Research on the potential of photovoltaic technologies in reducing energy consumption in an urban mixed use residential community.
A Case study for net zero energy community in Dubai, UAE.

بحث في امكانات التقنيات الكهروضوئيه في الحد من استهلاك الطاقه في المناطق الحضريه والمجتمعات السكنيه متعدده الإستخدامات

دراسة حالة مجتمع صفر الطاقة في إمارة دبي، دولة الإمارات العربية المتحدة

by
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Abstract

Humans have an unquenchable thirst for energy. Accelerated global economic and population growth are the main influencing factors that has led to the increase in electricity consumption. In addition, the release greenhouse gas (GHG) emissions from energy resources such as the fast depleting fossil fuels whose prices are rising globally. Therefore, the key challenge is to reduce the consumption of fossil fuels which decreases the production of greenhouse gases such as CO2 and CH4 by using renewable energy technologies to provide clean carbon free energy that can combat future energy security challenges.

Even though UAE has huge amount of solar resources available which if harnessed could resolve the energy crisis, much of it goes to waste. This is mainly because most of its domestic energy needs are meet by subsidized electricity tariffs in Abu Dhabi also to blame for their high per capita GHG emissions. The outcome of these events, abundant regional solar irradiation and drop in global PV prices has led to the significant developments and innovations in the solar energy sector. Consequently, a trending holistic integrated approach where renewable technologies such as solar photovoltaic' integrated on built environment at the community scale, namely the Net Zero Energy Community (NZEC) is paving way to future smart sustainable cities.

NZEC are the next frontier in energy efficiency and play a key role in fulfilling Dubai's ambitious sustainable targets by reducing the local carbon footprint with the help of a series of optimized and well balanced operations between energy consumption and production coupled with successful grid integration of photovoltaic energy technologies. Reaching net zero energy (NZE) status across every single building may not be feasible, but it is realistic if we evaluate them with their connected systems as a collective unit at the community scale. While, tangible benefits to the community such as internal exchange of energy, load diversity, reduction in dependency of electricity grid, reduction of long power transmission cables, substation sizes have been recognized.

The dissertation adapts the IES-VE computer simulation methodology to support the several applications of photovoltaic technologies that assist in the compensation of overall energy consumption for an existing community in the UAE to achieve net zero energy status. This paper illustrates the many strategies to bridge the deficiency energy gap in three categories; 1) increase PV panel energy production by optimizing the orientation, inclination angle, manual tracking, enhanced microcontrollers and inverters, 2) increase PV panel efficiency from better manufacturers, 3) increase the area of PV panel installation on the building fabric and exploring options beyond the building footprint at the community level.

The initial scenarios were simulated for the most optimum PV orientations, fixed inclination tilt angle, module technology, inverter and controller technology. The results reveal that the highest energy generation was the south facing polycrystalline PV panels at 25° fixed inclination tilt angle. With the enhancement of cost effective Maximum Power Point Tracking (MPPT) device and the addition of transformerless inverters increased the overall power output of polycrystalline from 216 KWh/m² to 262 KWh/m². Polycrystalline technologies with higher energy efficiencies from different

manufacturers with 18.15% module efficiency were simulated resulting in 24% energy generation more than the base case panel with 16% module efficiency but from an economic point of view it is not a cost-effective solution due to its high cost per production AED/KWh rate. Additional benefits of integrating PV panels on rooftops were noticed though passive panel shading which minimized the solar gain and reduced the overall community energy consumption.

On the account, insufficient rooftop area for PV installation that can compensate for the total community energy consumption, various scenarios for increasing the area of PV installation on the building envelope and options beyond the building footprint at the community level were explored. In this scenario, for aesthetic reasons the PV angles were changed to 2° inclination tilt angle. The Integration of community solar street lighting, additional PV panel installation on solar car parking integration, greenhouse PV farm, children's play area, multipurpose events park and PV covered walkway resulted in a surplus PV area of 736.58 m^2 for energy generation. These results prove that it is possible and feasible to convert an existing urban mixed use community to a Net Zero Energy Community in Dubai with a reasonable overall payback period of 4 years.

This research will provide as a stepping stone and support the Dubai government, policy makers, market stakeholders; private developers work together, develop objectives and achieve the set target towards Dubai Clean Energy Strategy 2050 for a net positive built environment and decarbonized global economy.

ملخص

الإنسان في حالة ظمأ شديد للطاقة.التسارع للاقتصاد العالمي والنمو السكاني هما المؤثران الرئيسيان اللذان أديا لزيادة استهلاك الكهرباء بالإضافة إلى إنبعاث الغازات من مصادر الطاقة مثل التناقص السريع في مصادر الطاقة والارتفاع المستمر لأسعار الطاقة عالميا. لذلك التحدي الرئيسي هو تخفيض استهلاك بقايا الطاقة والتي ستؤدي لانخفاض إنبعاث الغازات مثل ثاني أكسيد الكربون ورابع هيدرات الكربون عن طريق استخدام تقنيات الطاقة المتجددة لتوفير طاقة نظيفة خالية من الكربون والتي من الممكن أن تقاوم تحديات الطاقة المستقبلية.

وبالرغم من أن دولة الإمارات العربية المتحدة تمتلك كمية كبيرة من الطاقة الشمسية المتاحة والتي إذا استخدمت من الممكن أن تفرج أزمة الطاقة، الا ان معظمها يتم إهداره. وهذا في الأساس بسبب ان معظم احتياجات الطاقة المحلية مغطاه بالتكلفة المرتفعة للطاقة وارتفاع إنبعاث الغازات ونتيجة ذلك هو ارتفاع الانبعاثات الحرارية وانخفاض تكلفة الخلايا الشمسية والتي أدت لتطوير ملموس وابتكارات في مجال الطاقة الشمسية وبالتالي تكامل تام مابين تقنيات الطاقة المتجددة كالخلايا الشمسية مع البيئة على نطاق التجمعات السكنية وتحديدا تجمع الطاقة الصفرية والذي يعتبر نواة المدن المستقبلية الذكية المتجددة.

تجمع الطاقة الصفرية هو الواجهة الجديدة للاستعمال الأمثل للطاقة وتلعب دور رئيسي في طموحات دبي في زيادة معدل إنتاج الطاقة الشمسية في مجال الطاقة المتجددة عن طريق تخفيض الانبعاثات الكربونية التوازن المحسن مابين استهلاك الطاقة وإنتاجها بالتكامل الناجح لتقنيات الطاقة الشمسية. وتحقيق الطاقة الصفرية على مستوى كل مبنى قد لا يكون مفيد اقتصاديا ولكنه واقعي إذا قمنا بتقييمه بالإضافة الى الأنظمة المستخدمة على مستوى التجمع السكني. في حين أن النتائج الملموسة للتجمع السكني كالتبادل الداخلي للطاقة، تخفيض الأحمال، تخفيض الاعتماد على الكهرباء، تقليل كابلات توصيل الكهرباء الطويلة و حجم محولات الكهرباء.

الدراسة تتبنى نموذج محاكاة للعديد من التطبيقات لتقنيات الطاقة الشمسية والتي تساعد في استهلاك الطاقة الإجمالي لأحد التجمعات السكانية بالإمارات للوصول لحالة الطاقة الصفرية. هذه الدراسة توضح الاستراتيجيات المتعددة لتجاوز نقص الطاقة على ثلاث مستويات. 1- زيادة معدل إنتاج الطاقة الشمسية عن طريق تحسين توجيه الخلايا الشمسية. 2 - زيادة معدل إنتاج الطاقة الشمسية عن طريق استعمال خلايا شمسية من منتج أفضل. 3 - زيادة معدل إنتاج الطاقة الشمسية عن طريق زيادة مساحات الخلايا الشمسية واستكشاف خيارات خارج نطاق المبنى على مستوى التجمع السكني.

السيناريو المبدئي كان للتوجيه الأمثل للخلايا الشمسية عن طريق تثبيت زاوية الارتفاع وتغيير زاوية التوجيه. أثبتت الدراسة أن أعلى معدل توليد طاقة نتج عن التوجيه جهة الجنوب بزاوية ارتفاع 25 درجة وعن طريق تحسين المعدات وإضافة معدلات لامحولات زادت الطاقة المنتجة من 216 كيلو وات ساعة لكل متر مسطح إلى 262 كيلو وات ساعة لكل متر مسطح. وتقنية البوليكريستال بمعدلات طاقة مرتفعة من منتجين مختلفين عن طريق وحدة محسنة 18.15% تم تمثيلها أنتجت 24% طاقة أكثر من الحالة الأساسية بوحدة محسنة 16% بل من وجهة نظر اقتصادية هي ليست نموذج اقتصادي نظرا لارتفاع تكلفة الإنتاج درهم لكل كيلو وات ساعة.

فائدة إضافية تمت ملاحظتها من تركيب الخلايا الشمسية على الأسطح وهي الظلال التي ألقتها على الأسطح مما نتج عنه انخفاض الطاقة الحرارية المكتسبة على مستوى التجمع السكني. وفي حال عدم كفاية مساحة الأسطح للخلايا الشمسية فيمكن تعويض ذلك للتجمع السكني بشكل عام عن طريق احتمالات عديدة بزيادة مساحة الخلايا الشمسية على الأسطح واحتمالات تركيبها خارج المبنى على مستوى التجمع السكني حسب ظروف الموقع وفي هذا الاحتمال تم تغيير زاوية ارتفاع الخلايا الشمسية بمقدار درجتين لاضاءات الشوارع الشمسية تم تركيب خلايا شمسية إضافية على مبنى انتظار سيارات وساحة العاب اطفال ومزرعة توليد طاقة شمسية و قاعات متعددة الأغراض بالحديقة العامة أدى ذلك لفائض من مساحات الخلايا الشمسية بمقدار 736.58 متر مسطح لتوليد الطاقة. ذلك اثبت إمكانية تحويل تجمع متعدد الاستعمالات حالي إلى تجمع طاقة صفري بدبي وبمدة سداد التكلفة منطقية وهي 4 سنوات. هذه الدراسة ستكون بمثابة خطوة في طريق حكومة دبي وصناع القرار ومطوري القطاع الخاص والمشاركين الأساسيين في السوق للعمل معا وتطوير الأهداف وتحقيقها للوصول إلى هدف دبي ذات الطاقة النظيفة بحلول عام 2050 لتوفير بيئة إيجابية واقتصاد عالمي خالي من الكربون.

Dedication

I dedicate this dissertation to my beloved family, my mother and father, Sheela and Sugathan, my brother Suraj and to all my friends who wish me the success and prosperity.

Acknowledgement

This dissertation would never have been reality without the kind support, backing and patience of the following special people who I owe my sincere gratitude. The writing of this dissertation has been one of the most significant academic challenges I have ever faced in my life.

Firstly, I would like to acknowledge the Almighty God for giving me the strength and capability to complete this dissertation.

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I am deeply thankful to my mother and father (Sheela and Sugathan) and brother Suraj for their love, heartfelt prayers, limitless support and patience. Thank you for always wanting the best for me. Your unconditional love, concern and trust in me has made me a stronger person.

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CHAPTER 01
INTRODUCTION

1.1 Overview

The chapter includes the introduction of the dissertation that highlights the impacts of global warming and skyrocketing energy demand in the built environment. The outcome of these events has led to the significant increase in the use of renewable alternative energy sources in the past decade, with major developments and innovations in the solar energy sector because of its unlimited source of clean energy. A trending holistic integrated approach where renewable technologies such as solar photovoltaics’ integrated on built environment at the community scale, namely the Net Zero Energy Community (NZEC) is paving way to future smart sustainable cities.

This new concept means that these communities consume enough energy equal to the amount of energy that it generates over the course of a year. This concept offers opportunities for reduced utility grid energy consumption through energy sharing, load diversity and export of surplus energy. The purpose of this dissertation is to investigate a series of cost effective energy saving opportunities and innovative sustainable solutions on the building skin and beyond its footprint at a community level in Dubai in addition the role of solar energy as renewable source for a carbon free environment.

1.2 Climate Change

“Climate change is real. It is happening right now, it is the most urgent threat facing our entire species and we need to work collectively together and stop procrastinating,” quoted by Leonardo DiCaprio at his Oscar acceptance speech in 2016 (Washington Post, 2016).

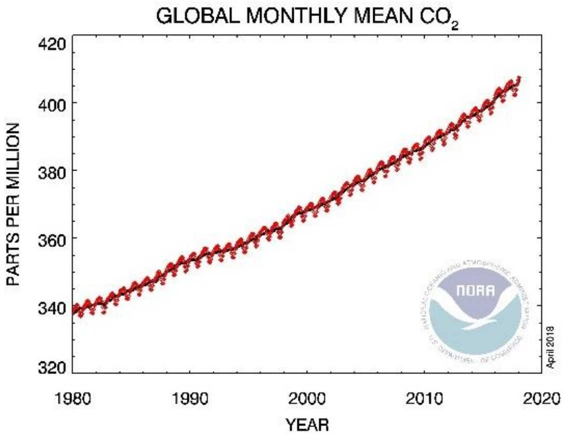


Figure 1.1 Monthly average atmospheric CO^2 recorded at the Mauna Loa Observatory, Hawaii (NOAA, 2018).

In the last three decades, the relationship between the global environmental pollution, energy consumption and economic growth has been subject to intense research. Recently studies have revealed the global atmospheric CO^2 emission concentration exceeded 400 parts per million and still constantly rising leading to global warming and climate change. In Figure 1.1 the increase in carbon dioxide level in the atmosphere from 1980 to 2018 based on National Oceanic & Atmospheric Administration has been depicted (NOOA, 2018).

Accelerated global economic and population growth are the main influencing factors that has led to the increase of CO^2 concentrations in the atmosphere particularly in developing emerging countries. When it comes to energy use per capita, the oil rich

GCC countries, particularly the UAE, which is ranked the second highest carbon emitting and electricity consuming per capita country in the world as stated by Hammad & Abu Hijleh (2010). The key challenge of climate change is to reduce the production and consumption of fossil fuels which produce greenhouse gases such as CO^2 and CH4 in the atmosphere. Global CO^2 emissions per capita (tCO^2/capita) as shown in Figure 1.2 demonstrate huge disparities between continents and countries (the UAE is at 19.7 tCO^2/c/year). Consequently, there is crucial obligation to plan renewable energy technologies which can cut off CO^2 emissions and combat future energy security challenges.

