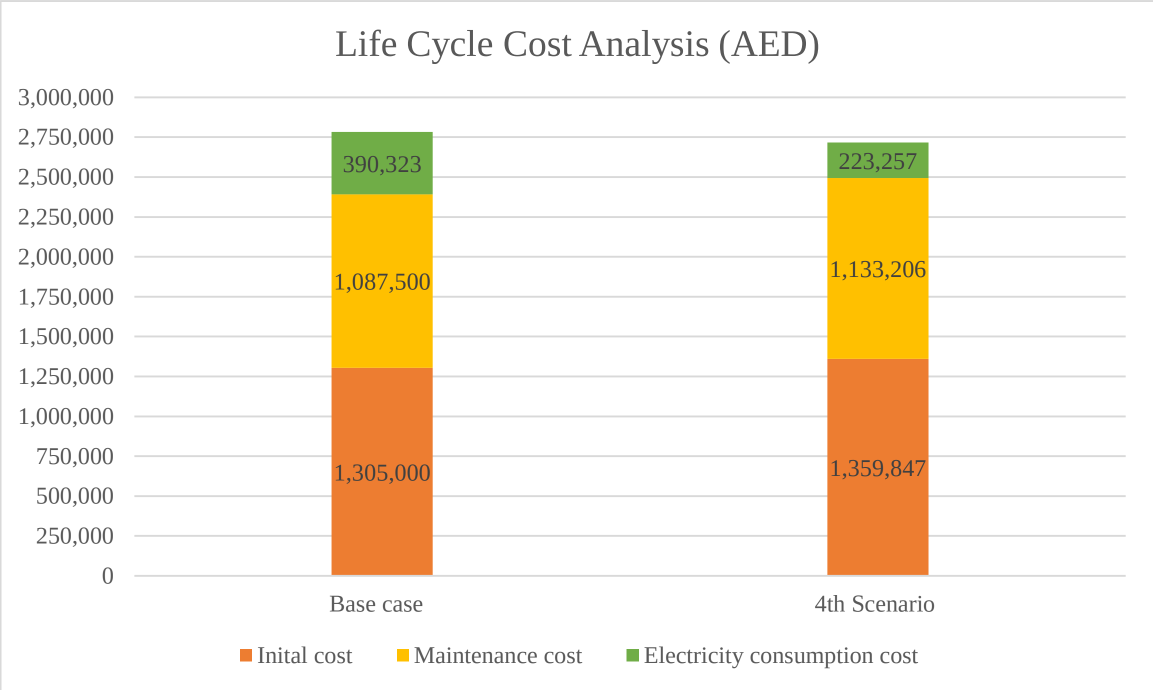


Figure 6.24: The life cycle cost analysis of 4th scenario against the MBRHE base case

6.11.5 5th scenario LCC results

The LCC analysis of the 5th simulation model represented in Fig (6.25) indicates that the integration between the courtyard and PV system in creating the simulation model reduces the case study expanses.

