Energy Optimization of an Existing Residential Villa in UAE Towards Net Zero Energy Building (NZEB) Concept

تحسين الطاقة لفيلا سكنية قائمة بالإمارات العربية المتحدة نحو مفهوم المباني ذات محصلة الطاقة صفر

by

Wael H M Altalaa

A dissertation submitted in fulfilment

of the requirements for the degree of

MSc Sustainable Design of The Built Environment

at

The British University in Dubai

Professor Bassam Abu-Hijleh
November 2017

DECLARATION

I warrant that the content of this research is the direct result of my own work and that any use made in it of published or unpublished copyright material falls within the limits permitted by international copyright conventions.

I understand that a copy of my research will be deposited in the University Library for permanent retention.

I hereby agree that the material mentioned above for which I am author and copyright holder may be copied and distributed by The British University in Dubai for the purposes of research, private study or education and that The British University in Dubai may recover from purchasers the costs incurred in such copying and distribution, where appropriate.

I understand that The British University in Dubai may make a digital copy available in the institutional repository.

I understand that I may apply to the University to retain the right to withhold or to restrict access to my thesis for a period which shall not normally exceed four calendar years from the congregation at which the degree is conferred, the length of the period to be specified in the application, together with the precise reasons for making that application.

____

Signature of the student

COPYRIGHT AND INFORMATION TO USERS

Abstract:

Buildings energy contributes in one third of the world's consumed energy. The use of fossil fuels to provide buildings energy contributes in the Global Warming phenomenon. To reduce the buildings impact on world's energy, concepts like net zero energy buildings were introduced. This study was conducted to test the possibility of achieving such concept in the UAE.

A two-story existing residential building was selected to apply energy saving measures and introduce renewable energy solutions to it with the aim of achieving a NZEB villa. Simulating the implementation of passive energy saving measures, efficient lighting and efficient HVAC systems reduced the energy massively, the remaining required electricity was provided by using PV panels. The study concluded that using external U-value of 0.29 W/m^2K, Roof U-value of 0.14 W/m^2K and Windows U-value of 1.61 W/m^2K together with Dubai Lamp bulbs reduced the energy by 59.04% in the case of using VRV HVAC system. The same measures used with connecting the villa to a district cooling plant and the energy reduction was simulated as 84.06% of the total energy without considering chillers energy at source, 57.72% of the total energy when considering the chillers energy.

The introduction of 49 PV panels with nominal efficiency of 20.6% was able to cover the remaining energy required by the villa for the VRV HVAC case. The district cooling connected case required using 19 PV panels when the chillers energy was not considered, and 51 panels considering the chillers energy.

The net zero energy building concept was achieved for both options and was able to upgrade the existing villa in UAE to become a NZEB.

ملخص:

الطاقة المستهلكة عن طريق المباني تمثل ثلث مجموع استهلاك الطاقة في العالم. استخدام المنتجات النفطية كوقود لإنتاج هذه الطاقة هو مسبب رئيسي لظاهرة الاحتباس الحراري في العالم. تم تطوير مفاهيم جديدة للحد من تأثير المباني على استخدام الطاقة، أحد هذه الأمثلة هو مفهوم المباني ذات محصلة الطاقة صفر. هذه الدراسة تبحث إمكانية تحقيق هذا المفهوم في الإمارات العربية المتحدة.

تم اختيار فيلا سكنية قائمة مكونة من طابقين أرضي وأول لاستخدامها كفيلا مرجعية وتطبيق معايير كفاءة الطاقة عليها واستخدام أحد أساليب الطاقة المتجددة للوصول لهدف تحويل الفيلا إلى مبنى ذو محصلة الطاقة صفر. تم محاكاة استخدام معايير كفاءة الطاقة والإضاءة ذات الكفاءة العالية وأنظمة تبريد ذات كفاءة عالية لتقليل الطاقة الكهربائية المستهلكة بشكل كبير، تم توفير الطاقة المتبقية والمطلوبة للفيلا عن طريق استخدام ألواح كهروضوئية. استنتجت الدراسة ان استخدام جدران خارجية ذات معدل انتقال حراري 0.29 واط/م^2 كلفن وأسطح ذات معدل انتقال حراري 0.14 واط/م^2 كلفن ونوافذ ذات معدل انتقال حراري 1.61 واط/م^2 كلفن بجانب استخدام (مصباح دبي) عوضاً عن المصابيح التقليدية قلل الطاقة المستهلكة بنسبة 59.04 % في حالة استخدام نظام التبريد ذو وسيط متغير الحجم. استخدام جميع هذه الأساليب ذات الكفاءة العالية مع توصيل الفيلا بمحطة تبريد مركزية قلل الطاقة المستهلكة بنسبة 84.06% عند عدم أخذ طاقة تبريد المصدر بالاعتبار، وتم تقليل الطاقة بنسبة 57.72% عند اخذ هذه الطاقة بالاعتبار.

استخدام 49 لوحاً كهروضوئي قام بتغطية الطاقة المتبقية والمطلوبة للفيلا في حالة نظام التبريد ذو وسيط متغير الحجم، بينما تطلب استخدام 19 لوحاً كهروضوئي فقط في حالة توصيل الفيلا بمحطة تبريد مركزية وعدم أخذ طاقة تبريد المصدر بالاعتبار، و51 لوحاً عند اخذ هذه الطاقة بالاعتبار.

تمكنت الدراسة من تحقيق مفهوم المباني ذات محصلة الطاقة صفر وتحويل الفيلا القائمة في الإمارات العربية المتحدة لفيلا ذات محصلة الطاقة صفر في كلتا الحالتين.

Table of Contents

Chapter 1 – Introduction

Chapter 2 - Literature Review

Chapter 3 - Methodology

Chapter 4: Case Study Validation & Simulations

Chapter 5: Discussion of Simulation Results

Chapter 6: Conclusions & Recommendations

List of Figures

List of Tables

CHAPTER 1: INTRODUCTION

1.1 Global Warming

The release of Greenhouse Gases (GHG) such as carbon dioxide, nitrous dioxide and Methane caused by humans' activities and modern life style emissions are trapped in the planets' atmosphere which causes the sun radiation to be scattered and trapped inside the atmosphere causing a greenhouse effect which commonly known now as the Global Warming phenomenon.

Dai (2012) simulations expected several highly populated regions of the globe to experience severe droughts in the second half of the century due to the effects of global warming. Brazil, Southeast Asia, East side of the United States, and Europe are all expected to experience such droughts if the simulations are accurate.

Peters et al. (2012) stated that keeping the global warming below 2°C requires the use of innovative technologies that reduces the GHG emissions and keeping it at a negative pace, the study suggested that unless global efforts are implemented soon achieving the targeted two degrees increase in global temperatures will become impossible.

Effects of global warming such as deforestation, the rise of oceans level and extreme weather conditions are expected to affect the entire planet if we fail to reduce the emissions and pollution levels immediately. emissions produced by industrial processes, construction, transportation, industrialized animal agriculture, the burning of fossil fuels to produce energy, and many other polluters are hazards that needs to be mitigated.

This dissertation will focus on the energy consumed by buildings which is usually produced in plants ran by fossil fuels combustion and try to find a way to reduce such unsustainable energy and replacing it by renewable energy sources.

1.2 Buildings Energy

The increasing population of the world is impacting directly the energy consumption worldwide. This continuous growth in energy demand is concerning scientists especially the traditional transformation of energy by using fossil fuels considering its negative impact due to the carbon dioxide and other emissions release to the atmosphere which certainly caused and still contributing in the Global Warming phenomenon. Many new technologies and ideas have been directed towards clearer sources of energy and power generation that have a low impact on the environment as well as reducing the consumption of energy by enhancing the efficiency of equipment. Since the buildings sector is one of the highest consumers of energy, it's necessary to mitigate the energy efficiency problems in buildings and improve buildings impact on the environment by reducing the total energy required to operate the building in addition to implementing new technologies that could generate a certain percentage of the total building energy.

Buildings, both commercial and residential are responsible for around sixty percent of the total electricity consumption and the emissions from these buildings are accounted for more than third of the total greenhouses global emissions (Fraunhofer ISI 2012; UNEP 2014, cited in Ascione et al. 2016, p. 938).

Holuj,(2010) Referring to an EIA study (2008) stated that commercial building in the united states are responsible for 18% of the green houses gases emitted to the atmosphere and 18% of the total consumed energy of the whole country while a recent study by U.S. Energy Information Administration (EIA) stated that Commercial and residential buildings Consumed forty percent of the U.S. total energy in 2016 (EIA, 2017), residential housing in Spain represents 18% of the total country energy consumption (IEA 2017, Cited in Carrasco, Lopez & Morcillo 2017) while the percentage is higher in France as stated by Lenoir, Garde and Wurtz (2011) commercial and residential buildings responsible for 43% of the power consumption and 25% of the carbon dioxide emissions.

World buildings account for almost third of the total global energy consumed as agreed by Han, Taylor and Pisello (2017) and Friess and Rakhshan (2017). The energy consumption of buildings has a direct relation to the weather conditions of the region, Friess and Rakhshan (2017) argues that energy required in cold climates depend on fossil fuels and biomass burning while hot climates consumes mainly electricity to condition the building spaces and as per their review of Morna (2009) study the heating energy over the current decade will decrease to reach 34% while cooling energy will increase to reach 72% due to the increase of global temperatures.

This means that buildings in hotter climates such as the Arabic Gulf countries need to mitigate the buildings energy and especially the cooling energy for all new buildings in order to match this increase of demand in a sustainable way which means reducing the energy required for cooling and using renewable energy to reduce the green houses emission which subsequently results in reducing the global temperatures.

1.3 Net-Zero Energy Buildings (NZEB)

Different definitions were given to express the meaning of Net-Zero Energy Buildings, several studies show that there's yet to be an unified definition of NZEB or which parameters to be considered in order for the building to be identified as a net-zero energy building, Lenoir, Garde and Wurtz (2011) and minor and Hallinan (2011) highlighted the same in their studies, ASHRAE Vision 2020 definition is "...a NZEB is a building that produces as much energy as it uses when measured at the site" (ASHRAE Vision 2020, cited by Minor & Hallinan 2011), Minor & Hallinan (2011, p.43) definition of NZEB was simplified as "the ability to operate off grid".

Torcellini and Crawley (2006) explored 4 different definitions in depth to describe a ZEB which are source & site energies, cost and emissions while Net zero source energy building generates enough energy to cover its source energy consumption taking into consideration the transmission and conversion losses according to building location compared to the energy source, Net zero site energy building focuses only on the site energy generation and consumption to equalize each other, Net zero energy cost building uses a type of renewable energy to cover the cost of energy consumed by selling back the extra generated power to the grid and as the authors argued that this type of NZEB is hard to achieve due to fluctuation in energy prices and utility providers prices in order to maintain their services, the last definition is Net zero energy emissions building which considers the emissions emitted due to the buildings energy usage.

1.4 Aims & Objectives

1.4.1 Research Aims

The main aim of this dissertation is to explore and test the possibility of upgrading an existing villa in the UAE to achieve a net-zero energy building. The thesis will study the design of an existing residential villa in Dubai – UAE, find the main parameters (e.g. building envelope, lighting and cooling systems) where electrical energy saving could be achieved and add PVs to cover the balance of the electricity consumption. This will be achieved by improving these parameters and applying energy saving measures to the building, to achieve the goal of transforming the existing villa to become a net zero energy building

1.4.2 Research Objectives

Literature review and methodology analysis of the NZEB parameters and strategies should provide a clear idea of the steps to be taken in order to achieve the research aims.

By studying other approaches through literature review in order to determine the parameters applied to the buildings in different climates and with different buildings scales, the most suited parameters will then be chosen according to its availability and feasibility in the United Arab Emirates and the direct impact on energy consumption reduction.

The elements and parameters which will be explored are:

- HVAC different options according to its efficiency and its effect on the total energy consumption.
- U-Value analysis for different components of the building (Wall, roof, and windows and glazed areas)
- Lighting energy saving strategies and latest lights solutions.
- The effect of shading elements on building internal heat gain and energy consumption.
- Air tightness and infiltration effects on the building’s energy consumption
- According to the energy saving resulted from using the previous measures, the best suited renewable energy source to be implemented to a small housing in Dubai will be determined and tested.

Since this research is focused only on the electricity consumption, GHG emissions and Cost will not be assessed.

Using computer software simulation as the dissertation methodology, the study will test all the selected energy saving measures and renewable energy sources, to determine accordingly if the goal of transforming the existing villa to a net zero energy building is achievable or not.

1.5 Dissertation structure

This research consists of 6 chapters that study NZEB and complement each other in order to reach to the desired aims of the dissertation, the description of each six chapter is as followed:

Chapter 1: Introduction, this chapter contains a general review of the energy problems around the globe, buildings energy and its effects on the global energy consumption in addition to a brief explanation of the meaning of NZEB, aims and objectives of the research, and dissertation structure.

Chapter 2: Literature review, which includes a deeper look into the concept of Net-zero energy buildings and different approaches taken to achieve this concept through studying different research papers, articles, and journals in addition to exploring the parameters used in each study to determine the best measures that would suit the case study chosen in Dubai.

Chapter 3: Methodology, this chapter will review different research methods and compare them to choose the best methodology approach suited for this study in addition to an explanation of the chosen methodology. case study details with site and climate brief analysis.

Chapter 4: Case Study Validation & Simulations, which will show the case study validation process and explain in detail the input and variation for each NZEB parameter with an explanation to the reasons behind each input and the method of applying these inputs to the simulation software.

Chapter 5: Results and Discussion, the findings from the previous chapter’s outputs will be analyzed and discussed in depth in this chapter in comparison to each other and a final review of all the parameters output will be presented and discussed to confirm the possibility of achieving NZEB.

Chapter 6: Conclusions and Recommendations, an overview of the whole research will be presented and recommendations for future researches will be suggested in this final chapter.

CHAPTER 2: LITERATURE REVIEW

2.1 Net-Zero Energy Buildings (NZEB) studies review

In order to understand the methods used previously to reach NZEB and the strategies followed during the design, simulation and validation, the following literature review is essential to follow successful examples and achieve the net-zero energy building aim of the research.

Dabaieh, Makhlouf and Hosny (2015) assessed the performance and occupants satisfaction of installing PV panels to vernacular houses in two remote villages in Egypt, both villages El-Gara and El-Heiz were provided with two PV panels for each house as a part of the New and Renewable Energy Authority in Egypt and through occupants survey and site analysis the authors found that more than three quarters of all residents gave a positive feedback regarding the new renewable energy addition to their homes and the remaining residents had some concerns regarding the low power generated by only two panels per house, however it was mentioned that most of the occupants appreciated having a more reliable source of energy instead of the non-dependent national grid in addition to the reduction in electricity bills. The authors recommended more similar projects to be placed on the ground and advised regarding the initial high cost of PV panels imported from abroad and recommended for such efficient technology to be manufactured and maintained locally to provide more options and more competitive prices.

Even though this research didn’t study the net or near zero energy buildings, but it’s considered as a valuable example of reducing building energy consumption by implementing a renewable energy source.

The Finnish model of a NZEB was investigated by Mohamed, Hasan and Siren (2014) studying two types of houses in Helsinki – Finland, both passive and standard houses were studied by applying different conventional and biomass systems which are Electric heating system, District heating, Ground source heat pump, Light oil boiler and wood pellet boiler as the conventional systems and the biomass systems are wood pellet Stirling engine, Direct Combustion Stirling Engine, Updraft Gasifier Stirling Engine, Indirect Fired Gas Turbine, Internal Combustion Engine with gasifier, direct combustion Organic Rankine Cycle and domestic scale polymer electrolyte membrane fuel cell.

All the mentioned systems efficiencies are rated according to both the Finnish and international code and the aim for the authors study is to reach the four cases of NZEB site, source, emission and cost. U-values of all aspects of the buildings' envelope were compared (roof, walls, windows and doors, ground, and air tightness) and all the system were simulated using Trnsys software in addition to adding PV panels to cover the remaining electricity required and studying the effect of adding Solar Thermal Collectors (STC) to reduce the number of PV panels.

It was found that using conventional heating systems did not achieve the required NZEB values however it was recommended that increasing the system efficiency and adding STCs will reduce the buildings energy consumption noticeably, while reducing the demand of thermal energy has an opposite effect and will not help achieve the NZEB emission and primary energy. The research concluded that achieving NZBE-emission is easiest to achieve according to the Finnish regulations while NZEB primary source is the second easiest option followed by cost and site NZEB and it was highlighted that using the international reference data was easier to achieve the last three options while NZEB-emission was easier with the Finnish code. The final recommendation of the study is that up to the date of publishing the research using a domestic biomass combined heat and power is not necessarily a better option to achieve a NZEB and the authors recommended using a centralized energy source instead.

Ascione et al. (2016) conducted a study using simulation tool and a multi-objective algorithm to search the best envelope material solution which save energy in both winter and summer and reach with the building to NZEB in four cities with Mediterranean climate which are Nice, Athens, Naples and Madrid.

The study explored 7 different types of window glazing with double and triple glazing, different gasses gaps (air & argon) and varies glass options such as Low-E, clear and reflective glass panels which resulted in U-values varying between 2.55 to 0.81 W/m^{2}k, three window external shading were investigated which are (no shading option, louvre 0.5 - 1.5 meter, and overhang 0.5 – 2 meters), internal window blinds options were also simulated as followed (no window blind option, medium reflective blind, medium weave blind, and shade roll).

Six types of walls with different U-values were used to reduce the thermal conductivity, two types are made of interlocking brick with holes filled with both rock-wool and expanded polystyrene, the other 2 wall options are made of autoclaved cellular concrete with varies densities, the fifth option is cross-laminated fiber which is considered as a new technology the researchers liked to include in the study, where the last option is a conventional hollow block with external wooden fiber insulation. Different external materials and different thicknesses were evaluated for all six types. Two roof options were simulated each consists of different insulation materials with U-values of 0.26 and 0.27 W/m^{2}k. an additional simulation was done to evaluate the integration of Phase Changing Material materials to the external and internal walls with different melting temperatures.

The study concluded that in order to achieve a zero energy building different approaches and energy efficiency measures need to be taken depending on the location of the building and the seasonal climate of the region. It was suggested that a comprehensive study must be conducted on a case by case situation according to building location and orientation in order to choose the most efficient materials and strategies, with number of occupants and behavior fixed between all 4 simulations of the four chosen cities. It was found that triple glazing windows with both internal and external shading is required to reduce the required cooling and heating energy. Aerated blocks with external insulation must be used to reduce to the total energy required and lower U-value roof with light colors is the best solution to reduce heat gain. Phase Changing Materials (PCM) integration must be selected according to the outdoor temperatures in winter and summer and using such material reduced the cooling demand by two percent in the Madrid case and up to 13 percent saving for Naples simulation (Ascione et al. 2016).

A comprehensive analysis done in 2015 included the simulation of different types and variations of insulations, walls, shading, glazing, Ventilation, cooling, and domestic water heating for a new office building in southern Italy, since it is considered as a warm region and has moderate winter temperatures, the study investigated the most suitable variations of materials and systems in terms of reaching a NZEB primary energy, emissions and cost. 256 variations were simulated to identify the most efficient scenarios. Accordingly, seven tables were presented to show the different factors and final results showing seven different scenarios taking into consideration all the variables, the highlighted best results with CO_2 emissions ranging between 22 to 23 $kgCO_2/m^2y$ and the worst variation with CO_2 emissions of 36 $kgCO_2/m^2y$. The best case tested showed a primary energy consumption ranging between 76.4 to 77.6 kWh/m^2y and the worst case showed an annual consumption of 121.5 to 123.1 kWh/m^2y (Congedo et al. 2015).

Kamenders et al. (2014) studied the requirements and solutions needed to convert a 2-story residential building in Latvia into a nZEB, the building had a conventional standard design that follows the Latvian building code and it was redesigned at a later stage and tested on site to achieve a minimum energy consumption by using different envelope and heating system enhancements.

The study showed a comparison between the initial design U-values and infiltration against the redesign values where walls U-value reduced to 0.06 W/m^2k down from 0.291 W/m^2k and roof U-value reduced to 0.05 W/m^2k from 0.194 W/m^2k, the U-value of ground floor was reduced from 0.242 W/m^2k to 0.1 W/m^2k while windows redesign U-value reached 0.8 W/m^2k down from 1.745 W/m^2k and infiltration was cut by more than half to reach 0.43 instead of 0.93. While it was not mentioned which insulating materials were used to reach such low U-values, it was mentioned that Passive House Planning Package PHPP strategy and TRNSYS simulation tool were used to calculate and simulate different scenarios and reach to these figures.

Two site monitoring and measurements were done on site during construction which are temperature & carbon dioxide monitoring and Building envelope tightness test using a blower door test. The paper mentioned using PV panels as a source for renewable energy. However, details of the PV panels and its output was not mentioned. The study concluded that near Zero Energy Building was achieved using passive measures and PV panels and it's considered as one of the first buildings of its kind in Latvia. The authors recommended the usage of similar envelope U-values as the ones implemented to this study and the use of mechanical ventilation with heat recovery higher than 85 percent, it was also mentioned that Latvia still lacks the regulations and guidelines for low energy buildings and the mentioned study will help development of such regulatory codes.

A recent study done in Korea examined 153 existing office buildings to highlight the energy factor required to be modified to transform office buildings to a near zero energy buildings and the study highlighted twenty four factors related to the early design decisions taken by Architects, the research studied the results of optimizing many envelope factors such as wall, roof, and windows U-values in addition to mechanical and electrical systems and compared the existing buildings case against the optimized option with relation to its initial cost as well as running cost in the duration of 40 years. The study resulted in lower energy values and faster decision making in relation to the 24 factors mentioned and showed a dramatic reduction in all these values, while the initial cost was relatively higher than the standard buildings cost the study showed the financial benefit of the building on the long run in addition to energy saving and lower CO_2 emissions, the research suggested that the findings could be used by Architects and designers to ensure lower energy output by such buildings if the studied strategies are implemented in the early design stages to save time and effort instead of doing individual studies for each building during the concept design stage (Kang 2016).

A PV panels-wind turbine hybrid system backed up with a storage battery and one inverter was used to study the possibility of generating a 100% renewable energy for 3 sites with three different climates in Romania. The output energy was simulated on hourly basis throughout the year and was able to generate enough energy to cover the buildings' consumption, in some sites there was excess energy which could be fed back to the grid. The use of battery to recover energy at peak times was highly useful in this case and the final simulation showed CO2 emissions reduction by minimum of 50% and up to 90% in one of the three sites, the PV panels used in the simulation had a nominal capacity of 280 Wp while the wind turbine used had a capacity of 3260 W at wind speed of 14 m/s (Badea et al. 2016).

Pescaru, Baran and Dumitrescu (2014) study for different educational buildings in Romania tried to reach a near zero energy building by using passive measures for the building envelope by adding insulation to external walls and replacing the glazing areas with more efficient types. However, the study concluded that even though the energy saving reached up to approximately 71 percent for one of the buildings, NZEB was not achieved and the authors recommended the use of more energy saving passive approaches combined with heating system improvement and the introduction of a renewable energy such as PV panels in order to cover the remaining required electricity. The study also showed that in the case of improving the envelope only the PV panels available area was not able to generate enough energy to cover the heating demand energy when compared annually.

Several studies as the mentioned above showed that reaching a near or net-zero energy building is highly possible in different climates and with different strategies, it was stated in many studies that a multi strategy plan is the most efficient method to reach the desired goals and in order to specify the different variables and parameters that could be improved in buildings the next section in this chapter will study each parameter in depth as researched by others to suggest the most suitable variables to be used for this dissertation.

2.2 NZEB energy efficient measures

2.2.1 Mechanical systems (Cooling, Heating and Ventilation)

de Santoli, Mancini and Rossetti (2014) analyzed the required energy needed for heating and cooling of the Pavilion EXPO 2015 building in Milan. Considering two scenarios for summer and winter seasons beginning and ending periods. The first scenario considering the summer season starting from mid-April and ending in mid-October where the second scenario has a shorter summer period starting mid-May and ending in mid-September. The study suggested the use of High efficiency geothermal energy from the warm water trapped in the location of the building. A reduction of around 50% of the required summer and winter cooling and heating energy was indicated if the mentioned system is used. However, it was highlighted that the 2 scenarios for seasons start and end are due to the building insulation which traps the heat inside the building and prolong the cooling period throughout the year.

In colder climates like Finland where most of the mechanical energy is used in heating the building's internal spaces Mohamed, Hasan and Siren (2014) simulated 5 types of conventional heating systems and 7 biomass systems as mentioned earlier and reported that all biomass options achieved proper reduction in energy needed for heating and achieved the four NZEB strategies for primary energy, emission, site and cost and suggested that a biomass centralized heating plant is only beneficial for a larger scale buildings or communities and not very energy efficient if used for a small scale house.

A multistory residential building in Italy replaced the traditionally used heat pumps and condensing boiler with two options to reduce the energy required for heating. The two options are a 99 percent efficiency condensing boiler and a heat pump with air source compressed vapor rated with 3.45 seasonal performance factor. The improvement of heating primary energy source showed a reduction in both cases from 62.66 kWh/m2y down to 11.52 kWh/m2y in the case of air heat pump. And 14.03 kWh/m2y in the high efficiency condensing boiler case (Gagliano et al. 2017).

Doiron, O'Brien and Athienitis (2011) were able to reduce the energy consumption required for heating and cooling of a house in Canada by improving the mechanical systems. This was achieved by changing the heating and cooling distribution fan controllers in order to operate during occupancy hours. This resulted in 722 kWh saving annually. Air cleaner removal resulted in 442 kWh saving annually considering that the system contains a built-in air filter which can replace the air cleaner in their case. heat recovery ventilator operational hours reduction according to occupancy profile also resulted in around 10 percent saving of the energy. It's worth mentioning that the researchers compared the heating / cooling systems of commercial buildings where an HVAC engineer is responsible of designing the full system which results in a higher efficiency of the system as a whole against a smaller residential house where the engineers input is not highly used. This can lead to lost energy where it's not needed. The authors also investigated the occupants' behavior and stated that when the occupants are informed of their energy usage they tend to reduce their consumption which results in approx. 10% reduction of the total equipment, lighting and systems energy used.

The mentioned studies show that an adequate reduction of the energy could be reached when high efficiency cooling and heating systems are used instead of traditionally used and widely commercial installed systems that have lower coefficient of performance. The use of sustainable or renewable ventilation and internal climate control systems are highly recommended if available on site and cost-effective compared to other systems. Economical occupant's behavior in using these systems is a beneficial addition to the total reduction of energy but since it's not entirely under the researcher or designer control. It's highly recommended to install controllers and sensors that regulate the cooling and heating process according to the occupancy of spaces.

2.2.2 Envelope energy efficient measures

Building envelope is considered one of the most important and feasible parameter to be improved in order to reduce the demand energy for heating and cooling and it's one of the easiest passive strategies to be simulated, forecasted and applied by designers during the initial building design stages. Most of the studies and research papers tend to reduce the U-values of all envelope parameters to ensure lower heat transfer rates in hot climates or reduce heat escape in cold climates.

Pescaru, Baran and Dumitrescu (2014) studied three public buildings in Romania and applied several energy reduction measures to the buildings envelopes. The study simulated the results of such strategies on the total building consumption to reach a NZEB. One of the measures was proposing the introduction of different insulating materials to the buildings external walls by adding 200 mm insulating materials made of extruded polystyrene, polyurethane foam, and mineral wool. Using a triple glazing with different gas filled gaps to reduce the U-value of the glazing was also one of the strategies. In addition to insulating the roof and ground slab. The study didn't mention the exact U-value of the walls before and after the introduction of the insulation material but rather noted a noticeable decrease in energy demand for the buildings by approx. 35 to 71 percent. The study concluded that passive measures to the building envelope will definitely reduce the energy demand. However, it needs to be combined with other renewable energy source and heating system enhancement in order to reach to the required near zero energy building.

(A) External walls U-value

Congedo et al. (2016) used two reference schools in Italy as case studies for achieving NZEB using simulation method by testing different elements efficiency improvement. The first school had several external walls thickness with U-value varies between 3.1 W/m^{2}K for 200 mm walls and 1.38 W/m^{2}K for 800 mm walls. The second school had a 300 mm wall with U-value of 1.37 W/m^{2}K. after testing different combinations the study was able to achieve 84 percent saving of the primary energy power and 82 percent carbon dioxide emission reduction compared to the first reference school. While the second reference school was able to achieve between 58 to 73 percent reduction in energy depending on the season. Both options found that the best external wall insulation is 60 mm hemp fiber panels which has an average transmittance value of 0.33 W/m^{2}K. Lower U-values were used by Kurnitski et al. (2013) in their four buildings simulation in Estonia using IDA-ICE simulation tool. The study used 200 mm thick Light Weight Aerated (LWA) block external walls with EPS insulation. The insulation thicknesses of 15, 20, 25, and 35 cm which is reflected into total wall U-values of 0.23, 0.17, 0.14, and 0.1 W/m^{2}K respectively. With combining other NZEB tactics the goal of reaching NZEB was achieved for all four options. However, the study didn't show the reduction resulted from wall insulation separately since the study was focused on the cost optimal solution for NZEB. It was highlighted that it's costlier to use insulation for a smaller residential building than a bigger public or office building when comparing the price with the square meter area of the building.

A different study was targeting a near zero energy building in Estonia in the value engineering stage for an office building with three floors and one basement. One of the envelope improvement methods was by increasing the insulation thickness. This resulted in U-values varying from 0.19 W/m^{2}K to 0.07 W/m^{2}K. The study showed that increasing the insulation thickness helped preserving the rooms' heat in unoccupied hours, but it had a reversed effect for warmer rooms as it showed an overheating of these rooms as high as 60 percent (Thalfeldt, Kurnitski & Mikola 2013). Mohamed, Hasan and Siren (2014) study of both standard and passive houses in Helsinki showed external walls U-values of 0.169 W/m^{2}K and 0.074 W/m^{2}K for standard and passive houses respectively. Their results showed similarity with the Estonian study above as the NZEB was achieved in all four aspects which are site, primary energy, emission and cost. It was still a concern that increasing the insulation and energy demand in colder climates could have a reversed effect in some cases, this is due to trapped solar heat in spaces or lost energy due to Primary Energy (PE) required power for heating which is not compatible with small individual houses.

The 6 wall types studied by Ascione et al. (2016) had U-values ranging between 0.312 W/m^{2}K and 0.286 W/m^{2}K.Tthe simulation results showed that a minimum of 15cm of EPS insulation is needed to reach the optimal external wall U-value of 0.13 W/m^{2}K in winter. U-value of 0.20 W/m^{2}K was used in summer with an average for both seasons as 0.18 W/m^{2}K for Madrid case study. The other three cases in Naples, Nice and Athens required lower average U-value of 0.16 W/m^{2}K for external walls. Kamenders et al. (2014) building optimization study in Latvia used external wall U-value of 0.06 W/m^{2}K instead of the initial design of 0.291 W/m^{2}K. The insulation material and thickness were not mentioned in the paper neither the energy reduction from improving this parameter individually. Kang (2016) showed the results of optimizing the U-value from the designer's preference of 0.27 W/m^{2}K to 0.09 W/m^{2}K which has a higher initial cost. When combined with other factors it showed a reduction of the running cost over 40 years by around sixty percent and a reduction of the life cycle cost by 35 percent.

All the mentioned studies showed that a well-studied reduction in external walls U-value will impact the energy demand directly and the reduction will be beneficial to the total consumed energy throughout the building life span. in colder climates the insulation must be studied against both summer and winter periods separately to avoid any excess use of energy due to overheating of spaces. As shown in Table 2.1, the lowest U-value of 0.06 W/m^{2}K was tested by Kamenders et al. (2014) however the energy reduction due to walls efficiency improvement was not mentioned in the paper.

Table 2.1: External walls U-value studies comparison

Study	Lowest U-value used (W/m^{2}K)	Insulation material	Energy Reduction (%)
Congedo et al. (2016)	0.33	60 mm hemp fiber panels	84% PE
Kurnitski et al. (2013)	0.1	35 cm EPS	Not mentioned
Thalfeldt, Kurnitski & Mikola (2013)	0.07	Not mentioned	Not mentioned
Mohamed, Hasan and Siren (2014)	0.074	Not mentioned	Not mentioned
Ascione et al. (2016)	0.13	15 cm EPS	Not mentioned
Kamenders et al. (2014)	0.06	Not mentioned	Not mentioned
Kang (2016)	0.09	Not mentioned	Not mentioned

(B) Roof and Ground U-value

Roof and ground slab insulation are usually improved in most of the researches aimed to reach with case studies to a near or net-zero energy buildings. Although the ground slab insulation is not usually given the bigger focus since it has to be insulated as a common practice to avoid the penetration of ground water. Ground slab close proximity to the original site level allows the filling soil to provide the needed protection from external temperature fluctuations. The roof is usually the most part of the building exposed to sun, snow and rain which impacts the spaces under the roof directly if not well insulated.

The same studies investigated in the wall U-value parameter improved the roof insulation and accordingly the U-value. Kurnitski et al. (2013) simulation of four cases for office building in Estonia investigated 4 different roof and ground floor scenarios. Using 250, 320, 500 and 800 mm mineral wool insulation for the roof resulting in U-values of 0.18, 0.14, 0.09 and 0.06 W/m^{2}K. The same U-values were achieved for the four cases at the ground level by using 180, 250, 450 and 700 mm EPS insulation. Combined with other energy efficiency measures NZEB were achieved for the four options despite some of the options not being cost effective.

The Finnish standard and passive houses used U-values for roof as 0.09 W/m^{2}K and 0.065 W/m^{2}K. ground level values were set at 0.16 W/m^{2}K and 0.07 W/m^{2}K respectively. This resulted in reduction of the total energy and achievement of the four NZEB aspects as mentioned previously (Mohamed, Hasan & Siren 2014).

Ascione et al. (2016) study improved the two initial roof layers which had U-values of 0.26 and 0.27 W/m^{2}K. Adding insulation of 200 mm EPS resulted in U-value reduction to reach approximately 0.16 W/m^{2}K. The Latvian improved house by Kamenders et al. (2014) defined the roof U-value as 0.05 W/m^{2}K down from 0.194 W/m^{2}K and ground floor U-value as 0.1 W/m^{2}K down from 0.242 W/m^{2}K. Congedo et al. (2016) two reference school buildings had a roof U-value of 1.76 W/m^{2}K and 1.66 W/m^{2}K and ground level U-values of 1.30 W/m^{2}K and 1.12 1.66 W/m^{2}K respectively, while many parameters were improved which resulted in 288 possible combinations the study did not mention any improvement of the roof or ground insulation and it focused only on walls and windows. Similarly, in Kangs' (2016) study of 153 office buildings he stated that Roof U-values ranged between 0.56 W/m^{2}K to 0.15 W/m^{2}K and Ground floor thermal index was measured between 0.69 W/m^{2}K and 0.19 W/m^{2}K but the cases chosen to be studied (A and B) did not mentioned any roof or ground U-value improvements.

A different study by Gagliano et al. (2017) suggested the improvement of roof insulation from U-value of 0.41 W/m^{2}K to 0.20 W/m^{2}K by adding only six centimeters of thermal insulation and the introduction of green roof as shown in Figure 2.1

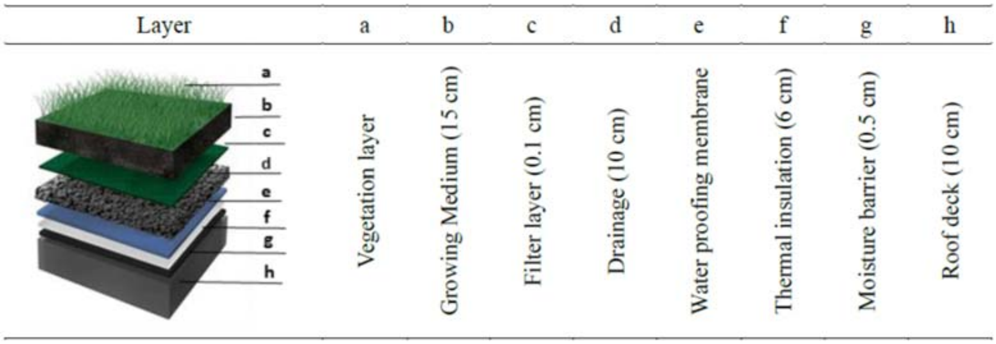


Figure 2.1 Green Roof Features (Gagliano et al., 2017)

which serves the two purposes which are thermal conductivity reduction and lower CO2 emissions through the vegetation layer photosynthesis process, it was also highlighted that the soil layer protects the roof from outdoor temperature fluctuations due to high soil and water absorbance and storage of heat (Gagliano et al. 2017). The use of green roofs studied by different authors in several studies. However, due to the case study of this dissertation being in hot climate this improvement measure will not be considered as an option. This due to the high water usage needed for irrigation and the need of roof area for AC machines and PV panels.

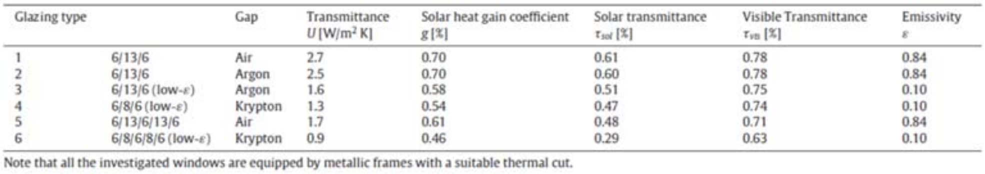
(C) Glazing U-value

Improvement of windows and glazing U-value is very essential to the energy saving process for NZEB. The glass transparency allows more sun radiation inside spaces. The improvement of this element of buildings plays a great factor in the reduction of building energy demand especially with buildings that have a high glass to wall ratio.