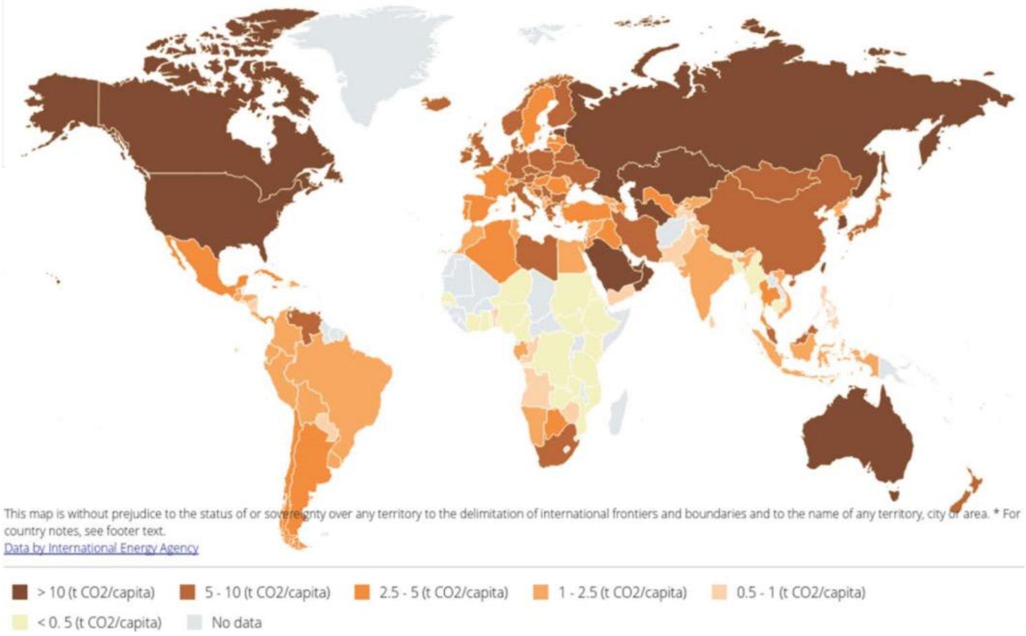


Figure 1.2 Global CO^2 emission per capita energy atlas by International Energy Agency (IEA, 2017).

1.3 Search for Renewable Energy

Humans have an insatiable thirst for energy. The global energy demand continues to rise rapidly because of urbanization, economic and world population growth. However, the dependence and depletion of energy resources such as fossil fuels that release greenhouse gas (GHG) emissions causing climate change have triggered many governments and encouraged researchers to implement renewable alternatives with less impact on the environment. Energies derived from sources which have constant factor for humans on earth are referred to as renewable energies. Manzoano et al. (2013) highlighted that renewable energy source which replaces fossil fuels is considered as a clean energy resource as they have zero impact on the environment, economy and society. There are various types of renewable energies available on earth based on its location and climate such as solar energy, hydroelectric power, wind energy, biomass energy, geothermal power, marine energy. Over the last 15 years, as shown in Figure 1.3 there has been a steady progress in the deployment of renewable energy (IRENA, 2017).

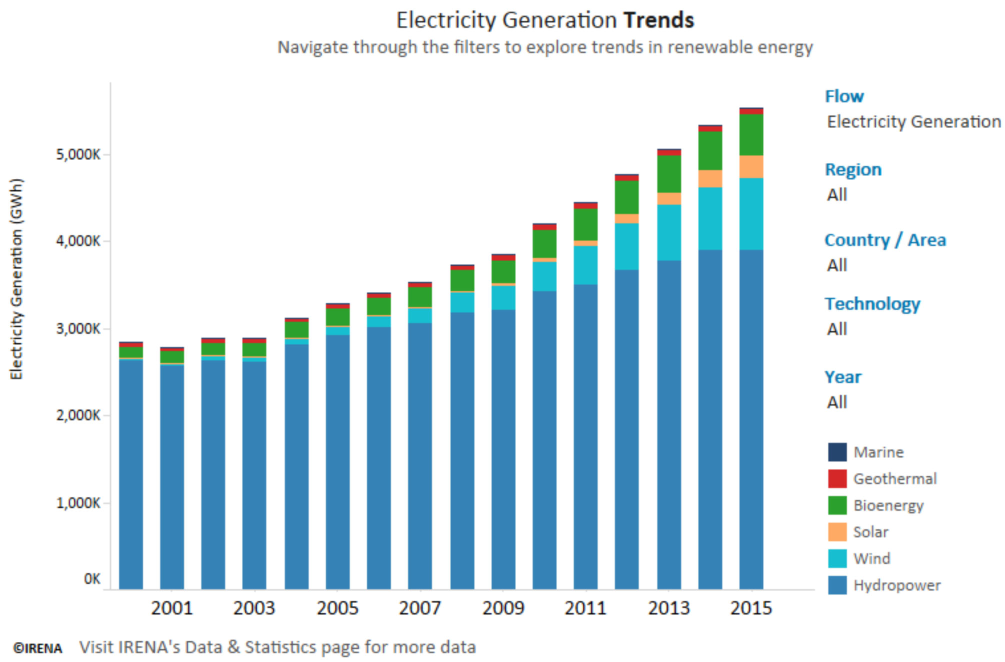


Figure 1.3 World RE Electricity Generation Trends (IRENA, 2018).

Castellana et al. (2015) states that the strong drivers to consider and invest in renewable energy resources in national and global scale can be summarized below; energy security, escalating cost of conventional energies, lesser price instability, competitive sustainable market, economic development with job creation, environmental concerns and minimizing the usage of fossil fuel resources. Advantages of RE are lack of damage to the natural environment and its safety from environmental hazards such as greenhouse warming and acid rains. However, the renewable energy technologies face several obstacles such high installation costs, absence of legislations, lack of political interventions and public awareness.

1.4 Renewable Solution – Solar Energy

Gherboudj & Ghedira (2015) noted that solar energy is the most potential, abundant and clean renewable energy source owing to its low environmental impacts, rapidly falling prices of PV modules, large scale PV manufacturing, government incentives and enhanced power converter technologies when compared to conservative sources of energy. Grossman (2010) described that on an average it is possible to generate 1,700 KWh per energy annually per square meter of surface on earth bare to sunlight using current available solar technology. Existing global energy requirement could be attained 10,000 times over with the present available solar energy which highlights the fact that the planet has abundance of solar irradiation to satisfy the energy demands of humans.

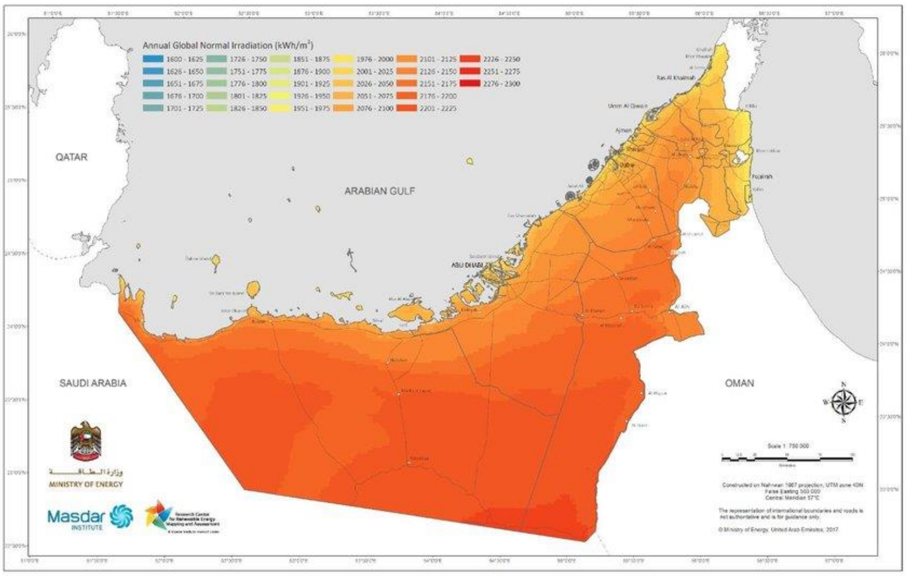


Figure 1.4 Annual Global Normal Irradiation (Masdar, 2017).

The oil rich GCC countries have huge solar power because to its topographical location called 'the solar belt'; around 500-600 W/m² for each km² per year (Alnaser & Alnaser, 2011). In 2012 as reported by Masdar (2017), the solar resource average was 900 KWh/m² for diffuse horizontal Irradiation, 1800 KWh/m² for direct normal irradiation and 2200 KWh/m² for global horizontal irradiation. Figure 1.4 illustrates the annual global normal irradiance demonstrating huge potential in energy production. The average daily energy input for the year 2009 was 5.13 KWh/m²/day and solar radiation level more than 400 W/m² during the year 2010. The key drivers that assist enhance the uses of solar energy are as follows; solar power is ubiquitous, free and infinite, available at several scales, deliver off grid electrification, and ability of interoperability.

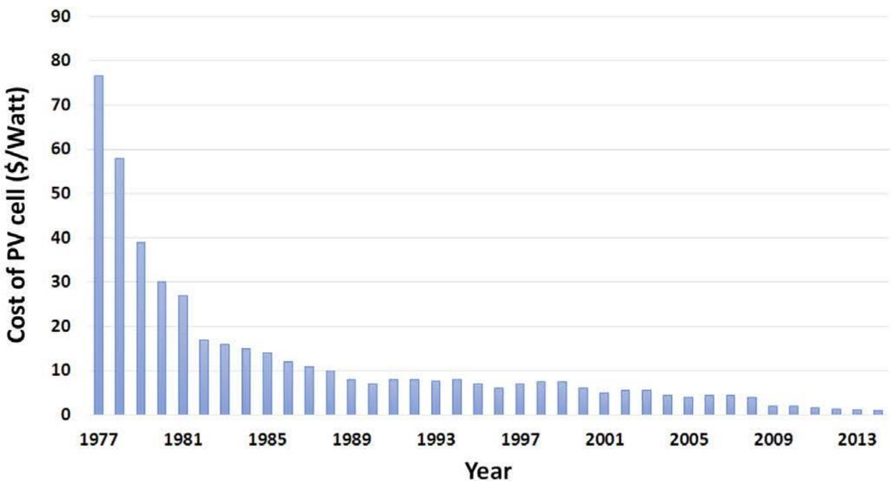


Figure 1.5 Price history of crystalline silicon PV cell in $/watt (Economist, 2017)

Even though UAE has huge amount of solar resources available which if harnessed could resolve the energy crisis, much of it goes to waste. This is mainly because most of its local energy needs such as in Abu Dhabi are meet by subsidized fossil fuels also to blame for their high per capita GHG emissions. However, recently these countries have had an environmental awakening especially due to growing pressure from world governments, international authorities and rising regional gas prices.

Bekhet, Matar & Yasmin (2017) described the UAEs national target Vision 2021 which aims to be one of the top locations to do business with sustainable development in future which is less dependent on oil and use of energy efficiently. The UAE is a step ahead as they have been strengthening the regulatory framework, encouraging innovation, research and development in the energy sector. This will help the UAE achieve pledge with the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (Bhatto et al., 2014).

Harnessing of solar energy can be done in two ways; one by using solar photovoltaics (PV) panels and second by solar thermal systems which includes concentrated solar power (CSP). However, practical disadvantages for solar energy technologies are relatively high installation cost, low module efficiency and regular cleaning maintenance to counter dust particles and high humidity (IRENA, 2017). While, in the past few years there has been a drastic fall in the prices of these technologies and increase in new efficient energy systems are stimulating solar energy deployment with no or nominal direct financial incentives. The fall in prices for the solar PV cell in $/watt can be seen in Figure 1.5.

1.5 UAE

The UAE, located in the Southwest Asia, bordering two counties - Saudi Arabia and Oman, between the eastern part of Arabian Gulf and Gulf of Oman as illustrated in Figure 1.6. It has 650 km long coast and surface area of 83,600km² (Mokri, Mona & Emziane, 2013). It lies in between 22degree50’26” north latitude and 51degree56’25 east longitude. There seven emirates in the UAE, Abu Dhabi is its capital, Dubai is the most populous and the second largest city in the UAE.

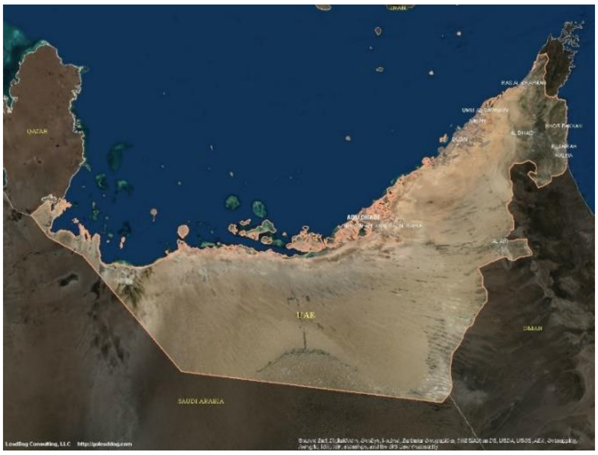


Figure 1.6 Satellite Map of UAE (Atlantislsc, 2017)

The climate of UAE is characterized by very small amount of cloudy skies or rain along with low latitude of area, allow high radiation levels to get to the ground surface in summer. During summer days, the weather conditions are hot and semi-arid and at night it is cool and humid. High global solar radiation or horizontal exteriors and an average sunshine of 10 hours enable UAE to be a positive candidate of solar energy (El Chaar & Lamont, 2010). According to Eissa et al. (2013), the high humidity and high concentrations of airborne dust particles are characteristics of UAE climate which incline to diffuse and ease the concentration of solar irradiance. Considering the high solar insolation and drop in PV prices, the UAE plan to install more solar capacity including distributed grid connected rooftop solar power as future renewable energy systems (Griffiths & Mills, 2016).

1.6 Energy demand and energy profile in the UAE

The single most impactful attribute to the built environment is the energy profile. In the Abu Dhabi, cost of production of electricity is very low and the electricity bills are subsidised to consumers compared to non-oil producing countries which does not encourage energy efficient behaviour. UAE is known for its huge oil and gas reserves; has the 7th largest oil and gas reserve in the world. In addition, UAE has one of the highest carbon footprints in the world; ranked 25th globally considered one of the highest energy consumer in the world.

In the last decade, electricity demand has increased drastically as presented in Figure 1.7. The UAE ranks 10th among the top 21 electric power consumption (kWh per capita) countries in the world. There has been an annual increase of more than 13.3% each year; in the year 2000 it was 39.9 TWh while in the year 2013 it was 110 TWh which means it has increased 5.14 TWh every year (Ministry of Energy and Industry, 2014). In the UAE, natural gas based utility power plants produce 98% of the electricity (Juaidi et al., 2016). The utility companies operate to meet the ever-growing demand which grows at the same rate as population growth which has been recorded between 6 and 11% per annum. Dubai Electricity and Water Authority states that the average individual electricity consumption is to be 20,000 kWh per annum, which makes Dubai in the midst of cities with the maximum consumption per capita in the world (MOENR, 2014).