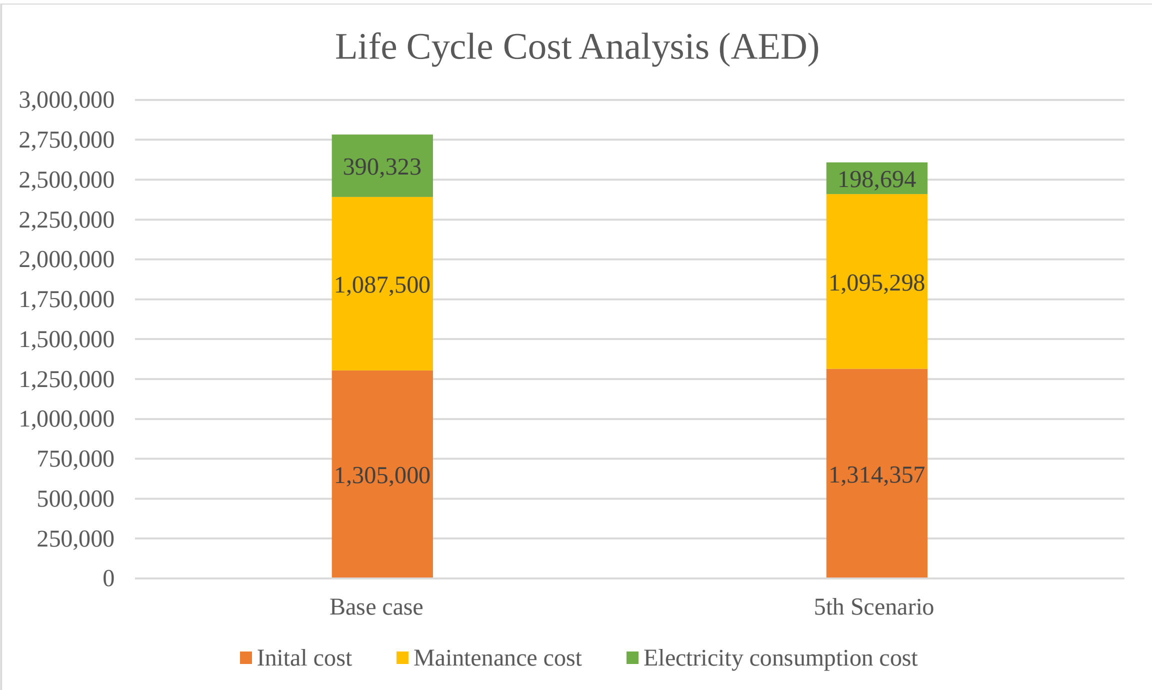


Figure 6.25: The life cycle cost analysis of 5th scenario against the MBRHE base case

In comparison between the scenario and the base case, the electricity consumption cost was minimized significantly. While the same of other scenarios, the initial cost and servicing expenses increased but slightly. This minor increase in the initial value due to little shrinkage in the villa's total built-up area, as presented in chapter five. The massive decline in the electricity cost covers these expenses and more. These scenario strategies have a vital influence on the case study performance regarding life cycle cost and energy.

6.12 MBRHE LCC analysis results comparison

Figure (6.26) presents the total life cycle cost of the MBRHE base case and its scenarios over 35 years. The last three scenarios enhance the LLC performance of the case study; but, the first two scenarios increase the case study's life cycle cost.

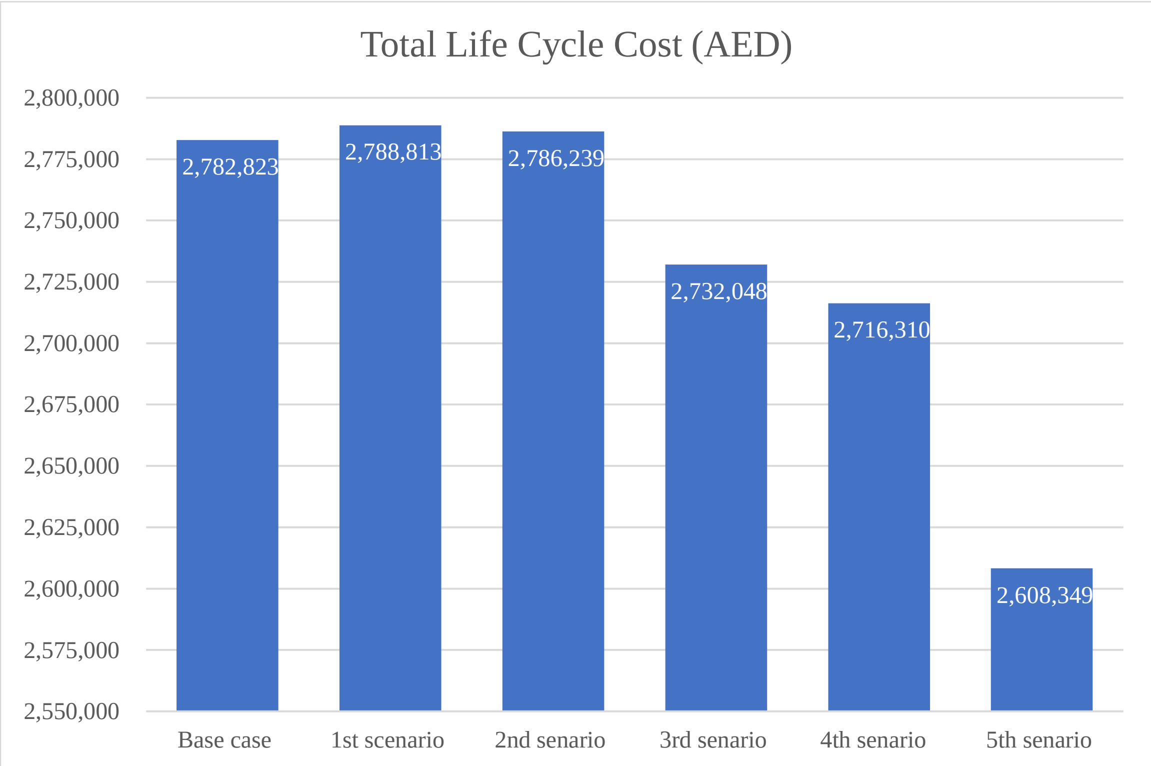


Figure 6.26: LCC analysis of the MBRHE base case and its developed scenarios for 35 years