Buonomano et al. (2016) investigated 6 types of glazing in his study of a non-residential building located in southern Europe with Mediterranean climate. As shown in Table 2.2 the types range between double and triple glazing with different filled gaps such as air, argon and krypton with some options using a low-e pane. It was also mentioned that the windows simulated had metallic frame with suitable thermal cut. The U-values ranged between 2.7 W/m^{2}K for the regular 6+13+6 mm air filled gap to 0.9 W/m^{2}K for the 6+8+6+8+6 krypton filled gaps and one low-e pane.

The results of the study stated that for some areas the option with 1.6 W/m^{2}K argon filled gaps glazing was adequate. While the lowest U-value glazing of 0.9 W/m^{2}K had to be used for all the other areas to achieve the required energy saving aim.

Table 2.2: Investigated Glazing types (Buonomano et al., 2016)

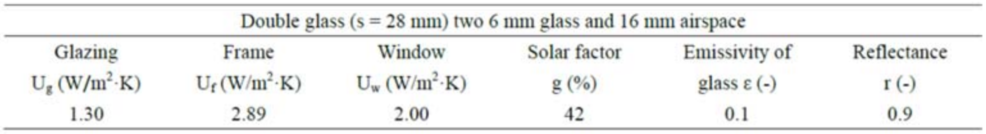


Glazing type		Gap	Transmittance U [W/m^2 K]	Solar heat gain coefficient g [%]	Solar transmittance τ_{sol} [%]	Visible Transmittance τ_{vis} [%]	Emissivity ε
1	6/13/6	Air	2.7	0.70	0.61	0.78	0.84
2	6/13/6	Argon	2.5	0.70	0.60	0.78	0.84
3	6/13/6 (low-ε)	Argon	1.6	0.58	0.51	0.75	0.10
4	6/8/6 (low-ε)	Krypton	1.3	0.54	0.47	0.74	0.10
5	6/13/6/13/6	Air	1.7	0.61	0.48	0.71	0.84
6	6/8/6/8/6 (low-ε)	Krypton	0.9	0.46	0.29	0.63	0.10

Note that all the investigated windows are equipped by metallic frames with a suitable thermal cut.

Gagliano et al. (2017) analysis of energy efficiency towards a NZEB for an existing building addressed the windows energy efficiency by replacing the windows in the simulated model to 6 mm double pane glass with 12 mm air gap and aluminum frame. This combination reduced the U-value of the window to 2.00 W/m^{2}K instead of the existing 3.16 W/m^{2}K as shown in Table 2.3.

Table 2.3: Low-E Windows Features (Gagliano et al., 2017)



Double glass (s = 28 mm) two 6 mm glass and 16 mm airspace					
Glazing U_g (W/m^2·K)	Frame U_f (W/m^2·K)	Window U_w (W/m^2·K)	Solar factor g (%)	Emissivity of glass ε (-)	Reflectance r (-)
1.30	2.89	2.00	42	0.1	0.9

The study found that the strategies used to improve different parameters of the building envelope helped reduce the building energy demand dramatically. It was mentioned that the low-e windows introduced helped reducing the required cooling load by 50% during the cooling season. However, it was highlighted that more measures were required to achieve the NZEB goal. Kang (2016) investigated windows U-values between 1.00 W/m^{2}K and 1.72 W/m^{2}K instead of the baseline model which had windows U-value of 2.1 W/m^{2}K. Kamenders (2014) reduced the windows U-value to 0.8 W/m^{2}K instead of 1.745 W/m^{2}K. While Ascione et al. (2016) studied 7 different types of windows with U-values as shown in ranging between 2.55 to 0.81 W/m^{2}K. All the mentioned U-values contributed in a noticeable energy savings when implemented with other different approaches as discussed in the previous section of NZEB studies review.

Almost all the studies that investigate the possibility of reaching a near or net-zero energy building use the approach of reducing the envelope thermal conductivity and subsequently the energy demand required for the building heating or cooling. These parameters vary between climates depending on the need for lower temperatures inside the spaces in warmer climates where reflective low-e and lower U-value glazing is used. In colder climates where the window insulation degree required to be adequate according to outdoor temperatures but still allows for the sun to enter the spaces and provides warmer temperatures indoors.

(D) Air tightness and infiltration

Air tightness is a very important factor for building energy saving and to avoid loss of energy due to poor construction work and insulation installation poor practices. Air tightness of the investigated house in Latvia was measured with the help of a door blower which helps calculate the indoor and outdoor pressure difference, the study suggested that in order to reach the NZEB the air tightness or air change rate measured at 50 Pa (n_{50}) recommended to be less than 0.41 h^{-1}, which is calculated by dividing the building volume in m^3 by the fan output in m^3/h (Kamenders et al. 2014).

One of the elements which were improved by Mohamed, Hasan and Siren (2014) in their study of a standard and a passive example houses in Finland was air tightness which was valued at 2.0 h^{-1} in the standard house and 0.6 h^{-1} in the passive house when measured at a pressure of 50 Pa.

Kang (2016) improved the air tightness for the optimized model to reach 0.5 h^{-1} compared to the proposed model by designers which had a value of 2.0 h^{-1}.

Study of Ecoterra house measured the airtightness of the house as 0.85 at 50 Pa, when compared with a standard Canadian house it was noted that Ecoterra used 12.4 percent of the standard house and the study highlighted that standard houses require envelope enhancements especially with regards to air tightness.

2.2.3 Internal Lighting Improvement

Five percent of Europe's residential buildings energy is consumed by lighting while non-residential buildings consume four percent of the total buildings energy (Capros et al. 2008, cited in Balaras & Dascalaki 2011).

Kang (2016) study took into consideration the lighting fixtures improvement, in the baseline model the lighting energy was rated at 15.1Watt per square meter. The study proposed replacing the traditional lights with LED lights which had an energy consumption of 7 watt per square meter. This resulted in increment of the cost by 300 thousand won per square meter but a reduction in the energy cost by the same figure which accordingly resulted in a reduction of the operation cost by sixty percent over the building life span of 40 years.

Badea et al. (2016) stated that the lighting configuration for the building studied in the process of reaching NZEB through introducing renewable energy was 1,68 kWh/m^2 annually which falls within the Romanian guidelines for NZEB. However, the type of lighting used was not mentioned in the paper.

Electric consumption of lighting for the standard and passive houses were not changed in study and was rated as 7.01 kWh per meter square annually for each house (Mohamed, Hasan & Siren 2014), while Ascione et al. (2016) simulated house defined the lighting consumption as 3.5 watt per square meter.

The mentioned studies show that the energy demand of buildings could be reduce slightly by using more efficient lighting appliances which helps reducing the required output by the renewable energy source in order to achieve a net zero energy building, A light-emitting diode LED light fixtures are usually used to reduce the running energy consumption instead of traditional halogen lights and the slightly more efficient Compact Florescent Lamp CFL fixtures.

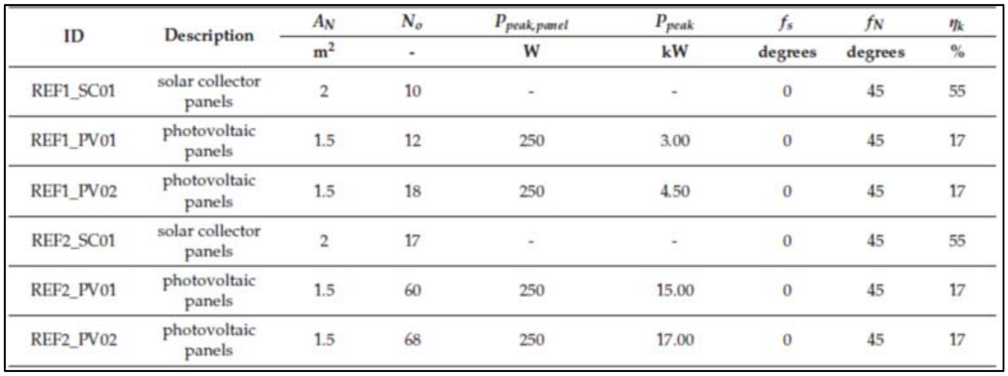
2.2.4 Renewable energy (PV Panels & Wind Turbines)

In the process of developing more efficient buildings towards a near and net zero energy buildings most researchers took steps to improve the building envelope and systems to reduce the total energy required to sustain the building. All these improvements are considered as passive design measures combined with lighting improvement. However, it cannot sustain the building on its own, in order to cover the electricity required for lighting, heating and cooling, and equipment many studies looked at the introduction of a renewable energy source such as photovoltaic panels, domestic wind turbines, or harvesting the geothermal energy.

In the study of Pescaru, Baran and Dumitrescu (2014) for three educational buildings studied the placement of PV panels on all solid areas of building's façade and compared the energy output of the PV panels against the 3 buildings demand after improving their envelopes, the buildings had an average available areas of around 1900 square meters each that generated annually around 75,000 KWh which was not enough to cover the buildings electricity needed for heating and some buildings was reported to require around 287,000 KWh additional power in order to for the renewable energy to cancel the demand energy.

Another research by Congedo et al. (2016) for the efficient solutions of 2 existing schools in Italy simulated several types of PV panels as shown in Table 2.4, for the first school it was found the best reduction of 84 percent in PE energy was achieved when using eighteen panels of PV panels REF-PV02 shown in the table which had a peak power of 4.5 KW and efficiency of seventeen percent, the second school required sixty eight panels from REF2-PV02 to achieve energy reduction between 73 and 58 percent in winter and summer respectively.

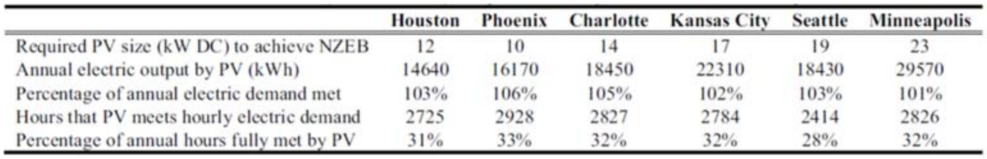
Table 2.4: PV panels variables (Congedo et al., 2016)



ID	Description	A_N	N_o	$P_{peak,panel}$	P_{peak}	f_s	f_N	η_k
		m^2	-	W	kW	degrees	degrees	%
REF1_SC01	solar collector panels	2	10	-	-	0	45	55
REF1_PV01	photovoltaic panels	1.5	12	250	3.00	0	45	17
REF1_PV02	photovoltaic panels	1.5	18	250	4.50	0	45	17
REF2_SC01	solar collector panels	2	17	-	-	0	45	55
REF2_PV01	photovoltaic panels	1.5	60	250	15.00	0	45	17
REF2_PV02	photovoltaic panels	1.5	68	250	17.00	0	45	17

Stephens (2011) used PV panels to meet the required electric demand of a residential building simulated in six cities in the United States, as shown in Table 2.5 all buildings where able to demand electricity needs by using different PV panels capacity for each city, it was found that Phoenix city required the smallest system with ten kilo watt DC while the highest demand was found in Minneapolis requiring twenty three kilo watt DC, annual hours of electricity need covered by using PV panels weighed around one third of the total hourly electricity for all buildings.

Table 2.5 PV Panels Simulation Summary (Stephens, 2011)



	Houston	Phoenix	Charlotte	Kansas City	Seattle	Minneapolis
Required PV size (kW DC) to achieve NZEB	12	10	14	17	19	23
Annual electric output by PV (kWh)	14640	16170	18450	22310	18430	29570
Percentage of annual electric demand met	103%	106%	105%	102%	103%	101%
Hours that PV meets hourly electric demand	2725	2928	2827	2784	2414	2826
Percentage of annual hours fully met by PV	31%	33%	32%	32%	28%	32%

Badea et al. (2016) studies the wind and solar characteristics of 3 cities in Romania and simulated the installation of two renewable energy systems which are PV panels with 280-watt peak and wind turbine that generates 3260 watts at wind speed of fourteen meter per second, the two systems were packed up with a battery and inverter to switch between systems and reserve energy in the proposed battery to be used during low energy production and high demand periods.

It was stated that for site number 1 the PV panels generated 63.62 percent of the required energy while wind turbine generated 36.38 percent, site number 2 had more sustained wind speed which generated 78.73 percent of the required power and the remaining power was covered by PV panels while the third site had the most suitable wind configurations which resulted in the generation of 90% of the energy and the remaining ten percent was covered by the photovoltaic panels.

The mentioned studies shows that the initial research of the building location to determine the potential renewable energy source is vital to the success of producing enough energy that meets the building demand after applying the suitable passive efficiency measures and accordingly the renewable energy system capacity selection could be determined through the simulations of the possible options and comparing it to other solutions taking into consideration the initial cost, life cycle cost and running cost savings.

2.2.5 Shading Elements

External and internal shading devices or structural elements are usually integrated into the design of the building to obstruct the sun rays from entering the buildings in warmer climates, such elements usually helps reducing the internal temperatures in spaces where cooling is needed and eventually the reduction of the energy required by mechanical systems to stabilize the buildings' internal temperature, shading elements are usually placed above the glazed areas of the southern façades in the northern hemisphere and over the glazed areas of northern facades in the southern hemisphere.

Some designers use natural elements like trees and other façade planted plants to reduce the solar effect and provide a natural feeling around the building.

It was stated that the use of algorithm controlled automated shading devices can help lower the site consumption by around 11.6 to 13 percent (Amaral et al. 2016, cited in Ascione et al. 2016)

Kang (2016) argued that introducing shading elements to the building exterior has different results in different climates as it reduces the cooling energy demand in summer and warm climates but could cause a reversed effect in winter or in colder climates where direct solar heating is required, and such elements may increase the heating energy and cost.

Al-Sallal (2010) study of schools in the UAE reviewed several solar shading technics such as eternal shading elements, internal shadings, and natural trees and plants used as shading elements which usually protects the inner spaces from direct sun light and glare by scattering the light and provides more uniform lighting for classes, it was suggested that solar shading should be taken in consideration in school buildings since many schools in the UAE use large areas of glazed facades which requires more cooling systems energy.

Ascione et al. (2016) simulation variables investigated different types of external shading and internal window blinds which are the use of no shading, projection between half to one and a half meters, and overhang between half and two meters while window blinds options were medium reflectivity slats, shade roll with medium obstructiveness, and medium weaved drapes. The study found that there was reduction in energy in using all types of shadings and different options had better results in different climates and the use of external shading is one of the final recommendations of the research for the development of NZEB. It was also Recommended by Kamenders et al. (2014) that cheaper automated shading systems to be researched in Lativa to provide cost effective net zero energy buildings.

2.2.6 Other energy efficient measures

Other energy reduction methods were reviewed and used in some studies such as Solar Water Heating which helps reduce the energy needed for heated water and commonly used in buildings that don't require large amounts of hot water consumption due to the large size of the roof panels.

Phase Changing Materials PCM are used sometimes as a coating for walls where the heat is absorbed by such material and stored in the form of changing the phase of material instead of being conducted to inner spaces which helps reduce the temperature fluctuation inside spaces.

Solar collectors are used in some studies to heat the building indoor directly with the help of solar energy.

Building orientation is a highly recommended factor to be investigated during the concept design of any project to avoid any unnecessary energy losses due to ineffective glazing orientation and solar shading location.

To achieve a comprehensive NZEB, it is highly important to select the energy efficient measures that suits the needs of the building taking into consideration building location, climate, availability of products, cost effectiveness, durability and running cost.

CHAPTER 3: METHODOLOGY

3.1 Research Methodologies

Research methodology is a set of practices and procedures which are used to interpret and solve the problems of a particular research, this is achieved by identifying the problems and challenges of the researched subject and accordingly follow certain steps to solve them and reach the research goal. This chapter describes briefly the types of methodologies used to achieve NZEB, and also highlights each methodology's advantages and disadvantages in order to select the best suitable methodology for this dissertation.

3.1.1 Computer simulation method

Computer simulating software provide many possibilities when predicting buildings behavior with the liberty of changing all needed parameters to find the best solution with low cost equipment needed to perform such simulations, weather data can also be selected according to the location intended to be simulated, weather data is an average weather parameter of the selected location over the period of many years which helps the simulation tool to predict more accurately.

A case study of 3 story commercial building was modeled and simulated for energy analysis in eight different cities covering all different climates in the US, the building components and its specifications were entered to the simulation software to simulate the buildings' heat gain from external weather factors as well as internal lighting, equipment and occupants heat gain, by using Energyplus software the study was able to investigate the concept of Inter-Building Effect (IBE) and the effects of shading and reflection on the cooling and heating loads (Han, Taylor & Pisello 2017). Energyplus was also used by Kang (2017) in his simulation of 153 office buildings in Seoul to determine the most important variables of the design, 81 models were simulated and accordingly the results analysis was done using a statistical model, this allowed the author to provide a basic early decision-making tool in concept design stages that helps architects in Korea chose building variables that achieve minimum and optimal energy efficiency. Kamenders et al. (2014) used Passive House Planning Package (PHPP) energy calculation program to reduce the building energy losses and increase its efficiency while replacing the needed consumption energy with a renewable energy form. Transient System Simulation

Tool (TRNSYS) was used to simulate the energy consumption of the proposed modifications to the building to reduce its energy consumption by applying energy efficiency measures to its envelope and was able to achieve the first NZEB house in Latvia using these passive strategies.

Other researchers used different simulation tools such as modeFrontier, MatLab and IES VE which is usually selected depending on its capacity to apply the required research parameters as well as the ease of obtaining and using such software by the authors.

Advantages of using computer simulation tools:

- Reduces the investigation time and can predict situations and factors that take place over several months or years.
- Could simulate scenarios that might be dangerous if applied in reality.
- No physical models are required.
- Can simulate complex systems that might be hard to investigate in reality.
- The ability to change the different parameters with different scenarios and locations if required.
- Results could be obtained and analyzed instantly.

Disadvantages of using simulation tools:

- Computer programs cannot be accurate and does not predict random or unexpected events.
- Some functions or data analysis may cause inaccurate results, mostly due to data entry and in rare cases due to software issues.
- Large scale simulations and complex simulations may require higher computation processors and might be costly, simplifying models to reduce the simulation time or cost might also affect the results accuracy.

3.1.2 Field measurements method

In addition to energy analysis using simulation tools Kamenders et al. (2014) have also used field measurement to monitor actual building performance with regards to air tightness through door blower test, internal spaces air temperatures, external air temperature, humidity in selected spaces, bedrooms carbon dioxide levels, and heat consumption which enabled the researchers to confirm or deny the simulations results when compared to actual measurements.

Mohamed, Hasan and Siren (2014) simulated different parameters to achieve a NZEB in Finland. However, occupancy profile, lighting loads and density, equipment power, and domestic water heating for the tested buildings were all measured in detail as a part of a renewable energy target project conducted by VTT research center in 2005.

In Doiron (2011) study to find the lessons learned from NZEB, a comparison between the NZEB house named ÉcoTerra and different typically found houses in Canada, more than 150 sensors were installed in the NZEB house to monitor and collect data of temperatures, energy consumption, solar radiation, etc. The collected data is stored automatically, and the annual results compared to regular Canadian houses to show the massive reduction in energy with the NZEB case.

Such method is very useful in terms of providing actual values of the investigated parameters and it’s required when constructing any building to evaluate its energy consumption. however, field measurements require expensive equipment in many cases and some measurements need to be taken over a long period of time to ensure the validity of results in different seasons.

Advantages of using field measurements method:

- It provides accurate actual results for the studied subject.
- Reliable results which represents and take into account the complexity and variation of parameters with relation to the studied environment.
- Many field measurements don’t require highly skilled staff and could be monitored remotely in some cases.

Disadvantages of using field measurements method:

- Hard to control variables.
- For some measurements access to certain places might be hard or even restricted.
- Some measurements need to take place over several months or years.
- In some experiments, expensive equipment must be purchased according to the tested parameter.

3.1.3 Literature review comparison method

Literature review is the study of different researches, articles and journal papers of the same investigated subject. Through reading and summarizing the paper aims, steps taken to achieve the required goals, and the final study conclusion. Most of studies refer to others pervious works to have a solid base of their research and either compare, validate, contradict, or find new aspects of the same researched subject.

Friess and Rakhshan (2017) compared several studies through literature review to find the best passive envelope energy efficient measures to improve buildings' energy in the UAE. Several aspects where compared which are energy efficient regulations, building orientation and layout, wall and roof treatment, wall and roof solar absorption, windows efficiency, natural ventilation and occupant's behavior. The study concluded that passive energy saving measures can reduce the buildings energy consumption significantly in the UAE. Passive measures were also investigated in Ascione et al. (2016) study by analyzing previous studies and their approaches. The paper also addressed the NZEB standards in Mediterranean climate through literature review. According to the findings from his review the passive measures were applied to a case study for performance analysis.

The same approach was taken by Buonomano et al. (2016) in the case study analysis of a non-residential building in Mediterranean climate. Papers studied as a part of the literature review to find the materials and renewable energy systems used in other studies and accordingly applying them to the case study.

Comparing different studies through literature review is very useful to determine which parameters are agreed on and which need more investigation, the only issue that might face the researcher in using such method is the lack of previous studies in the same subject and this usually is the case when studying new ideas and innovative technologies.

Advantages of Literature review comparison method:

- Identifying the issues faced in previous similar works.
- Identifying different approaches used by other authors for the same studied subject.

- Validation of information by comparing the conclusions and results similarities.

Disadvantages of Literature review comparison method:

- Availability of different sources for the same studied subject.
- This method could be expensive if free access is not available for the researcher.
- The results of different researches might not apply in all cases, changing one of the parameters studied might affect the overall results.

3.1.4 Field survey method

Commonly used to measure users and occupant's satisfaction of certain elements, survey method requires specific questionnaire to be distributed among random or selected category of people with different satisfaction scale set to measure each questions' response and according to the results analysis certain points could be highlighted to improve the quality of the subject investigated.

Dabaieh, Makhlouf and Hosny (2015) investigated occupant's satisfaction after installing PV panels in 2 remote villages in Egypt, analysis of the survey results showed that 2 thirds of the survey participants gave a positive feedback regarding the installed panels and preferred having a reliable energy source to cover the unreliable electricity grid. Lenoir, Garde and Wurtz (2011) study and feedback of the first 3 NZEB buildings in France monitored and surveyed occupants' feedback. Overall satisfaction of the design and thermal comfort was recorded through a survey over 2 years, mainly in hot months. As a total of more than 2000 questionnaires were completed by 600 users of the building.

Unlike the simulation method, this method could be used mainly after applying some physical measures related to a specific subject, but it's not expected to predict future expectations or results since it's only tested by users only after the implementation and usage.

Advantages of field survey method:

- Allows for large population opinion or experience data gathering.
- Some surveying methods such as online surveys could be relatively cheap and fast.

- Convenient, if done online.
- Provides average statistics and neglects odd results.

Disadvantages of field survey method:

- Not flexible enough to provide complex data with large amount of variables.
- Questions are standardized and mostly simple and general which cannot investigate detailed subject that might be too complicated for some participants.
- Some participants might react differently due to their knowledge that they are part of an experiment.

3.1.5 Selected Methodology

After reviewing different methodologies types through literature review analysis and comparing the methods used in previous researches, it was found that the most suitable approach for this dissertation is by using a simulation tool. Simulation method will help test and find the results of using different passive and active energy efficiency measures to a case study building towards reaching net zero energy building.

The simulation method was chosen due to the following positive factors:

- The ability to model and test existing or hypothetical buildings against different NZEB parameters.
- Ease of testing multiple variables in the same model which will not be possible through other methodologies.
- Outdoor weather parameters can be obtained for many cities around the world.
- Simulation method requires shorter time to investigate multiple variables at the same time.
- Low cost since the only required software is the simulation tool and no other measuring instruments need to be bought.
- availability of different simulation tools and ease of finding tutorials if needed.

To tackle simulation software issues, the investigated building model must be simplified which reduces the processing time, unexpected errors and false or inaccurate results. To ensure the validity of the simulated results, a validation model must be simulated and compared to the actual realistic data and become the base of all investigated variables.

3.1.6 Selected Simulation tool

Carwley et al. (2008) Showed in his comparison between different simulation software that IES VE contains all the required features for a successful simulation as highlighted in Table 3.1 and Table 3.2.

Table 3.1 Different simulation tools comparison (Crawley et al., 2008)

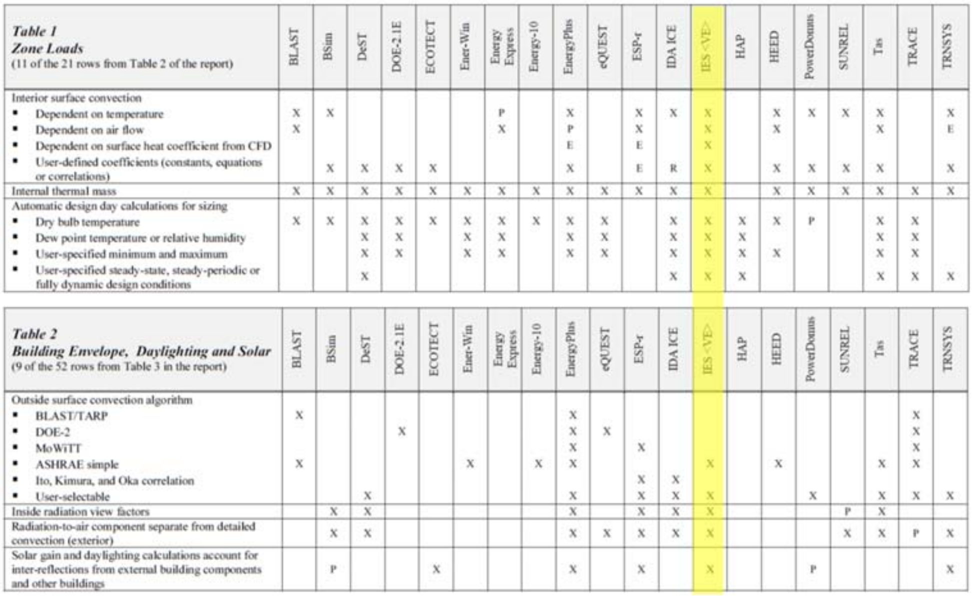


Table 1 ***Zone Loads*** (11 of the 21 rows from Table 2 of the report)	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Interior surface convection																				
▪ Dependent on temperature	X	X					P		X		X	X	X		X	X	X	X		X
▪ Dependent on air flow	X						X		P		X		X		X			X		E
▪ Dependent on surface heat coefficient from CFD									E		E		X							
▪ User-defined coefficients (constants, equations or correlations)		X	X	X	X				X		E	R	X		X	X	X	X		X
Internal thermal mass	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
Automatic design day calculations for sizing																				
▪ Dry bulb temperature	X	X	X	X	X	X	X	X	X	X		X	X	X	X	P		X	X	
▪ Dew point temperature or relative humidity			X	X		X	X		X	X		X	X	X				X	X	
▪ User-specified minimum and maximum			X	X		X	X		X	X		X	X	X	X			X	X	
▪ User-specified steady-state, steady-periodic or fully dynamic design conditions			X									X	X	X				X	X	X

Table 2 ***Building Envelope, Daylighting and Solar*** (9 of the 52 rows from Table 3 in the report)	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Outside surface convection algorithm																				
▪ BLAST/TARP	X								X										X	
▪ DOE-2				X					X	X									X	
▪ MoWiTT									X		X								X	
▪ ASHRAE simple	X					X		X	X				X		X			X	X	
▪ Ito, Kimura, and Oka correlation											X	X								
▪ User-selectable			X						X		X	X	X			X		X	X	X
Inside radiation view factors		X	X						X		X	X	X				P	X		
Radiation-to-air component separate from detailed convection (exterior)		X	X						X	X	X	X	X				X	X	P	X
Solar gain and daylighting calculations account for inter-reflections from external building components and other buildings		P			X				X		X		X			P				X

Table 3.2 Different simulation tools comparison (Crawley et al., 2008)

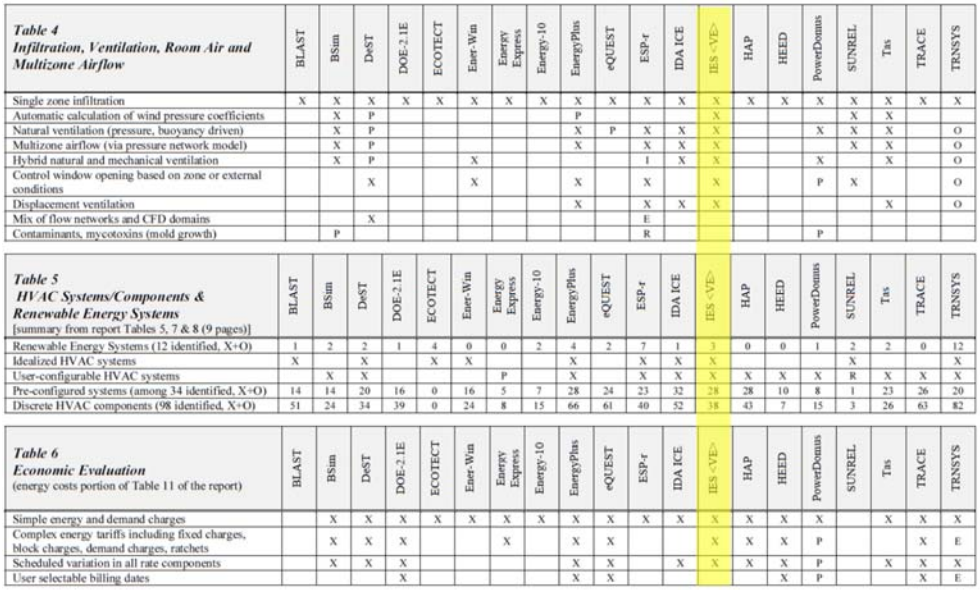


Table 4 ***Infiltration, Ventilation, Room Air and Multizone Airflow***	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Single zone infiltration	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Automatic calculation of wind pressure coefficients		X	P						P				X				X	X		
Natural ventilation (pressure, buoyancy driven)		X	P						X	P	X	X	X			X	X	X		O
Multizone airflow (via pressure network model)		X	P						X		X	X	X				X	X		O
Hybrid natural and mechanical ventilation		X	P			X					I	X	X			X		X		O
Control window opening based on zone or external conditions			X			X			X		X		X			P	X			O
Displacement ventilation									X		X	X	X					X		O
Mix of flow networks and CFD domains			X								E									
Contaminants, mycotoxins (mold growth)		P									R					P				

Table 5 ***HVAC Systems/Components & Renewable Energy Systems*** [summary from report Tables 5, 7 & 8 (9 pages)]	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Renewable Energy Systems (12 identified, X+O)	1	2	2	1	4	0	0	2	4	2	7	1	3	0	0	1	2	2	0	12
Idealized HVAC systems	X		X		X	X			X		X	X	X				X			X
User-configurable HVAC systems		X	X				P		X		X	X	X	X	X	X	R	X	X	X
Pre-configured systems (among 34 identified, X+O)	14	14	20	16	0	16	5	7	28	24	23	32	28	28	10	8	1	23	26	20
Discrete HVAC components (98 identified, X+O)	51	24	34	39	0	24	8	15	66	61	40	52	38	43	7	15	3	26	63	82

Table 6 ***Economic Evaluation*** (energy costs portion of Table 11 of the report)	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Simple energy and demand charges		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
Complex energy tariffs including fixed charges, block charges, demand charges, ratchets		X	X	X			X		X	X			X	X	X	P			X	E
Scheduled variation in all rate components		X	X	X					X	X		X	X	X	X	P		X	X	X
User selectable billing dates				X					X	X					X	P			X	E

IES VE is widely available in the United Arab Emirates and usually used by environmental consultants to simulate the energy analysis required by different authorities, IES VE contains a modelling tools, Thermal analysis tools, HVAC building and simulation tool, Sun cast tool and shading analysis tool, energy analysis tool, and many other features that helps building a model and simulate different parameters to achieve the required goal.

According to all the above reasons and the low cost of obtaining the software for students compared to commercial use, IES VE was selected to be the main simulation tool.

Other validation tools and drafting computer programs such as AutoCAD Architecture, Microsoft Office, and PV simulation tool will be used to demonstrate and analyze different aspects of this study.

The following steps will be taken as a part of transforming a residential villa building into a net zero energy building:

- Modeling of exact building rooms with exact HVAC and lighting system in addition to thermal properties of the envelope.
- Validation of the model with the actual energy consumption figures retrieved from the owner.

- Applying passive and active measures to reduce energy consumption and achieve NZEB
- Variable U-values for walls, roof, and windows will be tested to select the most energy efficient envelope combination type.
- Variable HVAC systems will be tested to select the most energy efficient type.
- Lighting options with different energy consumption will be tested and the lowest energy usage type will be selected.
- Shading elements will be added to the building according to the study of building exterior exposure to the sun to reduce the energy required by the building.
- Renewable energy source will be added to cover any remaining energy required by the building.

The study will combine the best results from all different combinations above and try to upgrade the existing villa into a net zero energy building. The possibility of both stand-alone villa that can operate without the use of grid and connected to grid villa option will be investigated.

3.2 NZEB & Green Buildings Codes Review

While there are no NZEB codes or regulations in the UAE yet, other sustainable and green building requirements are implemented and still being updated frequently to improve buildings' energy consumption.

Dubai Municipality latest regulations for green building evaluation system named Al Sa'fat contains seven chapters tackling different aspects of buildings and urban planning issues such as Ecology and planning which regulates the fuel-efficient parking spaces, Urban heat island effect, green roofs, orientation of glazed facades, exterior light pollution, the use of local species, and many other urban planning tactics (DM 2016)

Ventilation and air quality which regulates air quality, ventilation requirements, isolation of pollutant sources, thermal comfort, acoustic comfort, reduction of using hazardous materials, lighting and visual comfort, and construction activities impact (DM 2016)

Resources effectiveness which regulates the envelope performance and regulates the thermal conducting properties of different envelope parameters, and water conservation strategies.

Al Sa'fat evaluation system has 3 rating levels silver, golden and platinum depending on the type of building and the area were the building is constructed (DM 2016)

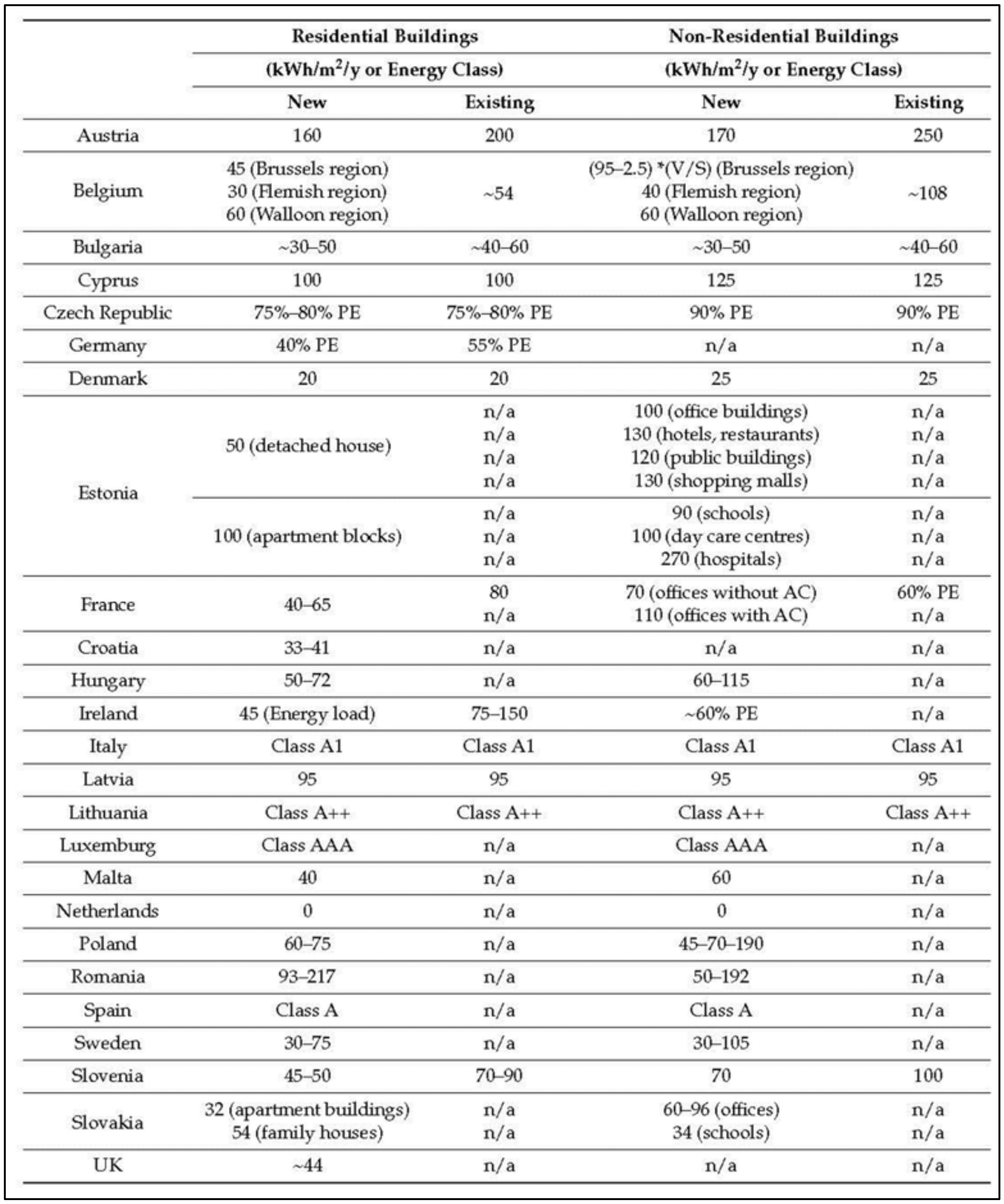
ESTIDAMA pearl rating system was initiated by Abu Dhabi Urban Planning Council (ADUPC) in 2010 to transform Abu Dhabi into a model of sustainable urbanization with the balance of four sustainability pillars: environmental, economic, cultural and social. ADUPC (2010) defined five different pearl ratings for buildings with mandatory and optional credits required for all new buildings. As per ADUPC (2010) all new residential buildings are required to achieve minimum or one pearl rating while governmental buildings are required to achieve minimum of two pearls by applying specific energy and conservations measures during all building stages from development stage through design, construction and operational stages.