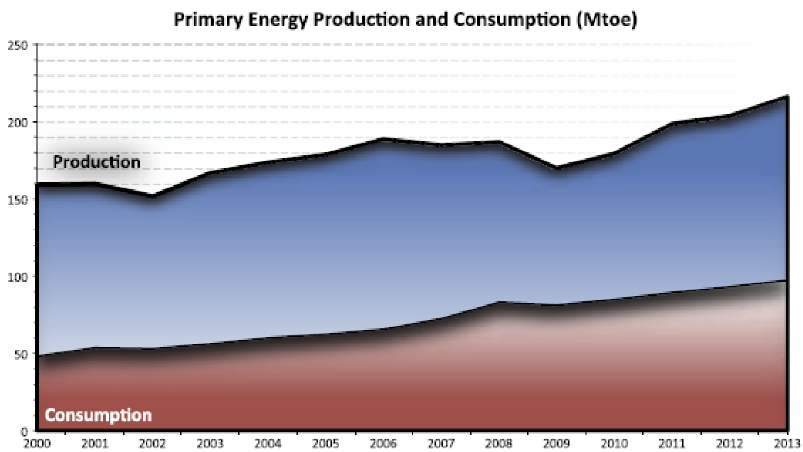


Figure 1.7 Primary energy production and consumption in UAE (Juaidi et al., 2016)

Juaidi et al. (2016) highlighted the high CO^2 emissions of 254kt in the UAE which has caused a high ecological footprint. Per capita footprint was found to be about 27.14 metric tons. In the UAE, buildings consume 70-80% of the electricity generation, amongst which 40% is consumed for air conditioning and cooling. Electricity power consumed by global residential sector and UAE is compared in Figure 1.8. Mokri, Mona & Emziane (2013) describes that the UAE has announced its vision 2030 to become an environmentally, socially and economically sustainable community with plans to reduce CO^2 emissions by 30%. As reported by the Dubai Supreme Council of Energy (DSCE), 25% of the existing building stock has been recognized as wasteful and has a high-energy saving potential.

Figure 1.8 Electricity power consumed by global residential sector and in the UAE (MBRSC, 2017)

Many investments, strategies supported by policy outlines like feed in tariffs (FiTs) and net metering have been introduced by the UAE to manage the reduce peak energy demand, diversify energy supply and propel the economy forward towards sustainability. The pioneering Masdar city by Mubadala Development, Sustainable city by Diamond Developers and the ongoing Desert Rose project by DEWA rely highly on renewable energy for most of its energy needs. The main objective is to take advantage of indigenous energy resource use and reduce energy subsidies to continue decreasing the CO^2 emissions. One such emerging initiative that has started to break new ground worldwide is the Net Zero Energy Community (NZEC).

1.7 Worldwide Trend - NZEC

Buildings are responsible for one third of the global greenhouse gas emissions and 40% of the total primary energy consumption in the world (UNEP, 2017). Additionally, the existing energy source materials consumed are radioactive, non-renewable and contribute to global warming. Moreover, these sources are centralized and distributed through long primitive transmission lines which impact its efficiency. Quite a lot of initiatives and codes have been set as minimum complex performance necessities for design, construction and operations to address the high-energy demand in buildings. Factors such as economics, climate, culture, politics, ambition and awareness result in varied building performance targets and codes that improve the built environment. Consequently, many high-performance building concepts have been developed to make communities sustainable such as utilization net zero energy, grid friendly, be healthy and comfortable, such as the Net Zero Energy Community (NZEC).

NZEC pave the way for the development of future smart cities and are the next frontier in energy efficiency. They play a vital role in fulfilling Dubai's ambitious sustainable targets by reducing the local carbon footprint with the help of a series of optimized and well balanced operations between energy consumption and production coupled with successful grid integration of renewable energy technologies. Reaching net zero energy (NZE) status across every single building may not be feasible, but it is realistic if we evaluate them with their connected systems as a collective unit at the community scale. NZEC offer opportunities for minimized energy consumption via building envelope optimization, building energy generation and community energy management. Micro climate improvement strategies allow optimizing the passive cooling strategies at the urban level landscape. Adjacent open spaces can be utilized for onsite renewable energy generation. Finally, NZEC recognizes alternative energy saving opportunities that goes beyond the building envelope such as energy storage systems, water supply and wastewater treatment, efficient transportation etc which also present a unique challenge.

In the US, net zero energy buildings targets for all new residential and commercial buildings have been set by 2020 and 2030 in the State of California (NBI, 2014) aiming for drastic reductions in greenhouse gas emissions. Many of the member states in European Union have set a target for all new buildings to achieve nearly zero energy buildings by 2020 (European Parliament, 2010). Advancing Net Zero is a global project has been announced by the World Green Building Council which aims to ensure that all buildings have zero carbon emissions by 2050. In the US. the West Village is a net zero community project in Davis, California with 343 single family homes and 662 apartments. International developments at a community level are the Beddington Energy Development (UK), Hammarby Sjosjad, Augustenborg and BO01 (Sweden), Vesterbro (Denmark) and Eva-Lanxmeer (Netherlands) are few examples of low energy communities. While in the GCC, some of the prominent examples include the Masdar City and the Dubai Sustainable City (UAE), King Abdullah University of Science and Technology (Saudi Arabia) and Msheireb Downtown Doha (Qatar).

1.8 Motivation of the Work

Considering the progress in the UAEs vision to position the countries leadership in employment of sustainable energy, the concept of development NZECs has become very vital to the UAEs national agenda as it bring into line with the important priorities of the country of driving innovation and sustainability. The application of NZEC's in the UAE raises many questions; what are the attainable targets for NZECs in the UAE? What are the various strategies than can be applied to attain of NZECs? What are the challenges, limitations and actions to reduce the overall energy consumption in UAE's built communities?

In the literature, there are several studies analysed describing few definitions and targets of Net Zero Energy Communities. Communities have more challenges and different requirements from buildings in terms of overall energy consumption, available area for PV installation and energy management. Various concepts, global and regional implementations of net zero energy communities are reviewed in this paper. The idea here is to look at holistic integrated approach where we can enhance an existing community to a net zero community status in which all characteristics of sustainability are considered. They support shared energy resources, efficient use of natural resources and energy efficiency across the community with a sense of good aesthetics.

Tangible benefits to the community such as internal exchange of energy, load diversity, reduction in dependency of electricity grid, reduction of long power transmission cables, substation sizes have been recognized. Case studies were used to showcase NZEC's in the UAE and validate the feasibility of this new concept. Overall most research's lacks enough technical data and case studies on strategies that help achieve the optimum methodology of achieving net zero energy community using solar renewable energy sources along with economical viabilities which becomes the motivation of this dissertation.

This dissertation adapts the computer simulation methodology to support the several applications of photovoltaic technologies that assist in the reduction of overall energy consumption for an existing community in the UAE to achieve net zero energy status. These strategies include incorporation of various PV configurations and technology, maximising area for PV installation at urban community level such as shaded pathways, community children's parks, greenhouse PV farms, and parking lots, and enhancement of the building envelope.

An actual built townhouse from another community with its building design specifications, electrical consumption and equipment data will be simulated and analysed for validation purpose using computer simulation software IES-VE. Consequent to the base case validation, three villa prototypes will be simulated for their respective energy consumption and a single PV test panel will be simulated to determine the energy production per m^2 in the selected community. These simulations will be conducted under UAE's climatic conditions considering the different types of occupancy schedules and design specification data as per Dubai Green Building Regulations & Specifications and ASHRAE code. Additional energy consumption from other buildings within the community such as school, hospital, clubhouse, community centre; infrastructure will be estimated. Finally, PV technologies with various configurations, angle of inclination, efficiency are integrated into the community and analysed for the optimum method of sustainable community electricity generation.

The results and recommendation will offer various scenarios and potential solutions that support the Dubai's present development and enhance future studies in regards to net zero energy communities in Dubai. This research will provide as a stepping stone to the success of a net positive built environment and decarbonised global economy, where economic growth and environment degradation are decoupled. This dissertation will also support the Dubai government, policy makers, market stakeholders; private developers work together, develop objectives and achieve the set target towards Dubai Clean Energy Strategy 2050 presented by the Dubai Supreme Council of Energy in November 2015 seen in Figure 1.9. The implementation is supported with funds over AED 100billion for R&D and various projects.

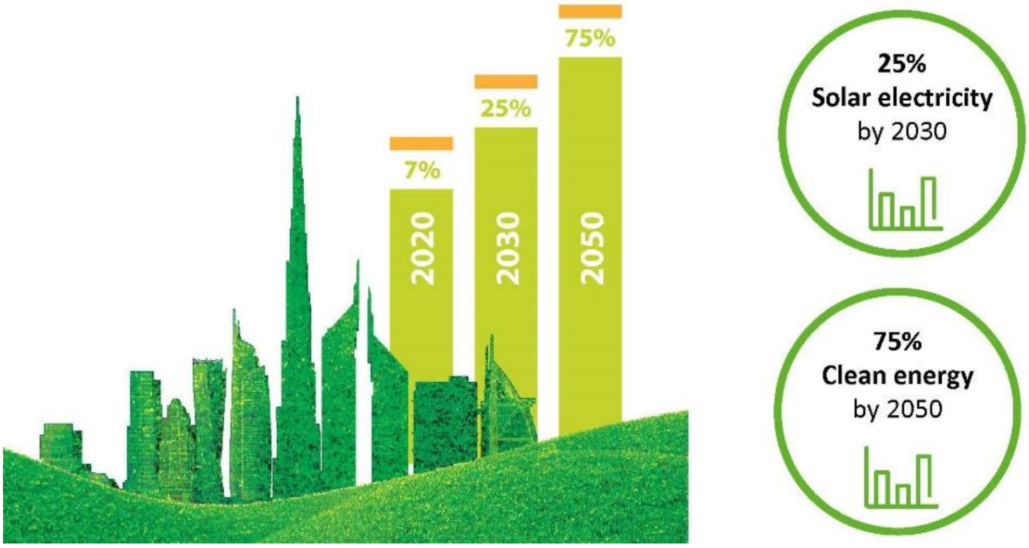


Figure 1.9 Dubai Clean Energy Strategy 2050 (SCE, 2017)

1.9 Outline of Dissertation

The dissertation comprises of six chapters. The structure of the content for all chapter are listed below:

Chapter 01

The chapter presents a general summary of all the important themes that leads to the concept of Net Zero Energy Communities. The reasons and motivation for the research are emphasized as well as the research structure in this section.

Chapter 02

The chapter presents the literature review which illustrates the various concepts of Net Zero Communities, incorporation of PV technology and its impact on zero energy buildings and urban level community's perspective. Few case studies of net zero communities in the world and UAE will be discussed to understand their different approaches and challenges. This section is concluded with the Problem Statement.

Chapter 03

The third chapter identifies the various methods used to investigate the different aspects related to net zero energy communities, PV technologies and building energy efficiency. Advantages and disadvantages of various methods are compared to select the most suitable methodology that will accomplish the research objectives. Simulation methodology is chosen as the most appropriate method to carry out analysis of identified parameters of this research due to the scale and complexity of the base case community. Finally, the validation model will be simulated and discussed.

Chapter 04

This chapter illustrates the simulations process for the incorporation of the different strategies and scenarios for the NZEC along with the description of the selected master community and its various building components. The section further explains the modelling process, the weather data, the range of simulation load profiles and the building construction template applied. Finally, the estimation of the community energy consumption and the calculation of a test PV panel used for the energy simulation is summarized.

Chapter 05

The fifth chapter demonstrates the various scenarios and strategies implemented to increase PV energy generation and maximize PV area installation at the urban community level. The obtained results and critical analysis from the simulation are presented in graphs and tables. This study will assist identify the most optimum scenario for integration of solar PV panel technology in a community for a carbon free clean energy generation that can achieve net zero energy community status.

Chapter 06

Built on the analysis in chapter five, the final chapter offers conclusion of this dissertation followed by recommendation to drive the transition of clean energy generation in an urban community located by use of solar PV energy. This chapter will illustrate the complete perspective of conclusions to answer the research question and potentials of net zero community in the Dubai.

CHAPTER 02
LITERATURE REVIEW

2.1 Overview

The biggest contributor to climate change and global warming is the built environment with approximately 40% of the total primary energy used in all sectors and 36% of the global GHG emissions in the world. However, there are many remarkable efforts and innovative solutions made to address and mitigate the high-energy use of buildings and communities. Globally, several initiatives and regulations have been assigned and set as minimum basic requirements to all new and existing buildings. Moreover, over the past few years many high performing building concepts have emerged beyond the building envelope that contribute in the decrease of energy demand and CO^2 emission at the community level such as the Net Zero Energy Community (NZEC). The development of NZEC framework is an essential measure for taking the UAEs current and future climate initiatives to the next level.

This literature review provides a detailed understating on the definition of NZEC, and solar energy as a source of renewable energy supply. Firstly, the chapter investigates previous studies on the trends, concepts, global definitions, and parameters of NZEC in the reduction in energy demand and carbon footprint. Furthermore, the chapter highlights the importance of NZECs, their challenges and opportunities in the UAE. Secondly, many papers discuss the various passive and active energy efficient strategies, urban level integration of photovoltaics', various photovoltaic technologies and parameters that impact energy balance and their economic feasibility. Finally, three case studies highlighting their strategies and their approach using different renewable systems, main barriers and opportunities in the field of NZEC that play in the global and UAEs road to sustainability.

2.2 Global Trend

The concern in the reduction of energy consumption in the built environment initiated at the onset of the World War II (Parker, 2009). In 1959, Massachusetts Institute of Technology (MIT) first carried out studies aimed at the reduction of energy consumption in buildings, focused on using solar energy to heat a structure. With the help of solar energy generated from $60m^2$ active solar collectors, they could offer 57% of space and domestic water heating (Engebretson, 1964).

The energy crisis of the 1970's gave rise to the next movement of development in the energy efficiency homes using strategies such as passive solar and super insulated homes that reduce energy required to heat. However, reduction in cooling, water heating and plug load energy profiles were neglected (Parker 2009). Hence to fight the whole spectrum of residential inadequacies, the concept of Net Zero Energy Buildings (NZEB) was conceived.

Parker (2009) highlighted that an NZEB uses improved building techniques and materials via super insulation, intelligent design, high efficiency appliances, lighting fixtures and produces enough onsite clean energy such as active and passive solar features that reduces building energy consumption that result in net zero energy use annually. The low cost of photovoltaic (PV) panels on the roof are primary technology that can convert solar energy to generate electricity drives the concept of NZEB. Yet, it is important to note that the energy from PV is not the only choice for renewable onsite energy generation, but it is the most widely used irrespective of climate. Other onsite renewable energy systems include solar thermal, geothermal and wind

(Fischer, Finnell & Lavoie 2007). These systems are installed and tied into the local utility grid depending on factors such as the climate, location, regulations and economics.