The 1st model energy refurbishment methods introduce the worst performance regarding LCC, where the total expenses by 6000 AED. Also, the 2nd model enhancement strategies increase the total LCC of the villa by 3.4 thousand. The 5th model boosts the villa LCC performance through the villa lifespan period, where it saved approximately 175 thousand dirhams for the house owner. Further, the energy strategies used in the 4th scenario have a significant impact in minimizing the case study lifespan expenditures. The third scenario also provides an excellent LCC performance, where its energy retrofitting process decreases the total life cycle. The last three scenarios, particularly the 5th developed model, are the ideal retrofitting models in terms of life cycle cost.

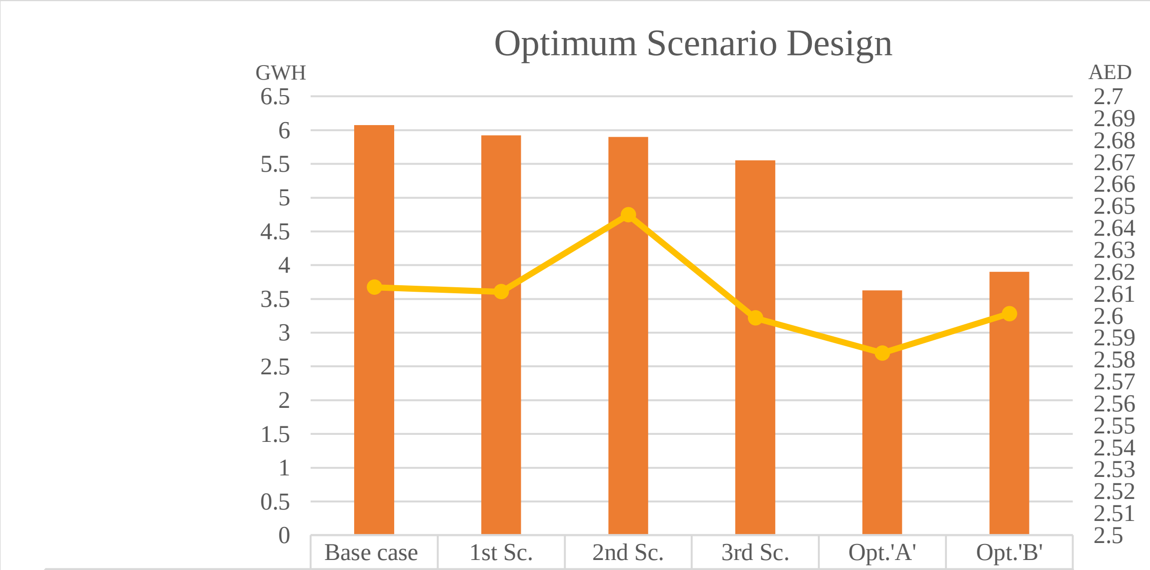
After conducting a comparison analysis of each case study and its scenarios, some scenarios provide a massive enhancement in the villa performance in respect to the LCC, especially the scenarios developed based on the integration of PV system with other passive design strategies. While few of these scenarios diminish the LCC performance of the villa, others provide an intermediate representation of the villa regarding the life cycle cost.

6.13 Scenarios energy and LCC comparison

The provided simulation models of both cases prove their efficacy in energy saving, and most of them present an efficient life cycle cost performance. A comprehensive comparison will be developed in this section to select the optimum models concerning energy consumption and LCC for both cases study.

6.13.1 SZHP optimum scenario

The optimum refurbishment scenario for the SZHP housing unit needs to be evaluated regarding the energy efficiency combined with effective life cycle cost. The below figure presents all proposed case study scenarios considering their energy performance (GWh) and Total LCC (millions).