Many strategies and regulations considering all buildings and urban planning aspects are detailed in the mentioned rating system for communities, villas and buildings.

Many of the mentioned parameters from both Dubai Municipality and ESTIDAMA rating and evaluation systems will be used in the simulation to compare the effectiveness of such values in the process of reaching net zero energy buildings.

D'Agostino, Zangheri and Castellazzi (2017) showed a comparison between NZEB regulations required in different European countries in relation to residential and non-residential buildings, Table 3.3 shows the performance targets by most European Union members rated by either kWh per square meter annually or percentage of primary energy, the targets are defined for both existing and new buildings while in some countries it's categorized according to the building type. NZEB target are shown in detail in Table 3.3, while it's not mandatory for all buildings to achieve a net zero energy building concept, implementing such guidelines increases the awareness of developers and investors in such energy saving possibilities as well as providing guidance for designers and engineers in design and construction stages.

Table 3.3: Energy requirements defined by EU Member States for NZEB levels (D'Agostino, Zangheri & Castellazzi, 2017)



	Residential Buildings		Non-Residential Buildings	
	($kWh/m^2/y$ or Energy Class)		($kWh/m^2/y$ or Energy Class)	
	New	Existing	New	Existing
Austria	160	200	170	250
Belgium	45 (Brussels region) 30 (Flemish region) 60 (Walloon region)	~54	(95–2.5) *(V/S) (Brussels region) 40 (Flemish region) 60 (Walloon region)	~108
Bulgaria	~30–50	~40–60	~30–50	~40–60
Cyprus	100	100	125	125
Czech Republic	75%–80% PE	75%–80% PE	90% PE	90% PE
Germany	40% PE	55% PE	n/a	n/a
Denmark	20	20	25	25
Estonia	50 (detached house)	n/a n/a n/a n/a	100 (office buildings) 130 (hotels, restaurants) 120 (public buildings) 130 (shopping malls)	n/a n/a n/a n/a
	100 (apartment blocks)	n/a n/a n/a	90 (schools) 100 (day care centres) 270 (hospitals)	n/a n/a n/a
France	40–65	80 n/a	70 (offices without AC) 110 (offices with AC)	60% PE n/a
Croatia	33–41	n/a	n/a	n/a
Hungary	50–72	n/a	60–115	n/a
Ireland	45 (Energy load)	75–150	~60% PE	n/a
Italy	Class A1	Class A1	Class A1	Class A1
Latvia	95	95	95	95
Lithuania	Class A++	Class A++	Class A++	Class A++
Luxemburg	Class AAA	n/a	Class AAA	n/a
Malta	40	n/a	60	n/a
Netherlands	0	n/a	0	n/a
Poland	60–75	n/a	45–70–190	n/a
Romania	93–217	n/a	50–192	n/a
Spain	Class A	n/a	Class A	n/a
Sweden	30–75	n/a	30–105	n/a
Slovenia	45–50	70–90	70	100
Slovakia	32 (apartment buildings) 54 (family houses)	n/a n/a	60–96 (offices) 34 (schools)	n/a n/a
UK	~44	n/a	n/a	n/a

3.3 Case Study Review

A two-story residential villa in Dubai was selected as a base model to be studied for the testing of improving its energy consumption and reach the required net zero energy. This particular villa was chosen due to the following reasons:

- This type of villas is largely used in the UAE, most of the villas are built as a part of a community with few repetitive types and approximately similar areas for the same community, this makes the villa a good example to be tested and the results can be applied on all similar villas of the community.
- The villa was built between 2003 and 2004 before Dubai green buildings regulations were implemented. This is the case for all villas built before 2014 and the results of this case could benefit a large number of existing villas.
- Availability of all Architectural, Structural & MEP drawings from the design consultant (Al Gurg Consultants)
- The owner of the villa archived all electricity bills from August 2016 to September 2017, this means that all the simulation results could be compared to actual recorded data.
- Occupants’ number and behavior was easy to obtain from the owner.

Building details, annual consumption and occupants behavior were collected from the villa’s owner in order to have actual figures as reference for the study.

The villas’ ground floor contains a covered car garage, main lobby, maid’s room with an attached water closet, Guest room with an attached bathroom, living and dining room, family room, kitchen, and a common water closet, store and laundry room covering a total built up area of 145 square meters excluding the 38 square meters garage, Figure 3.1 shows the ground floor plan rooms arrangement with all dimensions in millimeters.

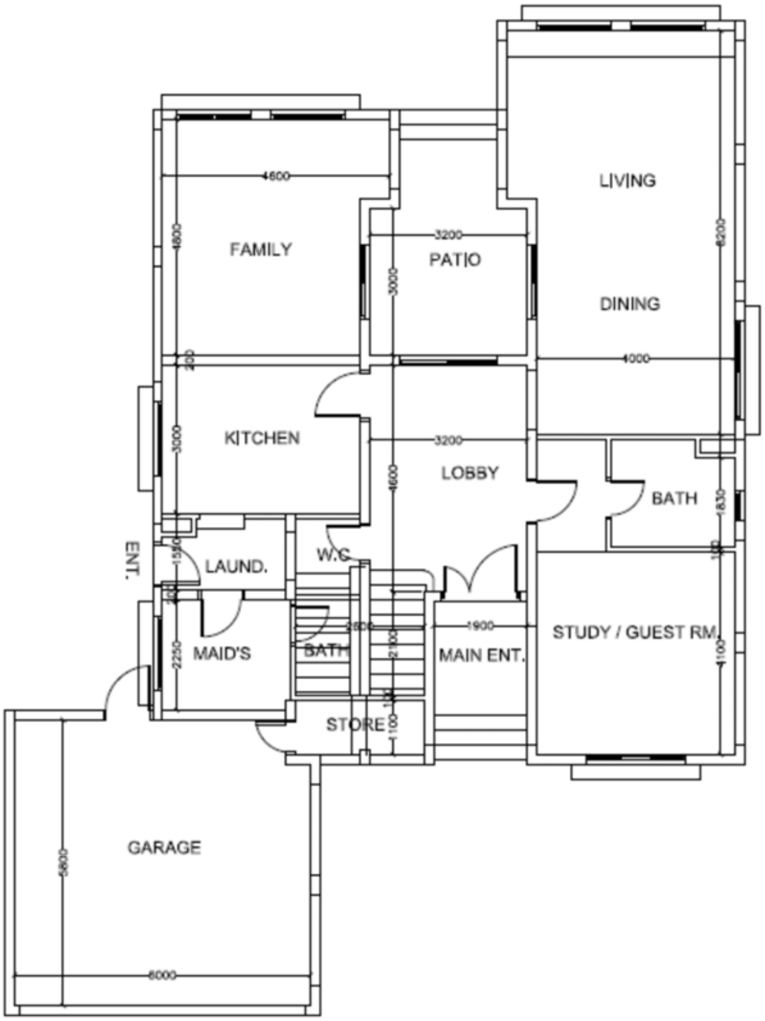


Figure 3.1: Case study villa ground floor plan

The first floor consists of one master bedroom and two other bedrooms with shared bathroom and one storage room, the master bedroom and one of the other rooms are connected to an outdoor terrace, the first-floor total built up area is 128 square meters, first floor plan shown in Figure 3.2 with all dimensions in millimeters.

The building roof contains the HVAC system machines which is covered by an open to sky enclosure.

The total building height is 6.75 meters excluding the roof services and parapet.

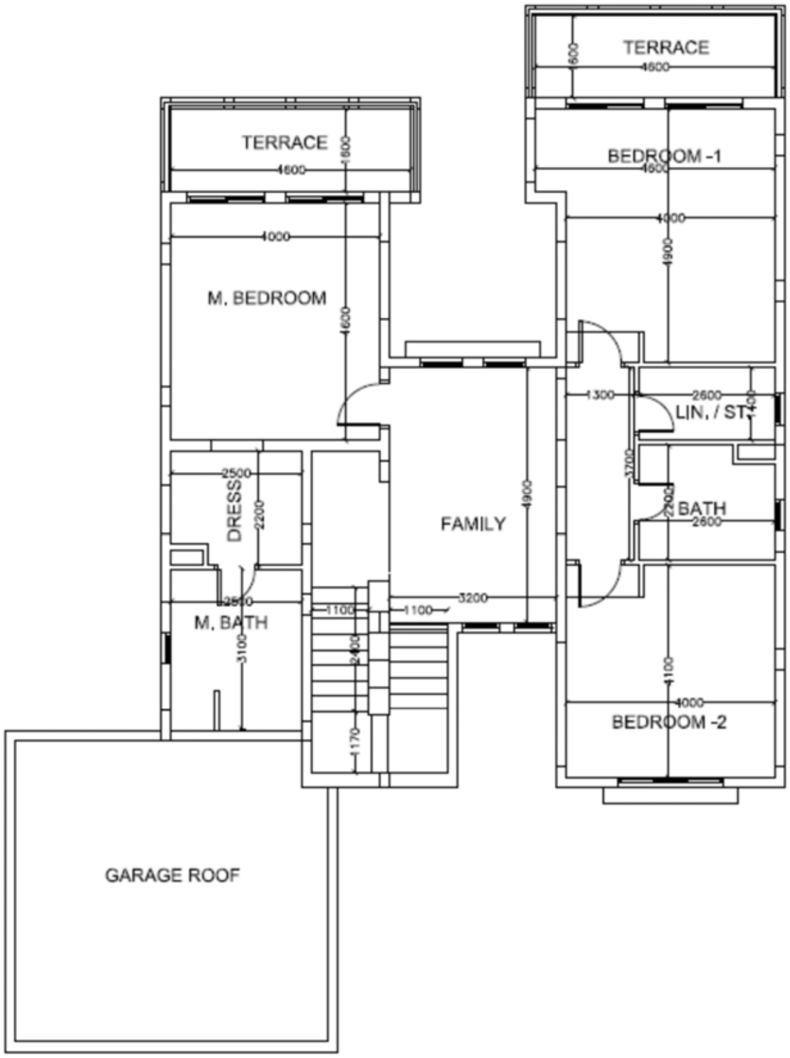


Figure 3.2: Case study villa first floor plan

The villa orientation as shown in the site setting layout Figure 3.3 with a tilt of 33.61 degrees from the north.

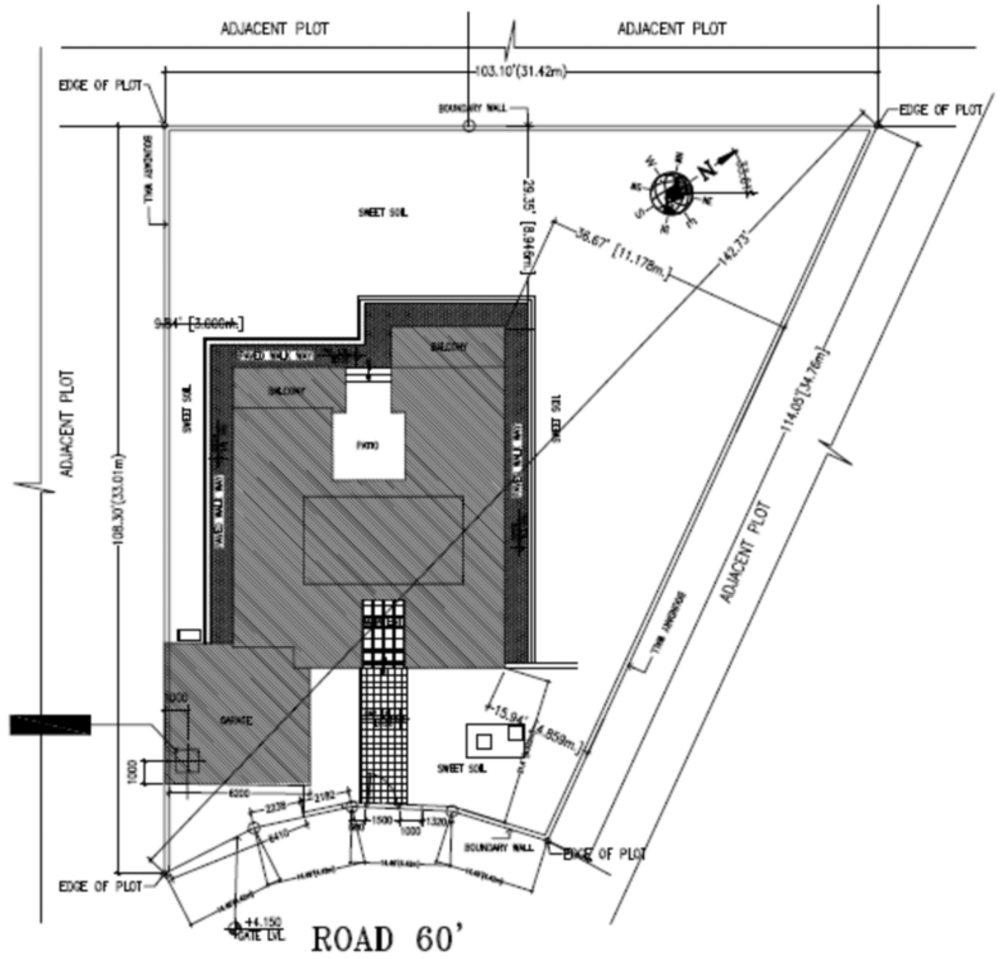


Figure 3.3: Case study site setting layout

The villa is using a combination of CFL and florescent lighting as light fixtures as acquired from the owner and the HVAC system used is a Hitachi DX split ducted HVAC system reference number RPI 8.0FSN3E for the indoor unit and RAS 8HRNSE for the outdoor unit with a coefficient of performance of 2.5 as obtained from the designers of the villa. All architectural, structural, mechanical and electrical drawings were obtained from the villa designer and owner in order to provide accurate measurements and validate the villa performance using the simulation tool IES VE.

The wall sections of the villa show no insulation layers were proposed for the envelope and only insulated blocks are used in some areas, this allows for thermal bridge effect to happen since all structural elements are not thermally protected, the thermal insulation was not introduced to the villa since it was not a mandatory regulation by Dubai Municipality at the time the villa was built in the period between 2003 and 2004. The windows used are double glazed windows with two 6 mm thick panes and 12 mm air gap with a thermal break, Figure 3.4 shows the wall section of the villa and the materials used for the interior and exterior rendering of the building envelope.

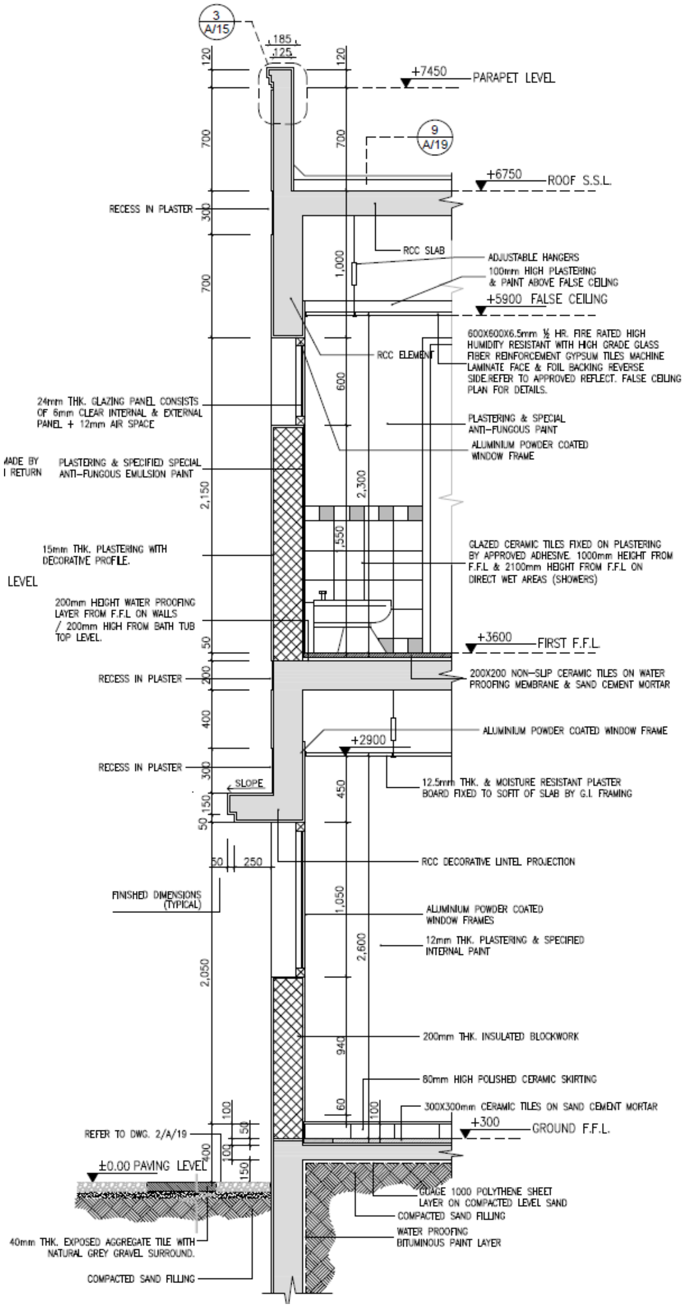


Figure 3.4: Wall section of the case study villa

It was possible to retrieve the monthly electricity consumption loads from the owner as shown in Table 3.4 with a total annual electricity consumption of 60.707 MWh. Table 3.4 shows that summer months are consuming most of the buildings' energy, in June, July, and August the building consumes around 40 % of the total consumed energy annually due to the extreme hot weather condition in Dubai during the summer, while no cooling or heating usually required for the building in winter months which is clear when looking at the difference in consumption figures that dramatically plummeted in winter months.

Table 3.4: Annual electricity consumption of the case study villa

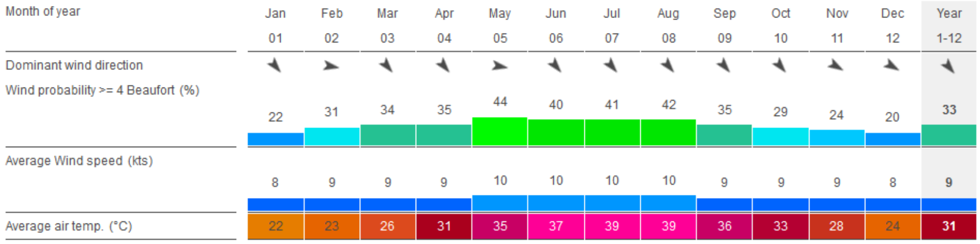
Month	Case study electricity consumption (MWh)
January	2.177
February	1.879
March	2.608
April	4.518
May	6.634
June	7.185
July	9.020
August	8.763
September	6.219
October	5.247
November	3.764
December	2.693
Total Energy	60.707

All the mentioned values in Table 3.4 and building parameters will be modelled and validated in the next chapter and then tested against the improvement parameters intended to reach with the total annual building energy to zero on site and at primary energy source.

3.4 Site Analysis

Dubai is located on the northern west coast of the United Arab Emirates with a longitude of 25°15'47" and Latitude of 55°17'50" with a population of approximately 2.8 million and it's well known for its luxuries sky scrapers.

As shown in Figure 3.5, Dubai Climate is mostly sunny throughout the year with mean annual sunshine hours of 3508 hours which represents around 78 % of the possible sunshine annually according to climatebase (2012) Dubai has high temperatures in the summer with an average of 41°C in the morning and around 30°C in summer nights with high humidity and temperatures could rise up to 50°C in some days of the year, January is the coldest month of the year in Dubai and average temperatures are measured around 25°C in the morning and 14°C at night (Wind finder 2017).



Month of year	Jan 01	Feb 02	Mar 03	Apr 04	May 05	Jun 06	Jul 07	Aug 08	Sep 09	Oct 10	Nov 11	Dec 12	Year 1-12
Dominant wind direction	↖	→	↖	↖	→	↖	↖	↖	↖	↖	↖	↖	↖
Wind probability >= 4 Beaufort (%)	22	31	34	35	44	40	41	42	35	29	24	20	33
Average Wind speed (kts)	8	9	9	9	10	10	10	10	9	9	9	8	9
Average air temp. (°C)	22	23	26	31	35	37	39	39	36	33	28	24	31

Figure 3.5: 2002 – 2017 Dubai wind & temperature statistics (Wind finder, 2017)

The wind dominant direction is the north-west direction as shown in Figure 3.6 and wind speed average between 9 and 10 kts throughout the year which is equal to 4.63 and 5.14 m/s respectively.

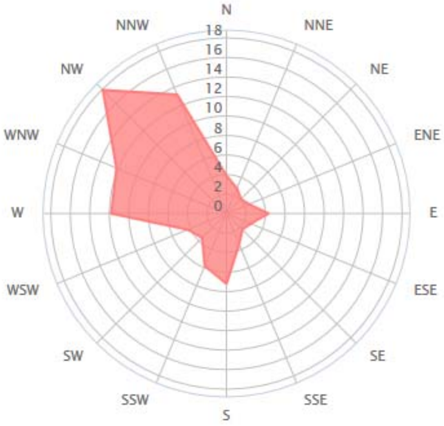


Figure 3.6: Dubai wind direction distribution (Wind finder, 2017)

These extreme temperature conditions will be taken into consideration while studying the NZEB case in Dubai especially in regard to achieving comfortable internal spaces temperatures with using the lowest energy possible for cooling spaces in addition to the insulation and U-value of the building, high temperatures effects and wind speed/probability will also be considered in the selection of the renewable energy source to be implemented to the case study building.

CHAPTER 4: CASE STUDY VALIDATION & SIMULATIONS

4.1 Case Study Modelling & Validation

In order to ensure the accuracy of results for any variables of the selected case study building, the building had to be modelled and monthly energy consumption had to match the electricity consumption provided by the owner shown in Table 3.4. Using Integrated Environmental Solutions Virtual Environment (IES VE) tool the building was modelled to the exact same dimensions as per the existing villa. Figures 4.1 and 4.2 show the building model after completion with added shading elements as designed and built with windows size and location defined exactly as per the design drawings. The roof enclosure and garage were also modeled to calculate their shading effect on the building.

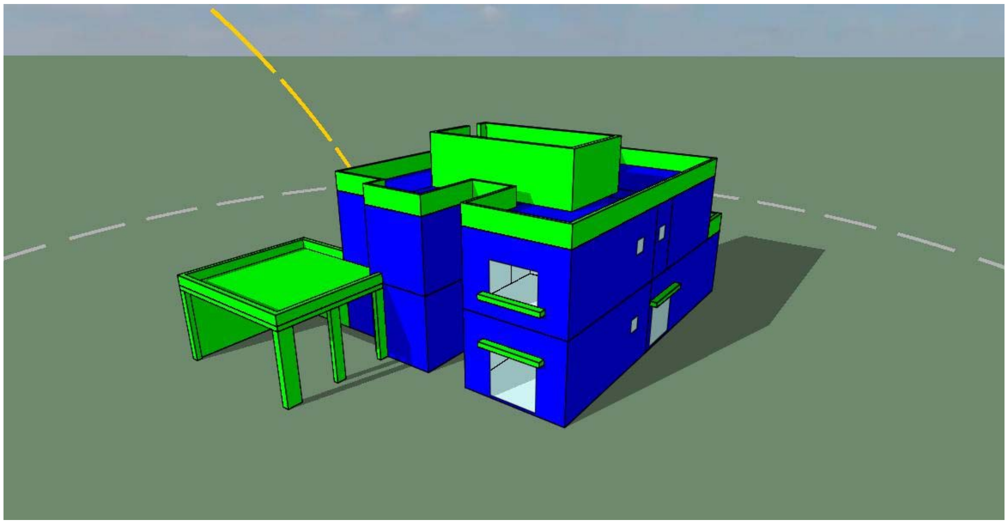


Figure 4.1: Case study model in IES VE (Front view)

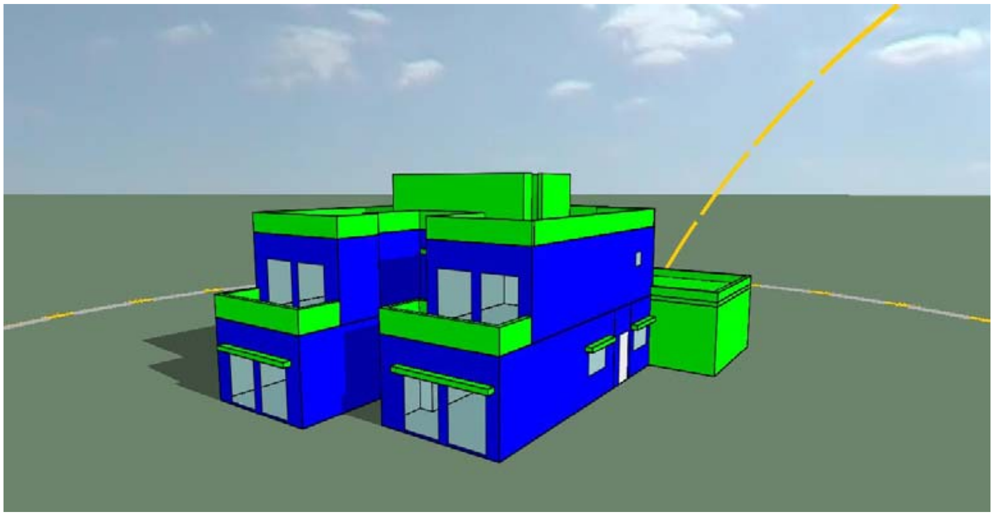
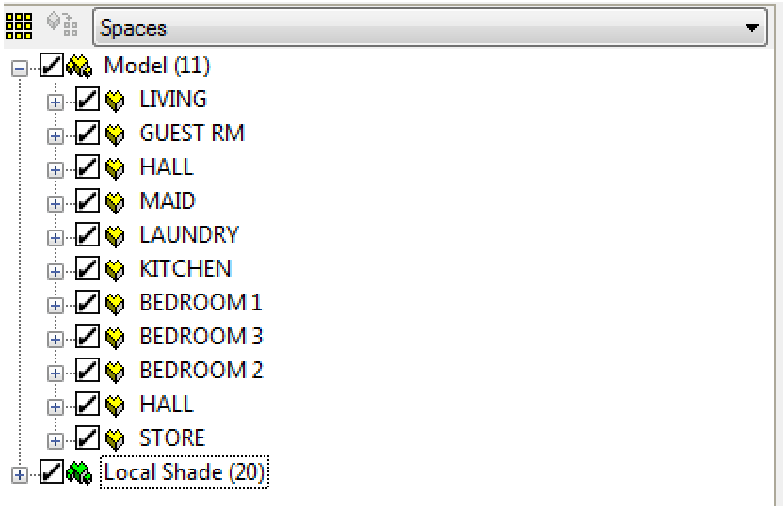


Figure 4.2: Case study model in IES VE (Rear view)

The building was divided into zones to calculate the heat gain and consumption from people, lighting, equipment, and HVAC more precisely, figure 4.3 shows the divisions of zones. The ground floor was divided into six areas (Living room, Guest room, Maids' room, Laundry room, Kitchen, and Hall which combines the common corridors, staircase and lobby). The first floor was divided into five areas (the three bedrooms including the bathrooms, store room, and Hall which combines the staircase, corridors and lobby)



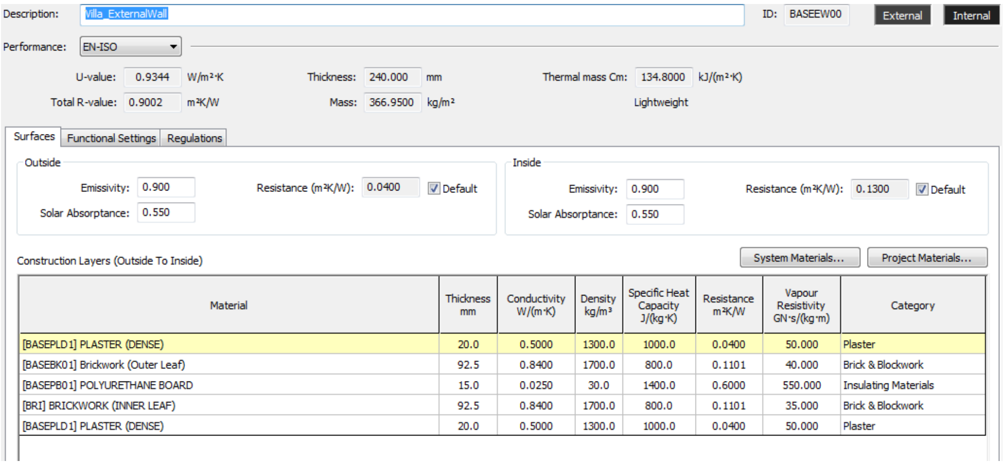
Spaces

- ☑ Model (11)
  - ☑ LIVING
  - ☑ GUEST RM
  - ☑ HALL
  - ☑ MAID
  - ☑ LAUNDRY
  - ☑ KITCHEN
  - ☑ BEDROOM 1
  - ☑ BEDROOM 3
  - ☑ BEDROOM 2
  - ☑ HALL
  - ☑ STORE
- ☑ Local Shade (20)

Figure 4.3: Case study zones in IES VE

The envelope detailed specifications and building external layers were identified in the software as followed:

External Walls details was obtained from the design consultant (Al Gurg Consultants). It consists of 20 mm Sand cement plaster layer as inner rendering finishing, Insulated blocks with total width of 200 mm, and 20 mm external plaster render. The total U-Value of the External wall came to 0.93 W/m^2 K as shown in Figure 4.4



Description: Villa_ExternalWall
ID: BASEEW00
Performance: EN-ISO
U-value: 0.9344 W/m²·K
Thickness: 240.000 mm
Thermal mass Cm: 134.8000 kJ/(m²·K)
Total R-value: 0.9002 m²K/W
Mass: 366.9500 kg/m²
Lightweight

Outside
Emissivity: 0.900
Resistance (m²K/W): 0.0400 ☑ Default
Solar Absorptance: 0.550

Inside
Emissivity: 0.900
Resistance (m²K/W): 0.1300 ☑ 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
[BASEPLD1] PLASTER (DENSE)	20.0	0.5000	1300.0	1000.0	0.0400	50.000	Plaster
[BASEBK01] Brickwork (Outer Leaf)	92.5	0.8400	1700.0	800.0	0.1101	40.000	Brick & Blockwork
[BASEPB01] POLYURETHANE BOARD	15.0	0.0250	30.0	1400.0	0.6000	550.000	Insulating Materials
[BRI] BRICKWORK (INNER LEAF)	92.5	0.8400	1700.0	800.0	0.1101	35.000	Brick & Blockwork
[BASEPLD1] PLASTER (DENSE)	20.0	0.5000	1300.0	1000.0	0.0400	50.000	Plaster

Figure 4.4: External Wall Layers in IES VE

In order to calculate the U-value of 0.93 W/m^2 K it was necessary to find the insulated blocks to reinforced concrete elements ratio and accordingly define the average U-value of the external walls. The building elevations were divided into reinforced concrete areas and insulated blocks areas, reinforced concrete where columns, beams, stairs, and other structural elements are designed and showed in Figure 4.5 in yellow color while the insulated blocks are shown in red color, the blue and green colors refer to windows, doors and glazed areas.

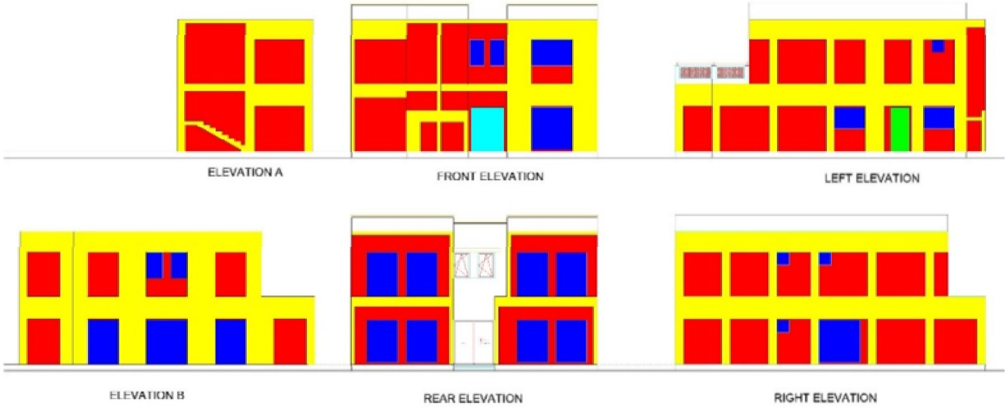


Figure 4.5: Elevations concrete to wall ratio

The areas of the 2 external walls materials are calculated as detailed in Table 4.1 with the areas almost divided in half between the two materials.

Table 4.1: Elevations areas and materials

Elevation	Reinforced Concrete (sq.m)	Insulated Blocks (Sq.m)
Front Elevation	31.74	33.88
Rear Elevation	10.12	27.29
Left Elevation	41.33	39.28
Right Elevation	40.72	45.82
Elevation A	15.75	26.82
Elevation B	52.16	19.78
Total	191.82	192.87
Percentage	**49.86%**	**50.14%**

Inside	Paint	Paint
	20 Plaster	20mm Plaster
	200 Concrete	200 Insulated Blocks
	20 Plaster	20 Plaster
Outside	Paint	Paint
	🟨	🟥

The two materials U-values were calculated as 1.32 W/m^2 K for the reinforced concrete and 0.54 W/m^2 K for the insulated blocks, according to the percentage of RC and Blocks the average elemental area weighted U-value was calculated as 0.93 W/m^2 K which confirms the value inserted in IES VE. Table 4.2 shows the materials and U-values used to calculate the average U-value of the external walls area.

Table 4.2: Average Wall U-value calculations

	Layer Description	**Thickness**	**Thermal Conductivity**	**Façade %**	**Element**
					U-Value
Unit		**(m)**	**W/(m^{2}K)**	%	**W/m^{2}K**
Reinforced concrete		**191.82**		**49.86 %**	
1	External Paint				
2	External Plaster	0.02	0.5		
3	Concrete	0.2	2.1		
4	Internal Plaster	0.02	0.5		
5	Internal Paint				
					1.32
Insulated Blocks		**192.87**		**50.14 %**	
1	External Paint				
2	External Plaster	0.02	0.5		
3	Concrete Block	0.075	0.84		
4	EPS	0.05	0.035		
5	Concrete Block	0.075	0.84		
6	Internal Plaster	0.02	0.5		
7	Internal Paint				
					0.54
Total Weighted U Value					**0.93**

Since it's not possible to divide each wall of each zone in IES VE software to two separate materials with different U-values, the average U-value was considered which is the main factor in heat conductivity which will affect the internal cooling load.

Roof layers were designed to have a water insulating membrane over the reinforced concrete slab,30mm screed layer for controlling the roof slopes, 50 mm thick insulation board, and gravel layer as shown in Figure 4.6

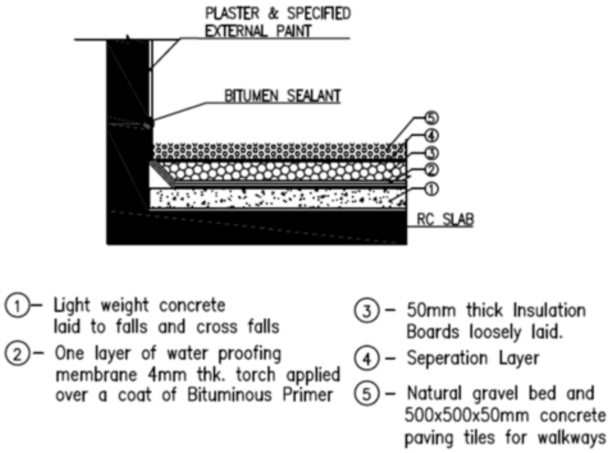
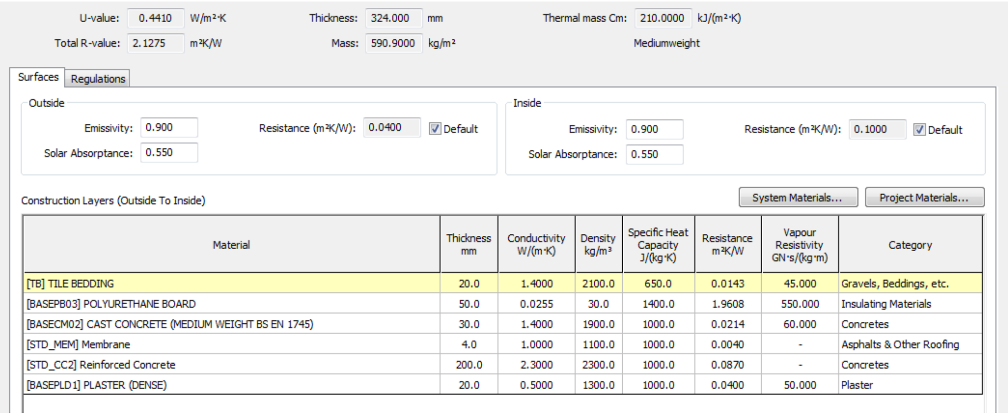


Figure 4.6: Roof insulation details

The same materials and thicknesses were entered to IES VE as shown in Figure 4.7 which had a total roof U-value of 0.44 W/m^2 K.