Edminster (2016) described that since 2015 there are 6,177 NZEB in the Canada and US, which are either completed, under construction or in design phase. There are 417 net zero energy buildings located in European countries as of 2017 which are either constructed or renovated, out of which 36% are non-residential and 64% are residential (Paoletti et al., 2017). In the US, 55 – 70% energy reductions have been achieved using todays technologies and best practices (Harris et al. 2011, NBI 2012b). Li et al. (2016) noted how the building energy consumption and CO^2 emissions were influenced by building typology and urban morphology.

But achieving net zero energy (NZE) for the isolated individual building scale might not feasible, it is realistic when they are evaluated collectively considering a community scale which offer better opportunities for building energy efficiency, energy exchange, cost effective renewable energy generation and micro climate improvement strategies. The NZEC concept looks beyond the building envelope and footprint through reduction of energy consumption by energy efficient insulation, optimum load diversity, adopting renewable sources, energy storage. The creation of a centralized community energy system that supports a more efficient diversification of electrical and thermal load is crucial. Also, drawing large area allows for use of nearby offsite renewable energy sources keeping urban densities and high rise building in the NZE mix. Microclimate design strategies enhance passive cooling effects to reduce surface temperature in the community and further benefit the indoor levels.

Many pilot projects have illustrated the feasibility of NZEC concepts in the UAE resulting it its popularity in recent years. Abu Dhabi launched 18 billion dollars for a self-sustaining solar powered sustainable city called the Masdar City as an NZEC model for the GCC countries. While in Dubai, the Sustainable City initiative developed by Diamond Developers rely on efficient grid PV systems installed on the building rooftop and parking lots to offset their power consumptions. The growth in quantity of academic research concerning NZEC begins to make it possible to see the variations in performance at multiple scales. The above concepts demonstrate there is clear increase in the number of successful zero energy projects globally and regionally priming buildings and communities to be future ready and ensuring the UAE’s sustainable growth.

2.3 Defining Net Zero Energy Community (NZEC)

Communities have become the center of the sustainable energy challenge due to rising population and growing urbanization in emerging developing countries (Hoeven, 2012). Today bridging the gap between renewable energy generation and the energy consumption by the community to become net zero energy is so big that energy efficiency, energy conservation and renewable energy incorporated at the community level is vital (NREL, 2009). Net Zero Energy Community (NZEC) is an emerging sustainable concept addressing the current energy and environmental sustainability challenges. The definition of NZEC originates from the Net Zero Energy Building (NZEB) definition which is the building block of the community that works by optimizing energy efficiency and use of onsite/offsite renewable power generation. The spatial scale of NZEC make them more complex than NZEB as it integrates the industry, vehicles and community based infrastructure apart from buildings which gives more opportunities for renewable integration.

Santamouris (2016) supports the concept of NZEC as it minimizes building energy consumption, abolition of energy poverty, urban heat island mitigation and regional climate change and creating substantial opportunities for future growth. Cortese & Higgins (2014) states that the New Building Institute (NBI) defines NZEB as a building with highly reduced energy demand that allows energy demand to be balanced by an equivalent production of electricity from any renewable sources of energy. Similarly, the idea of NZEC is essentially like that of the NZEB when applied to a geographic cluster of buildings, adjacent urban level landscape open space and infrastructure. Some of the existing energy efficient and zero energy buildings concepts are illustrated in Figure 2.1. Energy efficient buildings have applied energy conservation, energy efficiency and energy demand reduction measures to reduce their overall energy consumption and costs compared to Business as Usual Buildings (BAUs).

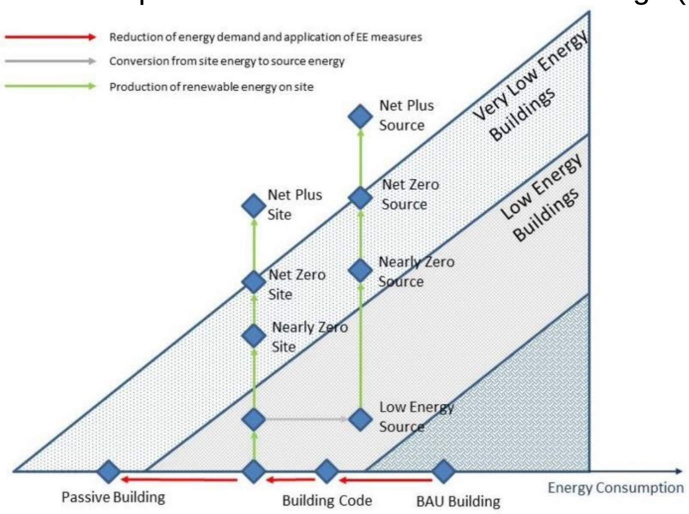


Figure 2.1 Current energy efficient and zero energy buildings concepts (Emirates GBC, 2017).

Buildings usually prioritize energy consumption reduction and system efficiencies before considering onsite renewable energy sources (typically rooftop PV's). The NBI 2014 defines NZEC as a group of buildings such as an urban community, public housing, campuses and neighborhoods with the goal of accomplishing net zero energy status (Cortese & Higgins, 2014). In this research, the community is defined as a mixed use of buildings such as villas, townhouse, apartments, hotels, clubhouse, hotel, schools, mosques including their surrounding environment such as the landscape, neighborhood parks, lakes, roads, infrastructure services, etc.

Carlisle, Geet & Pless (2009) describes that a Net Zero Community consumes no more energy that it can produce through reduced energy requirements by increasing energy efficiency and renewable energy positioned in the community or in adjacent non-urban areas. Malin (2010) highlighted that energy performance in individual buildings is pointless when the entire neighbourhood is not an energy saving one. The success of these communities depends on an integrated design approach to energy performance over the life cycle, designing, operation and maintenance, commissioning stages (Harris et al., 2011). Meanwhile, Torcellini (2006) noted that metrics of NZEC evaluation changes significantly per the different stakeholder priorities. For example, developers and home owners care about cost; government energy organizations are interested in primary energy sources; architects and designers are concerned about site energy code requirements; environmentalists are concerned about carbon emissions.

In addition to stakeholder priorities, factors such as energy balance boundary, renewable energy sources and infrastructure/utility connection need to be considered when developing the target for a NZEC (Marszal et al., 2011). They also highlight that generation of renewable energy can be of two types; firstly, onsite energy generation via systems installed on building footprint or on land within the perimeter of the building community such as rooftop photovoltaic's, advanced building integrated photovoltaic's, advanced wind driven energy production systems, secondly offsite generation that utilize land and investments in offsite renewable technologies such as combined heat and power systems, concentric solar power generation technologies and purchase of green power. This paper does not consider off grid communities.

Laustsen (2008) categorizes 5 concepts of Net Zero Energy Communities as listed below; some of them are illustrated in Figure 2.2.

a. **Net Zero Energy Community** – These communities transfer as much renewable generated energy to the connected utility grid as they have extracted. They do not require any conventional non-renewable energy sources for heating, cooling, and lighting. They are also linked to the national utility grid for backup and energy exchange.
b. **Zero Stand Alone Community** – These communities are not connected to utility grid. They function on their own onsite energy production and has provisions and capabilities to store energy in huge batteries for many nights and dark days.
c. **Net Plus Energy Community** – These communities produce more energy annually to the utility grid than it consumes.
d. **Zero Carbon Community** – These communities do not utilize energy that involves carbon dioxide emissions. It exclusively produces carbon free energy making it a carbon neutral or positive.
e. **Near Zero Energy Community** – This community demonstrates high energy performance but fails to reach the net zero energy targets. According to Kurnitski et al. (2011), a nearly zero energy community covers significant energy use through renewable energy production. Depending on factors such as climate, type of buildings, infrastructure, operations etc., any NZEC community may become a near ZEC for a period during the year.

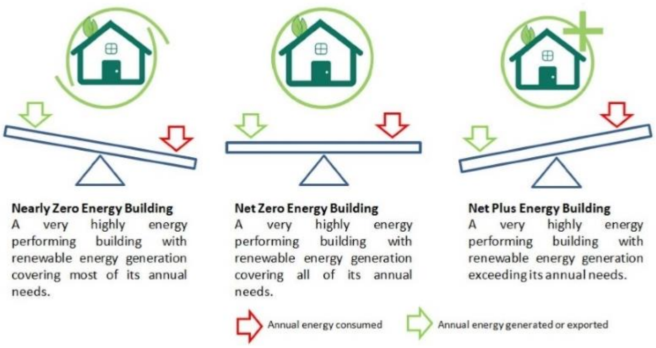


Figure 2.2. Definition of nearly, net and plus energy buildings (Emirates GBC, 2017).

2.4 NZEC Parameters

Torcellini (2006) defines NZEB based on four parameters; in this study, we further adapt them to community level scale and later use these four parameters to assess and evaluate the NZEC, these four parameters are listed below:

1) **Net Zero Site Balance Energy**: Boundary balance energy or site energy is defined as the volume of consumed and generated energy on site from various energy sources. This includes on site use of fossil fuels, electrical energy, renewable energy, thermal energy from district cooling/heating systems but not from an offsite electricity system. The energy balance can be accounted for at site, but the overall summation of energy in the community must be zero. Evaluation of site energy assists in understanding the change in rate of energy consumption over time. Thus, to establish the base case, the developer and community manager needs to access the total amount of energy consumed from the utility grid by the community annually in order to understand how it can be complemented by renewable energy systems at the community level.
2) **Net Zero Source Balance Energy**: Source balance energy is defined by the primary/secondary source energy that are needed to extract, convert and deliver to the community. For example, the conversion process of oil to electricity which includes electricity system delivery losses and wasted energy while generation, delivering and distribution. Deru & Torcellini (2007) notes that the transmission and distribution energy losses are to be accounted for when the energy is delivered to the facility. The utility grid can be used to account for energy balance, additional production of renewable energy can be used to offset the fossil fuel energy use.
3) **Net Zero Energy Cost**: The annual amount of money received by community from the utility for onsite energy exported to the grid for energy consumed annually is defined as energy cost (Harris et al., 2011). This is simplest metric to use as it defines the whole community receiving a total energy bill of AED0 after annual economic cycle from the local utility for renewable energy transferred to the grid (Aggerholm et al., 2011). Many organizations such as ASHRAE and LEED use energy costs as chief metric as an alternative for site source conversions. But they vary greatly with region, season and time of the day. Ueno & Straube (2010) explains how it is better to take the energy units and then assess the energy costs as this allows evaluating energy costs change over time.
4) **Net Zero Carbon Emissions**: This is defined as community which uses no operational energy from renewable energy sources that results in carbon emissions. EPA (2012) states that GHG emissions are produced directly or indirectly by an entity and categorized into three categories based on source of emissions. Emissions from fossil fuels burned on site such as occupant vehicles, indirect emissions from generation of electricity for heating and cooling needs and indirect emissions from sources not owned or directly controlled by user but part of consumer activities.

2.5 Significance of NZEC

The study of the various concepts and definitions of NZEC has led to the evaluation of some significant reasons for why communities need to be advanced to net zero energy on a global and regional scale.

a. Reason for choosing the community scale

The listed below points explain why community scale net zero energy projects are more worthwhile and efficient than building scale net zero energy projects.

- Load diversification at a wider community level offer diversity of thermal and electrical loads over different time scales for various mixes such as office building load, hotel and residential loads.
- Preserving urban density in net zero communities as most NZEB are typical low rise, they contribute to low density sprawl (Carlisle et al., 2009 and Malin, 2010). Considering a large perimeter allows for consideration of offsite renewables which are more economically feasible for high rise buildings and mixed use urban developments (Torcellini et al., 2006).
- Support many modern energy grid infrastructures such as smart/micro grid integration with energy storage systems which ensure effective optimization of energy resources at community level thus enabling community for enhanced efficiency, reliability and better control for near and long term energy decisions.
- Services limited to individual buildings like internal energy exchange, wastewater recycling, rainwater harvesting, district cooling and heating, electric car transport alternatives, local food production etc can be incorporated in a NZEC.
- Limitations within individual buildings such as energy dynamics, site constraints and preexisting grid planning requirements that restrict building energy storage and orientation benefits from passive design like solar and wind directions are overcome in a neighborhood level.
- Lower transmission line losses. Moore et al. (2010) has proved that in many parts of the world energy, efficient buildings and communities can be constructed cost effectively with up to 90% less primary energy for heating and cooling requirements.

Based on the above reasons, it is more efficient and worthwhile to work on a community scale when considering Net Zero Energy.

NZEC project development has few disadvantages as well;

- Limitations related to NZEC projects ownership, financing and initial budgeting/higher up front development cost (Steib & Dunkelberg, 2012). Many legal and commercial problems emerge without single ownership who is accountable and responsible for the project.
- Most community projects are developed and operated in phases. Power related infrastructure such smart micro grid integration, transportation networks, wastewater solutions may not be operational till the phase is completed as their workability needs to be tested and operated, hence phasing is another obstacle.
- Success of any net zero project trusts on the complete participation of its operators and occupants. It is easy to get the agreement and participation of the users of an individual building when compared to a community to abide by the net zero energy policy.

- The incorporation of overly complicated renewable energy systems or combination of multiple energy systems in the community which are not tried and tested is another limitation. These advanced systems result to a significant cost burden for the community (Synneda et al., 2017)
- Loss of high value use of land when unplanned community green space is utilized for renewable energy generation.

Nonetheless, the advantages of the development of a NZEC surpass its shortcomings, the concept of NZEBs and conventional communities.

b. Global Significance of NZEC

- NZEC provides for higher quality of urban life with the availability of clean environment and carbon free energy for daily use, hence better individual user satisfaction, health and productivity.
- Reduced dependency on conventional energy resources such as fossil fuels and natural gas which leads to global warming.
- The energy generated using renewable technologies improve their community energy efficiency leading to cost savings for residents residing in the community hence reducing the impact of rising volatile energy prices.
- Provides energy security as it does not completely rely on the national utility network especially for developing countries where energy sources are not constant.
- Energy autonomy, enhanced community reputation, and employment opportunities.
- Community awareness and enhancing of the local construction market towards green buildings. Encouraging government, private organizations, developers and investors to incorporate sustainable technologies in their respective developments.

Carmicheal & Managen (2013) highlighted that in the USA, it was found that in addition to the cleaner environment increased from quality ventilation, lighting, energy and water in green buildings and communities, the rental values went up by around 17% and sales market value were higher by 35%. However, Islas et al. (2004) highlighted that carbon emissions decrease through renewable energy use leads to unavoidable economic “mitigation costs”. These costs can be recovered by developers fully or partly by premium home prices and government subsidies.

c. NZEC significance in the UAE

UAE will become the first Middle Eastern Arab country preparing to host one of the most important sustainable world event The Expo 2020 focused on transforming into a sustainable country in the world. One of the key aims of the event is to produce 50% of the Expos operational energy from renewable sources on site. Many projects have been launched to accommodate millions of residents the highest quality of the city lifestyle, paired with the lowest environmental footprint. These projects have been driven by UAEs vision to position the country at the forefront of sustainable energy and development, encompassing three main pillars; environmental, economic and social sustainability.