	Base case	1st Sc.	2nd Sc.	3rd Sc.	Opt.'A'	Opt.'B'
Energy (GWh)	6.074	5.924	5.901	5.551	3.626	3.901
LCC (million AED)	2.613	2.611	2.646	2.599	2.583	2.601

Figure 6.27: A comparison between SZHP scenarios in terms of energy and LCC performance

The 2nd retrofitting model introduces the worst representation for LCC, which has the highest total LCC with slight enhancement in energy saving in contrast with the other scenarios. In the 1st scenario, the enhancement applications improve the villa effectiveness of the LCC slightly, but in terms of energy, their performance is intangibly comparing to others. The 3rd model presents a significant enhancement in respect to energy-saving and life cycle cost, as it records the second-best performance in total LCC with an average reduction of energy consumption.

The most compelling scenario regarding energy saving and LCC is option ‘A’ from the 4th scenario, where the energy consumption declines dramatically and has a vital improvement in reducing the LCC, in contrast with current villa conditions and the rest of the proposed models. The 4th scenario option ‘B’ retrofitting strategies indicate an excellent energy performance where it is considered the second conserver of energy and LCC. It also provides a better lowering in total LCC compared to the base case and the first two scenarios.

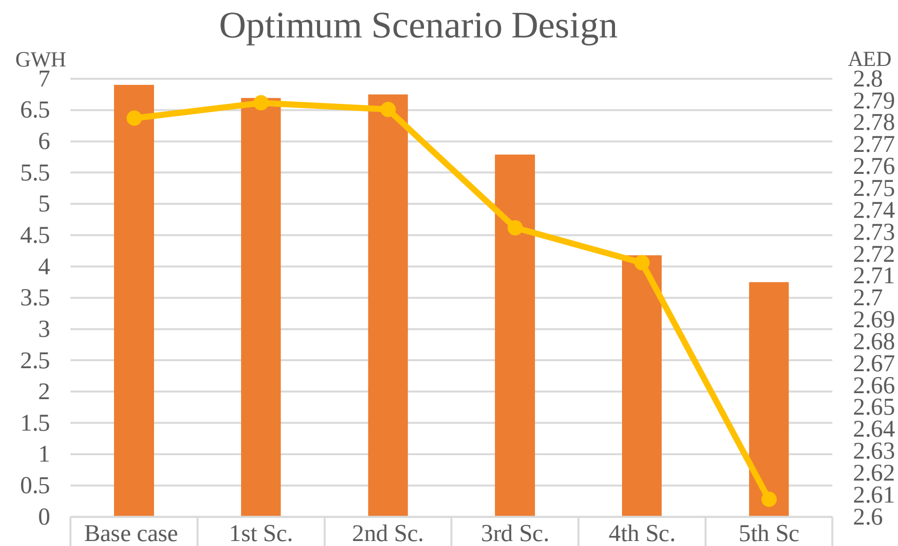
The scenario that provided the optimum performance in respect of building energy conservation and life cycle cost is option ‘A’ from the 4th scenario for SZHP housing units—followed by the 3rd scenario if the house owner concerns about the initial cost more than the consumption of energy.

6.13.2 MBRHE optimum scenario

Same as the previous case study, to identify the most efficient scenarios regarding energy conservation and total LCC for the building. Figure (6.28) presents MBRHE simulation models energy performance and LCC analysis results.

The 1st and 2nd models of MBRHE present a slight enhancement in the energy saving of the villa, but the 2nd scenario is better. Despite that, both increase the expenses of the house throughout its lifespan period. The refurbishment methods of the third model provide a moderate improvement where the consumption of energy and the total life cycle cost minimized compared to the first two simulation models. However, the efficiency of this scenario is lower than the last two scenarios.

The 5th scenario demonstrated the best performance in this case study, where it has recorded a significant enhancement in the reduction of energy consumption as well as in the total life cycle cost. Also, the 4th scenario identifies an impressive improvement in energy efficiency and LCC of the case study compared to other scenarios except for the 5th scenario.



	Base case	1st Sc.	2nd Sc.	3rd Sc.	4th Sc.	5th Sc
Energy (GWh)	6.9	6.69	6.75	5.79	4.18	3.75
LCC (million AED)	2.782	2.789	2.786	2.732	2.716	2.608

Figure 6.28: A comparison between MBRHE scenarios in terms of energy and LCC performance

The optimum model of MBRHE housing units is the 5th model, where the courtyard and the PV technology are implemented in the simulation models. Although the utilization of the courtyard enhancing the case study's performance, it reduces the total area of the building, which could be important for some owners who are looking for wider spaces. In that case, the 4th scenario will be a more efficient design for them.

6.14 Discussion

The comparison between the scenarios of each case study was conducted considering the improvement in energy performance and total life cycle cost, where the optimum models for each case were selected.