U-value: 0.4410 W/m²·K
Total R-value: 2.1275 m²K/W
Thickness: 324.000 mm
Mass: 590.9000 kg/m²
Thermal mass Cm: 210.0000 kJ/(m²·K)
Mediumweight

Outside
Emissivity: 0.900
Solar Absorptance: 0.550
Resistance (m²K/W): 0.0400 ☑ Default

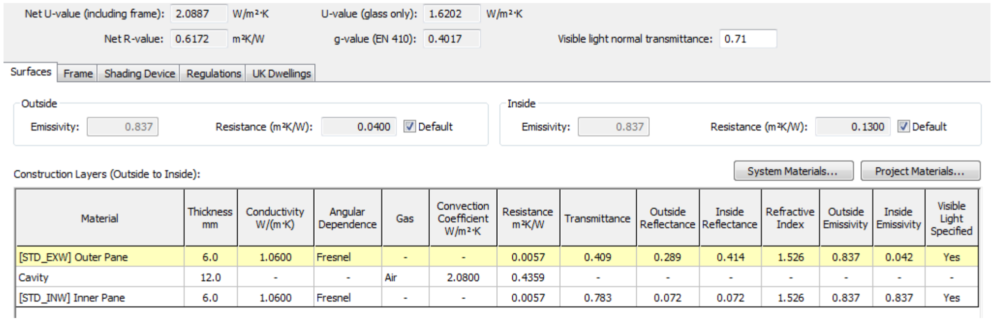
Inside
Emissivity: 0.900
Solar Absorptance: 0.550
Resistance (m²K/W): 0.1000 ☑ Default

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
[TB] TILE BEDDING	20.0	1.4000	2100.0	650.0	0.0143	45.000	Gravels, Beddings, etc.
[BASEPB03] POLYURETHANE BOARD	50.0	0.0255	30.0	1400.0	1.9608	550.000	Insulating Materials
[BASECM02] CAST CONCRETE (MEDIUM WEIGHT BS EN 1745)	30.0	1.4000	1900.0	1000.0	0.0214	60.000	Concretes
[STD_MEM] Membrane	4.0	1.0000	1100.0	1000.0	0.0040	-	Asphalts & Other Roofing
[STD_CC2] Reinforced Concrete	200.0	2.3000	2300.0	1000.0	0.0870	-	Concretes
[BASEPLD1] PLASTER (DENSE)	20.0	0.5000	1300.0	1000.0	0.0400	50.000	Plaster

Figure 4.7: Roof materials in IES VE

Glass windows and doors was defined as 6 mm double glazed windows with 12 mm gap and aluminum frame with thermal break which had a net U-value of 2.08 W/m^{2}K as shown in Figure 4.8



Net U-value (including frame): 2.0887 W/m²·K

U-value (glass only): 1.6202 W/m²·K

Net R-value: 0.6172 m²K/W

g-value (EN 410): 0.4017

Visible light normal transmittance: 0.71

Outside

Emissivity: 0.837

Resistance (m²K/W): 0.0400 ☑ Default

Inside

Emissivity: 0.837

Resistance (m²K/W): 0.1300 ☑ Default

Construction Layers (Outside to Inside):

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_EXW] Outer Pane	6.0	1.0600	Fresnel	-	-	0.0057	0.409	0.289	0.414	1.526	0.837	0.042	Yes
Cavity	12.0	-	-	Air	2.0800	0.4359	-	-	-	-	-	-	-
[STD_INW] Inner Pane	6.0	1.0600	Fresnel	-	-	0.0057	0.783	0.072	0.072	1.526	0.837	0.837	Yes

Figure 4.8: Windows details in IES VE

In order to calculate the internal heat gains, the wattage per square meter for equipment, people and lighting had to be defined in the software as shown in Table 4.3 for equipment power density which calculated according the occupancy of two persons only.

Table 4.3: Equipment Power Density as entered in IES VE

Zone Name	Power density baseline (W/m^2)	Power density proposed (W/m^2)
Corridors and Lobbies	0.0000	0.0000
Living room	5.3820	4.0000
Kitchen	12.0000	16.1459
Bedrooms & toilets	5.3820	3.0000
Storage & Laundry	1.0000	2.1528

Table 4.4 shows the occupancy density per square meter for each zone which was calculated by dividing the zones areas by the number of users.

Table 4.4: Occupancy Density as entered in IES VE

Zone Name	Occupancy Density (m^2/person)
Living room	19.7300
Kitchen	18.7500
Bedrooms & toilets	50.5960

Light Power Density (LPD) was calculated according to the designed electrical drawings and the exact number of lights in each space considering the use of Compact Florescent Light CFL and florescent tubes in some areas, the actual fixtures were confirmed by the owner and accordingly the wattage was divided on the different zones of the building as shown in and Table 4.5

Table 4.5: LPD Calculations as acquired from the designer (Al Gurg Consultants)

Zone Name	No. of Lighting points	Total Wattage (W)	Area (M^2)	LPD W/m^2
Corridors and Lobbies	15	644	62.56	10.294
Living room	4	368	39.46	9.326
Bedrooms & toilets	15	1173	151.79	7.728
Kitchen	5	380	37.5	10.133
Storage & Laundry	3	115	8.89	12.936

The HVAC system used is a DX split ducted system with coefficient of performance rated at 2.5 similar to the system installed in the existing villa. Figure 4.9 shows the air conditioning details defined in IES VE while Figure 4.10 shows the coefficient of performance for the system.

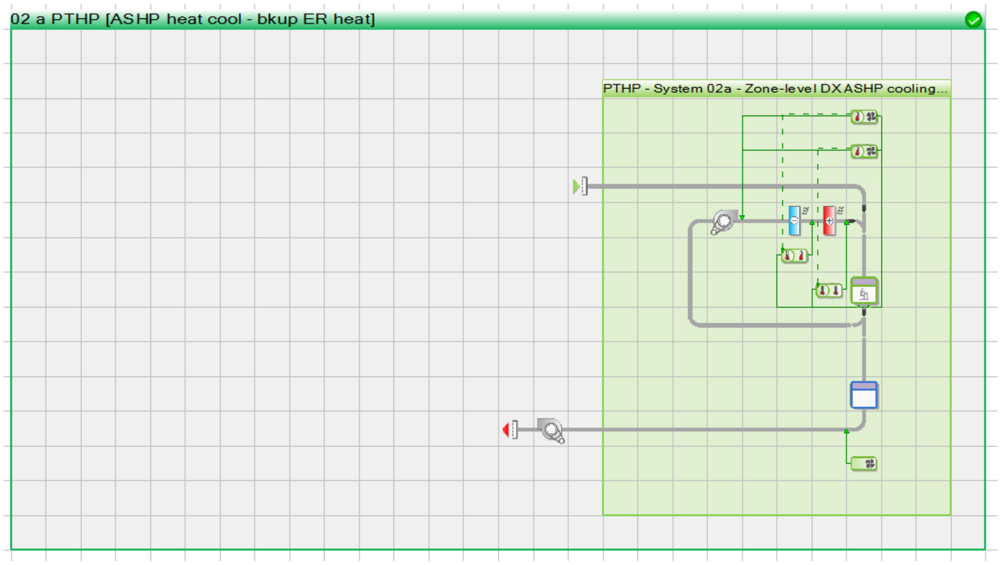
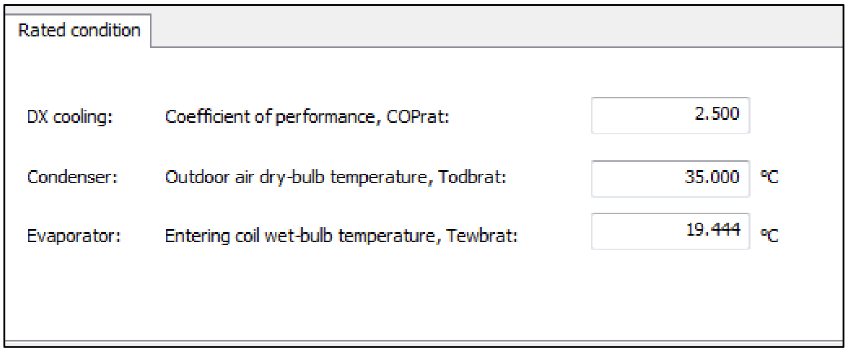


Figure 4.9: HVAC DX split ducted system in IES VE



DX cooling: Coefficient of performance, COPrat: 2.500

Condenser: Outdoor air dry-bulb temperature, Todbrat: 35.000 °C

Evaporator: Entering coil wet-bulb temperature, Tewbrat: 19.444 °C

Figure 4.10: HVAC Coefficient of Performance in IES VE

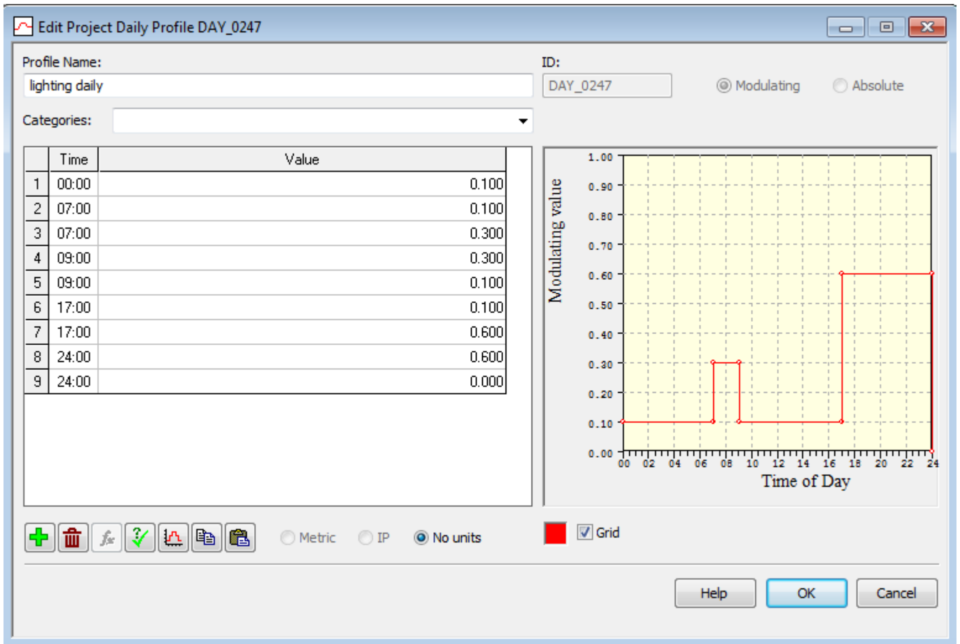
The HVAC system was defined in ApacheHVAC application and applied to all air-conditioned zones then equipment sizing calculation was run to ensure the system has the suitable sizing. A yearly profile for the HVAC usage was defined according to the usage of 2 users as interpreted from the final energy consumption values. Various daily, weekly, and yearly profiles were set according to the working hours and annual usage of the building in relation to occupancy, lighting, and cooling. The lighting daily profile as shown in figure 4.11 shows the usage of the two users, the usage of lighting at its minimum from midnight till 6:30am and increases in the time of preparing to go to work and since both users are employed. The lighting usage goes back to the minimum during work hours and at night the usage increases to the maximum of 0.6. A lighting usage of 1.0 was not considered since the 2 users will not usually occupy all the spaces at the same time thus the light in some rooms will be switched off even during the maximum usage. The daily profile was applied for the weekly profile after modifying the weekend profile to have a uniform 0.4 occupancy throughout the day. This 0.4 value was considered knowing that users spend some time outside the house on weekends but it’s difficult to measure it due to its randomness.

The occupancy profile also took into consideration the working hours of the users and the maximum occupancy hours were from 4:30 PM until 8:00 AM the next day, see figure 4.12. The same was applied to the weekly profile.

After several simulations, it was found that the cooling profile changes during the year and in different seasons according to users’ usage. This required the yearly profile to be divided into 4 profiles to get the validation model results to match the actual electricity consumption results. The best combination was found to be as followed:

- February 1st to March 31st with daily profile usage between 0.5 and 0.6
- April 1st to April 15th with daily profile usage of 0.55
- April 16th to August 31st with maximum daily profile usage of 1.0 in summer season.
- The daily profile usage goes back to 0.55 from September 1st till January 31st

The yearly profile is shown in Figure 4.13 was applied to all HVAC controllers to be reflected on the total energy usage throughout the year.



Edit Project Daily Profile DAY_0247

Profile Name: lighting daily

ID: DAY_0247

● Modulating ○ Absolute

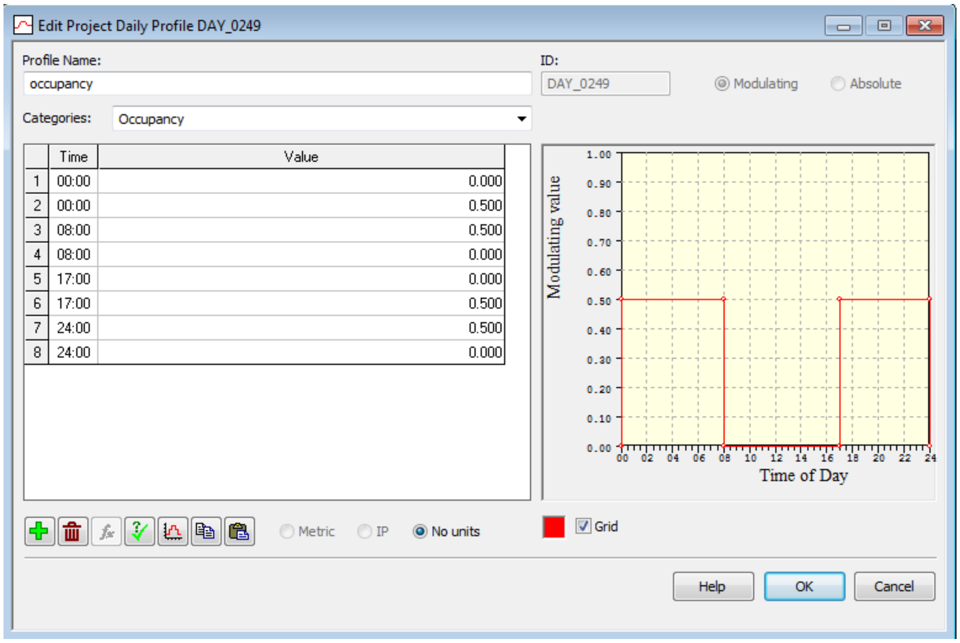
Categories:

	Time	Value
1	00:00	0.100
2	07:00	0.100
3	07:00	0.300
4	09:00	0.300
5	09:00	0.100
6	17:00	0.100
7	17:00	0.600
8	24:00	0.600
9	24:00	0.000

○ Metric ○ IP ● No units

☑ Grid

Figure 4.11: Lighting daily profile



Profile Name: occupancy

ID: DAY_0249 ● Modulating ○ Absolute

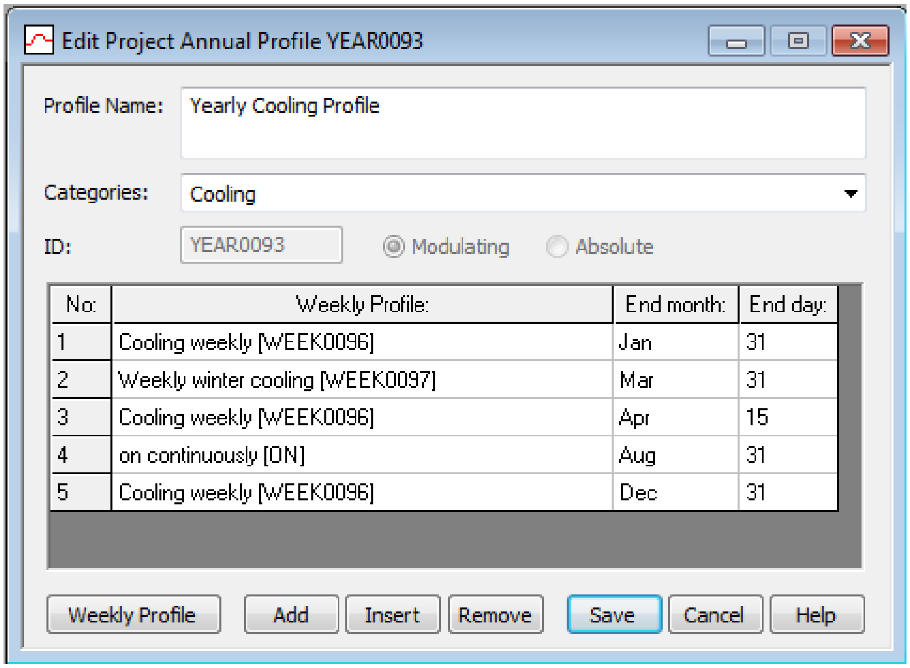
Categories: Occupancy

	Time	Value
1	00:00	0.000
2	00:00	0.500
3	08:00	0.500
4	08:00	0.000
5	17:00	0.000
6	17:00	0.500
7	24:00	0.500
8	24:00	0.000

○ Metric ○ IP ● No units

☑ Grid

Figure 4.12: Occupancy daily profile



Profile Name: Yearly Cooling Profile

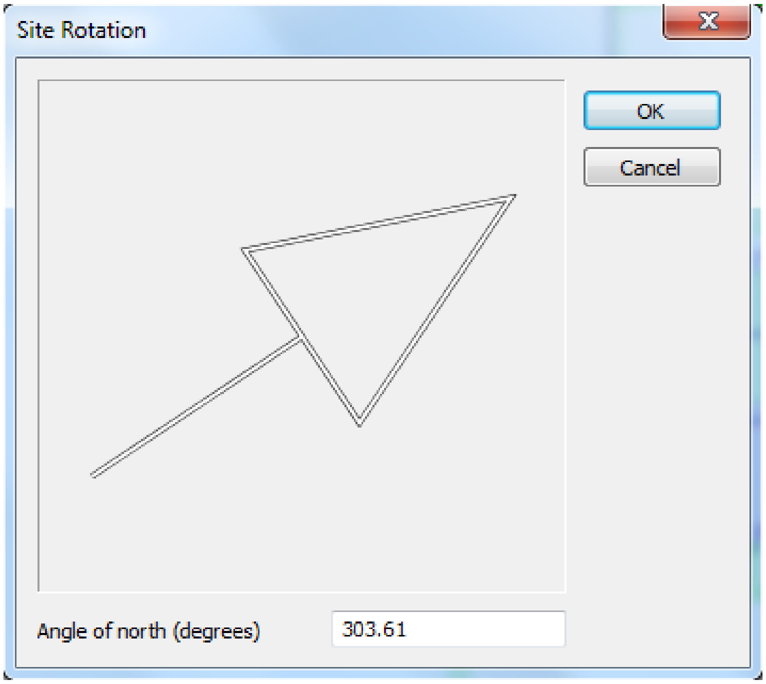
Categories: Cooling

ID: YEAR0093 ● Modulating ○ Absolute

No:	Weekly Profile:	End month:	End day:
1	Cooling weekly [WEEK0096]	Jan	31
2	Weekly winter cooling [WEEK0097]	Mar	31
3	Cooling weekly [WEEK0096]	Apr	15
4	on continuously [ON]	Aug	31
5	Cooling weekly [WEEK0096]	Dec	31

Figure 4.13: Yearly cooling profile

Building orientation was set as shown in the site setting layout and entered to IES VE as shown in Figure 4.14



Angle of north (degrees) 303.61

Figure 4.14: Site orientation as entered in IES VE

The location of the building was set as Dubai Intl Airport, United Arab Emirates and the closest city's' weather file of Abu Dhabi was selected since it has the same weather throughout the year and it's predefined in the software.

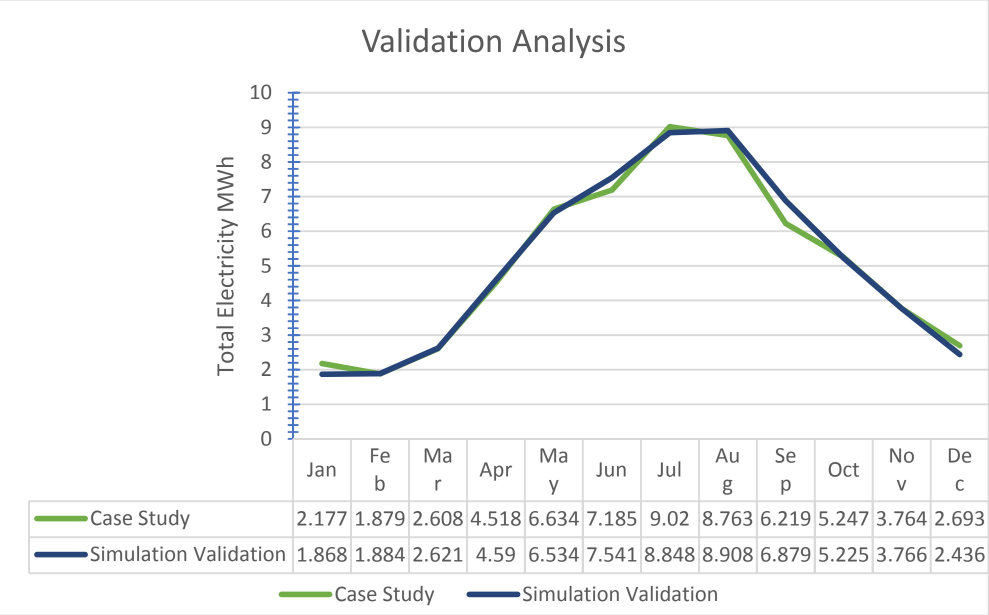
Apache simulation was run several times with many different profiles variations to reach to the closest usage behavior of the occupants. It was found that all the mentioned parameters above make the best combination to achieve the same electricity monthly usage as the electricity bills received from the owner.

Table 4.6 shows a comparison between the actual electricity consumption provided by the owner and the simulation model validation. Most of the consumption monthly loads are similar or relatively close to each other between both actual and simulated loads. The total simulated load is 61.0979 MWh annually which shows a difference of only 0.3909 MWh distributed between all months, this difference cannot be identified exactly since the occupant's behavior and usage cannot be 100% simulated due to unexpected events such as short vacations or holidays where the consumption drops

Table 4.6: Electricity consumption comparison between the actual villa and the validation model

Month	Case study electricity consumption (MWh)	Validation model electricity consumption (MWh)
January	2.177	1.868
February	1.879	1.8836
March	2.608	2.6207
April	4.518	4.5895
May	6.634	6.5336
June	7.185	7.5409
July	9.02	8.8484
August	8.763	8.9083
September	6.219	6.879
October	5.247	5.2247
November	3.764	3.7655
December	2.693	2.4357
Total Energy	60.707	61.0979

Figure 4.15 shows the minor differences between the simulation model results and the actual electricity consumption loads, the major differences are in June, July and September which may be caused by the unexpected occupancy loads as mentioned earlier or due to a sudden change in outdoor temperatures in the year when these consumption rates were taken, however the total annual difference is consider as a minor difference and this simulation model will be used as the base model for all the energy efficiency improvement measures to reach to a net zero energy building.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Case Study	2.177	1.879	2.608	4.518	6.634	7.185	9.02	8.763	6.219	5.247	3.764	2.693
Simulation Validation	1.868	1.884	2.621	4.59	6.534	7.541	8.848	8.908	6.879	5.225	3.766	2.436

Figure 4.15: Validation analysis graph

4.2 Energy Efficient Measures Implementation

Through literature review many parameters of using passive and active measures to reduce the energy consumption of buildings were studied and described in detail. The most suitable measures will be tested on the validated model to reduce its energy and reach the net zero energy point.

Envelope passive strategies by reducing the U-values of walls, roof and windows. Different HVAC systems, Lighting options, and shading elements will be tested as followed:

- HVAC option 1 is an improved DX split ducted system with COP of 3.6 which is the required COP by ESTIDAMA for villas.
- HVAC option 2 is a Variable Refrigerant Volume VRV system with COP of 3.6
- HVAC option 3 is a compact chiller type with COP of 3.6
- HVAC option 4 is the possibility of connecting the villa to a district cooling chilled water plant.
- Lighting first option is the replacement of all used lighting fixtures with Light Emitting Iodide LED.

- Lighting second option is also the use of LED lighting fixtures but according to Dubai Municipality circular and the introduction of Dubai Lamp.

-External walls U-value will be reduced from the original 0.93 W/m^{2}K to be lower than Dubai Al Sa'fat code of 0.42 W/m^{2}K which is applicable for the highest rating Golden and Platinum sa'fa.

- External walls U-value second option will be the reduction to match ESTIDAMA villa rating system which is equal or lower than 0.32 W/m^{2}K.

- Roof U-value as per Al Sa'fat system for Golden and Platinum sa'fa equal or lower than 0.3 W/m^{2}K down from 0.44 W/m^{2}K.

- Roof U-value second option will be the reduction to match ESTIDAMA villa rating system which is equal or lower than 0.14 W/m^{2}K.

- Glass U-value first variable will be according to Al Sa'fat for glazed area between 40% to 60% of the total external walls area where the U-value should be less than or equal to 1.9 W/m^{2}K, the same U-value is set by ESTIDAMA for villas rating.

- Second Option for glass will be a low-E glass with U-value of 1.68 W/m^{2}K.

- Third glass U-value option is 1.61 W/m^{2}K, both option 2 and 3 for the glass are available offered by different suppliers in the UAE and it's worth investigating the effects of lowering the glass U-value without the need to a triple glazing.

- External shading strategies will be implemented to the building façade after studying the sun cast and solar exposure of different sides of the façade.

- In the case of not reaching the required NZEB through passive measures, PV panels implementation to the roof and garage roof to produce the maximum energy output through IES VE simulation and the output energy will be validated through the Photovoltaic Geographical Information System.

A summary of all variables which will be tested in relation to validated model parameters is shown in Table 4.7

Table 4.7: Energy efficiency variables

System / Parameter	Existing	Option 1	Option 2	Option 3	Option 4
HVAC	DX split COP 2.5	DX split COP 3.6	VRV COP 3.6	Chiller COP 3.6	District Cooling
Lighting	CFL	LED	Dubai Lamp (LED)		
U-Value					
wall U-Value (W/m2K)	0.93	0.41 (Dubai GB)	0.29 (ESTIDAMA)		
Roof U-Value (W/m2K)	0.44	0.3 (Dubai GB)	0.14 (ESTIDAMA)		
Glass U-Value (W/m2K)	2.08	1.9 (Dubai GB)	1.68	1.61	
Shading	Minimum shading	Adding shading to 2 terraces, roof PV panels, extending windows shading			
PV Panels	N/A	IES simulation	PVGIS simulation		

Some energy efficient measures discussed in the literature review chapter will not be implemented to the case study for inadequately reasons. These include:

- Heating systems and solar collectors which are not very useful in the United Arab Emirates due to the hot climate most of the year and heating is rarely required during the winter
- Green roofs will require an added water consumption to the building and since the roof will be occupied by the PV panels it will not be suitable to use this measure in this case study
- Air tightness and infiltration can be a good parameter to investigate but it requires some site measurements and it was decided not to be investigated unless the building did not achieve the required NZEB level
- Since this is considered as a family house it was not found necessary to add motion sensors for the lights as it's more suitable for common areas of residential buildings or public buildings
- Due to low wind speeds throughout the year in Dubai as shown in the first chapter and not being widely used in the UAE, wind turbines option as a renewable energy source was dismissed

- Solar water heating is mandatory by Dubai Municipality for new villas but it will not be considered at this point unless the NZEB levels are not achieved.

4.2.1 HVAC Option 1 (DX Split COP = 3.6)

The first HVAC improvements option tested was to try and improve the same type of HVAC system used currently in the villa by increasing the coefficient of performance to become 3.6 instead of 2.5. The system was improved in IES VE as shown in figures 4.16 and 4.17 by integrating the enhanced COP to ApacheHVAC to replace the original HVAC system in the case study model application and the equipment sizing test was run again to ensure all HVAC system parts are according to the new COP.

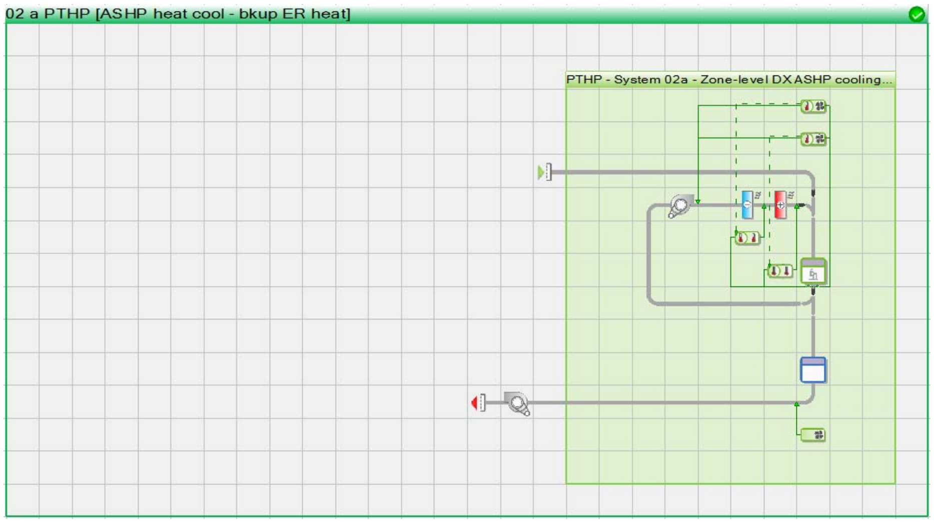
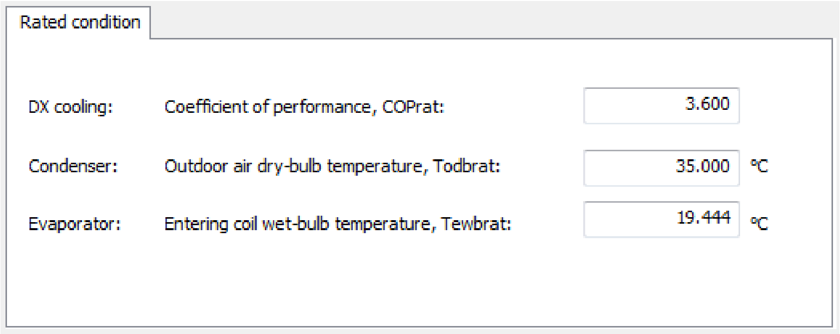


Figure 4.16: ApacheHVAC DX split system


Rated condition

DX cooling: Coefficient of performance, COPrat: 3.600

Condenser: Outdoor air dry-bulb temperature, Todbrat: 35.000 °C

Evaporator: Entering coil wet-bulb temperature, Tewbrat: 19.444 °C

Figure 4.17: HVAC Option 1 COP improvement

Apache simulation was run after the replacement of the HVAC system with the new properties and resulted in the optimized annual energy consumption values shown in Table 4.8 with a total annual consumed electricity of 46.8921 MWh reduced from the original simulated model which had a total annual consumed electrical energy of 61.2748 MWh. DX HVAC system with COP of 3.6 reduced the total consumed energy by 23.25%. The maximum energy reduction was simulated in August with 27.02% lower energy consumption.

Table 4.8: Monthly energy consumption and energy reduction after using the DX split system with COP = 3.6

Month	Energy consumption using DX HVAC with COP = 3.6 (MWh)	Validation model electricity consumption (MWh)	Energy reduction (%)
Jan	1.7894	1.868	4.21%
Feb	1.675	1.8836	11.07%
Mar	2.2006	2.6207	16.03%
Apr	3.5958	4.5895	21.65%
May	4.9734	6.5336	23.88%
Jun	5.5926	7.5409	25.84%
Jul	6.4657	8.8484	26.93%
Aug	6.5009	8.9083	27.02%
Sep	5.0634	6.879	26.39%
Oct	3.9653	5.2247	24.10%
Nov	2.9643	3.7655	21.28%
Dec	2.1057	2.4357	13.55%
Total	46.8921	61.0979	23.25%

4.2.2 HVAC Option 2 (VRV COP = 3.6)

The second HVAC option is a variable refrigerant volume (VRV) HVAC system which is known to be more efficient. VRV systems save energy by adjusting the refrigerant volume sent to each evaporator to keep the temperatures in each room as intended by the occupants instead of traditional HVAC systems where the system works only when the internal spaces are too cold or too hot. This strategy usually provides higher efficiency and better results.

The system was selected in ApacheHVAC with an energy recovery device and a coefficient of performance of 3.6 as shown in figures 4.18 and 4.19. This replaced the original HVAC system in the case study model in addition to applying the same yearly cooling profile used in the case model validation to all system controllers to unify the usage and find the optimization results of the system itself.

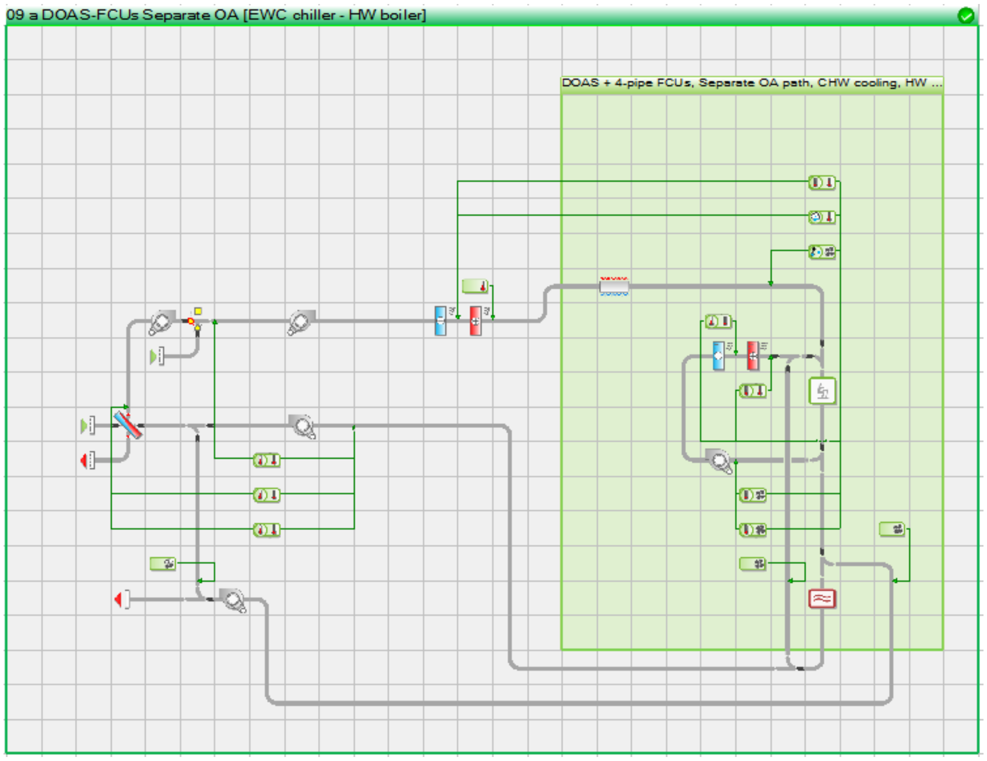
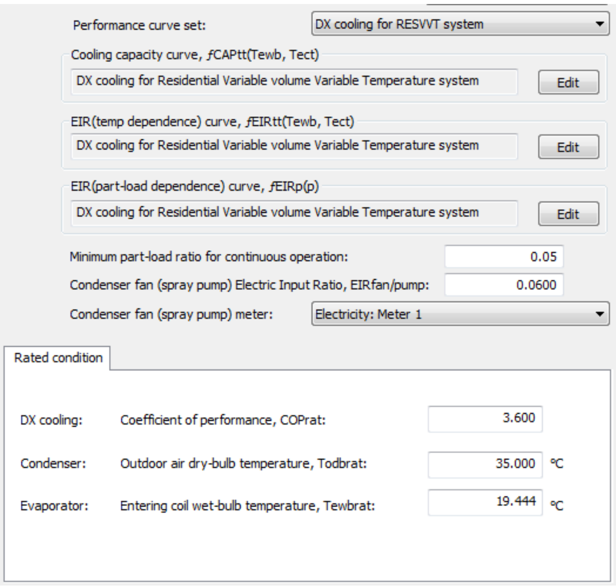


Figure 4.18: VRV system in ApacheHVAC



Performance curve set: DX cooling for RESVVT system

Cooling capacity curve, ƒCAPtt(Tewb, Tect): DX cooling for Residential Variable volume Variable Temperature system

EIR(temp dependence) curve, ƒEIRtt(Tewb, Tect): DX cooling for Residential Variable volume Variable Temperature system

EIR(part-load dependence) curve, ƒEIRp(p): DX cooling for Residential Variable volume Variable Temperature system

Minimum part-load ratio for continuous operation: 0.05

Condenser fan (spray pump) Electric Input Ratio, EIRfan/pump: 0.0600

Condenser fan (spray pump) meter: Electricity: Meter 1

Rated condition

DX cooling: Coefficient of performance, COPrat: 3.600

Condenser: Outdoor air dry-bulb temperature, Todbrat: 35.000 °C

Evaporator: Entering coil wet-bulb temperature, Tewbrat: 19.444 °C

Figure 4.19: VRV system properties and COP

After running the room and equipment sizing test and accordingly Apache simulation, the results of the total monthly consumed energy showed a reduction in the energy reaching 38.3366 MWh as shown in Table 4.9. VRV HVAC system with COP of 3.6 reduced the total consumed energy by 37.25%. The maximum energy reduction was simulated in January with 47.63% lower energy consumption.

Table 4.9: Monthly Energy Consumption after using the VRV system with COP = 3.6

Month	Energy consumption using VRV HVAC system (MWh)	Validation model electricity consumption (MWh)	Energy reduction (%)
Jan	0.9783	1.868	47.63%
Feb	1.0816	1.8836	42.58%
Mar	1.7398	2.6207	33.61%
Apr	2.8874	4.5895	37.09%
May	4.1768	6.5336	36.07%
Jun	4.7883	7.5409	36.50%
Jul	5.572	8.8484	37.03%
Aug	5.6107	8.9083	37.02%
Sep	4.5579	6.879	33.74%
Oct	3.3588	5.2247	35.71%
Nov	2.3256	3.7655	38.24%
Dec	1.2594	2.4357	48.29%
Total	38.3366	61.0979	37.25%

4.2.3 HVAC Option 3 (Compact Chiller COP = 3.6)

While air cooled chillers are usually used in larger buildings which requires higher cooling tonnage to cool the building, a compact version of the air-cooled chiller could be used for a villa studied, air cooled chiller is a machine that removes heat from liquid through absorption or vapor compression.