The national initiative under the slogan 'A Green Economy for Sustainable Development' aims to establish UAE as a world leader in green economy and center for green technology market maintaining sustainable development to support long term economic growth. Many national strategies, policies and codes have been developed by UAE in addition to research and development to reach its sustainable goals. Figure 2.3 summaries the many federal and local sustainability targets in the UAE. Dubai targets to reduce water and energy consumption by 30% by 2030 and rise the segment of clean energy to 75% by 2050.

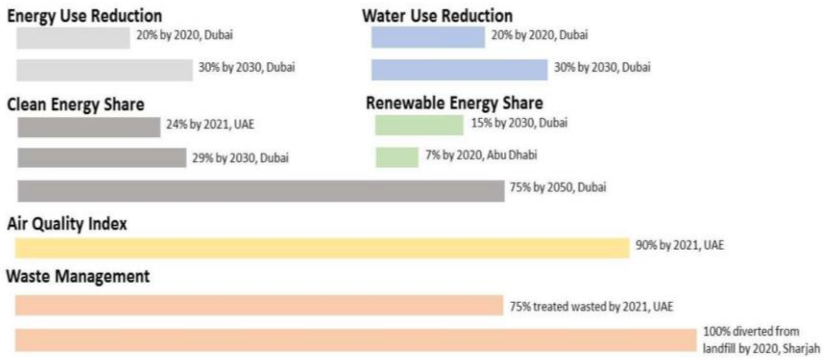


Figure 2.3: Federal and local sustainability targets in the UAE (Emirates GBC, 2017).

The Estidama Pearl Rating System (PRS) was launched by Abu Dhabi in 2010 which is a compulsory standard for green building regulations for all new construction buildings and community projects. Dubai Green Building Regulation and Specifications (GBRS) mandated by Dubai government on all government buildings in 2011 and all new public and private constructions since 2014. The Dubai Municipality and ESMA together work for the aim of energy labelling system which reduce energy consumption by appliances and equipment's.

In 2011, the Dubai Municipality and DEWA removed energy and water tariff subsidies. The tariff structure may change as an outcome of the Demand Response program which address time of use, direct load control and load management. Consequently, the Dubai Municipality launched the Al Sa'fat rating system for commercial and residential projects in 2016 to score a buildings total energy efficiency which enhances the energy performance of built environment, combat global warming and support the UAE's goal of Dubai Plan 2021 (Emirates GBC, 2017).

Shams Dubai program under executive council resolution number 46 of 2014 is an initiative launched by the Dubai Municipality illustrated in Figure 2.4 to facilitate and regulate the linking of renewable solar energy generating unites on the building site to Dubai's power distribution grid. The program promotes home and commercial building owners to incorporate rooftop photovoltaic systems onsite and connect them national utility under a net metering mechanism.

The concept of NZECs is very vital and attractive to the UAE national agenda as it aligns with the key priorities of the countries goal towards innovation and sustainability. In the UAE, Abu Dhabi launched the Masdar City as an NZEC model project also the first in the GCC area as a model that support the idea of development, commercialization and adoption of renewable energy and clean energy technology systems. The Sustainable City is a NZEC in Dubai with practical employment of social, economic and environmental sustainability. TSC generates sustainable living through stakeholder engagement, innovative design and energy monitoring.

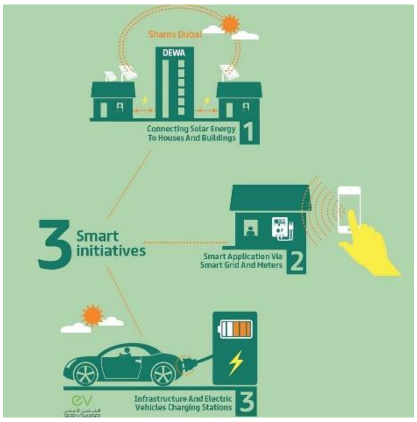


Figure 2.4 Three Smart Initiatives by Shams Dubai (DEWA, 2017).

However, there are many limitations when it comes to adopting NZECs in the UAE.

- Market readiness for retrofitting on the existing building stocks with efficient solutions and renewable energy systems is a challenge. The cost effectiveness of energy efficient buildings amongst end users.
- Additional barriers such as low utility energy price and value added taxes on renewable energy equipment restrict the competitiveness of NZEC's and renewable energy sources.
- Another big challenge in the UAE is occupant behavior and awareness is still lacking; the maintenance, operations and the indoor environment of the NZEC are not the same as conventional communities.
- Installation of renewable energy systems such as PV on high rise buildings in a NZEC may not be feasible due to space limitation on the envelope of the building. So, Katz & Wacks (2014) established that it is impossible for a super high rise office tower in the USA to achieve net zero energy goal using on site renewable energy systems. Community renewable energy systems or renewable energy credits are strategies to mitigate this space limitation challenge.
- Literature and case studies that focus on NZEC and the integration of PV on urban landscape in the UAE is limited in number, however there exists a small but growing number of articles examining their relationship.

2.6 Strategies to develop a Net Zero Energy Community

Achieving net zero energy targets is the primary goal for any sustainable community which can be achieved by increasing the energy efficiency of building components, optimized energy conservation via highly efficient insulation, smart LED lighting, highly efficient HVAC systems, automated building energy management system and renewable energy generation via advanced building integrated photovoltaics'. The energy efficient strategies and design principles need to be developed and integrated to minimize current community energy consumption to the lowest possible amount and by using renewable energy systems the remaining energy consumption can be further reduced to achieve optimum thermal comfort and net zero community status (Malin, 2010).

2.6.1 Energy Efficiency Strategies

Santos et al. (2012) defines energy efficiency as the balanced effective use of energy which provides proper environmental conditions for user comfort, productivity gains and reducing negative impacts on the environment. In recent years, the critical interaction between energy efficiency and environment in achieving sustainable growth has increased rapidly. Assuming an average life span of buildings to be 50 years, optimizing their energy efficiency as early as possible is vital for increasing potential energy savings. IEA (2014) highlights that Energy Efficiency Strategies are important tools for analyzing the interaction between user activities, energy use, economics and carbon emissions. Different strategies such as orientation, efficient façade, thermal insulation construction material and air tightness help in minimizing heat gain.

The key factor in mitigating global warming issues where local climatic and site factors highly affect is the passive energy efficiency strategies. However, Chan, Saffa & Zhu (2010) stated that for extreme weather condition there are restrictions for many energy efficient strategies and it is difficult to achieve thermal comfort. Implementing energy efficient strategies such as building orientation and form in early design phases provide better energy performance in reducing total energy consumption. It was concluded by Gong, Akashi & Sumiyoshi (2012) that passive strategies are the most practical and economical way to improve building energy performance and cost savings. The strategies listed in this research are applicable for new construction communities.

a. Orientation

One of the most critical energy efficient design strategies that can affect a buildings energy performance and microclimate potential is the orientation. Correct orientation can reduce the impact of direct solar radiation on its building envelope. Design of the windows, openings and external walls are influenced by the orientation of the building. Hachem et al. (2017) related the electricity performance of thermal and cooling with the power generation potential of communities and discovered it can be achieved with the help BIPV housing units of certain shape, orientation and site configurations. The study has highlighted the impact of urban form on the energy consumption of transportation in contrast to building energy consumption.

Song and Choi (2015) highlights the increase in energy production benefits by optimizing the PV panels tuned to suitable azimuth and tilt orientations. Al Tamimi (2011) describes the vital role of urban streets that are defined by a height/width ratio (H/W), length width ration (L/W) and the orientation of its long axis. The geometry and orientation of the street impact the outdoor and indoor environment, solar admission to the inside and outside of building, urban ventilation which affects the thermal comfort, air quality, buildings energy performance and human health.

b. Thermal Insulation

Insulation that reduces the conductivity of heating and cooling of a building by adding extra materials into the building envelope is referred to as Thermal Insulation. They act as heat flow barriers which improves the building energy efficiency, reducing energy demand and increasing the thermal comfort inside the building. In summer, it prevents heat entering the space, while in winter it prevents warm air from escaping.

The roof alone allows for 60% thermal transfer hence the need for quality thermal insulations. Effective reduction in heating and cooling energy by up to 50% and reduction of GHG emissions have been achieved using thermal insulation and air tightness (Fletcher, 2013).

Synnefa et al. (2017) engaged innovative composite thermal insulating materials customized and optimized for four demo projects in the Europe. A system based on a new generation of extruded polystyrene (XPS) incorporated on the building envelope that is lightweight, has better vapor permeability, self-cleaning properties and cool material properties contribute to lesser energy demand for cooling, GHG emission and UHI mitigation.

Gong, Akashi & Sumiyoshi (2012) explained that there many factors that affect the results of deployment of thermal insulation such as the climate, the type, thickness and placement of the material. Kolaitis et al. (2013) highlighted that the use of internal and external insulation exhibits great reduction of energy. Moreover, the external layer performed better than the internal layer configuration by an average of 8%. However, the payback period for internal insulation layers was lower associated to external insulation. Friess et al. (2012) examined the effects of implementing thermal insulation to control thermal bridging effect on energy consumption on villas in Dubai. The outcome demonstrated energy savings vary depending on thermal insulation of the material used. Several Insulation materials that minimize heat loss are available in the market such as polystyrene, urethane foam, rock wool, fiberglass and vermiculite.

c. Building materials

Various properties of building materials that affect its performance against temperature, solar radiation, humidity, noise, pollution have been displayed. But the most important properties that affect the performance of a NZEC is the U-Value. Brennan (2014) defines U-value as a degree of heat loss in a building element such as wall, floor or roof. The Passive House institute established the Passive House standard which emphasize on the energy reduction and efficiency; it mandates that the primary energy demand of a building must be less than 60kWh/m²/year and U-value requirement less than 0.15 W/m-²K (Passive House Institute, 2015).

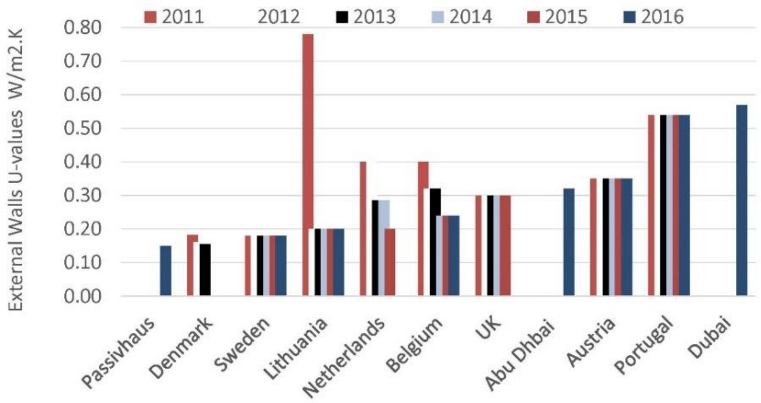


Figure 2.5 External U-values of Passive House, Abu Dhabi, Dubai and few European countries (Emirates GBC, 2017).

The minimum U-value requirements for external walls for few European countries, Abu Dhabi, Dubai collected from ZEBRA 2020, PRS and DGBRS respectively as shown in

Figure 2.5. An important observation to be noted is that many countries have made tremendous improvements to the thermal performance of their external wall such as Lithuania, Belgium and Netherlands. The external U-value requirements of UAE are far from Passive House requirements and higher than many European countries. Denmark has the same U-value of that of Passive House shows their aggressive NZEB targets are matched by their building requirements.

In addition, Volatile Organic Compounds (VOC) are toxic chemical gases which are emitted by materials after they are applied, they can damage the indoor thermal comfort and indoor air quality (IAQ). Thus, NZEC require the application of low emitting materials or VOC free materials mandated by environmental rating systems such as LEED and GSAS.

d. Efficient Facades Thermal Performance

Facades of buildings have significant impact on the thermal performance of the building as they impact air conditioning, ventilation and lighting. External windows account for 25-28% of total heat gain that can raise upto 40% during summer (Al Tamimi, 2011). Facades are an important component of modern architecture which allow for natural light, visual communication with the outdoors, reduce structural load and develop aesthetic appearance on the building, but they allow for absorption of heat and radiation. Other factors such as air gap, gas fill between the glazing, coating on the glazing, frame of the glazing construction impact the thermal performance of the glazing.

Tokbolat, Tokatayeva & Al Zubaidy (2013) highlights the orientation of the building façade can significantly affect the energy required to cool or heat the internal space. It Is the location and latitude of the country which governs the best façade orientation of the building. Figure 2.6 highlights few façade factors that affect energy consumption. Lopez and Molina (2013) and Ihm et al. (2012) illustrate an increase of 18.26% of energy savings in residential buildings with the use of double glazed windows with circulating chamber water and low-e glazing. They conclude that three primary factors affecting thermal performance of the glazing are; wall to window ratios, glazing U-value and SHGC.

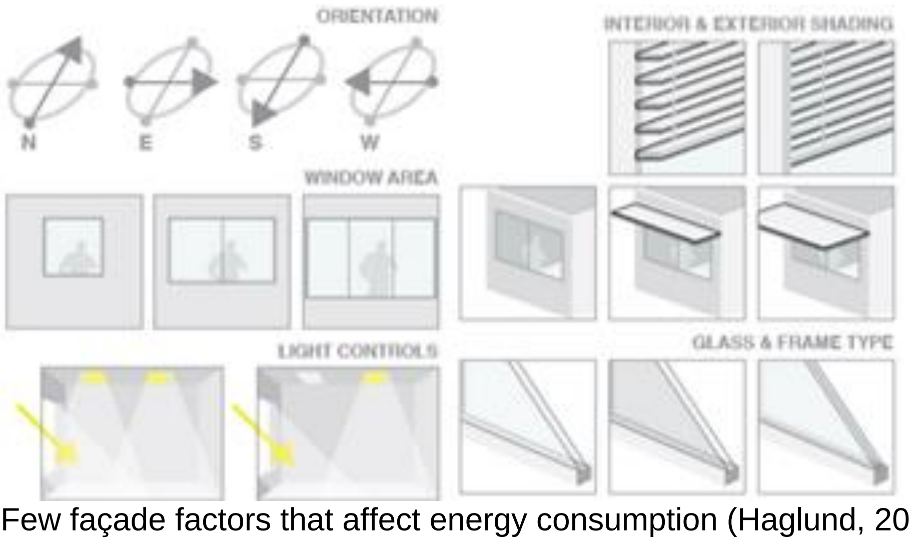


Figure 2.6 Few façade factors that affect energy consumption (Haglund, 2012).