The results and comparison process present that the efficient building energy could introduce a profitable life cycle cost for the building. Various models were developed with different integrated passive and active design strategies in each scenario.

The selection of the proper passive design strategies, as shown in some cases, positively impacts conserving the energy. The appropriate construction materials with adequate thickness and properties for the housing envelope contribute to upgrading the performance of the selected cases. Even if the initial cost of the construction will increase, the operation costs will decrease. Also, the green roof system improves roof U-value, which can minimize the heat transfer.

Furthermore, some scenarios replaced the CFL with LED lamps, introducing a significant lowering in electricity; therefore, choosing the appropriate lighting system plays a critical role in improving the building's energy efficacy.

Despite the initial cost of the building, the implementation of PV technology systems in the housing units contributes a considerable reduction in energy consumption and enhances the total life cycle cost. Moreover, if the author assumes a full roof area covered with PV panels, the housing units could become a zero-net-energy home.

In addition, considering the courtyard in the design of the housing units as presented in the last scenario of the MBRHE case study boosted the reduction of energy.

A well residential building design consideration to the surrounding conditions and climate of the area will avoid several problems generated defect from the design, which needs more energy consumption to enhance the indoor environment for the inhabitants. Moreover, preventing extra spaces and less used areas in designing any house, as shown in the SZHP villa, will decrease the initial cost, which could be used for more energy-efficient applications as the installation of the PV system.

Most of the developed scenarios addressed an amelioration in total life cycle cost in contrast with the current conditions of selected housing. Although all the results introduced an increment in the initial cost of the construction and the maintenance cost over the building lifespan period, the total life cycle cost covers these inflations and some of them provide more than this against the current situation of the villa.

That means designing and constructing affordable energy-efficient housing units for UAE citizens is possible, as mentioned in the previous section, where at least two simulation models introduce a massive enhancement in the reduction of energy consumption with effective life cycle cost compared with the selected villas.

Chapter 7

Conclusion

7- Conclusion

Climate change is a significant environmental issue facing the world, which needs series of reactions to eliminate this phenomenon. Several human behaviors contribute to expanding the problem. The construction sector is responsible for produce approximately 50% of greenhouse gases. Furthermore, the residential sector consumes around 15% to 30% of global energy consumption, that generated from fossil fuels.

Recently, many organizations in different sectors are more aware of this crisis's negative influences and accompanying problems on human health and worldwide economics. The construction industry introduces several solutions to reduce their harmful effects on consuming energy and generating pollutants, such as developing new regulations, efficient strategies and new materials to enhance their behaviors in terms of energy.

Sustainable and energy-efficient housing terms combined various retrofitting processes that upgrade the level of living and reduce the consumption of energy, which consequently results positively in electricity bills. These types of housing are better to be available for all society segments, which needs to be affordable even for low-income households.

Providing affordable energy-efficient housing units' design in UAE for moderate- and low-income households is the target of this study. Therefore, the research selected two types of housing units designed and constructed by organizations aiming to offer appropriate and affordable housing to the UAE citizens, which are the Mohammed Bin Rashid Housing Establishment (MBRHE) and the Sheikh Zayed Housing Programme (SZHP).

The study was starting with evaluated the real energy performance for the selected cases, where several scenarios developed also examined in terms of energy saving. The developed scenarios included various refurbishment strategies that aim to enhance the performance of each villa, such as passive design methods and renewable energy technology.

Several passive design processes addressed in the simulation models focused on the various envelope construction material, green roof systems, shading devices and courtyard effect. The active design method was also being considered in this analysis to evaluate its impact on building electricity consumption. Further, renewable energy technologies influences were part of this study investigation, where the PV panels implemented in different systems in several models.

The first two scenarios of each case were mostly developed based on the impact of the passive design methods, particularly envelope construction materials and horizontal shading devices and the rest combined the utilization of the passive design and active design strategies.

An inclusive assessment was conducted through IES-VE software to extract the energy performance after setting up the computational models, followed by a comprehensive analysis conducted to investigate the life cycle cost. The initial and operation cost was identified and calculated for each base case and its scenarios over 35 years estimated lifespan period.

The results and findings of each investigation were presented and compared to each other. Several comparisons were carried out in terms of energy and LCC for each case study. The first one focused on the impact of the retrofitting methods in each scenario individually over the 12 months compared to the base case. The second comparison was built based on each model's total energy consumption to find the best scenario energy representation. The third one concentrated on the LCC costs: the initial maintenance and electricity price for each model against the current case study. Followed by a comparison developed regarding the total LCC of each scenario to explore the most effective scenario in terms of LCC. The last one conducted for all scenarios based on both LCC and energy consumption performance to identify and select the optimum models that achieved the best LCC and energy efficacy.