The Chiller system was modeled in ApacheHVAC application with a COP of 3.6 as shown in figures 4.20 and 4.21 to replace the original HVAC system in the case study model. Room and equipment sizing test was run after applying the validated yearly profile to all system controllers. Accordingly, Apache simulation was run which resulted in a total annual reduction in the energy to reach a total of 39.3092 MWh as shown in Table 4.10. Using chiller HVAC system with COP of 3.6 reduced the total consumed energy by 35.66%. The maximum energy reduction was simulated in April with 38.41% lower energy consumption.

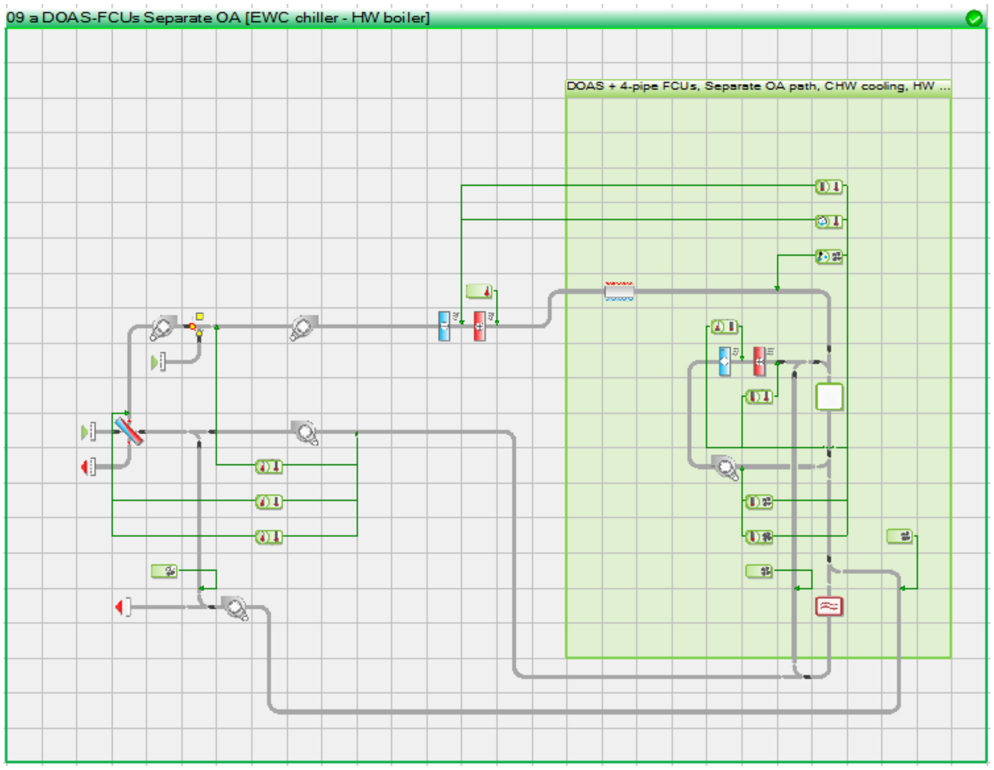
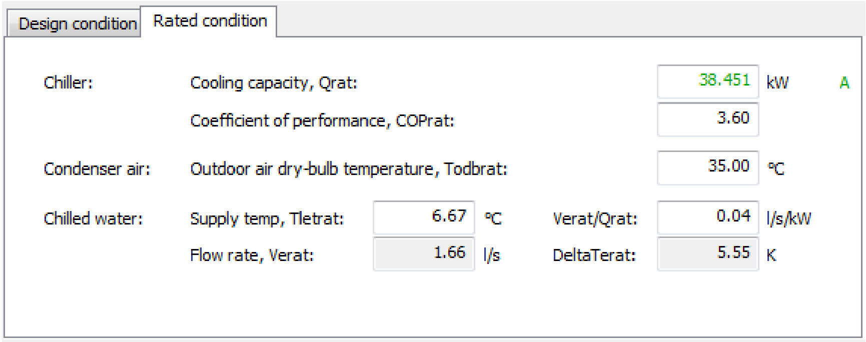


Figure 4.20: Chiller system diagram in ApacheHVAC



Chiller: Cooling capacity, Qrat: 38.451 kW A

Coefficient of performance, COPrat: 3.60

Condenser air: Outdoor air dry-bulb temperature, Todbrat: 35.00 °C

Chilled water: Supply temp, Tletrat: 6.67 °C Verat/Qrat: 0.04 l/s/kW

Flow rate, Verat: 1.66 l/s DeltaTerat: 5.55 K

Figure 4.21: Chiller system COP of 3.6

Table 4.10: Monthly Energy Consumption after using Chiller HVAC system with COP = 3.6

Month	Energy consumption (MWh)	Validation model electricity consumption (MWh)	Energy reduction (%)
Jan	1.4098	1.868	24.53%
Feb	1.2734	1.8836	32.40%
Mar	1.8123	2.6207	30.85%
Apr	2.8268	4.5895	38.41%
May	4.0648	6.5336	37.79%
Jun	4.7703	7.5409	36.74%
Jul	5.6942	8.8484	35.65%
Aug	5.7221	8.9083	35.77%
Sep	4.4432	6.879	35.41%
Oct	3.2453	5.2247	37.89%
Nov	2.3711	3.7655	37.03%
Dec	1.6759	2.4357	31.19%
Total	39.3092	61.0979	35.66%

4.2.4 HVAC Option 4 (District Cooling COP = 4.5)

The last HVAC optimization option is hypothesis of connecting the case study villa to a district cooling plant, the centralized plant is a replacement to the individual buildings refrigerant side of the system and can provide chilled water for cooling to a large number of buildings or communities. The system was inserted in ApacheHVAC to replace the original HVAC system in the case study model with a COP of 4.5 as shown in figures 4.22 and 4.23. Yearly cooling profile was defined to all system controllers, system sizing analysis was run to integrate the new system to the base model Accordingly Apache simulation was run which produced lower monthly electricity consumption with a total annual energy consumption of 39.3821 MWh.

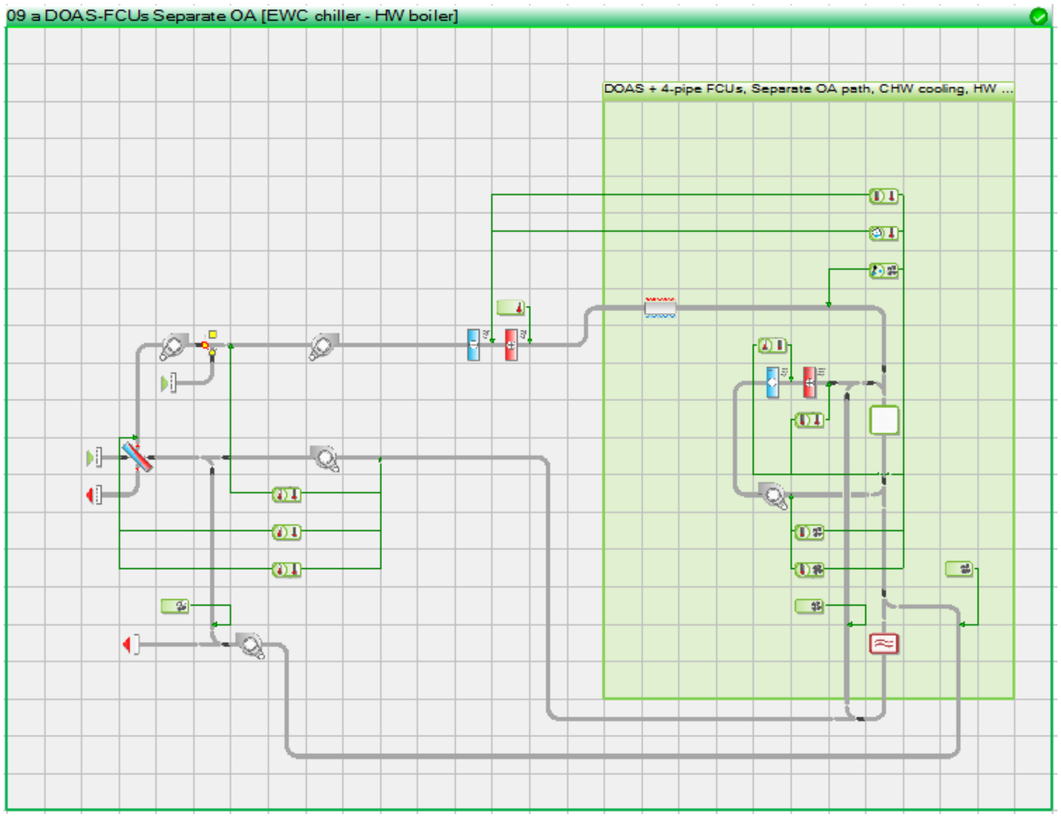
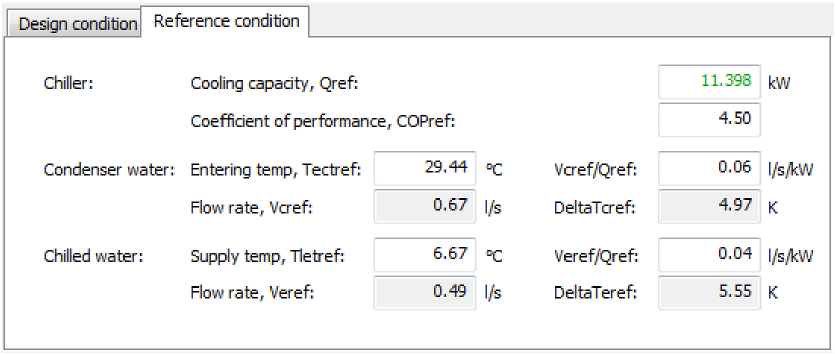


Figure 4.22: Case study connected to District Cooling Plant in ApacheHVAC



Chiller:	Cooling capacity, Qref:				11.398	kW
	Coefficient of performance, COPref:				4.50	
Condenser water:	Entering temp, Tectref:	29.44	°C	Vcref/Qref:	0.06	l/s/kW
	Flow rate, Vcref:	0.67	l/s	DeltaTcref:	4.97	K
Chilled water:	Supply temp, Tletref:	6.67	°C	Veref/Qref:	0.04	l/s/kW
	Flow rate, Veref:	0.49	l/s	DeltaTeref:	5.55	K

Figure 4.23: District cooling plant COP of 4.5

Table 4.11 shows the monthly energy consumption of the villa after connecting it to a district cooling plant. Two energy consumption columns are shown. The first column represents the villa consumption including the energy required for cooling from the primary source which is in this case the district cooling plant. The second column show the consumption for the villa only without district cooling energy;

this component is equal to 16.4997 MWh. These figures will be used in the next chapter to verify the possibility of NZEB-PE and NZEB-site. Connecting the villa to district cooling plant reduced the total consumed energy by 35.54% considering DC power and 72.99% without considering DC power. The maximum energy reduction was simulated in May with 36.50% lower energy consumption when considering DC power. 80.09% energy reduction was simulated in August when DC power was not considered.

Table 4.11: Monthly Energy Consumption after connecting to a chilled water system provided by a district cooling plant with COP = 4.5

Month	Total energy consumption including DC power (MWh)	Villa energy consumption excluding DC power (MWh)	Validation model electricity consumption (MWh)	Energy reduction with DC power (%)	Energy reduction without DC power (%)
Jan	1.19	0.9787	1.868	36.30%	47.61%
Feb	1.22	0.9263	1.8836	35.23%	50.82%
Mar	1.8304	1.1747	2.6207	30.16%	55.18%
Apr	2.934	1.3877	4.5895	36.07%	69.76%
May	4.149	1.6066	6.5336	36.50%	75.41%
Jun	4.8078	1.6332	7.5409	36.24%	78.34%
Jul	5.6611	1.7743	8.8484	36.02%	79.95%
Aug	5.6772	1.7733	8.9083	36.27%	80.09%
Sep	4.5075	1.516	6.879	34.47%	77.96%
Oct	3.3458	1.37	5.2247	35.96%	73.78%
Nov	2.4783	1.2564	3.7655	34.18%	66.63%
Dec	1.581	1.1025	2.4357	35.09%	54.74%
Total	39.3821	16.4997	61.0979	35.54%	72.99%

4.2.5 Lighting Option 1 (LED Lighting)

The first option of improving the lighting efficiency inside the villa is by replacing all the conventionally used lights which are compact florescent light bulbs with lower power usage LED which stand for light emitting diode and replacing the light power density in IES VE to reflect the new values. The 23 watts CFL bulbs were replaced by 14 watts LED lights which is considered to have approximately 40% lower lighting power demand, Table 4.12 shows the revised light power density after considering LED light. The values in watt per square meter entered in IES VE to simulate the energy consumption accordingly.

Table 4.12: Light Power Density (LPD) calculations after using LED bulbs

Zone Name	No. of Lighting points	Total Wattage (W)	Area (M2)	LPD W/m2
Corridors and Lobbies	15	308	62.56	4.923
Living room	4	224	39.46	5.677
Bedrooms & toilets	15	714	151.79	4.704
Kitchen	5	200	37.5	5.333
Storage & Laundry	3	70	8.89	7.874

ApacheHVAC simulation was run to update the heat gains from lighting and accordingly Apache simulation was run to calculate the revised monthly energy consumption after introducing the LED lights. This resulted in a total annual energy consumption of 56.5444 MWh as shown in table 4.13. Using LED reduced the total consumed energy by 7.45%. The maximum energy reduction was simulated in December with 12.47% lower energy consumption. The highest reduction value was simulated in August with 0.6015 MWh less consumed energy.

Table 4.13: Monthly Energy Consumption after using LED bulbs

Month	Energy consumption (MWh)	Validation model electricity consumption (MWh)	Energy reduction (MWh)	Energy reduction (%)
Jan	1.6726	1.868	0.1954	10.46%
Feb	1.6636	1.8836	0.2200	11.68%
Mar	2.3453	2.6207	0.2754	10.51%
Apr	4.2621	4.5895	0.3274	7.13%
May	6.1124	6.5336	0.4212	6.45%
Jun	7.0355	7.5409	0.5054	6.70%
Jul	8.2556	8.8484	0.5928	6.70%
Aug	8.3068	8.9083	0.6015	6.75%
Sep	6.4606	6.879	0.4184	6.08%
Oct	4.8581	5.2247	0.3666	7.02%
Nov	3.4399	3.7655	0.3256	8.65%
Dec	2.1319	2.4357	0.3038	12.47%
Total	56.5444	61.0979	4.5535	7.45%

4.2.6 Lighting Option 2 (Dubai Lamp)

In August 2017 Dubai Municipality issued a circular for the compulsory use of Dubai Lamp initiative. Dubai Lamps were developed by Philips Lighting and provides a high efficiency LED lights with the same lumen and color temperature. Conventional halogen bulbs with 25 watts could be replaced with a 1-watt bulb from the Dubai Lamp products, 40 watts halogen bulbs replaced by 2-watt Dubai Lamp, higher wattage conventional bulbs are replaced with 3-watt Dubai Lamp (Philips 2017).

For the case study, all CFL light bulbs which had 23 watts are replaced with 3-watt Dubai Lamp to keep the same lumen since it's equal to 60 watts halogen light bulb. Table 4.14 shows the Light Power Density calculations after changing the light bulbs to Dubai Lamp.

Table 4.14: Light Power Density calculations after using Dubai Lamp bulbs

Area	No. of Lighting points	Total Wattage (W)	Area (M2)	LPD W/m2
Corridors and Lobbies	15	66	62.56	1.055
Living room	4	58	39.46	1.470
Bedrooms & toilets	15	153	151.79	1.008
Kitchen	5	156	37.5	4.160
Storage & Laundry	3	15	8.89	1.687

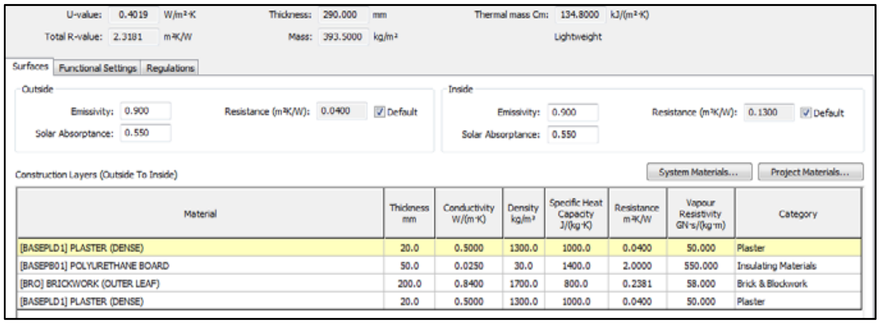
LPD calculation results were entered to IES VE and applied to different building zones as shown in Table 4.12. ApacheHVAC simulation was run to calculate the updated heat gains for the system followed by Apache simulation for the revised monthly energy consumption. As shown in Table 4.15 the simulation resulted in a total annual energy consumption of 53.3944 MWh after replacing the light bulbs with Dubai Lamp 3-watt. A total annual electricity of 7.7035 MWh was saved using Dubai Lamp which account for 12.61% annual energy reduction. The highest saving was simulated in December with 24.34% reduction.

Table 4.15: Monthly Energy Consumption after using Dubai Lamp bulbs

Month	Energy consumption (MWh)	Validation model electricity consumption (MWh)	Energy reduction (MWh)	Energy reduction (%)
Jan	1.44	1.868	0.428	22.91%
Feb	1.444	1.8836	0.4396	23.34%
Mar	2.1018	2.6207	0.5189	19.80%
Apr	4.003	4.5895	0.5865	12.78%
May	5.8357	6.5336	0.6979	10.68%
Jun	6.7649	7.5409	0.776	10.29%
Jul	7.9733	8.8484	0.8751	9.89%
Aug	8.0242	8.9083	0.8841	9.92%
Sep	6.1957	6.879	0.6833	9.93%
Oct	4.591	5.2247	0.6337	12.13%
Nov	3.1779	3.7655	0.5876	15.60%
Dec	1.8429	2.4357	0.5928	24.34%
Total	53.3944	61.0979	7.7035	12.61%

4.2.7 Wall U-Value Option 1 (Lower than 0.42 W/m^{2}K)

To match Dubai Al Sa'fat code for Golden and Platinum sa'fa, the external walls U-value must be lower than or equal to 0.42 W/m^{2}K. To reach such a U-value a 50 mm Polyurethane board was added to all external walls, columns, beams, and all exposed parts of the solid façade. This resulted in a U-value of 0.4019 W/m^{2}K for all external walls. As mentioned in the model validation section, the wall U-value entered in IES VE is an average U-value for all external walls regardless of the wall or concrete areas. In order to achieve the required U-value for concrete elements the insulation board needs to be 55 mm thick, while the existing insulated blocks required an additional 15 mm of polyurethane board to be installed externally. The focus in this option will be on achieving the Golden and Platinum sa'fa rating. Thus the U-value will be considered as 0.4019 W/m^{2}K as a consistent U-value for all external walls modeled in IES VE. Figure 4.24 shows the external wall layers consisting of 20 mm external sand cement plaster followed by the 50 mm insulation board over 200 mm brick wall and 20 mm internal plaster.



U-value: 0.4019 W/m²·K
Total R-value: 2.3181 m²K/W
Thickness: 290.000 mm
Mass: 393.5000 kg/m²
Thermal mass Cm: 134.8000 kJ/(m²·K)
Lightweight

Outside
Emissivity: 0.900
Solar Absorptance: 0.550
Resistance (m²K/W): 0.0400 ☑ Default

Inside
Emissivity: 0.900
Solar Absorptance: 0.550
Resistance (m²K/W): 0.1300 ☑ Default

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
[BASEPLD1] PLASTER (DENSE)	20.0	0.5000	1300.0	1000.0	0.0400	50.000	Plaster
[BASEPB01] POLYURETHANE BOARD	50.0	0.0250	30.0	1400.0	2.0000	550.000	Insulating Materials
[BRO] BRICKWORK (OUTER LEAF)	200.0	0.8400	1700.0	800.0	0.2381	58.000	Brick & Blockwork
[BASEPLD1] PLASTER (DENSE)	20.0	0.5000	1300.0	1000.0	0.0400	50.000	Plaster

Figure 4.24: (Option 1) External wall layers and U-value as entered in IES VE

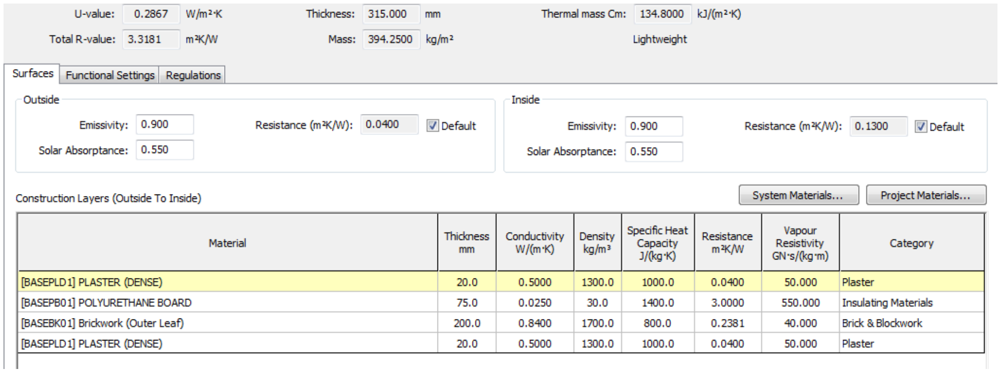
After running ApacheHVAC analysis for heat gains and Apache simulation, the total energy consumption annually showed a reduction reaching to 51.4923 MWh annually as shown in Table 4.16. Using this wall U-value reduced the energy consumed by 15.72% with the most energy saved in August by 17.95%. This shows that reducing the U-value of the external works reduces the thermal conduction especially in hotter months.

Table 4.16: Monthly Energy Consumption using 0.4 W/m^{2}K U-value for the external walls

Month	Energy consumption (MWh)	Validation model electricity consumption (MWh)	Energy reduction (MWh)	Energy reduction (%)
Jan	1.7462	1.868	0.1218	6.52%
Feb	1.746	1.8836	0.1376	7.31%
Mar	2.3593	2.6207	0.2614	9.97%
Apr	3.8689	4.5895	0.7206	15.70%
May	5.3832	6.5336	1.1504	17.61%
Jun	6.2114	7.5409	1.3295	17.63%
Jul	7.2753	8.8484	1.5731	17.78%
Aug	7.3091	8.9083	1.5992	17.95%
Sep	5.7374	6.879	1.1416	16.60%
Oct	4.3994	5.2247	0.8253	15.80%
Nov	3.2235	3.7655	0.542	14.39%
Dec	2.2326	2.4357	0.2031	8.34%
Total	51.4923	61.0979	9.6056	15.72%

4.2.8 Wall U-Value Option 2 (Lower than 0.29 W/m^{2}K)

To achieve ESTIDAMA villa rating for the walls the external walls U-value must be lower than or equal to 0.32 W/m^{2}K. This was achieved by adding an insulating polyurethane board to the external walls and columns similar to option one but with a thickness of 75 mm, Figure 4.25 shows the layers as defined in IES VE with 20 mm plaster for both inside and outside as a finishing layer and the 75mm insulation board over 200 mm block work wall. This combination resulted in a total wall U-value of 0.2867 W/m^{2}K which achieves ESTIDAMA pearl 2 rating for buildings.



U-value: 0.2867 W/m²·K
Total R-value: 3.3181 m²K/W
Thickness: 315.000 mm
Mass: 394.2500 kg/m²
Thermal mass Cm: 134.8000 kJ/(m²·K)
Lightweight

Outside
Emissivity: 0.900
Solar Absorptance: 0.550
Resistance (m²K/W): 0.0400 ☑ Default

Inside
Emissivity: 0.900
Solar Absorptance: 0.550
Resistance (m²K/W): 0.1300 ☑ Default

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
[BASEPLD1] PLASTER (DENSE)	20.0	0.5000	1300.0	1000.0	0.0400	50.000	Plaster
[BASEPB01] POLYURETHANE BOARD	75.0	0.0250	30.0	1400.0	3.0000	550.000	Insulating Materials
[BASEBK01] Brickwork (Outer Leaf)	200.0	0.8400	1700.0	800.0	0.2381	40.000	Brick & Blockwork
[BASEPLD1] PLASTER (DENSE)	20.0	0.5000	1300.0	1000.0	0.0400	50.000	Plaster

Figure 4.25: (Option 2) External wall layers and U-value as entered in IES VE

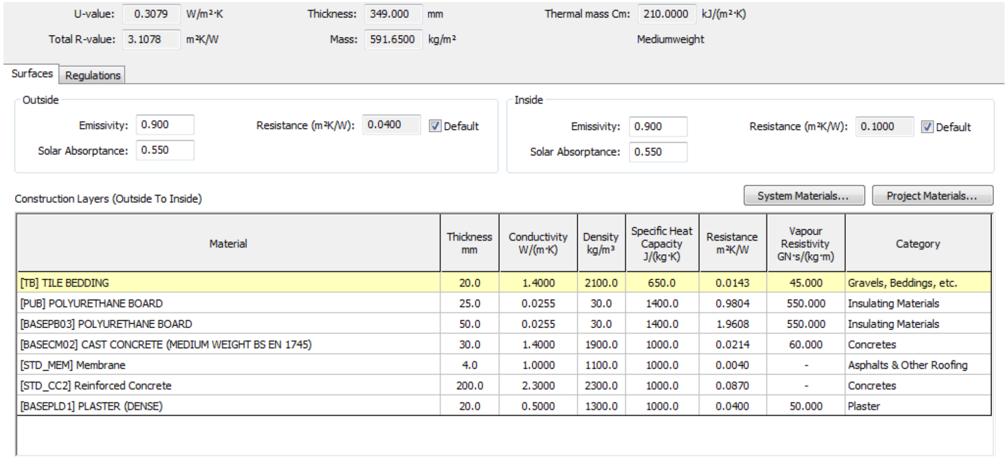
After updating the sizing simulation analysis in ApacheHVAC and running Apache simulation for the revised wall combination, the total consumed energy as shown in Table 4.17 was reduced to reach 49.6918 MWh annually. Using this wall U-value reduced the energy consumed by 11.4061 MWh which account for 15.72% with the most energy saved in July by 20.88%

Table 4.17: Monthly Energy Consumption using 0.28 W/m^{2}K U-value for the external walls

Month	Energy consumption (MWh)	Validation model electricity consumption (MWh)	Energy reduction (MWh)	Energy reduction (%)
Jan	1.7274	1.868	0.1406	7.53%
Feb	1.7116	1.8836	0.172	9.13%
Mar	2.303	2.6207	0.3177	12.12%
Apr	3.726	4.5895	0.8635	18.81%
May	5.1708	6.5336	1.3628	20.86%
Jun	5.9729	7.5409	1.568	20.79%
Jul	7.0007	8.8484	1.8477	20.88%
Aug	7.0273	8.9083	1.881	21.12%
Sep	5.5135	6.879	1.3655	19.85%
Oct	4.2368	5.2247	0.9879	18.91%
Nov	3.1148	3.7655	0.6507	17.28%
Dec	2.187	2.4357	0.2487	10.21%
Total	49.6918	61.0979	11.4061	18.67%

4.2.9 Roof U-Value Option 1 (Lower than 0.3 W/m^{2}K)

As per Dubai Al Sa’fat, Roof total U-value of 0.3 W/m^{2}K or less must be met for all 4 rating categories. In order to reach this value in the existing villa, an additional layer of polyurethane board was added to the roof with 25 mm thickness, as shown in Figure 4.26, which achieved a total roof U-value of 0.3079 W/m^{2}K. Since the roof exposed layer is loosely laid tiles which could be easily removed and the new insulating layer could be added before reinstalling the tiles again. It is recommended to add a sand cement screed layer over the insulation board for protection before installing the last layer. Since the U-value is the point of focus for this study, the protection screed layer will not be considered. After simulating the model with the new roof U-value, the total energy consumption was reduced to reach a totally of 60.3472 MWh annually as shown in Table 4.18. Using this roof U-value reduced the energy consumed by 0.7507 MWh which account for 1.23%.



U-value: 0.3079 $W/m^2 \cdot K$

Total R-value: 3.1078 m^2K/W

Thickness: 349.000 mm

Mass: 591.6500 kg/m^2

Thermal mass Cm: 210.0000 $kJ/(m^2 \cdot K)$

Mediumweight

Outside

Emissivity: 0.900

Solar Absorptance: 0.550

Resistance (m^2K/W): 0.0400 ☑ Default

Inside

Emissivity: 0.900

Solar Absorptance: 0.550

Resistance (m^2K/W): 0.1000 ☑ Default

Construction Layers (Outside To Inside)

Material	Thickness mm	Conductivity $W/(m \cdot K)$	Density kg/m^3	Specific Heat Capacity $J/(kg \cdot K)$	Resistance m^2K/W	Vapour Resistivity $GN \cdot s/(kg \cdot m)$	Category
[TB] TILE BEDDING	20.0	1.4000	2100.0	650.0	0.0143	45.000	Gravels, Beddings, etc.
[PUB] POLYURETHANE BOARD	25.0	0.0255	30.0	1400.0	0.9804	550.000	Insulating Materials
[BASEPB03] POLYURETHANE BOARD	50.0	0.0255	30.0	1400.0	1.9608	550.000	Insulating Materials
[BASECM02] CAST CONCRETE (MEDIUM WEIGHT BS EN 1745)	30.0	1.4000	1900.0	1000.0	0.0214	60.000	Concretes
[STD_MEM] Membrane	4.0	1.0000	1100.0	1000.0	0.0040	-	Asphalts & Other Roofing
[STD_CC2] Reinforced Concrete	200.0	2.3000	2300.0	1000.0	0.0870	-	Concretes
[BASEPLD1] PLASTER (DENSE)	20.0	0.5000	1300.0	1000.0	0.0400	50.000	Plaster

Figure 4.26: (Option 1) Roof layers and U-value as entered in IES VE

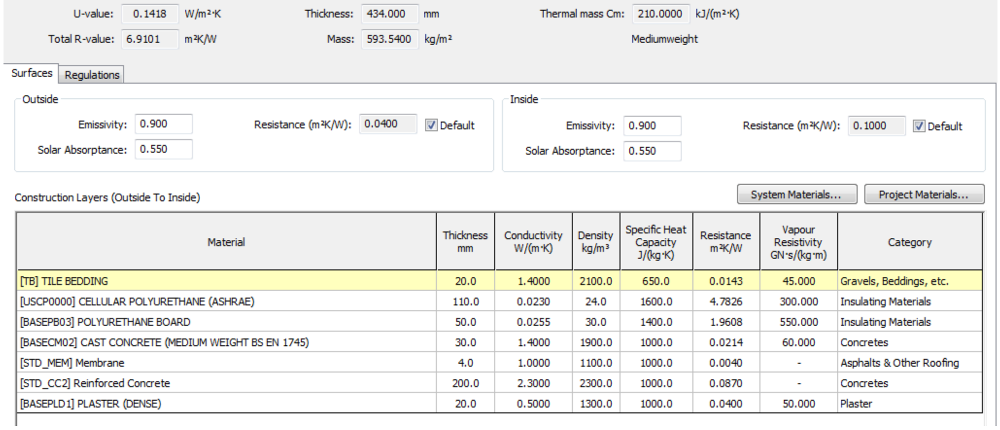
Table 4.18: Monthly Energy Consumption using 0.3 W/m^2K U-value for the roof

Month	Energy consumption (MWh)	Validation model electricity consumption (MWh)	Energy reduction (MWh)	Energy reduction (%)
Jan	1.8607	1.868	0.0073	0.39%
Feb	1.8724	1.8836	0.0112	0.59%
Mar	2.5981	2.6207	0.0226	0.86%
Apr	4.5281	4.5895	0.0614	1.34%
May	6.4435	6.5336	0.0901	1.38%
Jun	7.4373	7.5409	0.1036	1.37%
Jul	8.7295	8.8484	0.1189	1.34%
Aug	8.7878	8.9083	0.1205	1.35%
Sep	6.7856	6.879	0.0934	1.36%
Oct	5.1579	5.2247	0.0668	1.28%
Nov	3.7225	3.7655	0.043	1.14%
Dec	2.4238	2.4357	0.0119	0.49%
Total	60.3472	61.0979	0.7507	1.23%

4.2.10 Roof U-Value Option 2 (Lower than 0.14 W/m^2K)

ESTIDAMA villa rating system requires achieving a total roof U-value equal to or lower than 0.14 W/m^2K. By testing different insulating materials in IES VE to reach this value, it was found that the least thickness could be used is by adding a 110 mm cellular polyurethane board to the existing roof layers, as shown in Figure 4.27. This addition resulted in a reduction of the total U-value to reach 0.1418 W/m^2K.

After reducing the roof U-value and updating the HVAC sizing accordingly, the simulation showed a reduction of the total annually consumed energy to reach a total of 59.394 MWh as shown in Table 4.19. Using this roof U-value reduced the energy consumed by 1.7039 MWh which account for 2.79%.



U-value: 0.1418 W/m²·K
Total R-value: 6.9101 m²K/W
Thickness: 434.000 mm
Mass: 593.5400 kg/m²
Thermal mass Cm: 210.0000 kJ/(m²·K)
Mediumweight

Outside
Emissivity: 0.900
Solar Absorptance: 0.550
Resistance (m²K/W): 0.0400 ☑ Default

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

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
[TB] TILE BEDDING	20.0	1.4000	2100.0	650.0	0.0143	45.000	Gravels, Beddings, etc.
[USCP0000] CELLULAR POLYURETHANE (ASHRAE)	110.0	0.0230	24.0	1600.0	4.7826	300.000	Insulating Materials
[BASEPB03] POLYURETHANE BOARD	50.0	0.0255	30.0	1400.0	1.9608	550.000	Insulating Materials
[BASECM02] CAST CONCRETE (MEDIUM WEIGHT BS EN 1745)	30.0	1.4000	1900.0	1000.0	0.0214	60.000	Concretes
[STD_MEM] Membrane	4.0	1.0000	1100.0	1000.0	0.0040	-	Asphalts & Other Roofing
[STD_CC2] Reinforced Concrete	200.0	2.3000	2300.0	1000.0	0.0870	-	Concretes
[BASEPLD1] PLASTER (DENSE)	20.0	0.5000	1300.0	1000.0	0.0400	50.000	Plaster

Figure 4.27: (Option 2) Roof layers and U-value as entered in IES VE

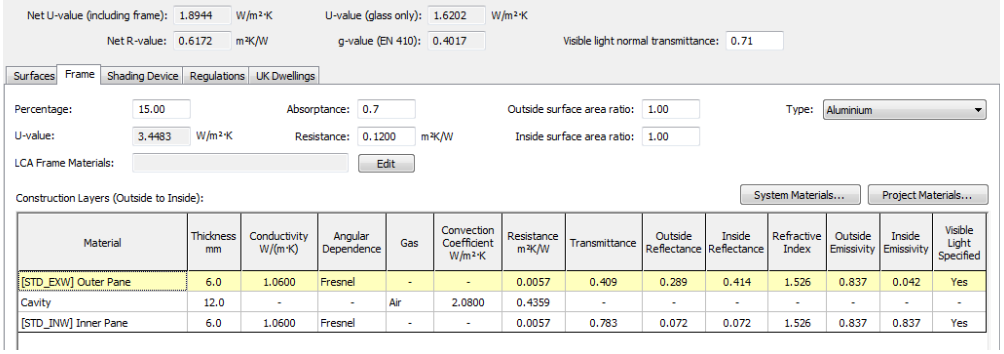
Table 4.19: Monthly Energy Consumption using 0.14 W/m^{2}K U-value for the roof

Month	Energy consumption (MWh)	Validation model electricity consumption (MWh)	Energy reduction (MWh)	Energy reduction (%)
Jan	1.8524	1.868	0.0156	0.84%
Feb	1.8577	1.8836	0.0259	1.38%
Mar	2.5692	2.6207	0.0515	1.97%
Apr	4.4509	4.5895	0.1386	3.02%
May	6.3276	6.5336	0.206	3.15%
Jun	7.3066	7.5409	0.2343	3.11%
Jul	8.5786	8.8484	0.2698	3.05%
Aug	8.6345	8.9083	0.2738	3.07%
Sep	6.6668	6.879	0.2122	3.08%
Oct	5.0729	5.2247	0.1518	2.91%
Nov	3.6679	3.7655	0.0976	2.59%
Dec	2.4089	2.4357	0.0268	1.10%
Total	59.394	61.0979	1.7039	2.79%

4.2.11 Glass U-Value Option 1 (Lower than 1.9 W/m^{2}K)

Al Sa'fat rating system requires glazed elements to have a total U-value less than 1.9 W/m^{2}K for wall to window ratio higher than 40%. In the case study villa the ratio is 28.5%, ESTIDAMA requirements for fenestration is 2.2 W/m^{2}K or less.

However, in this option Dubai Al Sa’fat requirement will be considered by replacing all glazed areas with higher efficiency glazing. U-value of 1.8944 W/m^{2}K was achieved by improving the aluminum frame thermal resistance to 0.12 m^{2}K/W as shown in Figure 4.28. After recalculating the HVAC system sizing according to the new windows U-value and running Apache simulation, it was found that the total annual energy consumption was reduced to 60.614 MWh instead of the original 61.0979 MWh as shown in the monthly consumption Table 4.20. Using this windows U-value reduced the energy consumed by 0.4839 MWh which account for 0.79%.