Berardi (2015) and Cuce, Young & RIffat (2014) investigated the use of innovative materials for energy efficiency in multi layered glazing such as monolithic silica aerogel in double pane glazing cavity and Heat Insulation Solar Glass technologies. Berardi (2015) evaluated the thermal and lighting characteristics of glazing with silica aerogel system with the help of simulation.   The HIGS technology is an interesting technology which has thermal, optical and acoustical insulation, self-cleaning and electricity generating properties (Cuce, Young & RIffat, (2014).

Chan et al. (2008) studied the impact of solar window film used for solar gain reduction in a hotel in China; annual electricity savings of 155 kWH per room was discovered proving its financial benefits. Alkhateeb and Taleb (2013) studied thermal performance in few residential homes in Dubai by substituting single glazing with double glazing which resulted in 15% energy savings. Awdah (2013) investigated window configurations in Abu Dhabi that consist of triple glazing PVC frame windows and 60 cm projecting egg crate shading device which resulted in 6% energy savings. Synnefa et al. (2017) incorporated an innovative energy technology capable of performing as an active and passive system. The system is made of precast, dry assembled and pre-stressed translucent BIPV glass components made of Dye Sensitized Solar Cells.

e. Efficient electrical equipment and Building Automation Systems

Integration of high energy star rated (energy efficient) appliances, energy efficient CFLs or LED lighting, efficient HVAC systems such as the smart energy efficient VRF air condition system and the new solar Desiccant Evaporative Cooling concept along with intelligent energy resource management system minimize the community infrastructure loads. Furthermore, smart grids with medium voltage and low voltage distribution networks with solar inverter/ storage are installed to deliver power more efficiently and reliable through demand response and monitoring capabilities (Synnefa et al., 2017).

The energy performance of building can be affected by installed equipment systems in two ways; due to their own energy demand for space heating, hot water, cooling, lighting and appliances and from the production of waste heat which in turn can increase or decrease the heating load (Laustsen, 2008). Hence inefficient appliances and lack of maintenance can cause double the energy loss as they consume more energy than required in addition to production of wasted energy. Thus, incorporation of high efficiency HVAC equipment's and intelligent home energy management system (HEMS) become vital.

The HEMS technology is a smart interface network with wireless communication as seen in Figure 2.7 that integrates the smart meters, indoor environmental wireless sensors and monitoring system in one platform combined with SDHW and PV solar panels can reduce power demand and improve energy performance by 37% than ASHRAE 100-2015 benchmark standards for villas. These systems can control the dimming level of lighting, reset room temperature for each zone based on occupancy, control shutters and blinds and connect disconnect home appliance based on the peak loads and demand to conserve the energy generated by the photovoltaics installed (AlFaris, Juaidi & Agugliaro, 2017).

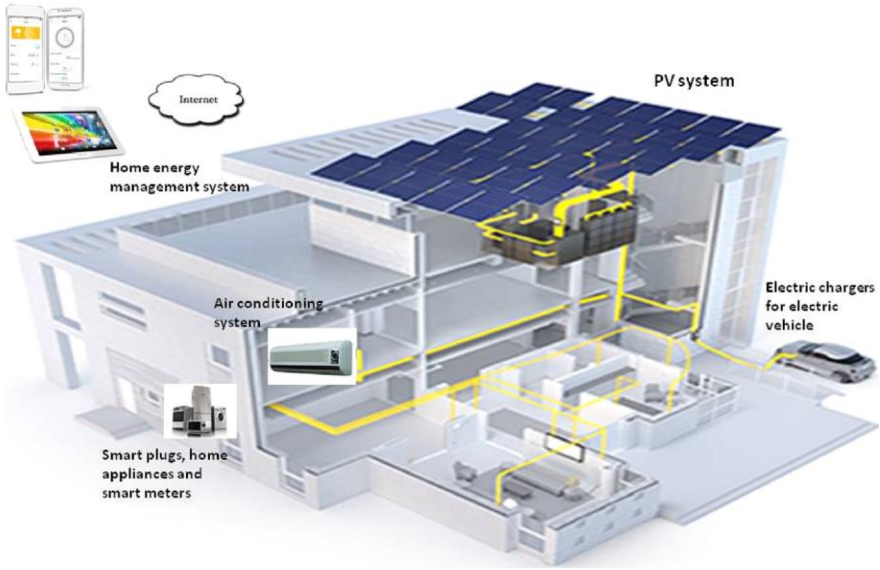


Figure 2.7 Intelligent home energy management system (AlFaris, Juaidi & Agugliaro, 2017).

f. Urban Landscape Design

Renewable energy collectors and outdoor energy technology sensitively designed and integrated in the green spaces, common areas and public spaces within the community or in an external location near the community boundary provide for large potential for cost effective sustainable clean energy generation. Furthermore, microclimate improvement strategies such as passive cooling effects from the use of local green flora, cool paving strategies reduce surface temperature at the environment level and passively cooling building elements. Both these strategies when combined produce optimum scenarios that can be developed towards achieving a NZEC (Synnefa et al. 2017).

Moussa & Mahmoud (2017) describe how a well-planned landscape site and energy scape elements contribute to the physical quality of the urban community by becoming more energy efficient and reduce GHG emissions. The authors study the integration of low energy density/m² renewable energy devices such as PV, small hydropower, piezoelectric cells, biomass, small wind turbines in a framework of landscape elements divided in five categories as identified in Figure 2.8. Remarkably, photovoltaic can be integrated to 26 landscape elements making it the most important and cost effective energyscape element.

Aman et al. (2015), Jacobson and Delucchi (2011) & Rayner et al. (2016) describes the integration of aesthetically designed solar PVs in the urban community scale such as street furniture’s, parking structures, kiosks, booths, play & rest roof areas, shaded pathways apart from residential and commercial rooftop PV installation. This strategy reduces the need for long distance transmission lines and conventional generators besides the mitigation of urban heat island effect with examples illustrated in Figure 2.9.

Landscape Elements		Piezoelectric cells (Pavement)	Piezoelectric cells (Roads)	P.V	Concentrated solar thermal heat	Solar thermal heat	Biomass	Small Wind Turbines	Geothermal	Hydroelectric
		Piezoelectric		Solar						
		Renewable Energy								
Total		8	5	26	2	2	10	15	13	7
1- Trails & Paths	Trails	*	*	*				*	*	
	Path	*	*	*				*	*	
	Pavements	*	*	*				*	*	
	Footpath networks	*	*	*				*	*	
2- Designated & Specific Use Areas	Open space	*		*	*	*	*	*	*	
	Wooded area			*			*		*	
	Picnic area			*			*	*	*	
	Camping site						*	*	*	
	Pavilion						*	*	*	
	Area surrounding park			*			*	*	*	
	Wildlife or pet area						*		*	
	Parking lot		*	*			*	*	*	
3- Water Areas	Lakes			*						*
	Ponds			*						*
	Fountains									*
	Fishing area			*						*
	Stream									*
	Wetland									*
	Reflective pools			*						
	Waterfall									*
4- Other Amenities & Facilities	Benches			*						
	Trash box			*						
	Tables									
	Vending mach.			*						
	Telep. booths	*		*						
	Kiosks			*				*		
	mailboxes			*						
	Sculptures			*	*	*		*		
	Walls									
	Fences									
	Drink fountains	*		*						
	Picnic shelters						*			
5- Playground Equipment & Fields & Courts	Play set			*						
	Play structure			*						
	Ground surface						*	*	*	
	Things to swing/hang			*				*		
	Things to climb on/up/through			*				*		
	Things to stand or walk on	*								
	Things to slide down			*						

Figure 2.8 Landscape elements framework integrated with renewable energy devices (Moussa & Mahmoud, 2017).

Figure 2.9 Pictures and schemes of some PV technologies integrated into the urban landscape. a) Stand-alone PV integrated shaded bus shelter (Polysolar, 2015) b) PV integrated walk way at the Euro University (Alnaser, 2008).

Strazzera & Statzu (2017) highlights the fact that photovoltaic technology application may have positive or negative impacts on the appearance of the urban landscape therefore seen as an opportunity to modernize the city and barrier for historical monuments. The added visible impact on the surrounding landscape makes it important to understand the community context. Kannan & Vakeesan (2016) illustrates the development of solar greenhouse farms replacing horticulture glass and improving the plant production for through by allowing selective light wavelength and temperature control. This strategy of capturing solar power within the urban landscape used for heating and lighting have increased as it delivers large surface area for energy generation and leave the ground level completely free from any installation, suitable for agricultural purposes as seen in Figure 2.10.

Figure 2.10 Agrivoltaic photovoltaic scheme combining food production and energy generation (REM, 2016).

Kovacs et al. (2016) proposed an intelligent energy efficient system that minimizes the energy consumption and the operating costs of the community lighting system as seen in Figure 2.11 by applying energy efficient LED luminaires coupled with photovoltaic panels, adjusting the switch on/off times and dimming levels to current weather conditions and by applying adaptive lighting to actual environment conditions that focus the lighting service to location and times with respect to automobile or pedestrian traffic controlled by a microcontroller. These self-sustaining maintenance free outdoor solar lighting systems can be utilised for bicycle paths, promenades, parking areas and shopping plazas. The author emphasis the potential benefits of intelligent solar lighting system in residential areas by about 55.71%, do not require excavation works, cable laying and public grid connection and zero carbon emissions. However, the individual luminaires require rechargeable batteries which need replacing every 4-5 years can come at a considerable extra cost.

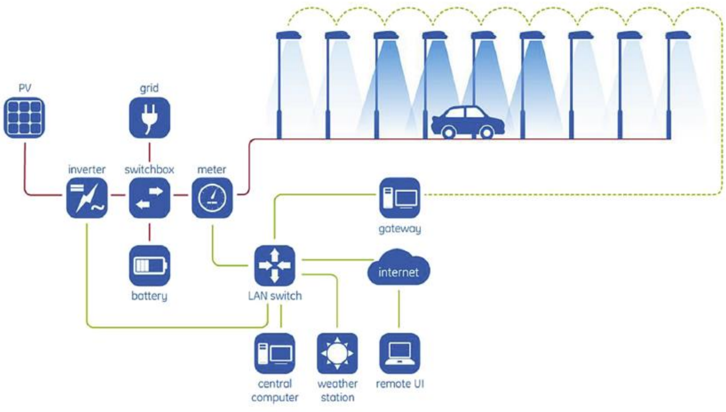


Figure 2.11 Schematic for an intelligent energy efficient community solar lighting (Kovacs et al., 2016).

Meanwhile, the Shams Dubai and Smart Dubai initiative by DEWA installed a total of 902 solar carports at DEWAs headquarters and Ministry of Climate Change and Environment building as seen in Figure 2.12 with capacity of 1780 KW and 220KW respectively generating a total of 2759 MWp clean energy annually (Khaleej Times, 2017). Market for solar carports is set to grow significantly with the advent of electric vehicles (EV).

Figure 2.12 PV integrated car ports at DEWA, Dubai (Khaleej Times, 2017).

Integration of a community scale microgrid with storage unit as seen in Figure 2.13 connect the entire distributed renewable systems internally on buildings within the community to the utility grid can share the excess PV generated energy to all the users within the community. In this case, there is no need of transformers or high voltage transmission lines thus avoiding power transmission losses. This strategy is vital during peak power needs, night time loads or during seasonal loads solving the problem of community energy storage (NREL, 2009). However, there are limitations as procedural issues in the implementation of this strategy at the local context. The local utility provider in Dubai, DEWA do not have distributed energy sharing as a part of their connection guidelines.

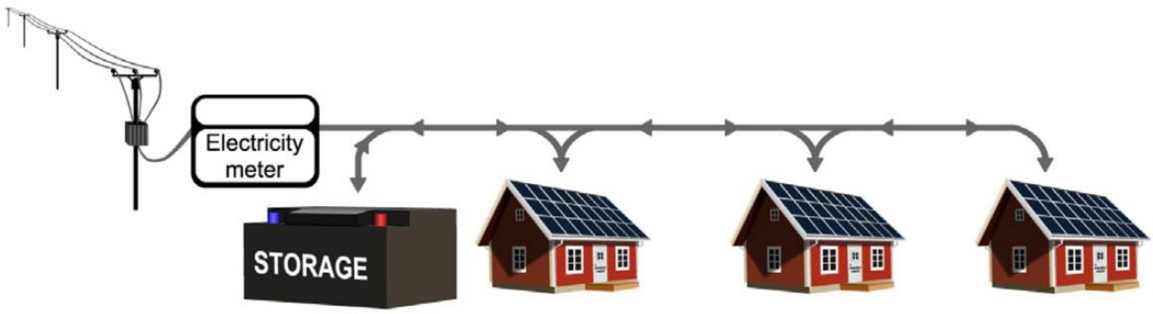


Figure 2.13 Schematic illustrating exchange of PV generated energy using the community grid and storage unit (Luthander et al., 2016).

Total energy consumption for heating and cooling costs can be reduced by 30% with the help of efficient landscaping design of green areas in urban environment. The local flora such as the date palm tree act as large canopies to provide shade to building roof, reduce cooling loads and increase human comfort. In the UAE, they are best planted on the east and south side of the buildings, which can stop 60% of the direct summer sun and allow the winter low angle to warm the building (McGee, 2013).

However, maintenance of these green areas can result in high consumption of water hence the incorporation of an efficient solar micro irrigation systems as demonstrated in Figure 2.14 for the urban landscape that use alternative sources of energy and water, towards its sustainability. This solar energy application has major components such as photovoltaics, battery, microprocessor and micro irrigation system (Kannan & Vakeesan, 2016).

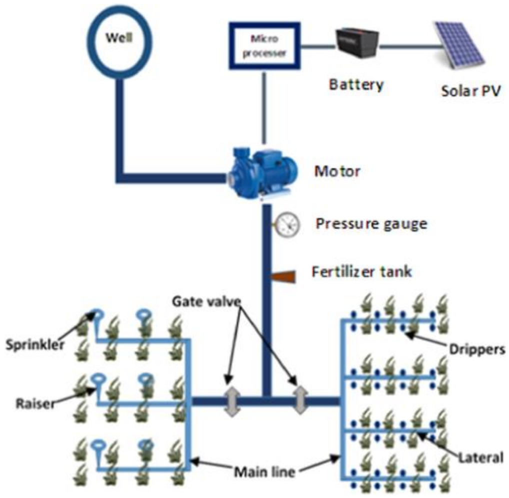


Figure 2.14 Solar micro irrigation system (Kannan & Vakeesan, 2016).

2.6.2 Renewable Energy Systems

The World Bank (2014), IEA (2014) and IRENA (2014) emphasized that the demand for electricity has exceeded beyond predicted expectation at a very fast rate and expected to rise even further. Implementing renewable energy systems can assist in this energy crisis by containing the electricity consumption to 40% by 2030 and increase 75% of its clean energy share by 2050 (IEA, 2012). Annually 40% of the total energy in the world is consumed by the built environment and reason for 50% of the carbon emissions generated from the use of fossil fuels. Studies has proved renewable energy (RE) sources as the most widely adopted efficient source of energy in buildings and received immense global and national attention due to its ability to overcome negative environmental impacts, depleting fossil fuels, energy security, generation of carbon free energy and high energy efficiency (IPCC, 2013).