In general, the results presented an enhancement of energy consumption for the developed scenarios but at various rates, where the best performance was recorded for the scenarios that integrated the PV technologies with passive strategies. The LCC results illustrated that most of the models had a higher initial cost than the base case but, their total life cycle cost was more effective. For each villa, the optimum and most effective model regarding LCC and energy conservation parameters was explored.

Investigation findings introduced a proper implementation of suitable passive design methods for the building in the design and construction phase to minimize the electricity uses, leading to a reduction in building life costs and other expenses.

Furthermore, construction materials play an essential role in the building energy performance where in some scenarios showed a slight enhancement and a few differences in the initial building cost due to the selected villas current construction material followed the Dubai green building regulations and strategies.

Besides, lighting systems are considered one of the primary energy consumption in buildings, which vary in a wide range of types and forms. LED bulbs used in the research evaluation recorded a significant drop in building energy uses even if their prices were slightly higher than the current systems.

Moreover, as presented in previous chapters, both solar panels technologies increase the initial and maintenance cost of the construction, but PV panels produce electricity that could make these selected cases either semi or total self-sufficiency in terms of energy. Where inhabitants preserve electricity bills fees during the building life span, and subsequently a dramatic reduction in life cycle cost.

In the investigation of SZHP case study developed models, the 4th scenario opt. 'A' presented the best performance in both energy consumption and LCC terms. The reduction of the electricity consumption compared to the base case equal to 40.3%, and regard life cycle cost was lower by 1.15%. Followed by opt. 'B', which displayed a significant enhancement in decreased electricity uses in the villa, but in reference to LCC, it had a higher cost than the third scenario.

The fifth simulation model in the second case study analysis provided the most efficient energy and LCC scenario where the minimize in electricity consumption equal to 45.7% with a 6.25% reduction in life cycle cost. The 4th scenario's outcomes introduced the second-best energy and life cycle cost performance, that the energy and LCC reduction around 39.4% and 2.4%, respectively.

In the first three proposed scenarios of each case study, the differences in the life cycle cost were range between 1.72% and 0.25% less or more and the initial cost differences percentage were negligible as shown in the previous chapter, but their impact on the energy performance were better than the base case where the electricity consumption decreased ranged between 2.5% to 8.6% and 16.1% as illustrated 3rd model findings.

7.1 Research recommendation

Eventually, the study presented several methods that house owners and designers and establishments could use to build energy-efficient houses as well as their life cycle cost lower than the current building.

Building an affordable, energy-efficient home, the author recommended starting from the design phase, where designers and specialists identify owners' objectives and needs—

followed by studying and analyzing building location, climate conditions and environmental and human-made influencing factors. Accompanied with an implementation for a suitable site and climate passive design methods and technologies such as select an appropriate orientation of the building configuration and glazing, use eco-friendly construction material, add proper insulation material, etc. In addition, encourage house clients to use energy-efficient appliances and technologies practically lighting system as the investigation presented. Harness the natural elements to produce energy by utilizing PV panels in places like the UAE. Moreover, it is better to introduce life cycle cost calculation details to convince homeowners that energy-efficient houses are affordable.

Energy-efficient housing saves electricity consumption by building a life-span period and generating energy; in some time, owners could also earn profit from producing electricity. So, even if this house's initial cost is slightly higher than a traditional home, the long-term advantages and future benefits, particularly in reducing costs, are more important for house owners comfort. Therefore, these housings are affordable for their users.

In conclusion, the study answered the main research question and attained the main aim and objectives, providing an energy-efficient affordable model for UAE citizens.

7.2 Future recommendation

This study's findings can be a vital reference for future research, which could upgrade and improve the outcomes of this research. The future studies could concentrate on:

1- Exploring the impact of the new brands of windcatcher on the residential building energy performance in UAE with ignoring the utilization of AC cooling system.
2- Studying the influences of the passive design strategies on low-income human health and level of indoor comfort.
3- Comparing the research results with other countries sharing the same economic level and climatic conditions with UAE to emphasize the efficiency of the outcomes.
4- Investigating material market prices changes through the lifespan period of a sustainable residential building.
5- Studying the impact of the passive strategies on water-conserving for affordable housing.

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