Net U-value (including frame): 1.8944 W/m²·K
U-value (glass only): 1.6202 W/m²·K
Net R-value: 0.6172 m²K/W
g-value (EN 410): 0.4017
Visible light normal transmittance: 0.71

Percentage: 15.00
Absorptance: 0.7
Outside surface area ratio: 1.00
Type: Aluminium
U-value: 3.4483 W/m²·K
Resistance: 0.1200 m²K/W
Inside surface area ratio: 1.00
LCA Frame Materials:

Construction Layers (Outside to Inside):

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_EXW] Outer Pane	6.0	1.0600	Fresnel	-	-	0.0057	0.409	0.289	0.414	1.526	0.837	0.042	Yes
Cavity	12.0	-	-	Air	2.0800	0.4359	-	-	-	-	-	-	-
[STD_INW] Inner Pane	6.0	1.0600	Fresnel	-	-	0.0057	0.783	0.072	0.072	1.526	0.837	0.837	Yes

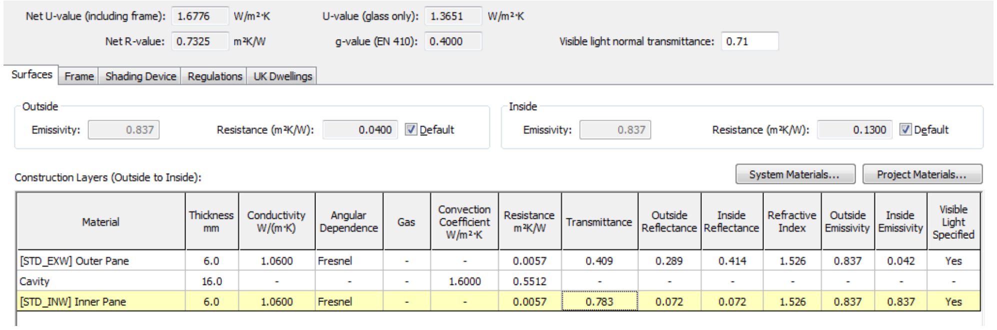
Figure 4.28: (Option 1) Windows U-value less than 1.9 W/m^{2}K

Table 4.20: Monthly Energy Consumption using 1.8944 W/m^{2}K windows U-value

Month	Energy consumption (MWh)	Validation model electricity consumption (MWh)	Energy reduction (MWh)	Energy reduction (%)
Jan	1.8522	1.868	0.0158	0.85%
Feb	1.8692	1.8836	0.0144	0.76%
Mar	2.6031	2.6207	0.0176	0.67%
Apr	4.5502	4.5895	0.0393	0.86%
May	6.4774	6.5336	0.0562	0.86%
Jun	7.4788	7.5409	0.0621	0.82%
Jul	8.7786	8.8484	0.0698	0.79%
Aug	8.8378	8.9083	0.0705	0.79%
Sep	6.8249	6.879	0.0541	0.79%
Oct	5.1827	5.2247	0.042	0.80%
Nov	3.7378	3.7655	0.0277	0.74%
Dec	2.4213	2.4357	0.0144	0.59%
Total	60.614	61.0979	0.4839	0.79%

4.2.12 Glass U-Value Option 2 (1.68 W/m^{2}K)

Other glazing options are investigated to test its efficiency and total energy saving even though it's not mandatory by the green building regulation in the UAE. Adding a low-e glass pane or a reflective film to the inner surface of the external pane reduces the total U-value of the glazing. This could be reflected in IES VE by adjusting the air gap's convection coefficient which is the element affected directly by such improvement. In this option the air gap thickness was considered as 16 mm and the convection coefficient as 1.6 W/m^{2}K which resulted in a total U-value of 1.6776 W/m^{2}K as shown in Figure 4.29. The total annual energy consumption of 60.2358 MWh as shown in Table 4.21. Using this windows U-value reduced the energy consumed by 0.8621 MWh which account for 1.41%.



Net U-value (including frame): 1.6776 W/m²·K
U-value (glass only): 1.3651 W/m²·K
Net R-value: 0.7325 m²K/W
g-value (EN 410): 0.4000
Visible light normal transmittance: 0.71

Outside
Emissivity: 0.837
Resistance (m²K/W): 0.0400 ☑ Default

Inside
Emissivity: 0.837
Resistance (m²K/W): 0.1300 ☑ Default

Construction Layers (Outside to Inside):

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_EXW] Outer Pane	6.0	1.0600	Fresnel	-	-	0.0057	0.409	0.289	0.414	1.526	0.837	0.042	Yes
Cavity	16.0	-	-	-	1.6000	0.5512	-	-	-	-	-	-	-
[STD_INW] Inner Pane	6.0	1.0600	Fresnel	-	-	0.0057	0.783	0.072	0.072	1.526	0.837	0.837	Yes

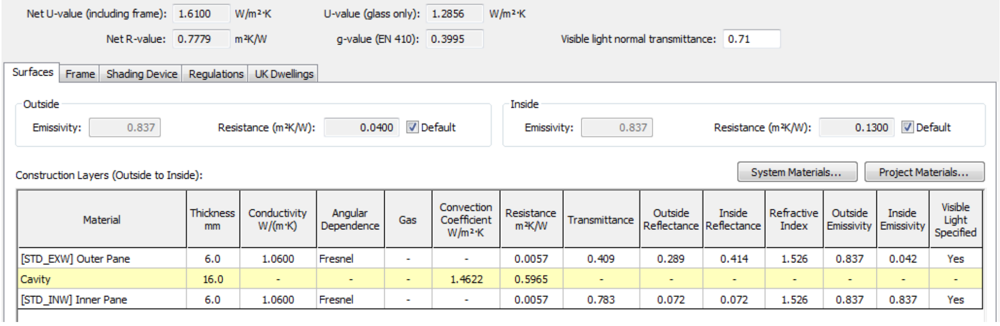
Figure 4.29: (Option 2) Windows U-value less than 1.68 W/m^{2}K

Table 4.21: Monthly Energy Consumption using 1.6776 W/m^{2}K windows U-value

Month	Energy consumption (MWh)	Validation model electricity consumption (MWh)	Energy reduction (MWh)	Energy reduction (%)
Jan	1.842	1.868	0.026	1.39%
Feb	1.8614	1.8836	0.0222	1.18%
Mar	2.5921	2.6207	0.0286	1.09%
Apr	4.5207	4.5895	0.0688	1.50%
May	6.4311	6.5336	0.1025	1.57%
Jun	7.4283	7.5409	0.1126	1.49%
Jul	8.7199	8.8484	0.1285	1.45%
Aug	8.7784	8.9083	0.1299	1.46%
Sep	6.7793	6.879	0.0997	1.45%
Oct	5.1491	5.2247	0.0756	1.45%
Nov	3.7183	3.7655	0.0472	1.25%
Dec	2.4152	2.4357	0.0205	0.84%
Total	60.2358	61.0979	0.8621	1.41%

4.2.13 Glass U-Value Option 3 (1.61 W/m^{2}K)

The last glazing improvement option is a low-e glass with a total U-value of 1.61 W/m^{2}K. This is translated to IES VE by revising the convection coefficient to 1.4622 W/m^{2}K, which achieved the required U-value as shown in Figure 4.30. The simulation of this option showed a slight reduction of energy compared to the first two options as shown in Table 4.22 with a total annual energy consumption of 60.1177 MWh. Using this windows U-value reduced the energy consumed by 0.9802 MWh which account for 1.60%.



Net U-value (including frame): 1.6100 W/m²·K
U-value (glass only): 1.2856 W/m²·K
Net R-value: 0.7779 m²K/W
g-value (EN 410): 0.3995
Visible light normal transmittance: 0.71

Outside
Emissivity: 0.837
Resistance (m²K/W): 0.0400 ☑ Default

Inside
Emissivity: 0.837
Resistance (m²K/W): 0.1300 ☑ Default

Construction Layers (Outside to Inside):

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_EXW] Outer Pane	6.0	1.0600	Fresnel	-	-	0.0057	0.409	0.289	0.414	1.526	0.837	0.042	Yes
Cavity	16.0	-	-	-	1.4622	0.5965	-	-	-	-	-	-	-
[STD_INW] Inner Pane	6.0	1.0600	Fresnel	-	-	0.0057	0.783	0.072	0.072	1.526	0.837	0.837	Yes

Figure 4.30: (Option 3) Windows U-value of 1.61 W/m^{2}K

Table 4.22: Monthly Energy Consumption using 1.61 W/m^{2}K windows U-value

Month	Energy consumption (MWh)	Validation model electricity consumption (MWh)	Energy reduction (MWh)	Energy reduction (%)
Jan	1.839	1.868	0.029	1.55%
Feb	1.859	1.8836	0.0246	1.31%
Mar	2.5888	2.6207	0.0319	1.22%
Apr	4.511	4.5895	0.0785	1.71%
May	6.4169	6.5336	0.1167	1.79%
Jun	7.4126	7.5409	0.1283	1.70%
Jul	8.7017	8.8484	0.1467	1.66%
Aug	8.7596	8.9083	0.1487	1.67%
Sep	6.765	6.879	0.114	1.66%
Oct	5.1386	5.2247	0.0861	1.65%
Nov	3.7122	3.7655	0.0533	1.42%
Dec	2.4133	2.4357	0.0224	0.92%
Total	60.1177	61.0979	0.9802	1.60%

4.2.14 Shading Elements

One of the investigated passive parameters is introducing shading elements to the façade of the existing villa and calculate its effect on the annual energy consumption. In order to determine the required shading elements location on the façade, solar energy analysis was run for the existing villa using the SunCast module in IES as shown in Figures 4.31, 4.32 and 4.33. The analysis shows that the most affected elevations of the villa are the southern two facades in addition to the roof. The most affected areas of the façade are the windows of these two southern oriented elevations of the building This affects the building thermal gain due to sun radiation entering the spaces through glass, improving this element should benefit the total energy consumption.

Figure 4.31: Solar exposure analysis of North-East and South-East facades

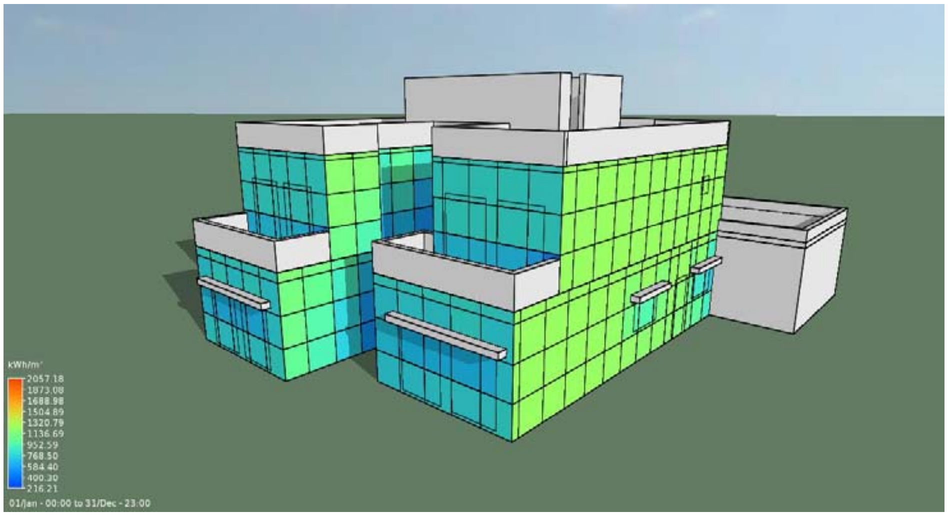


Figure 4.32: Solar exposure analysis of North-West and South-West facades

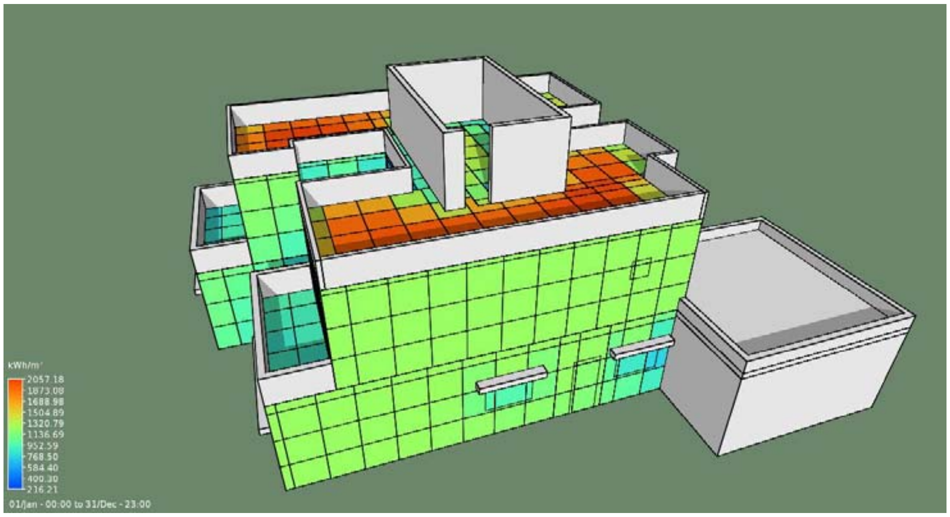


Figure 4.33: Solar exposure analysis of the roof

To reduce the sun radiation, shading elements were added to the South-East and South-West facades above the windows. The existing 300 mm shading lintels were extended to be 600 mm. Some windows had no extruded lintels in the original design which was treated by introducing 600 mm new lintels and vertical elements. The 2 terraces on the North-Eastern façade had no roof which affected the solar exposure of their flooring and accordingly the spaces under them. Two new 1.8 meters roofs were added to the terraces accordingly. The roof HVAC machines enclosure was designed to be without a roof and accordingly a roof was added to this area. All the elements shown in red in Figures 4.34 and 4.35 are the newly added shading elements to the building. This was reflected in the revised solar analysis simulated using SunCast application and shown in Figures 4.36, 4.37 and 4.38.

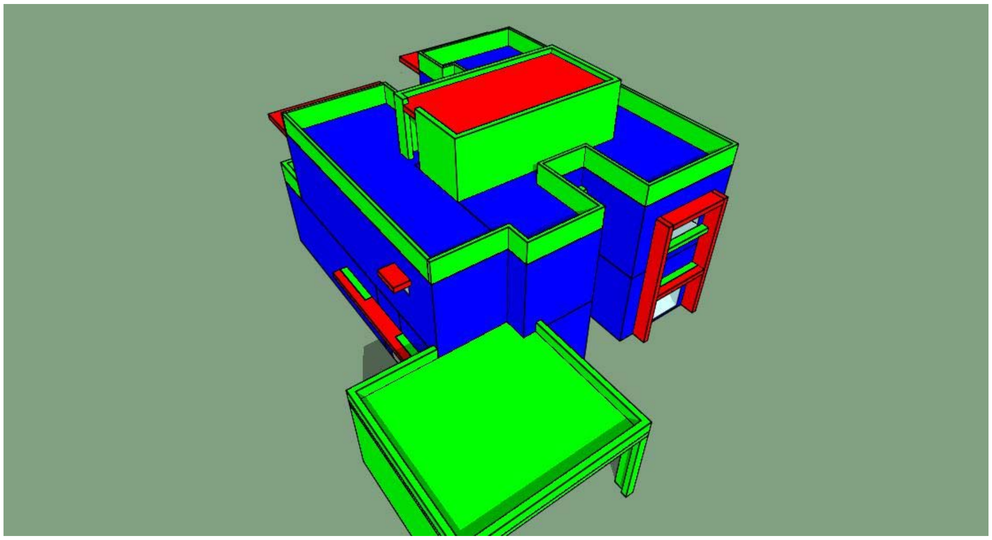


Figure 4.34: Added shading elements (Southern facades)

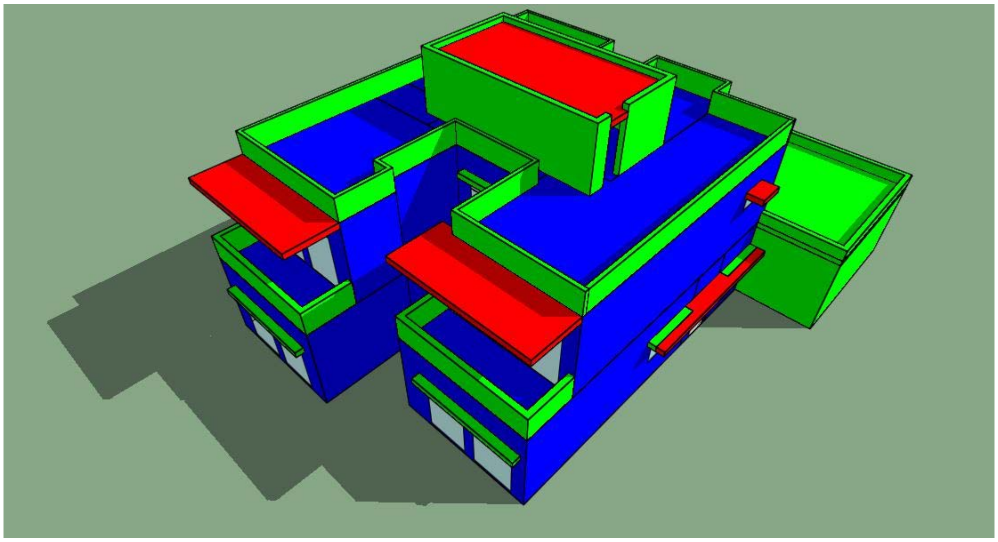


Figure 4.35: Added shading elements (South-West & North-West facades)

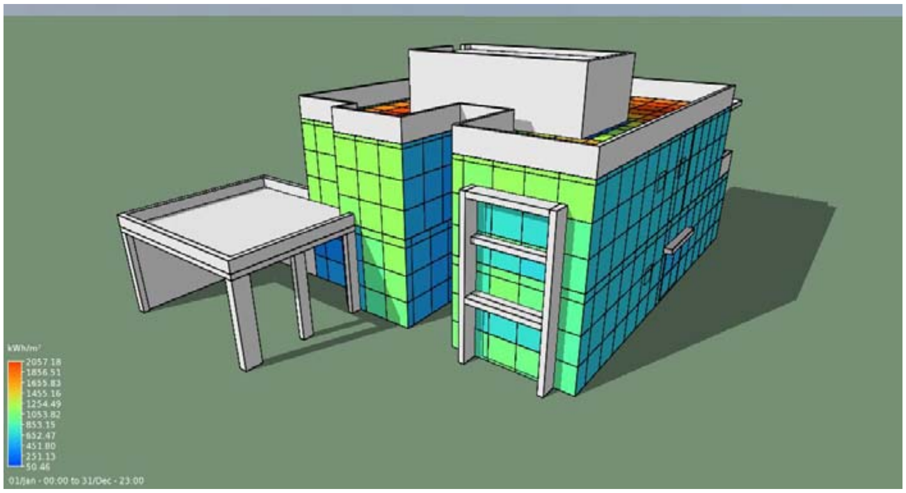


Figure 4.36: Solar exposure analysis of North-East and South-East facades

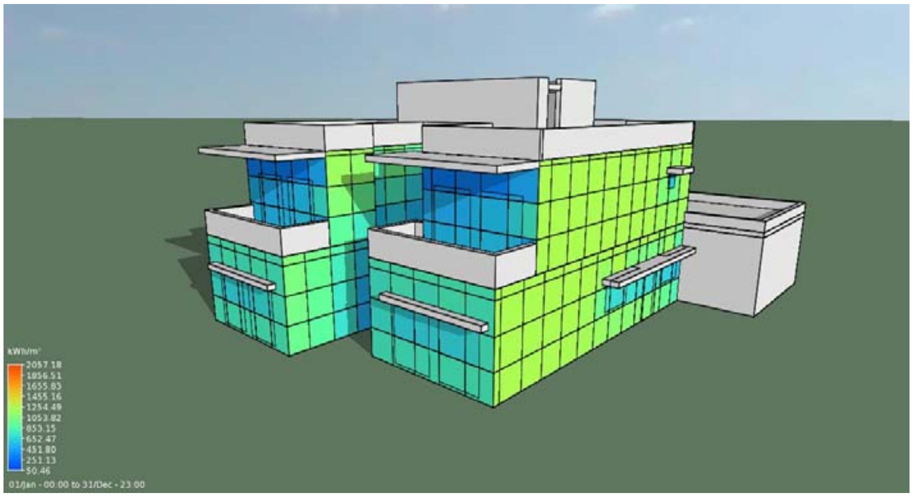


Figure 4.37: Solar exposure analysis of North-West and South-West facades

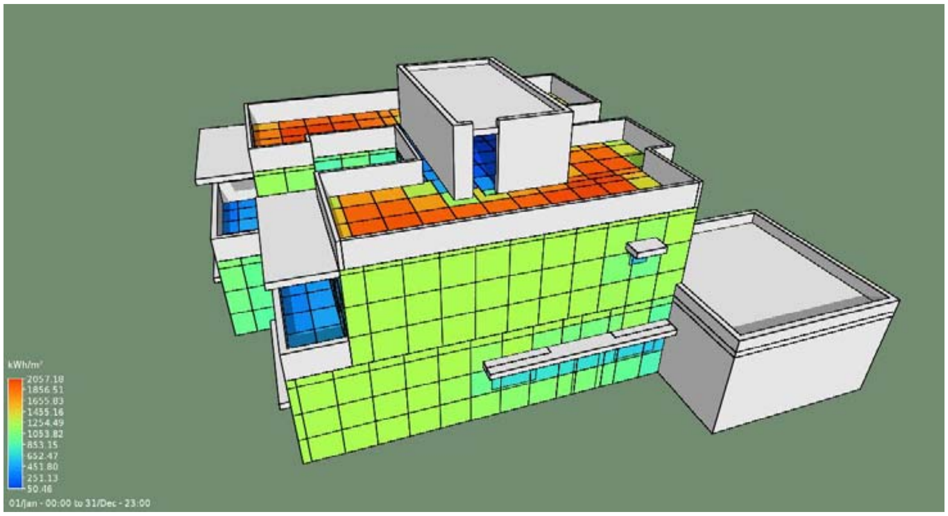


Figure 4.38: Solar exposure analysis of the roof

The blue color shows a lower solar exposure for the windows, terraces and the proposed new roof slab. The total energy consumption was calculated according to the new façade treatments and showed a reduction of the annual consumption reaching 60.1285 MWh as shown in Table 4.23. Shading elements reduced the annual energy consumption by 0.9694 MWh which accounts for 1.59% of the annual power.

Table 4.23: Monthly Energy Consumption after adding the external shading elements

Month	Energy consumption (MWh)	Validation model electricity consumption (MWh)	Energy reduction (MWh)	Energy reduction (%)
Jan	1.8193	1.868	0.0487	2.61%
Feb	1.8313	1.8836	0.0523	2.78%
Mar	2.5645	2.6207	0.0562	2.14%
Apr	4.5105	4.5895	0.079	1.72%
May	6.4294	6.5336	0.1042	1.59%
Jun	7.428	7.5409	0.1129	1.50%
Jul	8.7308	8.8484	0.1176	1.33%
Aug	8.7993	8.9083	0.109	1.22%
Sep	6.7936	6.879	0.0854	1.24%
Oct	5.1499	5.2247	0.0748	1.43%
Nov	3.7014	3.7655	0.0641	1.70%
Dec	2.3705	2.4357	0.0652	2.68%
Total	60.1285	61.0979	0.9694	1.59%

CHAPTER 5: DISCUSSION of SIMULATION RESULTS

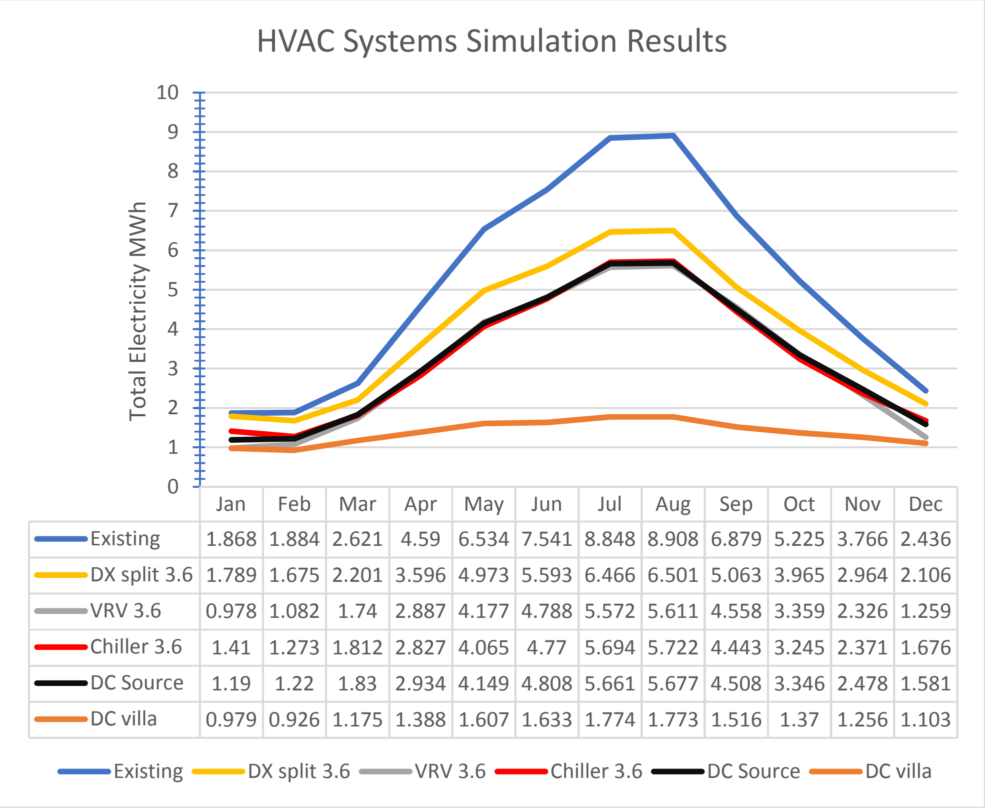
5.1 Simulation Results

It is necessary to compare the simulation results to determine the best combination of parameters which will be used to achieve the lowest energy consumption of the existing villa. The final simulation should combine the best passive measures tested to achieve a NZEB. In case the required savings are not achieved through passive measures, a renewable energy source will be introduced and tested to cover the remaining energy required.

5.1.1 HVAC results analysis

The four HVAC options simulated showed a noticeable reduction in electricity consumption compared to the original DX split system installed. Figure 5.1 and Table 5.1 shows that the lowest annual energy consumption was achieved by connecting the villa to a district cooling plant. This was considered with the assumption that chillers energy is not added to the villa total consumption. The total annual energy consumed was 16.4997 MWh which reduced the total energy consumed by around 73% of the original consumption. If the chillers' energy at source is to be considered, the total reduction of energy by connecting to district cooling plant would be 35.5%. The VRV HVAC system was the second best with 37.25% reduction of energy, while using a compact chiller reduced the energy by 35.6% and the improvement of DX split system reduced only 23.25% of the total annual energy. There's a noticeable difference in energy consumption in the winter months between the VRV system and all the other options investigated. This is due to the use of such variable system that controls the pumping of the refrigerant according to space usage to improve efficiency. Other systems need to reach a certain temperature for the system to start working. This gives an advantage to this system in addition to the energy saving it achieved in the simulation.

The results show that district cooling is the best option to reduce the total consumed energy if the chiller energy at source is not accounted for, this option will be simulated in the final model in both situations with and without the sources chiller energy. VRV scored the best results in terms of total energy saving. It has an advantage of being able to operate off-grid if the remaining energy required can be generated on site. Accordingly, VRV HVAC system will be considered in the final simulation option.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Existing	1.868	1.884	2.621	4.59	6.534	7.541	8.848	8.908	6.879	5.225	3.766	2.436
DX split 3.6	1.789	1.675	2.201	3.596	4.973	5.593	6.466	6.501	5.063	3.965	2.964	2.106
VRV 3.6	0.978	1.082	1.74	2.887	4.177	4.788	5.572	5.611	4.558	3.359	2.326	1.259
Chiller 3.6	1.41	1.273	1.812	2.827	4.065	4.77	5.694	5.722	4.443	3.245	2.371	1.676
DC Source	1.19	1.22	1.83	2.934	4.149	4.808	5.661	5.677	4.508	3.346	2.478	1.581
DC villa	0.979	0.926	1.175	1.388	1.607	1.633	1.774	1.773	1.516	1.37	1.256	1.103

Figure 5.1: HVAC Systems Simulation Results

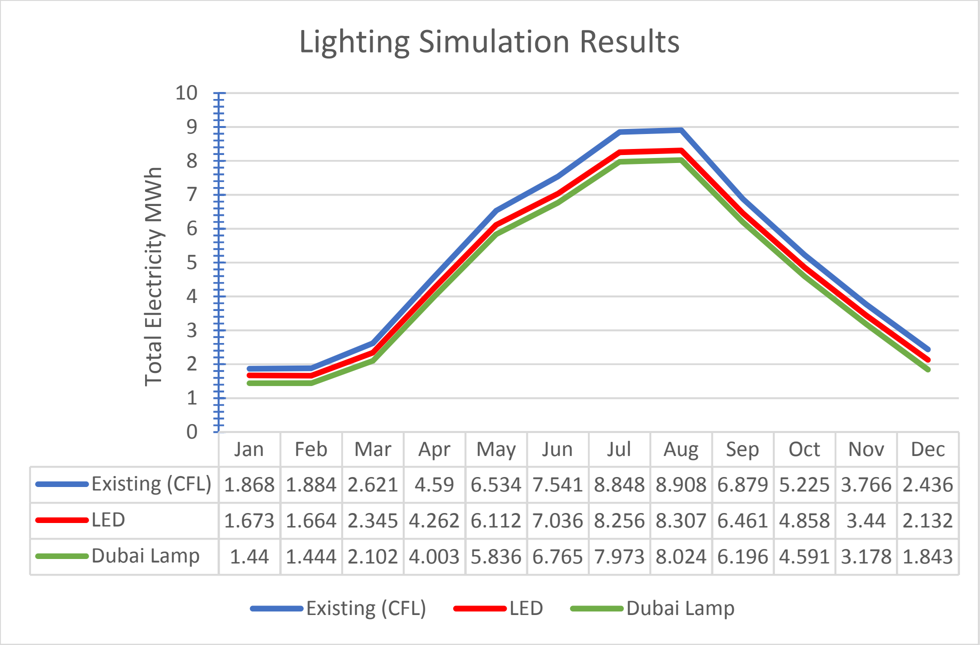
Table 5.1: HVAC systems energy reduction

HVAC System	DX 2.5 (Existing)	DX 3.6	VRV 3.6	Chiller 3.6	DC Source	DC villa
Energy (MWh)	61.0979	46.8921	38.3366	39.3092	39.3821	16.4997
Energy Saving	--	23.25%	37.25%	35.66%	35.54%	72.99%

5.1.2 Lighting results analysis

The two lighting options simulated showed a reasonable energy reduction. Figure 5.2 and Table 5.2 show that the energy saved by using LED lights was 7.45% or

4.5535 MWh annually, while using Dubai Lamp bulbs saved 12.61% or 7.7035 MWh of the energy compared to the existing villa’s CFL lights.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Existing (CFL)	1.868	1.884	2.621	4.59	6.534	7.541	8.848	8.908	6.879	5.225	3.766	2.436
LED	1.673	1.664	2.345	4.262	6.112	7.036	8.256	8.307	6.461	4.858	3.44	2.132
Dubai Lamp	1.44	1.444	2.102	4.003	5.836	6.765	7.973	8.024	6.196	4.591	3.178	1.843

Figure 5.2: Lighting Options Simulation Results

Figure 5.2 shows that the reduction was consistent throughout the year which confirms the validity of the values entered in the simulation model.

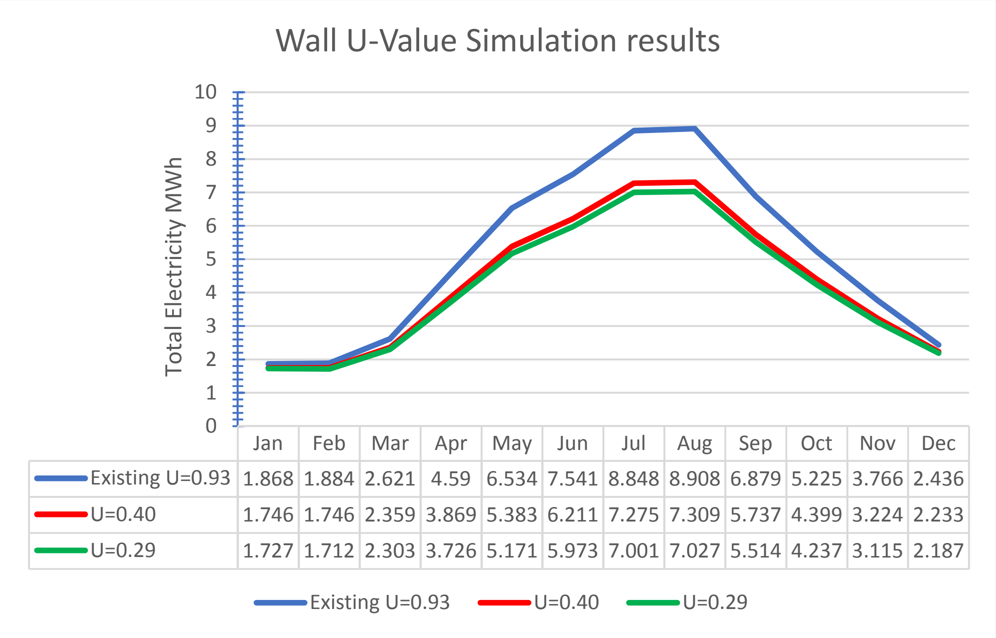
Table 5.2: Lighting options energy reduction

Lighting System	CFL (Existing)	LED	Dubai Lamp
Energy (MWh)	61.0979	56.5444	53.3944
Energy Saving	--	7.45%	12.61%

It’s clear from the simulation results that Dubai Lamp is the option to be used in the final simulation model to achieve the most efficient lighting results.

5.1.3 Walls U-value results analysis

The two external wall U-values tested were 0.4 and 0.29 W/m^{2}K and resulted in energy saving of 15.72% and 18.67%, respectively. Figure 5.3 and Table 5.3 show the monthly consumption of both options in comparison to the existing villa external wall which had a U-value of 0.93 W/m^{2}K. The energy saving for the two cases were 9.6056 and 11.4061 MWh annually, respectively. The most energy saving achieved was during the summer months since the insulation added to the walls reduced the internal heat gain from outdoor hot conditions. For the case of U-value 0.29 W/m^{2}K, out of the 11.4061 MWh reduction in energy almost 80% of this energy was saved in summer months, from 1st of April to the end of September 8.8885 MWh was reduced due to the improvement of external walls U-value.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Existing U=0.93	1.868	1.884	2.621	4.59	6.534	7.541	8.848	8.908	6.879	5.225	3.766	2.436
U=0.40	1.746	1.746	2.359	3.869	5.383	6.211	7.275	7.309	5.737	4.399	3.224	2.233
U=0.29	1.727	1.712	2.303	3.726	5.171	5.973	7.001	7.027	5.514	4.237	3.115	2.187

Figure 5.3: External Walls U-value Options Simulation Results

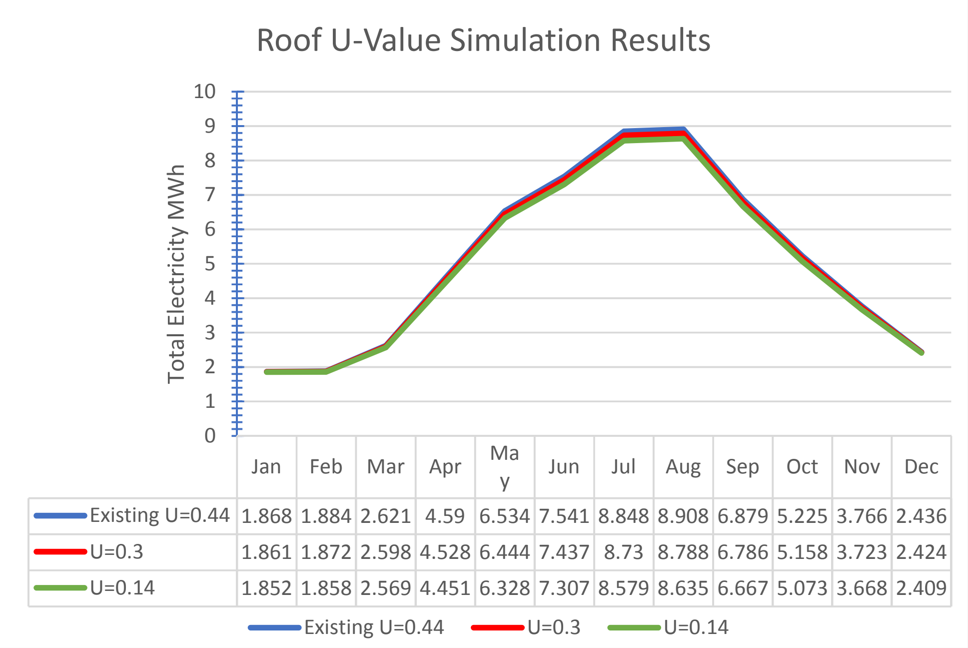
Table 5.3: External Walls U-value options energy reduction

Walls U-value	0.93 (Existing)	0.40 W/m^{2}K	0.29 W/m^{2}K
Energy (MWh)	61.0979	51.4923	49.6918
Energy Saving	--	15.72%	18.67%

Considering that the second option with U-value of 0.29 W/m^{2}K had the most annual energy saving, this option will be considered in the final simulation. In order to achieve this U-value on site and due to different materials existing on the façade, the insulating material should be added to the concrete elements and insulated blocks and the average U-value should reach the required 0.29 W/m^{2}K. This solution should be taken to keep the architectural consistency of the facades.