Consequently, in 1997 to address and combat the issues of global warming and mitigate GHG emissions, the Kyoto Protocol was adopted and implemented in 2005 by the United Nation Framework Convention on Climate Change (UNFCC) to encourage governments to look towards renewable energy. The UAE, along with 187 states signed and ratified the protocol in Nov 2009. Further to this advancement, in 2015 the UAE pledged its support at the COP 21 and its ratification of the Paris Agreement in 2016.

In the Middle East, diversification of energy from fossil fuel into RE power generation systems accelerated in 2008-2009 to also mitigate the high per capita energy consumption footprint and GHG emissions. In 2013, the UAE advanced in the solar renewable energy sector with the first largest solar renewable energy utility scale project in the middle east, the 100MW Shams 1 CSP plant in Abu Dhabi. Additionally, the Mohammad Bin Rashid Solar Park with 1,000MW for 2020 and 5,000 MW by 2030, with total investment of AED 50 billion is the largest single site solar park implemented by the Dubai Electricity and Water Authority (DEWA).

Availability of high solar irradiation and decline in cost of PV panels make solar technology the most attractive renewable energy source and suitable of the local environment in the UAE. The remarkable leap in solar power capacity in the UAE based on IRENA as shown in Figure 2.15 stressing their role and ambition towards energy goals and targets set for 2020 and 2030. The distributed rooftop PV in the UAE aims to reach 500MW installed capacity in 20 years (Asif, 2016). Over the last decade, many studies as described below have been conducted on generating electricity from renewable solar sources and to achieve energy reduction.

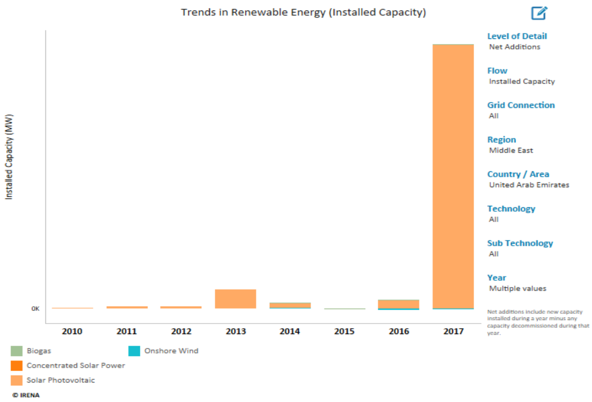


Figure 2.15 Annual solar power capacity trends in the UAE (IRENA, 2017).

Griffiths & Mills (2016) highlight the opportunity of rooftop distributed solar PV as a strategic energy option in UAEs growing local clean energy solar sectors. Policies that simulate rooftop solar in the UAE such as Feed-In-Tariffs (FiTs), rooftop tendering equipment subsidies or rebates, Net metering policies and other best practices are summarized in the paper. The financial attractiveness of rooftop PV installation depend on site characteristics, installation size and ease, capital cost, high quality panels and demand patterns of the deployment site.

Alnaser & Alnaser (2011) investigated many renewable energy projects in the Middle East which defined the cost of KWh from renewable sources from solar thermal, photovoltaics' and wind. The study highlighted the large solar power reserve of around 500-600 W/m² for each km² of land which is corresponding to 1.5 million barrels of crude oil. The study describes the growing environmental pressure on UAE from international authorities pushing it towards better and strong sustainable initiatives and green legislations.

Abdmouleh, Alammari & Gastli (2015) summarized in his studied the present state of renewable energy policies, regulations, codes and the need to develop more strategies to promote the renewable energy systems in the market in the GCC. It also described the difficulties of choosing RE sources as an alternative for fossil fuels for various stakeholders' developers, government, designers and common citizens. The study highlights a big gap between the construction industry and sustainable principles which requires more awareness.

Juaidi et al. (2016), Al Amir & Abu Hijleh (2013) and Jamil et al. (2016) investigated and researched on the various strategies, potentials and challenges of renewable energy systems in the UAE. Sgouridis et al. (2016) investigated on the remapping of renewable energy technologies in the UAE. Costs analysis studies between the projected demand and actual unsubsidized costs of fossil fuel were included. It was concluded that renewable energy systems will contribute to 10% of the total energy consumption by 2030. Laughten (2010) and Stapleton & Neil (2012) examined the different solar power technologies and their installations to convert electricity resulting to reduction in energy demand.

Solar power technology is abundant, free and relevant at many scales and can also provide off grid electrification. Globally, the PV technology and industry witnessed a growth of 16.8% per year in research, development and manufacturing resulting in a cumulative global solar PV installed capacity of 177GW, when in Europe alone PV technology growth reaches 33% per year. Fang & Li (2013) noted China has witnessed the highest production of PV cells ad solar water heaters; about 2/3 production of PV's of the world in 2011which is approximately 42% leading to 60% drop in PV prices. They conclude their studies proving the hybrid combination of Solar Domestic Hot Water with PV panels as the ideal solution to solving the energy crisis of the world.

The next section will explain the two types of solar energy systems such as solar domestic hot water (DWH) and photovoltaic systems (PV); specifically, on the photovoltaic systems due to its advantages, availability and economics supported by several previous papers that employ photovoltaics and their various strategies that approach net zero energy communities in the UAE.

a. Solar Domestic Hot Water (SDWH)

Solar Domestic Hot Water are efficient systems with solar panels that accumulate thermal energy from the sun to heat water for domestic use in homes, the hot water is stored in large hot water cylinders (Haillot et al., 2011). The system consists of thin metal flat plates painted in black to collect and maximize heat absorption. The sunlight strikes the panel which gets heated and this thermal energy is transferred through a network of copper heat transfer pipes filled with water the heat transfer fluid attached to the flat plate collector connected to the domestic water tank of the home as shown in Figure 2.16.

The system can be operated in any climate and categorized in two categories; passive (for hot and warm climates) and active (for moderate and cold climates). Sizing a SHWH involves evaluating the total flat plate collector area and the volume of hot water storage tank required to provide 100% residential hot water during the summer. By rule of thumb approximately 20 ft^2 of collector area for each two members of the family with an 80-gallon storage tank for 4 people.

An investigation on the production efficiency and type of SDHW used in UK was conducted by Boit et al. (2012). Results showed 18% of the total energy consumption in a home was from heaters with five different types used. Studies concluded the SDWH electric hybrid has the highest potential because of the reduced energy consumption and zero carbon emission properties. Review on the development of SDWH covering technological and economic aspects were evaluated by Chow et al. (2011) and Srinivas (2011). Chow et al (2011) further assessed the performance of two popular SDWH systems using experimental and numerical methods resulting in similar payback periods due to high primary cost. Lastly in 2011, Dubai Municipality mandated the installation of SDWH for all newly constructed villas in DM Circular number 183 issued in 06.12.2011 seen in Appendix 04.

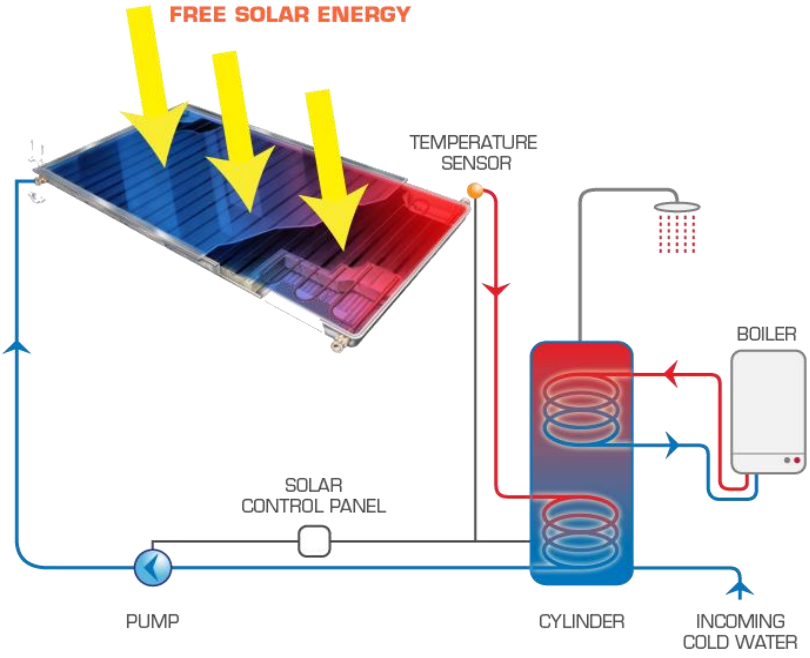


Figure 2.16 Solar Domestic Hot Water mechanism (NorthStar, 2017).

Biaous & Bernier (2008) investigated the total domestic hot water production with renewable solar energy sources in two locations (Montreal and Los Angeles) with different climatic zones. Results proved that SDWH presented the most significant solution with an electric backup connected to the utility grid or PV panels for net zero homes.

b. Solar Photovoltaic (PV) and its Types

Solar energy can be harnessed and converted in to electricity in two ways; using solar photovoltaic systems such as mono and poly crystalline silicon (c-Si and mc-Si), thin film technologies, organic PVs or by solar thermal systems such as concentrated solar power such as Linear Fresnel Reflector (LFR) which use mirrors or lens to reflect concentrate large area of sunlight onto PV panels allowing higher energy performance and efficiency. In this research, focus will be on grid connected photovoltaic panel systems as they can be easily integrated into the built environment in a community scale.

Monocrystalline cells (c-Si) are extracted from a single hexagonal shaped crystal of silicon. Their texture is thick, smooth, and have high energy and space efficiency but expensive to produce and high payback period. Polycrystalline cells (mc-Si) are extracted from several square shaped crystals of silicon in a block. Their texture is shiny, reflective, and has lesser energy efficiency when compared to monocrystalline but less expensive to produce as well. High performance crystalline modules are optimized for 1000 W/m² but the performance drops at low irradiance.

Thin film cells made of non-crystalline amorphous silicon (a-Si) such as copper indium gallium selenide (CIGS) and cadmium telluride (CdTe). They have flexible properties unlike the mono and polycrystalline panels, which makes them adapt on any surfaces, capable of generating energy in diffused, indirect and low light conditions and least expensive, but have low efficiency. They also perform well in high temperature, work in ambient reflected light and much resistant to module soiling. Standard Test Conditions (STC) is standardized measurements which determine the rated yield of each solar module output which the manufacturer is obliged to state. Generally, monocrystalline have 20% module efficiency value, polycrystalline have 12% - 17% module efficiency value and thin films range from 6% - 13% module efficiency value. The co-efficient of temperature / power (%/°C) for the thin-film a-Si equivalent is -0.1 - 0.2 while for c-Si crystalline modules it is -0.4 - 0.5 (Polysolar, 2015).

Components of a grid connected residential PV system primarily as revealed in Figure 2.17 comprises of a solar PV module or an array of multiple module (DC current), an Inverter (DC current is converted to AC current), an electrical panel, interface protection element and meter monitoring system DEWA Standards for DRRG (2015). The grid connected residential PV system does not require batteries or storage systems as the work in parallel with the electric utility grid and reduce transmission and distribution losses. A smart community micro grid with power storage system can provide effective optimization and efficiently manage the energy output from grid connected PV systems (Obi & Bass, 2016).

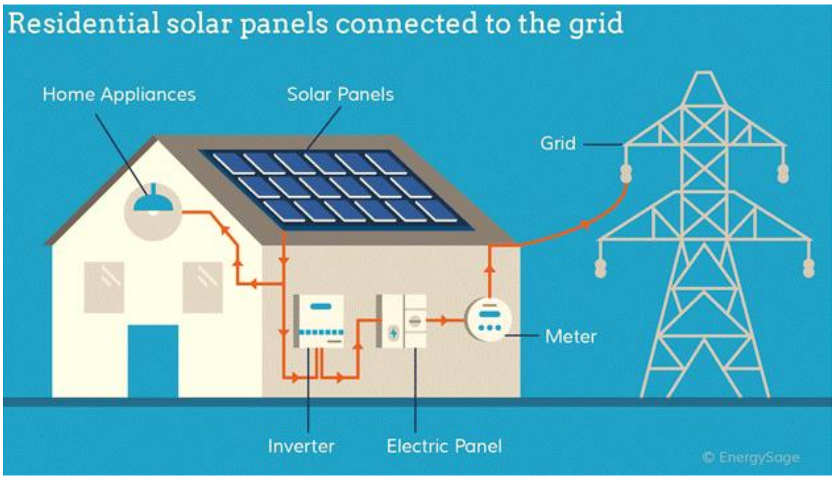


Figure 2.17 Grid connected residential solar PV system (Energysage, 2017).

Gaur and Tiwari (2015) states that there was 31% rise in the demand for PV modules in 2008 – 2009. The demand for monocrystalline cells was the highest at 46%, poly crystalline at 32% and thin film (CIGS) at 22%. Prayas (2012) highlights the estimation of European Photovoltaic Association which states that 40% energy demand of European Union will be generated through roof top PV system installation by 2020. Harvey (2010) demonstrates the various integration of PV modules to buildings such as facades, flat or inclined roof, on sunshades, on skylights in atria which provide electricity generation with roof surfaces as chosen area for installing PV elements due to their valuable irradiation.

Ortega-Bielsa & Martinez-Gracia (2011) investigated the energy efficiency of roof top PV installations and discovered their high-energy generation potential. It was also noted that the flexibility in adopting optimum location and angles to maximize the amount of thermal gain as a noteworthy advantages of roof top PV installations.

Studies investigated by Mirhashani et al (2015) and Cellura et al. (2012) recommended a method that enhance efficiency of PV energy and assists in disabling the challenges that link to the PV system installation in a dense urban setting. The cell efficiency of various solar photovoltaics types in the world is shown in Figure 2.18. However, in reality the cell efficiencies have significant variations over a year for given location as they are not exposed to constant test conditions.

Aman et al. (2015) & Tsoutsos et al. (2005) highlight the dependence of solar PV systems on the aesthetic context. Solar panels are more visually intrusive on historic and cultural buildings than on modern architecture. The author explores the reduction of cooling demand in high irradiance regions and increase of energy production with use of optimal tilt and azimuth angles.