5.1.4 Roof U-value results analysis

Two options were simulated for the roof U-value options, complying with Dubai Al Sa'fa and ESTIDAMA regulations. The results showed a slight reduction in energy over the course of a year the Al Sa'fa option with U-value of 0.3 W/m^{2}K resulted in a total annual energy reduction of 0.7507 MWh while the ESTIDAMA option with 0.14 W/m^{2}K U-value reduced the energy by 1.7039 MWh annually. Figure 5.4 and Table 5.4 show these savings in electricity at 1.24% and 2.87% of the annual electricity for the 2 options respectively. While it is not a major reduction, this can still help improve the cooling energy required for the building.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Existing U=0.44	1.868	1.884	2.621	4.59	6.534	7.541	8.848	8.908	6.879	5.225	3.766	2.436
U=0.3	1.861	1.872	2.598	4.528	6.444	7.437	8.73	8.788	6.786	5.158	3.723	2.424
U=0.14	1.852	1.858	2.569	4.451	6.328	7.307	8.579	8.635	6.667	5.073	3.668	2.409

Figure 5.4: External Walls U-value Options Simulation Results

Table 5.4: Roof U-value options energy reduction

Roof U-value	0.44 (Existing)	0.30 W/m^{2}K	0.14 W/m^{2}K
Energy (MWh)	61.0979	60.3472	59.394
Energy Saving	--	1.24%	2.87%

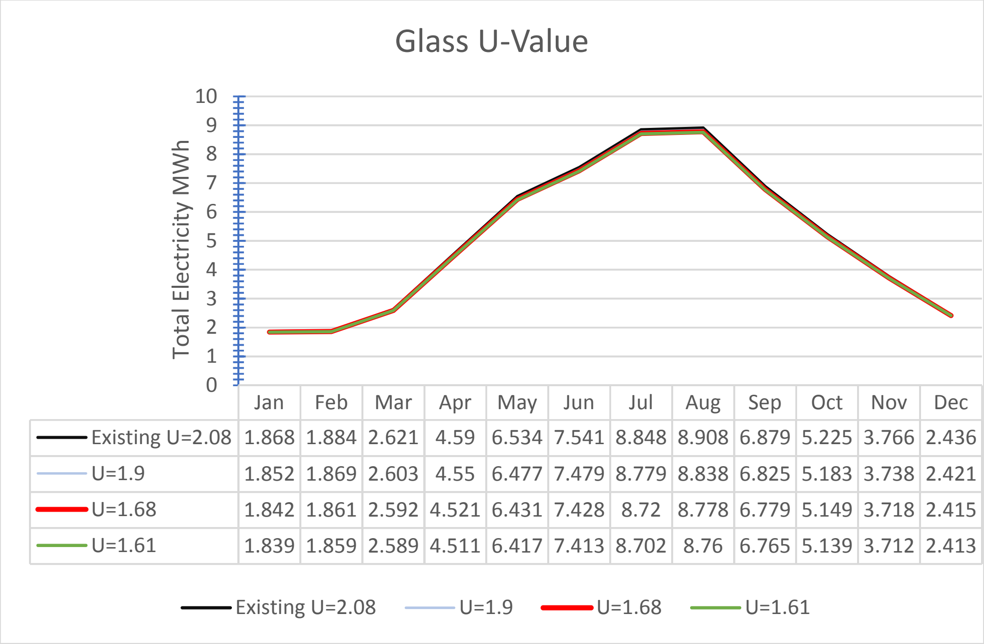
Compared to the walls improvement energy reduction, the roof U-value improvement was not significant, this is due to the ratio of the roof area to the wall area since the roof area is around one third of the external wall area. The other reason is the constant solar exposure of the roof compared to the façade walls which is shown in Figure 4.39. Still the second option with 0.14 W/m^{2}K roof U-value will be chosen as the best energy saving measure for the roof, and will be implemented in the final proposed simulation combining all energy efficiency measures.

5.1.5 Windows U-value results analysis

Compared to the external walls area, the windows and glazed areas occupied 28.5% of the elevation. Windows and glazing are the most heat gain factors in hot climates. Reducing the U-value of windows can reduce the energy required for cooling. However, the initial design didn't take into consideration this aspect. The large glazed areas of the façade contribute largely in the high demand energy required to cool the building in summer. Although the total windows and frame U-value was reduced for the three options investigated, the effect of this was minimal on the energy saving compared to other parameters. The first option with U-value of 1.9 W/m^{2}K resulted in a reduction of 0.7% of the annual electricity consumption, this is considered the mandatory requirement by Dubai and Abu Dhabi regulatory, the second and third options showed reduction of total energy by 1.41% and 1.60% respectively, as shown in Figure 5.5 and Table 5.5. The best results achieved by using 1.61 W/m^{2}K U-value for the windows with a total energy saving of 0.9802 MWh annually. The third option will be chosen as the best improvement for the glazing in the final model, however, less cost-effective measures could be used in the case of not achieving the required NZEB, options like triple glazing or gas filled gaps could have lower U-values and contribute in reducing more energy.

Table 5.5: Windows U-value options energy reduction

Windows U-value	2.08 (Existing)	1.9 W/m^{2}K	1.68 W/m^{2}K	1.61 W/m^{2}K
Energy (MWh)	61.0979	60.614	60.2358	60.1177
Energy Saving	--	0.79%	1.41%	1.60%



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Existing U=2.08	1.868	1.884	2.621	4.59	6.534	7.541	8.848	8.908	6.879	5.225	3.766	2.436
U=1.9	1.852	1.869	2.603	4.55	6.477	7.479	8.779	8.838	6.825	5.183	3.738	2.421
U=1.68	1.842	1.861	2.592	4.521	6.431	7.428	8.72	8.778	6.779	5.149	3.718	2.415
U=1.61	1.839	1.859	2.589	4.511	6.417	7.413	8.702	8.76	6.765	5.139	3.712	2.413

Figure 5.5: Windows U-value Options Simulation Results

5.1.6 Shading elements results analysis

Northern hemisphere buildings are mostly exposed to the sun from the south direction. The existing villa has two facades oriented towards the south, the main entrance façade facing South-East has two windows exposed to the sun most of the day and the South-Western elevation which has smaller windows but is also exposed to the sun most of the day. The addition of shading elements or extending the window lintels reduced the energy exposure per square meter on these areas. The windows on the main entrance elevation had energy consumption per square meter between 1000 to 1300 kWh/m^2. The introduction of shading devices reduced the energy consumed due to solar exposure to below 800 kWh/m^2 as shown in Figure 5.6.

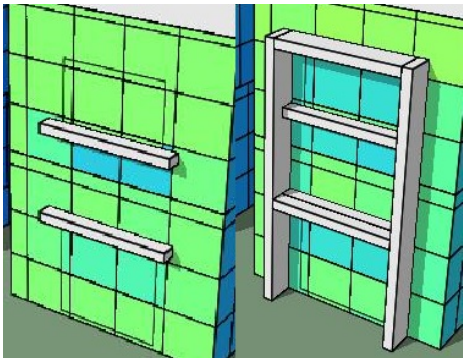


Figure 5.6: Solar exposure comparison after applying shading devices to the South-Eastern façade

The same results were found for the South-Western façade after adding shadings above the windows Figure 5.7 shows the solar exposure before and after introducing the shading devices for the windows. The solar exposure of the two terraces was reduced in the mentioned areas and accordingly the energy consumption.

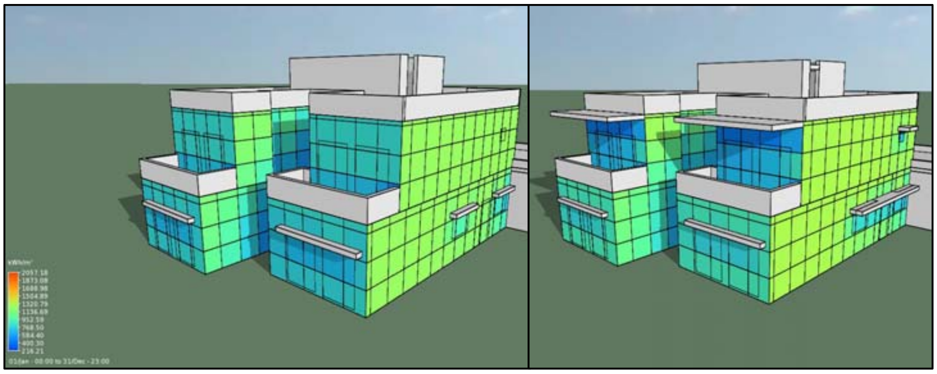


Figure 5.7: Solar exposure comparison for the Western facades

The terraces' roofs served two purposed. The first was reducing the sun exposure for the glazed doors, and the second was the reduction of solar exposure for the terrace flooring, which is the roof of the ground floor. This is shown in Figures 5.8 as the dark blue color inside the terraces represents a low solar exposure for these areas.

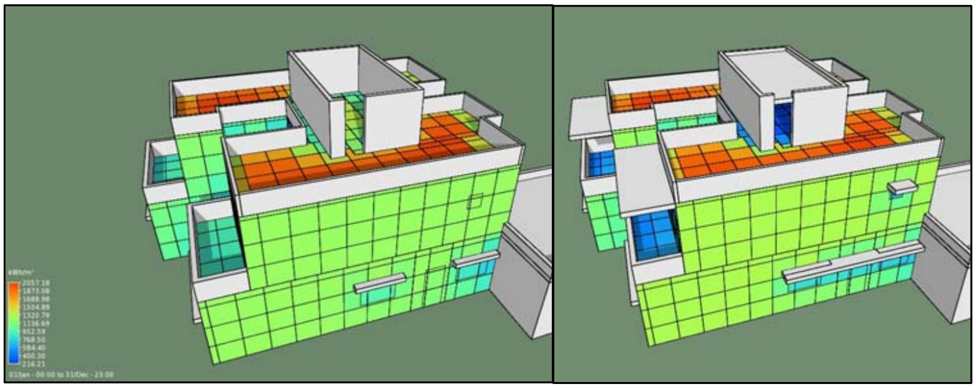
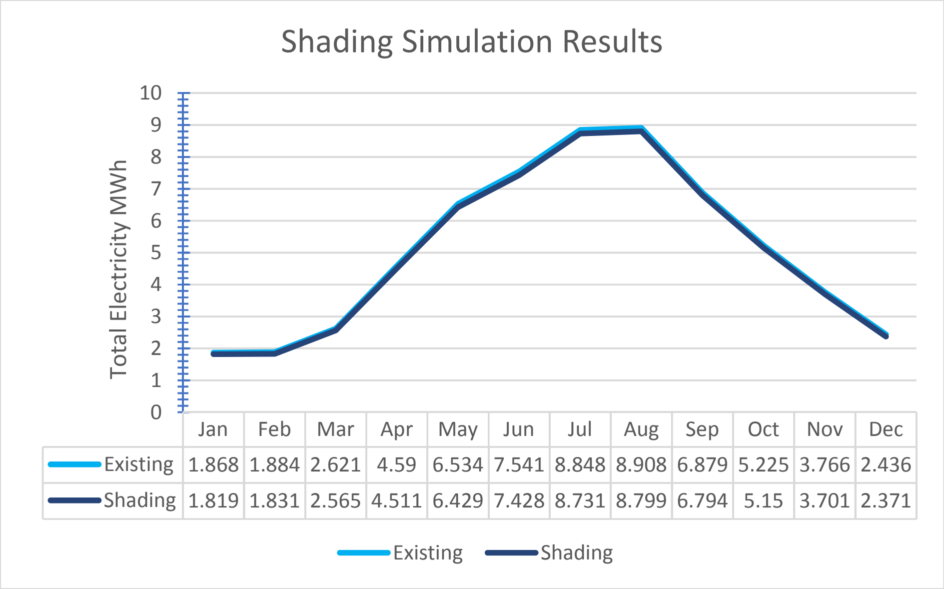


Figure 5.8: Solar exposure analysis of the roof and terraces

Figure 5.8 also shows a noticeable reduction in solar exposure for the new covered area on the roof. The energy reduced from around 1400 kWh/m^2 to less than 400 kWh/m^2 for this area. The North-Eastern façade has few small windows and is not directed to the sun thus no further treatment was required for this façade. The simulation results after adding the shading elements shows a reduction in the total energy annually by 0.9694 MWh. This accounts for approximately 1.58% of the total annual energy consumed by the villa. Figure 5.9 and Table 5.6 show the reduction in demand energy after the introduction of this passive measure.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Existing	1.868	1.884	2.621	4.59	6.534	7.541	8.848	8.908	6.879	5.225	3.766	2.436
Shading	1.819	1.831	2.565	4.511	6.429	7.428	8.731	8.799	6.794	5.15	3.701	2.371

Figure 5.9: Shading Elements Simulation Results

Table 5.6: Shading elements energy reduction

Walls U-value	Existing villa	Shading Elements
Energy (MWh)	61.0979	60.1285
Energy Saving	--	1.58%

In the case of adding a renewable energy source such as PV panels, these panels would be placed on the roof and will result in further reduction of the solar exposure in the remaining roof areas. This option will be studied according to the need of such solution.

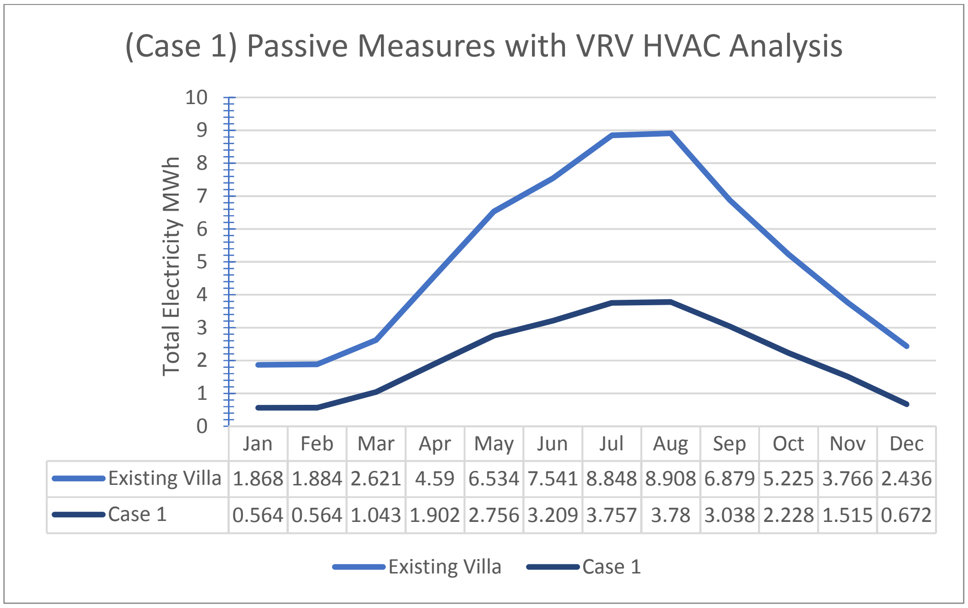
5.2 Selected Passive Energy Efficiency Measures

As discussed in this chapter, and due to scoring the best energy saving results, the following parameters and systems are selected to provide the best combination of energy saving. This will help achieve a net zero energy building for the studied existing villa.

- Variable Refrigerant Volume (VRV) HVAC system with COP of 3.6 as a stand-alone villa option. This HVAC option will be used in Case 1
- District cooling option for the maximum saving of cooling energy, this option is only possible if the developer of the community decided to construct a chilled water plant to reduce the total cooling energy for a group of villas. This HVAC option will be used in Case 2.
- Dubai Lamp bulbs for all lighting fixtures of the villa.
- External walls U-value of 0.2867 W/m^{2}K as per ESTIDAMA requirements.
- Roof U-value of 0.1418 W/m^{2}K as per ESTIDAMA requirements.
- Windows U-value of 1.61 W/m^{2}K
- Shading elements for southern façade windows, first floor terraces and roof HVAC enclosure.

5.3 Selected passive measures combination with VRV HVAC (Case 1)

The best of all the energy parameters were combined in one IES VE model. The HVAC system used in this test was the variable refrigerant volume system with 3.6 coefficient of performance. The model was simulated with ApacheHVAC to calculate the HVAC system sizing and accordingly the Apache simulation was run to calculate the monthly electricity consumption. The simulation results in figure 5.10 and Table 5.7 show the results of the passive measures and lighting improvement combined using VRV HVAC system. The total consumed energy by the building was reduced to 25.0259 MWh annually down from 61.0979 MWh. This considerable reduction account for 36.072 MWh of saved energy amounts to 59.04% energy reduction. Most of the saved power was simulated during summer months due to the improvement of AC system and building envelope. the total energy saved from April to September is 24.8589 MWh. This energy accounts for around 69% of the total energy saved across the year. The building's existing situation allows a large amount of solar energy to enter the building. This results in heating the internal spaces causing higher cooling demand.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Existing Villa	1.868	1.884	2.621	4.59	6.534	7.541	8.848	8.908	6.879	5.225	3.766	2.436
Case 1	0.564	0.564	1.043	1.902	2.756	3.209	3.757	3.78	3.038	2.228	1.515	0.672

Figure 5.10: (Case 1) Passive measures with VRV HVAC simulation results

Table 5.7: (Case 1) Passive measures with VRV HVAC energy reduction

	Existing villa	Case 1
HVAC Energy	52.489	20.9716
Lighting Energy	5.4685	0.9145
Equipment Energy	3.1396	3.1396
Total Annual Energy Consumption (MWh)	61.0979	25.0259
Energy Saving (%)	--	59.04%

Using a high efficiency HVAC system contributed positively in reducing the total electricity consumption. The total energy used by the HVAC system in this scenario was 20.9716 MWh compared to the existing villa's HVAC system which used 52.4898 MWh. This accounts for more than double the total energy used by all systems, lighting and equipment in the proposed option. The energy used for lighting was reduced from 5.4685 MWh annually to 0.9145 MWh annually. This is equal to less than one fifth of the energy used currently for lighting. The remaining energy of 3.1396 MWh annually is consumed by the equipment and electrical appliances in the building. This energy did not change between the existing and the proposed models since it's related to occupant's daily usages of such appliances.

Despite the high energy saving after applying all the passive measures, the remaining 25.0259 MWh annually needs to be generated on site through the use of a renewable energy source. , Installing PV panels on the roof of the villa should lead to further reduction in the energy demand by providing extra shading to the roof. The potential of generating enough energy to cover the villa's consumption will be tested and validated to confirm if this option can reach the intended net zero energy building.

5.4 Selected passive measures combination with district cooling plant connection (Case 2)

The same passive parameters used in Case 1 will be used in this case with the only modification being replacing the VRV system with a district cooling plant connection. This should reduce the villa need for electricity since the required cooling energy is not consumed on site. The district cooling plant usually has a higher energy efficiency due to the large-scale production of chilled water. However, the distance between the district cooling plant and the supplied building will affect the chilled water temperature, this option will study both scenarios of considering the cooling load required for the villa from the cooling plant and the second scenario will only focus on the villa electricity consumption.

After running ApacheHVAC analysis to calculate the system sizing and cooling load required, Apache simulation was run to calculate the total villa energy consumed annually, the results listed in Table 5.8 and 5.9, Figure 5.11 confirms the feasibility of introducing this HVAC system as the best energy reduction combination.

Table 5.8: (Case 2) Passive measures with district cooling energy reduction

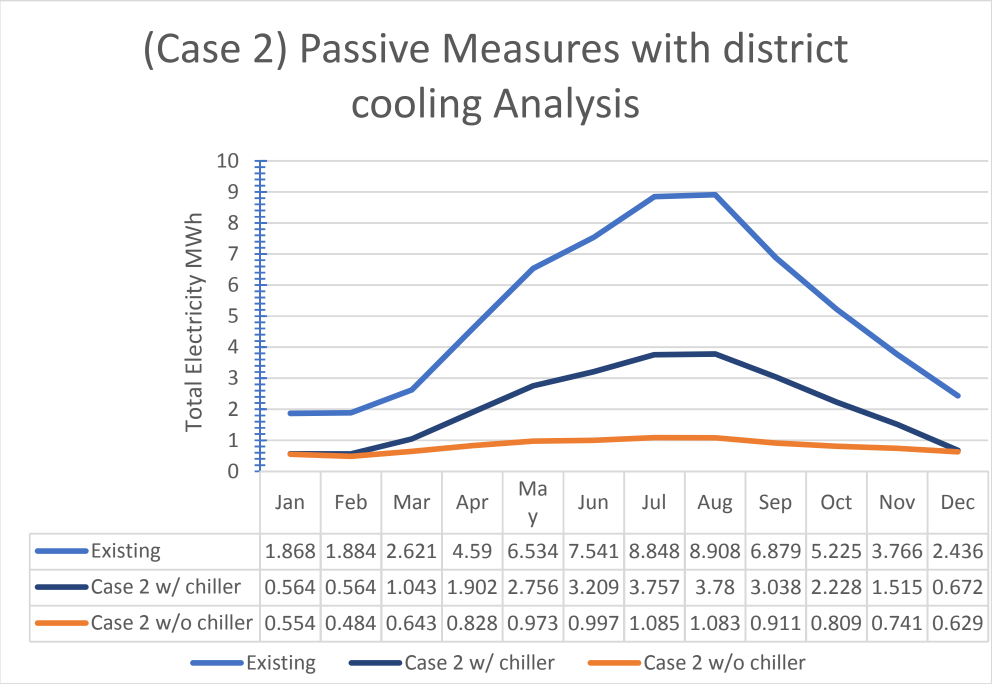
	Existing villa	Case 2
Chillers Energy	52.489	5.682
Lighting Energy	5.4685	0.9145
Equipment Energy	3.1396	3.1396
Total Annual Energy Consumption (MWh)	61.0979	9.7364
Energy Saving (%)	--	84.06%

Case 2 shows a huge energy reduction reaching around 84 percent of the original energy consumed by the existing villa, a total energy demand of 9.7364 MWh only required annually. The required systems energy is only 5.682 MWh annually which is consumed by the distribution fans, controllers and other parts of the system. Eliminating the cooling energy has a huge impact on the energy demand. The required power in this case could easily be generated by PV panels on the building's roof. The total lighting and equipment energy saving are the same as Case 1 since these parameters didn't change in both cases. Table 5.9 shows the monthly electricity consumption of Case 2 against the existing villa energy consumption, it's also shows the energy required to cover the chillers energy required for the villa at the district cooling plant. The total energy demand in this case will increase to 25.83 MWh annually. The chillers energy required is 16.0938 MWh annually, this demand was reduced by 0.4059 MWh compared to the test simulation using district cooling plant option .The chillers energy in the test model considered the higher demand of the villa before applying the passive energy efficiency measures to the building envelope, 14.1158 MWh of the chillers energy required in summer months. This explains the gap between the two options in Figure 5.11. Around seven months of the year have very hot weather which increases the demand of electricity to achieve the required cooling.

Table 5.9: Case 2 monthly energy consumption with and without chillers energy at source against the existing villa consumption

Month	Existing villa	Case 2 with chillers energy	Case 2 without chillers energy
Jan	1.868	0.7128	0.554
Feb	1.8836	0.6718	0.4837
Mar	2.6207	1.1037	0.6427
Apr	4.5895	1.8986	0.8278
May	6.5336	2.7271	0.9733
Jun	7.5409	3.2482	0.9973
Jul	8.8484	3.8689	1.085
Aug	8.9083	3.8741	1.0831
Sep	6.879	3.0083	0.9107
Oct	5.2247	2.1766	0.8088
Nov	3.7655	1.5861	0.7411
Dec	2.4357	0.9538	0.6289
Total Energy	61.0979	25.83	9.7364

Figure 5.11 shows a relatively consistent consumption of energy for case 2 option without chillers energy at source. This due to the regular usage of lighting and equipment throughout the year. The slight increase in summer months reflects the increase of distribution fans usage due to the need of cooling all summer long.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Existing	1.868	1.884	2.621	4.59	6.534	7.541	8.848	8.908	6.879	5.225	3.766	2.436
Case 2 w/ chiller	0.564	0.564	1.043	1.902	2.756	3.209	3.757	3.78	3.038	2.228	1.515	0.672
Case 2 w/o chiller	0.554	0.484	0.643	0.828	0.973	0.997	1.085	1.083	0.911	0.809	0.741	0.629

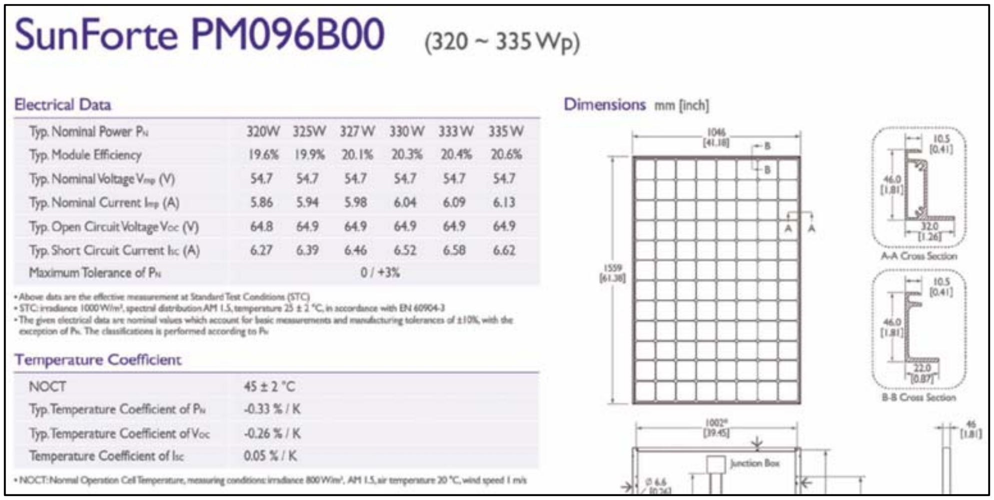
Figure 5.11: (Case 2) Passive measures with district cooling simulation results

Case 2 without considering source energy is clearly the best energy saving option. However, relatively low energy still need to be generated by renewable energy sources to cover the balance of the villa’s demand. PV panels implementation will be tested for both options of case 2 to achieve the net zero energy building goal.

5.5 Renewable Energy Source (Photovoltaic Panels Implementation)

5.5.1 Selected PV Module

Several suppliers of PV panels were contacted and researched to find high efficiency panels in the UAE. AU Optronics Corporation (2015) produce the best commercially efficient PV panels found in UAE which has 20.6% module efficiency. The panels manufactured by BenQ Solar and named SunForte PM096B00, with normal operation cell temperature of 45±2 °C, Figure 5.12 is extracted from the product’s datasheet and it shows a nominal power of 335 W for the mentioned efficiency of 20.6% and -0.33%/K as temperature coefficient of power. Each panel measures 1046 mm by 1559 mm and contains 96 back contact mono-crystalline cells. The operating temperatures for the panels ranges between -40 and +80 °C (AU Optronics Corporation 2015). Due to its high efficiency and availability in the UAE, this module will be selected and tested to generate the demanded electricity for the proposed villa Case 1 and Case 2.



SunForte PM096B00 (320 ~ 335 Wp)

Electrical Data

Typ. Nominal Power P_N	320W	325W	327 W	330 W	333 W	335 W
Typ. Module Efficiency	19.6%	19.9%	20.1%	20.3%	20.4%	20.6%
Typ. Nominal Voltage V_{mp} (V)	54.7	54.7	54.7	54.7	54.7	54.7
Typ. Nominal Current I_{mp} (A)	5.86	5.94	5.98	6.04	6.09	6.13
Typ. Open Circuit Voltage V_{OC} (V)	64.8	64.9	64.9	64.9	64.9	64.9
Typ. Short Circuit Current I_{SC} (A)	6.27	6.39	6.46	6.52	6.58	6.62
Maximum Tolerance of P_N	0 / +3%					

- Above data are the effective measurement at Standard Test Conditions (STC)
- STC: irradiance 1000 W/m², spectral distribution AM 1.5, temperature 25 ± 2 °C, in accordance with EN 60904-3
- The given electrical data are nominal values which account for basic measurements and manufacturing tolerances of ±10%, with the exception of P_N. The classifications is performed according to P_N

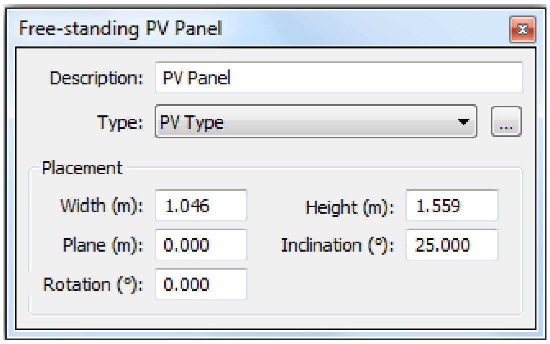
Temperature Coefficient

NOCT	45 ± 2 °C
Typ. Temperature Coefficient of P_N	-0.33 % / K
Typ. Temperature Coefficient of V_{OC}	-0.26 % / K
Temperature Coefficient of I_{SC}	0.05 % / K

- NOCT: Normal Operation Cell Temperature, measuring conditions: irradiance 800 W/m², AM 1.5, air temperature 20 °C, wind speed 1 m/s

Figure 5.12: PV panels datasheet extract (AU Optronics Corporation, 2015)

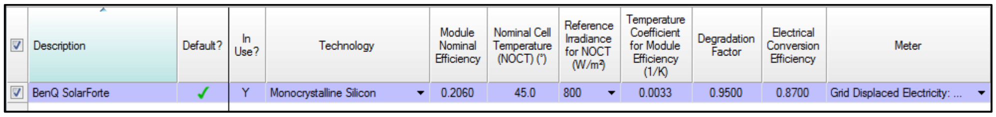
To use the same selected PV panel properties in IES VE, the same panel dimensions were entered to the software with inclination of 25° as shown in Figure 5.13, covering a surface area of approximately 1.6 meters for each panel.



Description: PV Panel
Type: PV Type
Placement
Width (m): 1.046
Height (m): 1.559
Plane (m): 0.000
Inclination (°): 25.000
Rotation (°): 0.000

Figure 5.13: PV panels dimensions and inclination as entered in IES VE

Other module details are also entered to IES VE according to the manufacturer datasheet as shown in Figure 5.14. Monocrystalline silicon was selected, the efficiency entered as 20.6%, the temperature coefficient for module efficiency is 0.0033 (1/K) as per the datasheet. Irradiance for NOCT selected as 1000 W/m^2, electrical conversion efficiency was considered as 87% as the software default for monocrystalline cells, Normal Operation Cell Temperature (NOCT) as 45°C and degradation factor as 95%. These entered parameters should give accurate results of the module-generated power.



☑	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
☑	BenQ SolarForte	✓	Y	Monocrystalline Silicon	0.2060	45.0	800	0.0033	0.9500	0.8700	Grid Displaced Electricity: ...

Figure 5.14: PV Panel properties as entered in IES VE to match the manufacturer datasheet

To validate that the PV panels data entered in IES VE will have accurate results. 10 PV panels were added to IES VE and the energy output was simulated according to manufacturer data mentioned above. The total annual electricity output of the 10 panels simulated as 5.3046 MWh. The same number and data of the PV panels were validated using Photovoltaic Information System – Interactive Maps, a simulation tool developed by the European Commission, Joint Research Center (JRC European Commission). The simulation resulted in an annual output of 5.3 MWh for the 10 PV panels. Confirming that the results simulated through IES VE are reliable in the entered format. Table 5.10 shows the monthly electricity outputs simulated by both IES VE and the validation tool. The simulation result is also added as Appendix A.

Table 5.10: PV panels energy output validation

Month	10 PV Panels output simulated with IES VE (MWh)	10 PV Panels output simulated with validation tool (MWh)
Jan	0.3987	0.4050
Feb	0.4247	0.4100
Mar	0.4337	0.4860
Apr	0.4406	0.4530
May	0.4877	0.4760
Jun	0.4598	0.4490
Jul	0.4625	0.4370
Aug	0.4792	0.4480
Sep	0.4712	0.4580
Oct	0.4698	0.4740
Nov	0.4016	0.4090
Dec	0.3749	0.3910
Total Energy	5.3046	5.3000

5.5.2 PV panels implementation for Case 1

The PV panel's parameters were added to Case 1 model simulation in IES VE. After simulating one panel in the simulation model, it was found that one panel generates approximately 0.5 MWh annually depending on its location on the building roof since some areas are shaded for more hours of the day than others. The required electricity that must be generated by PV panels for Case 1 is 25.0259 MWh as shown previously in Table 5.7. This will require around 50 panels to be installed on the villa and garage roofs. Prior to calculating the energy consumption and PV panels' power generation, SunCast analysis was run to calculate the shading effect of the PV panels. The result of this analysis shows a reduction of solar exposure of the roof in comparison to the previously simulated shading measures model as shown in Figure 5.15

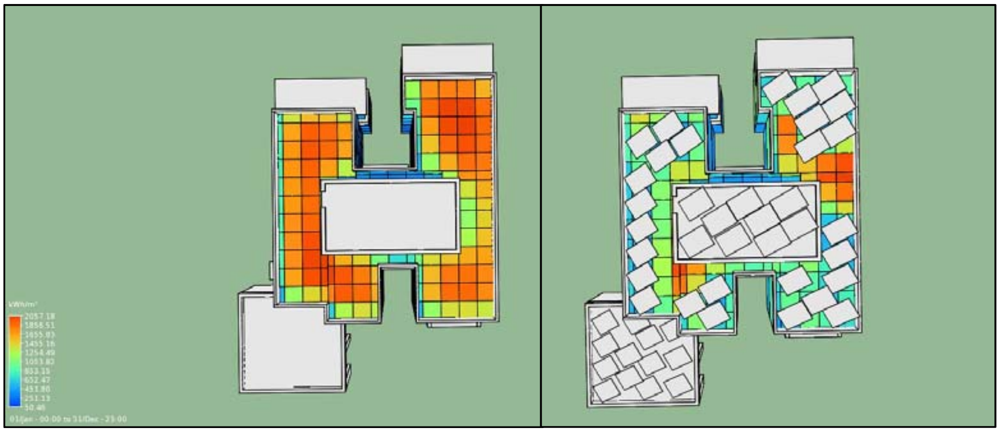


Figure 5.15: Solar exposure comparison before and after adding PV panels to the roof for Case 1

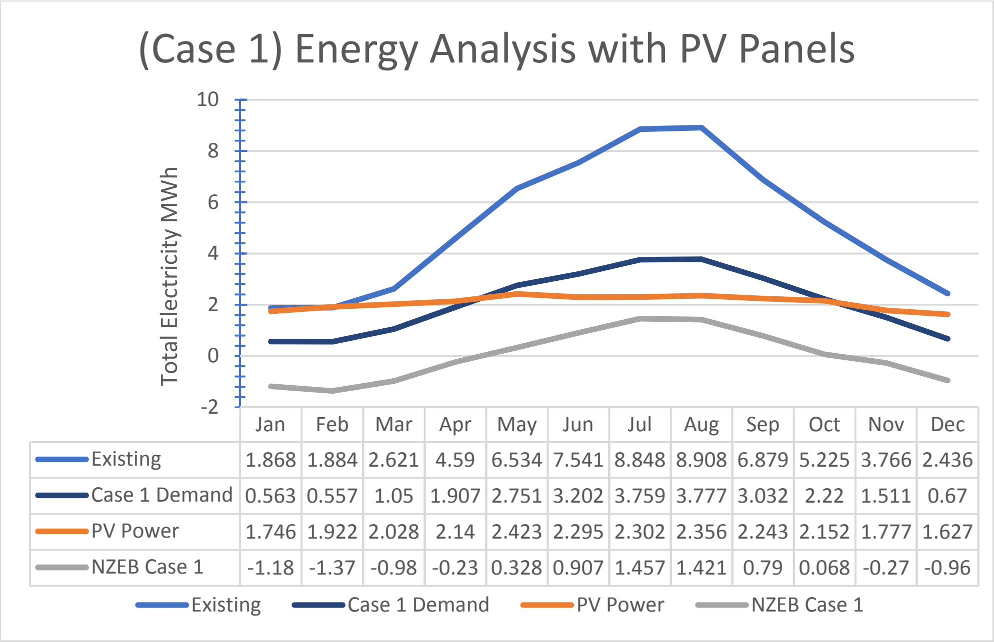
A noticeable reduction of energy per square meter is shown for the roof after the introduction of PV panels as most of the roof area is now shaded by the solar panels. This should further reduce the villa's electricity demand.

After the addition of the south facing roof PV panels and updating ApacheHVAC calculations for the system sizing, Apache simulation was run to calculate the monthly electricity consumption of the villa. Table 5.11 shows the final simulation results.

Table 5.11: Case 1 monthly electricity consumption results with PV panels

Month	Monthly Demand (MWh)	Monthly PV Panels generated electricity (MWh)	Total Consumption
Jan	0.5631	1.7461	-1.183
Feb	0.557	1.9221	-1.3651
Mar	1.0497	2.0281	-0.9784
Apr	1.9073	2.1398	-0.2324
May	2.7513	2.4232	0.3281
Jun	3.2019	2.2949	0.907
Jul	3.7593	2.3022	1.457
Aug	3.7774	2.3563	1.4211
Sep	3.0324	2.2426	0.7898
Oct	2.2196	2.152	0.0676
Nov	1.5105	1.7767	-0.2662
Dec	0.6698	1.6267	-0.957
Total Energy	24.9993	25.0107	-0.0113

The results shown in Table 5.11 were simulated using 49 panels with a total active surface area of 79.9 m^2 on the garage and villa roofs. Using 50 panels resulted in extra generated power and accordingly one panel was reduced. The monthly demand shows a reduction of energy required by 0.0266 MWh annually as a result of the PV panels shading, the total energy consumption was simulated as 24.9993 MWh annually. While the PV panels generated enough electricity to cover this demand, the total energy generated by the renewable energy source is 25.0107 MWh annually. Table 5.11 shows that the total power consumed was less than the electricity generated by 0.0113 MWh annually. This extra power generated could be fed back to the grid to reduce utilities bills for the building occupants. The total energy saved by applying all passive measures compared to the existing villa consumption is 59.08%, an increase of 0.04% as a result of PV panels shading of the roof. In order for the villa to operate off-grid a battery and inverter need to be introduced to the electricity system. This is due to summer months demand which cannot be covered by the PV generated electricity; 4.9706 MWh need to be provided by the grid or battery saved energy in the period from May to October. During the other six months of the year the PVs generate extra energy that could be fed back to the grid. This power is simulated as 4.9821 MWh, the total of both demand and extra electricity adds up to confirm that net zero energy building goal was achieved for Case 1 with 0.0113 MWh extra generated power. Figure 5.16 shows the reduction of energy between the existing villa, Case 1 energy demand, and the final case 1 demand after introducing the PV panels.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Existing	1.868	1.884	2.621	4.59	6.534	7.541	8.848	8.908	6.879	5.225	3.766	2.436
Case 1 Demand	0.563	0.557	1.05	1.907	2.751	3.202	3.759	3.777	3.032	2.22	1.511	0.67
PV Power	1.746	1.922	2.028	2.14	2.423	2.295	2.302	2.356	2.243	2.152	1.777	1.627
NZEB Case 1	-1.18	-1.37	-0.98	-0.23	0.328	0.907	1.457	1.421	0.79	0.068	-0.27	-0.96

Figure 5.16: Energy comparison between existing villa and Case 1 demand before and after installing PV panels

5.5.3 PV panels implementation for Case 2

For Case 2, The required electricity to be generated by PV panels without considering the chillers load is 9.7364 MWh, as discussed for Case 1 this should be generated using 20 PV panels or less. In order to calculate the exact energy required after introducing the panels, SunCast analysis was run to calculate the roof solar exposure. PV panels were placed along the roof facing south to cast the maximum shadow on the roof. The solar exposure analysis showed some reduction in the roof areas where panels are located as shown in Figure 5.17

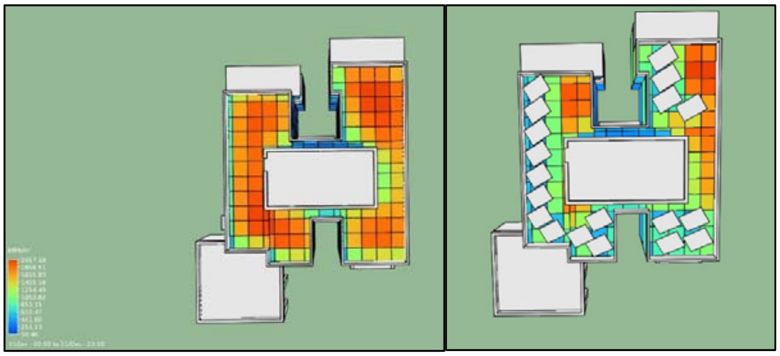


Figure 5.17: Solar exposure comparison before and after adding PV panels for Case 2

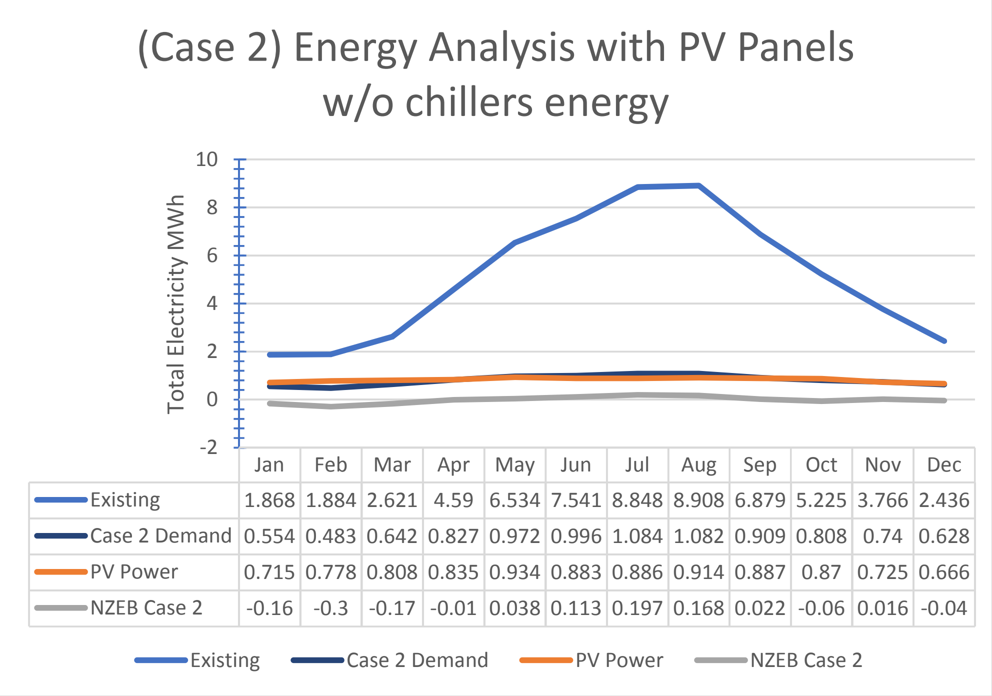
19 panels were used in the simulation with the same properties for each module as entered for Case 1, with total active panels area of around 31 m^2. The orientation of the panels is 183.6 degrees from North which is in this case gives the panels a south facing direction to have the most exposure to the light all year round. After updating ApacheHVAC calculations for the system sizing and running Apache simulation, the villa's monthly electricity consumption was calculated as listed in Table 5.12.

Table 5.12: Case 2 (w/o chillers) monthly electricity consumption using PVs

Month	Monthly Demand (MWh)	Monthly PV Panels generated electricity (MWh)	Total Consumption
Jan	0.5537	0.7147	-0.161
Feb	0.4827	0.7784	-0.2957
Mar	0.6415	0.808	-0.1665
Apr	0.8267	0.835	-0.0083
May	0.9718	0.934	0.0378
Jun	0.9962	0.883	0.1132
Jul	1.0837	0.8863	0.1974
Aug	1.0816	0.9141	0.1675
Sep	0.909	0.8874	0.0216
Oct	0.8075	0.8697	-0.0622
Nov	0.7401	0.7246	0.0155
Dec	0.6281	0.6662	-0.0381
Total Energy	9.7226	9.9014	-0.1788

The simulation results show a total electricity demand of 9.7226 MWh annually. This power demand was reduced by 0.0138 MWh annually due to the PV panels shading, compared to the existing villa energy consumption. Case 2 provides energy reduction of 84.08% of the total energy required annually. This is 0.02% saving more than the calculated energy saving before adding the PV panels. The 19 photovoltaic panels generated an annual electricity of 9.9014 MWh which is enough electricity to cover the villa demand in addition to an extra 0.1788 MWh that could be fed back to the grid. Unlike Case 1, the energy demand and renewable power generation in summer months are very close, the villa requires only 0.5375 MWh from May to September in order to operate off-grid. If this was the target, then adding few extra PV panels should cover this remaining energy in summer months.

A battery could also be used to save the extra generated power in winter months to be used in summer. Figure 5.18 shows the proximity of achieving such results as well as the total energy reduction compared to the existing villa case and how close the energy input and output monthly to the zero MWh line.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Existing	1.868	1.884	2.621	4.59	6.534	7.541	8.848	8.908	6.879	5.225	3.766	2.436
Case 2 Demand	0.554	0.483	0.642	0.827	0.972	0.996	1.084	1.082	0.909	0.808	0.74	0.628
PV Power	0.715	0.778	0.808	0.835	0.934	0.883	0.886	0.914	0.887	0.87	0.725	0.666
NZEB Case 2	-0.16	-0.3	-0.17	-0.01	0.038	0.113	0.197	0.168	0.022	-0.06	0.016	-0.04

Figure 5.18: Energy comparison between existing villa and Case 2 (w/o chillers) demand before and after installing PV panels

The extra energy produced from October to April is calculated as 0.7163 MWh. When fed back to the grid, this electricity should cover the demand during the summer months. Case 2 with connection to a district cooling plant and without considering the chillers load at source is considered the best option for NZEB by far. It achieved the lowest energy consumption and will be the cheapest initial cost option considering the lower number of PV panels that needs to be installed. However, in order to determine if this is the best option on the long run, a life cost analysis need to be done to compare the running cost against the initial cost. The running cost when a building is supplied with chilled water in Dubai differs depending on the district cooling company providing the service. Further research is required to understand the cost impact of using such systems and strategies.

Case 2 was also investigated considering the possibility for the villa to cover its own energy in addition to the chillers energy at source. As shown previously, the required chillers energy for Case 2 from the district cooling plant is 16.0938 MWh annually. This puts the total yearly required energy for the villa at 25.83 MWh. This will require installing 51 PV panels on the roof with total active surface area of 83.17 square meters. Shading analysis was calculated using SunCast application before running Apache simulation. The solar exposure of the roof was reduce similar to Case 1 as shown in Figure 5.19. ApacheHVAC sizing calculation was run to update the system sizing after installing the PV panels in order to calculate the model energy consumption with chillers and the power generated by the PV panels. The monthly energy consumption of this simulation is shown in Table 5.13

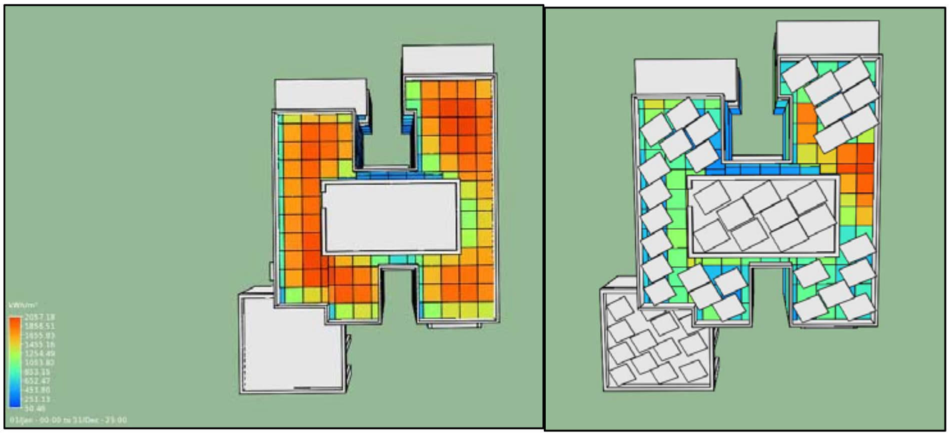
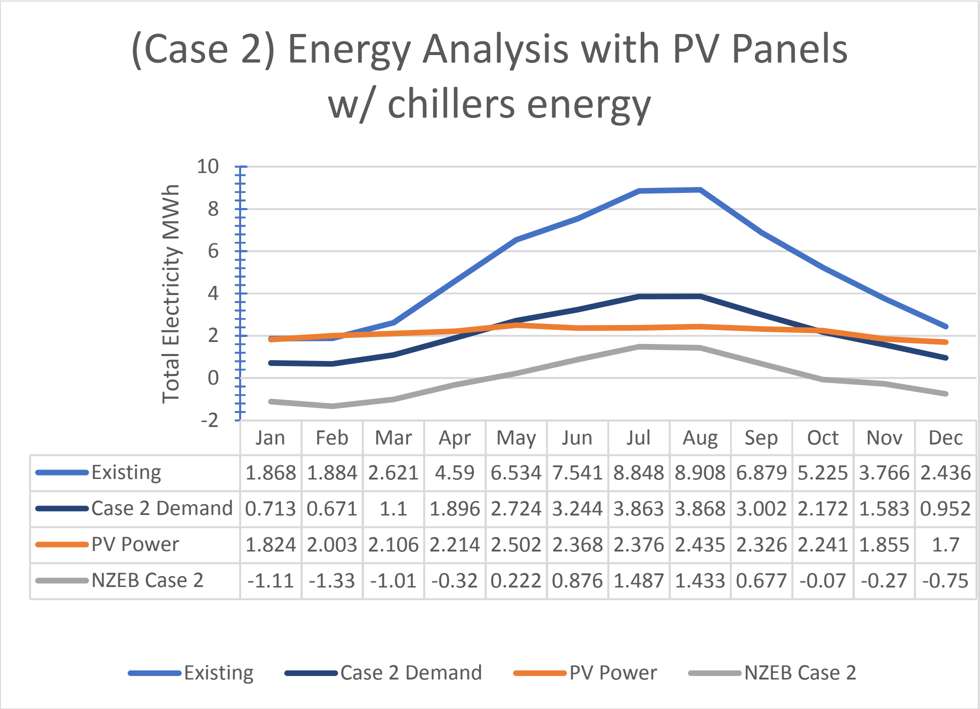


Figure 5.19: Solar exposure comparison before and after adding PV panels to the roof for Case 2 with chillers energy

Table 5.13: Case 2 (w/ chillers) monthly electricity consumption results with PV panels

Month	Monthly Demand (MWh)	Monthly PV Panels generated electricity (MWh)	Total Consumption
Jan	0.7128	1.8241	-1.1113
Feb	0.6708	2.0033	-1.3325
Mar	1.0997	2.1063	-1.0066
Apr	1.8958	2.2135	-0.3177
May	2.7236	2.5019	0.2217
Jun	3.2439	2.3679	0.876
Jul	3.8629	2.3761	1.4868
Aug	3.8679	2.4352	1.4327
Sep	3.0021	2.3256	0.6765
Oct	2.1723	2.2409	-0.0686
Nov	1.5833	1.855	-0.2717
Dec	0.9523	1.6997	-0.7474
Total Energy	25.7874	25.9495	-0.1621

Table 5.13 shows a reduction of the total demand energy by 0.0426 MWh annually due to the PV panels provided shading on the roof. The total energy consumption yearly was simulated as 25.7874 MWh, and the total generated electricity by the 51 PV panels was simulated as 25.9495 MWh annually. The generated power was enough to cover the consumption of the villa in addition to the villa's chillers energy required at the district cooling plant. An extra 0.1621 MWh annually was generated by the PV panels which could be fed back to the grid.

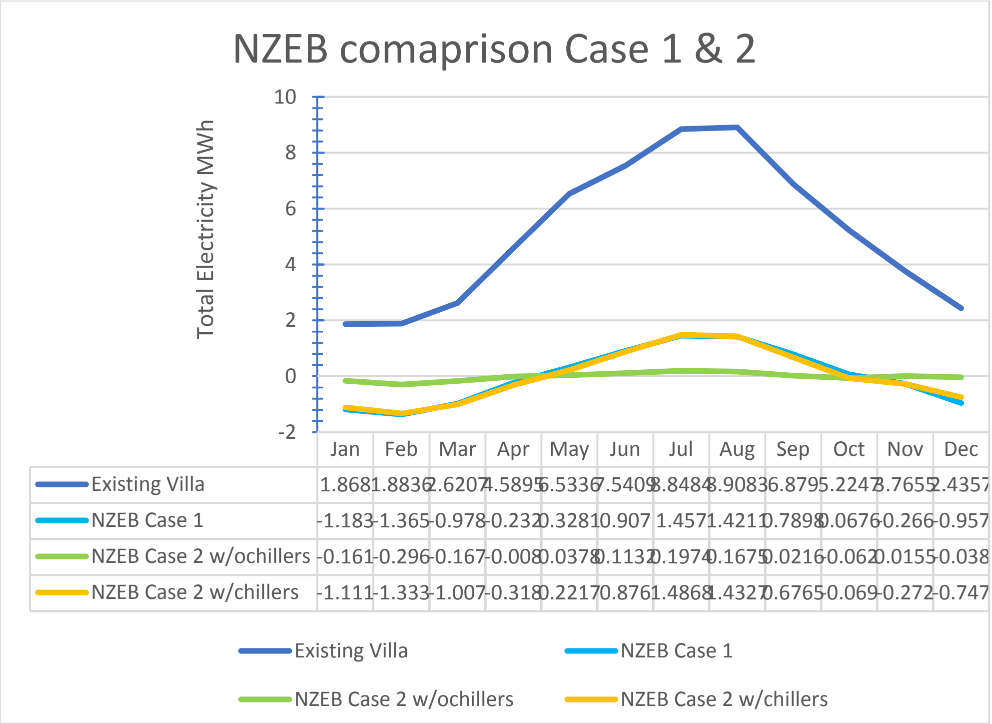


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Existing	1.868	1.884	2.621	4.59	6.534	7.541	8.848	8.908	6.879	5.225	3.766	2.436
Case 2 Demand	0.713	0.671	1.1	1.896	2.724	3.244	3.863	3.868	3.002	2.172	1.583	0.952
PV Power	1.824	2.003	2.106	2.214	2.502	2.368	2.376	2.435	2.326	2.241	1.855	1.7
NZEB Case 2	-1.11	-1.33	-1.01	-0.32	0.222	0.876	1.487	1.433	0.677	-0.07	-0.27	-0.75

Figure 5.20: Energy comparison between existing villa and Case 2 (w/ chillers) demand before and after installing PV panels

The net zero energy building concept was achieved for this case as shown in Figure 5.20 by comparing the energy consumption of the existing villa and Case 2 considering the DC plant chillers.

Figure 5.21 shows the great optimization in energy between both cases and the existing villa. It also shows the close proximity of the energy demand and PV power generation between using VRV HVAC system and DC including the chillers at source. The best option as shown is the DC Case 2 without considering the chillers; the energy input and output almost equalize around the year. This is considered more consistent and reliable in case of extreme hot or cold outdoor conditions. The PV panels provide almost all the energy required all year and with little improvements this option could operate of the electricity grid.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Existing Villa	1.868	1.8836	2.6207	4.5895	6.5336	7.5409	8.8484	8.9083	6.8795	5.2247	3.7655	2.4357
NZEB Case 1	-1.183	-1.365	-0.978	-0.232	0.3281	0.907	1.4571	1.4211	0.7898	0.0676	-0.266	-0.957
NZEB Case 2 w/ochillers	-0.161	-0.296	-0.167	-0.008	0.0378	0.1132	0.1974	0.1675	0.0216	-0.062	0.0155	-0.038
NZEB Case 2 w/chillers	-1.111	-1.333	-1.007	-0.318	0.2217	0.8761	1.4868	1.4327	0.6765	-0.069	-0.272	-0.747

Figure 5.21: Total monthly energy comparison between existing villa and Case 1 & Case 2

CHAPTER 6: CONCLUSIONS & RECOMMENDATIONS

6.1 Conclusions

This study was conducted to test the possibility of transforming an existing villa in Dubai to a net zero energy building. A residential villa was selected according to its size and availability of the research related data, all the Architectural, Structural and MEP drawings were obtained from the owner in addition to number of occupants and electricity monthly consumption over the course of a year. The study focused on improving passive and active parameters of the building. This was tested by using different envelope energy efficiency measures for the external walls, roof and windows. Different HVAC systems were tested to determine the most efficient system for the studied villa. Lighting system improvements were done by replacing the existing light bulbs with more efficient bulbs. The study aimed to reduce the energy consumption of the villa as much as possible through the passive measures and systems improvements, the remaining consumed energy needed to be generated by a renewable energy source in order to achieve the net zero energy building intended goal.

The villa was simulated using IES VE software. The validation of the software was based on the villa's electricity consumption which was very close to the actual electricity consumption throughout the year. Accordingly, different U-values for external walls, roof, and windows were tested. Four HVAC options, and two lighting options were simulated. The best results out of all parameters were selected to provide one combination to be simulated as the final model. Two HVAC options out of the four options were selected to be tested in the final model simulation, the options provide two possibilities which are a stand-alone villa as Case 1 and connected to a cooling plant as Case 2, from comparing the results and analysis of both cases the following conclusions were found:

- The best envelope energy efficiency measures between all the options tested are an external walls U-value of 0.29 W/m^{2}K which is in line with ESTIDAMA requirements, Roof U-value of 0.14 W/m^{2}K also meeting ESTIDAMA guidelines, and windows U-value of 1.61 W/m^{2}K which is lower than the required U-value for windows by all guidelines in the UAE.

- Using Dubai Lamp bulbs resulted in the best energy saving in comparison to commercially used CFL lights and regular LED lights.
- Using a higher efficiency DX cooling HVAC system or a compact chiller system reduced the energy less than using a variable refrigerant volume HVAC system or connecting the villa to a district cooling plant.
- Both Case 1 and Case 2 with the use of the best parameters and the best two HVAC systems were able to reduce the consumed energy dramatically, the introduction of PV panels was able to cover the remaining energy for both cases and even the required chillers energy at the district cooling plant.
- Case 1 reached the goal of NZEB with the use of VRV system with COP of 3.6 combined with Dubai Lamp lights and passive energy saving measures. This reduced the electricity consumption by 59.04%. 49 PV panels installed on the roof, the PV panels had to have high efficiency of 20.6% in order to produce the remaining demand energy and achieve the NZEB target.
- Case 2 achieved the required NZEB as well. Connecting to a district cooling plant the villa and using Dubai Lamp and Passive measures reduced the energy consumption by 84.06%. NZEB was achieved using 19 PV panels only and had a consistent input to output ratio throughout the year compared to Case 1.
- Case 2 was also able to achieve a NZEB by covering the cooling source energy, this was reached by installing 51 PV modules to the building roof. The total energy saving before introducing the PV panels was 57.72% compared to the existing villa consumption.
- As a conclusion, transforming an existing villa to become a net zero energy building is achievable for such building size in the UAE, complying with all the current sustainable buildings regulations in UAE could help reduce the energy consumption to reach as low as possible, this allows the introduction of a renewable energy source to cover the remaining required energy.

6.2 Recommendations for future studies

During the research and analysis period of this study, several issues and concerns were faced, the following recommendations and ideas need to be considered in future studies, and some areas need to be investigated further to reach more accurate results:

- Building orientation found to be designed according to the plot regulations, the required setbacks and plot orientation are often the reason for the building orientation, this mostly applies for small villas in communities similar to the case study, it’s recommended that the master plan design takes into consideration the orientation of each individual villa, this will allow the building designer to have a consistent orientation for all villas inside the community, the common practice in Dubai gives the land developer the freedom to design the master plan of communities and accordingly approve it from the Dubai Municipality Planning Department, the master plan design usually considers maximizing the allowable built-up area regardless to plots orientation, this consequently affect the building orientation and as a result similar buildings in the same community will have different orientation and accordingly different solar exposure, the best plot orientation should consider the south facing facades, the glazed areas of the building should face north, which will reduce the total energy demand for cooling and ultimately the total electricity consumption of the villas.
- After testing different envelope parameters, it was found that ESTIDAMA required U-values for external walls and roof can easily reduce the total energy consumed by the building, however the windows U-value did not affect the energy consumption greatly, this is due to the high U-values required by both ESTIDAMA and Dubai Municipality, more energy efficient glazing options such as triple glazing and gas filled gaps could help reduce the U-value of windows as well as the cooling energy required.

- by comparing both Dubai and Abu Dhabi green buildings regulations, it’s clear that ESTIDAMA requirements are more efficient and energy saving, Dubai Al Sa’fat system needs to be updated to reduce the total building energy as a result of passive measures.
- So far, there are no NZEB regulations in the UAE, studying such option by the regulators would provide a base for developers and investors who are willing to invest in sustainable buildings and new technologies, this thesis could help identify the challenges faced while reaching to a NZEB.
- District cooling plant option was investigated and tested in this study. however, it’s not mandatory for the developer to provide such cooling option, it’s always recommended to use one source of cooling energy to serve a big community instead of dividing the machines to individual buildings, district cooling plants have higher efficiency, and it’s cost saving as a total compared to providing an HVAC system for each building, Case 2 investigated in this dissertation was able to cover the energy required at source, however, we suggest that developers try to implement renewable energy sources to provide the power needed for the cooling plant, this will reduce the operation cost for both developers and occupants, consequently the use of renewable energy sources will reduce the GHG emissions to the atmosphere.
- It was found that high efficiency PV panels are not common in the UAE, while the country is going towards a sustainable future for new buildings, this element should be encouraged by authorities, developers and investors.
- One of the intended goals of this study was to investigate the cost implications of transforming the existing villa to NZEB, several contractors and suppliers of HVAC systems, insulation, glazing, PV panels and lighting were contacted, however due to their confidentiality terms and other reasons, there was no reply from most of the suppliers and contractors, this resulted in eliminating this study from the dissertation due to lack of data, even though it was highlighted to all

suppliers that the data needed for an academic study, we recommend the cooperation of all parts of the building sector in the UAE to find accurate results by providing the needed information especially for the purpose of academic studies, providing cost analysis will present a clear picture of the initial and running cost compared to the conventional buildings, which will encourage owners and investors to participate and invest in sustainable and zero energy buildings.

- This study was conducted for a selected existing villa in the UAE, the parameters and variables were chosen according to this specific villa and the weather profile of Dubai. Further studies for different building or a group of buildings in different location should take into consideration the actual parameters of the study subject and will need to be tested and analyzed accordingly.

REFERENCES

References

Abu Dhabi Urban Planning Council (ADUPC). (2010). *The pearl rating system for Estidama, villa rating system: design & construction* [online]. Version 1.0. [Accessed 9 March 2017]. Available at: https://www.upc.gov.ae

Al-Sallal, K. A. (2010). Daylighting and visual performance: evaluation of classroom design issues in the UAE. *International Journal of Low Carbon Technologies*. Vol. 5 (4), pp. 201-209.

Ascione, F., De Masi, R. F., de Rossi, F., Ruggiero, S. & Vanoli, G. P. (2016). Optimization of building envelope design for nZEBs in Mediterranean climate: performance analysis of residential case study. *Applied Energy*. Vol. 183 (4), pp. 938-957.

AU Optronics Corporation. (2015). *SunForte PM096B00* [online]. [Accessed 22 September 2017]. Available at: https://drive.google.com/file/d/0B-SvoV2rWQWjSXVrMDN2a2lTVW8/view

Badea, G., Felseghi, R., Răboaca, S., Aşchilean, I., Bolboacă, A., Mureşan, D., Moldovan, E. & Şoimoşan, T. (2016). Hybrid solar and wind electric system for Romanian nearly zero energy buildings (nZEB). case study. *Applied Mechanics and Materials*. Vol. 841, pp. 110-115.

Balaras, C. A. & Dascalaki, E. G. (2011). European efforts towards NZEB and energy conservation in Hellenic buildings. *ASHRAE Transactions*. Vol. 117 (1), pp. 290-297.

Buonomano, A., De Luca, G., Montanaro, U. & Palombo, A. (2016). Innovative technologies for NZEBs: an energy and economic analysis tool and a case study of a non-residential building for the Mediterranean climate. *Energy and Buildings*. Vol. 121, pp. 318-343.

Cárcel-Carrasco, J., Peñalvo-López, E. & Morcillo, I. (2017). Legal challenges in the implementation of Nearly Zero Energy Buildings (nZEB) in Spain. *Vitruvio - International Journal of Architectural Technology and Sustainability*. Vol. 2 (1), pp. 1-11.

Climatebase. *Dubai, Emirates #41194* [online]. [Accessed 30 October 2017]. Available at: http://climatebase.ru/station/41194/?lang=en

Congedo, P. M., Baglivo, C., Zacà, I. & D′Agostino, D. (2015). High performance solutions and data for nZEBs offices located in warm climates. *Data in Brief*. Vol. 5 (4), pp. 502-505.

Congedo, P. M., D'Agostino, D., Baglivo, C., Tornese, G. & Zacà, I. (2016). Efficient solutions and cost-optimal analysis for existing school buildings. *Energies*. Vol. 9 (10), pp. 851-851.

Crawley, D. B., Hand, J. W., Kummert, M. & Griffith, B. T. (2008). Contrasting the capabilities of building energy performance simulation programs. *Building and Environment*. Vol. 43 (4), pp. 661-673.

Dabaieh, M., Makhlouf, N. N. & Hosny, O. M. (2016). Roof top PV retrofitting: a rehabilitation assessment towards nearly zero energy buildings in remote off-grid vernacular settlements in Egypt. *Solar Energy.* Vol. 123, pp. 160-173.

D'Agostino, D., Zangheri, P. & Castellazzi, L. (2017). Towards nearly zero energy buildings in Europe: a focus on retrofit in non-residential buildings. *Energies*. Vol. 10 (1).

Dai, A. (2012). Increasing drought under global warming in observations and models. *Nature Climate Change* [online]. Vol. 3. [Accessed 25 October 2017]. Available at: https://www.nature.com/articles/nclimate1633

de Santoli, L., Mancini, F. & Rossetti, S. (2014). The energy sustainability of palazzo Italia at EXPO 2015: analysis of an nZEB building. *Energy and Buildings*. Vol. 82 (7), pp. 534-539.

Doiron, M., O'Brien, W. & Athienitis, A. (2011). Energy performance, comfort, and lessons learned from a near net zero energy solar house. *ASHRAE Annual Conference 2011, ASHRAE Annual Conference Montreal, ASHRAE Transactions*. Vol. 117 (Part 2), pp. 585-596.

Dubai Municipality (DM). (2016). *Al sa'fat: Dubai green building evaluation system* [online]. version 1.1. [Accessed 9 March 2017]. Available at: http://www.dm.gov.ae

Friess, W. A. & Rakhshan, K. (2017). A review of passive envelope measures for improved building energy efficiency in the UAE. *Renewable and Sustainable Energy Reviews*. Vol. 72, pp. 485-496.

Gagliano, A., Giuffrida, S., Nocera, F. & Detommaso, M. (2017). Energy efficient measure to upgrade a multistory residential in a nZEB. *AIMS Energy*. Vol. 5(4), pp. 601-624.

Han, Y., Taylor, J. E. & Pisello, A. L. (2017). Exploring mutual shading and mutual reflection inter-building effects on building energy performance. *Applied Energy*. Vol. 185 (2), pp. 1556–1564.

Holuj, B. J. (2010). Commercial buildings as clean domestic energy assets by 2025? doe's roadmap for a net-zero energy built environment. *Cogeneration and Distributed Generation Journal* [online]. Vol. 25 (2). [Accessed 9 March 2017]. Available at: http://www.tandfonline.com/doi/abs/10.1080/15453669.2010.9914395

JRC European Commission. *Photovoltaic geographical information system - interactive maps*. Available at: http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?map=africa&lang=en

Kamenders, A., Rušenieks, R., Vanaga, R., Rochas, C. & Blumberga, A. (2014). Nearly Zero Energy Building (nZEB) in Latvia. *The 9th International Conference "Environmental Engineering"* [online]. [Accessed 4 October 2017]. Available at: http://leidykla.vgtu.lt/conferences/ENVIRO_2014/Articles/6/263_Kamenders.pdf

Kang, H. J. (2017) Development of an nearly zero emission building (nZEB) life cycle cost assessment tool for fast decision making in the early design phase. *Energies*. Vol. 10 (1).

Kurnitski, J., Saari, A., Kalamees, T., Vuolle, M., Niemelä J. & Tark, T. (2013). Cost optimal and nearly zero energy performance requirements for buildings in Estonia. *Estonian Journal of Engineering*. Vol. 19 (3), pp. 183-202.

Lenoir, A., Garde, F., & Wurtz, E. (2011). Zero Energy Buildings in France: Overview and Feedback. *ASHRAE Transactions*. Vol. 117 (2), pp. 817-829.

Minor, J. & Hallinan, K. (2011). Renewable energy design and performance of LEED EB platinum building for zero energy performance. *ASHRAE Transactions*. Vol. 117, pp. 43-50.

Mohamed, A., Hasan, A. & Sirén, K. (2014). Fulfillment of net-zero energy building (NZEB) with four metrics in a single family house with different heating alternatives. *Applied Energy*. Vol. 114 (4), pp. 385-399.

Pescaru, R. A., Baran, I. & Dumitrescu, L. (2014). Energy efficiency of public buildings toward NZEB possibilities and constraints, *Bulletin of the Polytechnic Institute of Jassy - Construction & Architecture Section*. Vol. 64 (4), pp. 163-172.

Peters, G. P., Andrew, R. M., Boden, T., Canadell, J. G., Ciais, P., Le Quéré, C., Marland, G., Raupach, M. R. & Wilson, C. (2012). Commentary: the challenge to keep global warming below 2 °C. *Nature Climate Change* [online]. Vol. 3. [Accessed 25 October 2017]. Available at: https://www.nature.com/articles/nclimate1783

Stephens, B. (2011). Modeling a net-zero energy residence: combining passive and active design strategies in six climates. *ASHRAE Transactions*. Vol. 117 (1), pp. 381-388.

Thalfeldt, M., Kurnitski, J. & Mikola, A. (2013). Nearly zero energy office building without conventional heating. *Estonian Journal of Engineering*. Vol. 19 (4), pp. 309-328.

Torcellini, P. A. & Crawley, D. B. (2006). Understanding zero-energy buildings. *ASHRAE Journal*. Vol. 48 (9), pp. 62-64.

U.S. Energy Information Administration (EIA). (2017). *How much energy is consumed in U.S. residential and commercial buildings?* [online]. [Accessed 25 October 2017]. Available at: https://www.eia.gov/tools/faqs/faq.php?id=86&t=1

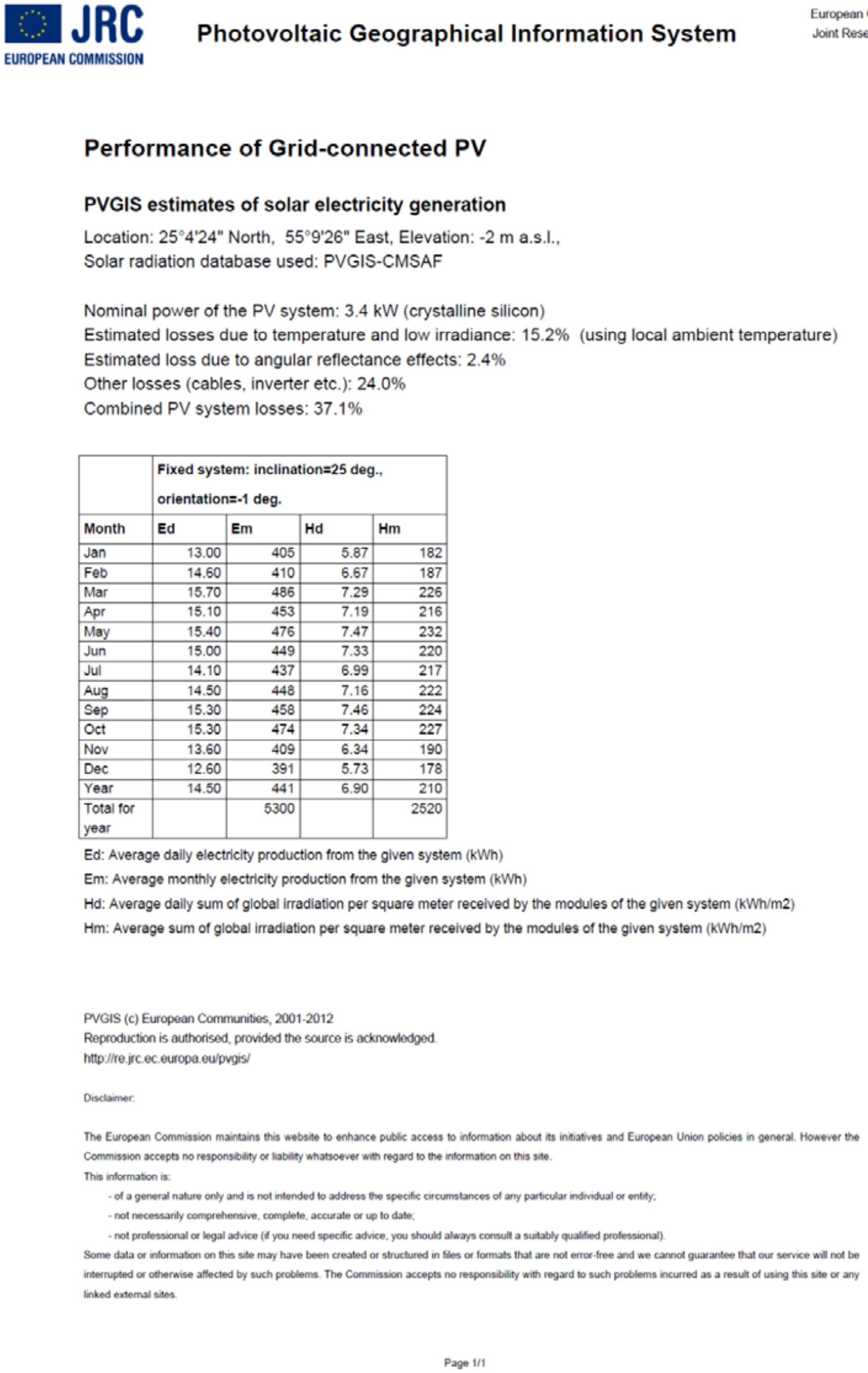
Windfinder. (2017). *Wind direction in distribution in (%%)* [online]. [Accessed 18 October 2017]. Available at: https://www.windfinder.com/windstatistics/dubai

Windfinder. (2017). *Wind statistics* [online]. [Accessed 18 October 2017]. Available at: https://www.windfinder.com/windstatistics/dubai

APPENDIX A

PV Panels Validation

PV panels simulation (JRC European Commission)



JRC
EUROPEAN COMMISSION

Photovoltaic Geographical Information System

European Commission
Joint Research Centre
Ispra, Italy

Performance of Grid-connected PV

PVGIS estimates of solar electricity generation

Location: 25°4'24" North, 55°9'26" East, Elevation: -2 m a.s.l.,
Solar radiation database used: PVGIS-CMSAF

Nominal power of the PV system: 3.4 kW (crystalline silicon)
Estimated losses due to temperature and low irradiance: 15.2% (using local ambient temperature)
Estimated loss due to angular reflectance effects: 2.4%
Other losses (cables, inverter etc.): 24.0%
Combined PV system losses: 37.1%

	Fixed system: inclination=25 deg., orientation=-1 deg.			
Month	**Ed**	**Em**	**Hd**	**Hm**
Jan	13.00	405	5.87	182
Feb	14.60	410	6.67	187
Mar	15.70	486	7.29	226
Apr	15.10	453	7.19	216
May	15.40	476	7.47	232
Jun	15.00	449	7.33	220
Jul	14.10	437	6.99	217
Aug	14.50	448	7.16	222
Sep	15.30	458	7.46	224
Oct	15.30	474	7.34	227
Nov	13.60	409	6.34	190
Dec	12.60	391	5.73	178
Year	14.50	441	6.90	210
Total for year		5300		2520

Ed: Average daily electricity production from the given system (kWh)
Em: Average monthly electricity production from the given system (kWh)
Hd: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m2)
Hm: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m2)

Page 1/1