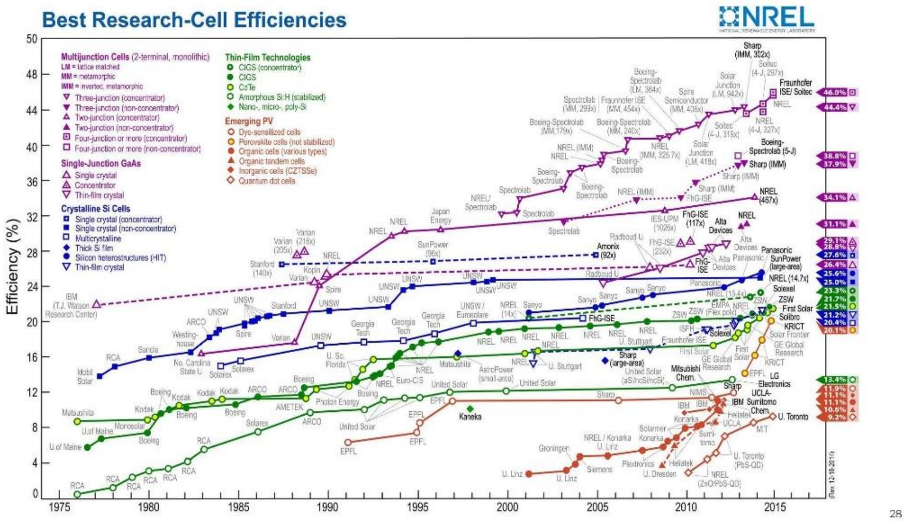


Figure 2.18: Cell efficiency of various solar photovoltaics types (NREL, 2017).

Tsalikis & Martinopoulos (2015) studied the solar photovoltaic and thermal potential in a standard residential home. They described the capabilities of photovoltaics to be able to supplement the annual electricity demand with less than 7 years' payback period. However, on using hybrid solar systems the payback period can be further reduced to around 5 to 6 years.

Eicker et al. (2015) explains the benefits of exporting surplus energy generated from PV systems to the utility grid. Residents of community utilizing PV's connected to the grid allow for production and use of their own solar generated electricity along with transfer of excess energy to the main utility grid. Grid connected PVs work in parallel with the utility grid hence require no storage systems, reduce transmission and distribution loses and offset GHG emissions by shifting power needed from the connected grid.

Darwish et al. (2015) explored in their research the influence of dust particles and humidity on solar panels on voltage, current, efficiency and power. Even though there is no effect of dust deposition in open circuit voltage of PV systems, there is impact on the short circuit which effect the system performance due to drop in the current and power output. To tackle effects of dust particles, Moki et al. (2013) studied methods such as wet cleaning and self-cleaning coating. Rahman et al. (2015) highlights the need for periodic cleaning of PV panels (once every 14 days) due to reduced performance from soiling. Regular monitoring of system performance will remedy to routine faults.

In the UAE, rooftop photovoltaics initiative kicked off in 2017 with around 4 MW connected in the beginning of the year which increased to 20 MWp by December 2017. While in 2018, it is predicted that the rooftop market in the UAE could reach 200 MW rooftop solar that is connected to the UAE grid. However, residential rooftop remains negligible as there is very slow volume uptake from individuals in the UAE.

Figure 2.19 Enerwhere, 311kWk solar PV plat at Elcome Headquarters DIP. (MESIA, 2018)

2.7 Case Studies

The global trend of NZEC that helps in the reduction of energy consumption in from utility grid and GHG emissions have been highlighted with the help of three comprehensive case studies reviewed below. The research will choose two case studies, one international and two regional. Based on the reports, conference papers and books accurate information on their background, strategies and renewable energy systems was investigated as much as possible.

2.7.1. The Beddington Zero Energy Development – UK

The BedZED project was built in 2002 and designed to be UKs largest sustainable community as seen in Figure 2.20 for people with high quality of life living with their earth resource share (Barry, 2012). The development consisted of 82 residential buildings with 271 habitable rooms and 2,500 m² commercial unit (office, retail and services). It was developed on an urban brownfield site in South London. The project was developed by Bioregional Development Group and designed by Arup, Bill Dunster Architects and Gardiner & Theobald.

The perception of BedZED project was to develop a Net Zero Energy Community in London which is free from carbon emission and fossil fuel consumption as seen in Figure 2.21 with a mission to be the first carbon neutral development in UK using only renewable energy for its operation.


Figure 2.20 The Beddington Zero Energy Development (Alamy, 2017).

a) Energy Efficient Strategies

- Orientation and Facades – All residential terraces are south facing which utilize suns natural light and heat based on passive solar principles. The glazing materials for these homes are triple glazed and super insulated which helps in minimizing HVAC cooling and heating loads (Lazarus, 2003). The selection of materials was influenced by thermal requirements of London which requires to minimize the cold climate and benefit from suns heat. High performance glazing facing the north and west were applied as the cold is most effective and opening filled by silicon sealants. External walls made of isolated brick walls with cavity construction and timber (local oak) stud weatherboardings which maintained the aesthetics of local architecture.

- Urban Structure and Integration of the Community – The BedZED community had most of the required facilities within the community such as organic food grown in community gardens, pedestrian walkways and cycle ways, bus and train stops in close range to residential buildings (Standley, 2009). The community is high density settlement containing residential, commercial and mixed use buildings. The project operator Bioregional assessed resident satisfaction which stated 84% had increased quality of life after they shifted into their homes.

- Thermal Insulation – In BedZED, the walls were insulated with rock wool, while expanded polystyrene was used to insulate the ground floor and extruded polystyrene was used for insulate the roofs which was effective in reducing the cooling and heating loads (Lazarus, 2003).

- Materials – The materials used for the construction of BedZED buildings are natural, recycled materials and sourced within a 35-mile radius of the site (Hodge & Haltrecht, 2009). Brick and blockwork are produced locally within 20miles radius. Internal wooden partitions and steel frames are reclaimed materials, Interior finishing materials have been avoided wherever possible.

UPVC was used in minimum for wirings, water pipes and cable sleeves. Nontoxic paints made from water, chalk, powdered marble and other natural material are used.

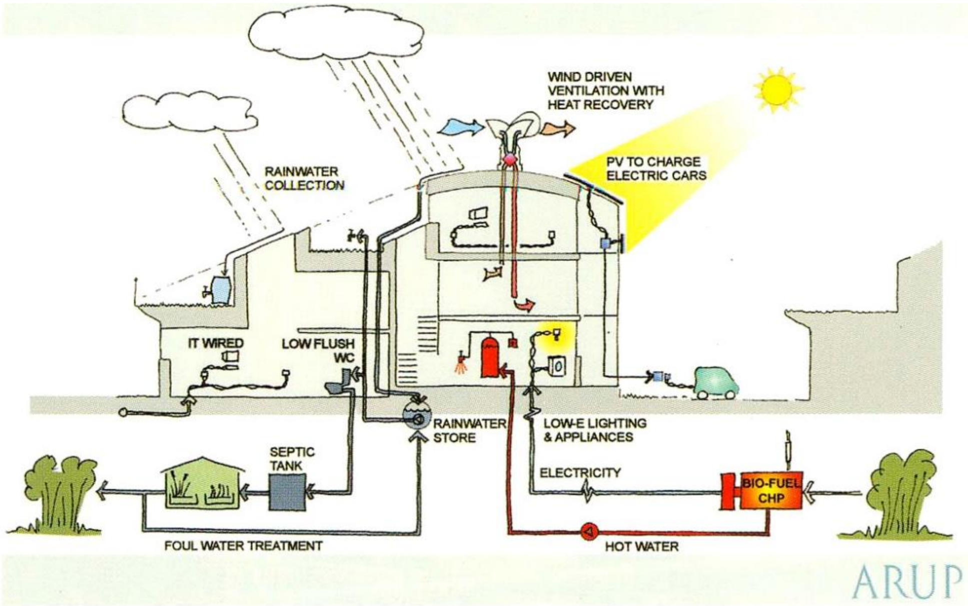


Figure 2.21 Renewable Energy System Concept of BedZED (Arup, 2017).

b) Renewable Energy Systems

- Wood fueled combined heat and power (CHP) – Combined heat and power generates heat and electricity at the same time with no carbon emissions. (Speirs et al., 2010). The primary source for the CHP is wood chips burned in waste heat consumed by the spark ignition engine for water and space heating. The engine is also connected to a generator for electricity production (Hodge & Haltrecht, 2009). In theory, this system was designed to provide for BedZEDs 80% of heat and energy requirements but failed due to many technical problems, durability of system parts and high operating costs replaced by gas boilers.

- Photovoltaics – BedZED has 777m² installed photovoltaic panels integrated on second floor windows and building rooftops which provide only 20% of required community electricity. It has enough power generated to operate 40 electrical cars. The energy efficient strategies and PV generated power was responsible in 56% reduction in carbon emissions when compared to a standard UK home. However, the generated electricity from PV's are used for other purposes in the community and no electrical power is exported to the national grid (Chance, 2009).

2.7.2. Masdar City, UAE

The first multifaceted multibillion dollar NZEC in the GCC powered by onsite and offsite renewable energy systems located in Abu Dhabi called Masdar City as shown in Figure 2.22. The city was implemented to combat climate change, GHG emissions, developing renewable energy and reducing energy demand (Btebbia & Beriatos, 2011). It was established in 2006, master plan was completed in 2013 and developed by the city owned Mubadala Development to set a model for sustainable and green living. The project is located 17 km southeast of Abu Dhabi city with 600-hectare area, 3.7 million GFA, 40,000 residents with 50,000 commuting daily. The masterplan is a high density mixed use urban community with residential housing, offices, retail, schools, masques and parks (Masdar, 2017).

The designers and planners of Masdar City reduced energy consumption by incorporating building energy efficacy guidelines, thermal insulation, LED lighting, low external glazing, passive solar design, high efficiency appliances, smart audit and meter systems as seen in Figure 2.23. The Masdar Energy Design Guidelines was developed for the purpose of an efficient city covering 100% energy consumption from renewable sources (Masdar, 2017).

Figure 2.22 Masdar City Birds eye view (constructionweekonline, 2017)

The goals of Masdar City are listed below:

- Total energy consumption of city to be generated from renewable energy.
- To achieve net zero waste through efficient waste management system.
- to mitigate carbon and GHG emissions.
- to achieve a fossil free zone.

a) Energy Efficient Strategies

- Orientation and Facades – The grid and buildings of the Masdar City was oriented perpendicular to suns track during the day. The orientation of buildings offer for shaded sikkas and corridor design which reduces the outdoor temperature and increases indoor comfort. The city orientation along with wind tower design cools hot winds through linear green parks which providing fresh streel ventilation, maximizing night breeze and reduce cooling loads. Red sand colored highly sealed and insulated facades with GRC screen designed to the traditional Mashrabiya provide, shade, privacy and allows for breeze to crawl into the balconies.

- Urban Structure and Integration of the Community - The Masdar city is an integrated closely networked city with vibrant urban realm; the residential, commercial, recreation areas are well connected to the transportation hub. Each street in the city is furnished with many services such as retail, food, health spas, organic supermarket and wind cooling towers which work as urban squares or landmarks. The squares offer enhanced public space for recreation and social interaction also car free corridors or sikkas (Masdar, 2017). The factors that characterize the urban fabric of the city as, high density, low rise buildings (not more than 5 storeys) which assists in developing roof tops PV installations.

- Materials – The Masdar City guidelines mandated local and regional resources to support the national economy, the sustainable mission and reduce material transportation impacts such as GHG emission. The facades developed are wrapped in 90% recycled aluminum. Lifecycle assessments were conducted for all materials incorporated in Masdar City (Masdar, 2017).

- Transportation – The Masdar City developed a unique transportation system called as Surface Transport Master Plan (STMP) which is an integrated system including the Metro and the Personal Rapid Transit (PRT) system connecting Abu Dhabi city center. The PRT network consists of cabin cars powered by electricity generated from renewable energy plants (Masdar, 2017).

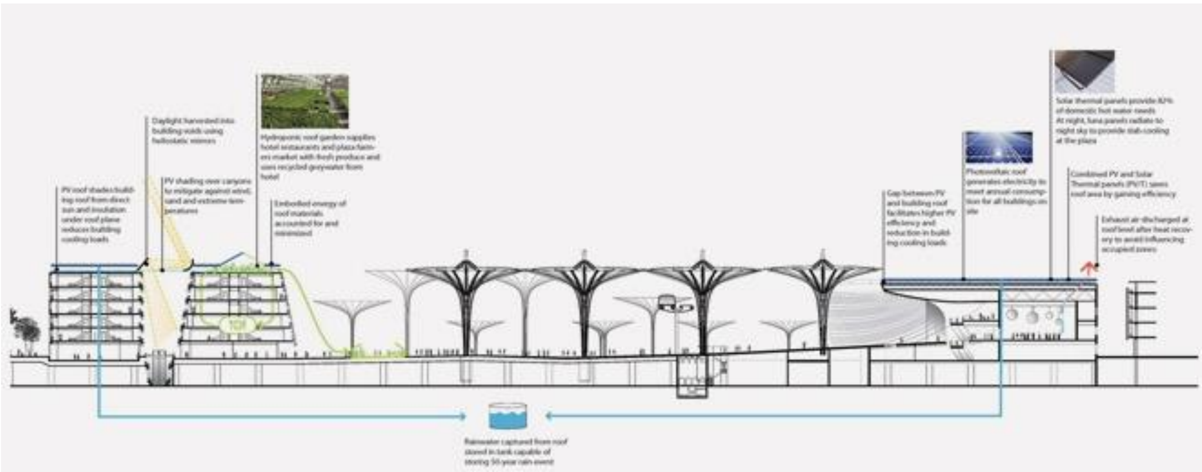


Figure 2.23 cross section view of Masdar City (Lava, 2017)

a) Renewable Energy Systems

- 10 MW Solar power plant – The adjacent lands of the Masdar City were designed to core most of the city's energy demand. 35% of the renewable energy resources installations is generated from the 10MW concentrated solar power systems occupied on 22 hectares of land. This system linked to the national grid in 2009.

- Rooftop Photovoltaics – All residential buildings and Masdar Institute's laboratories are installed with rooftop photovoltaics to generate clean energy and deliver additional shading to corridors and courtyards. They covered 75% of the energy demand in the city. These corridors are lit at night by self-recharging solar powered LED lights which require less maintenance.

2.7.3. Sustainable City, UAE

The Sustainable City is a net zero energy freehold development launched in 2013 with 46 hectares or 5 million ft² area located in Dubai housing over 160,000 people as shown in Figure 2.24. The TSC is developed by Diamond Developers who follow a sustainable development model combining social, economic and environmental goals aligning with the Paris agreement and sustainable targets of the UAE. TSC is built with the goal to reduce the per capita carbon footprint of its users by incorporating passive and active design methods that also surpass requirements by local building rating systems (Seenexus, 2017).

Figure 2.24 Master community of The Sustainable City (Seenexus, 2017).

TSC consists of 500 villas, a mixed-use center, and innovation center, an urban farm, equestrian center, mosques, educational and health care which successfully produce clean energy of around 200MW of electricty via 60,000 solar panels to operate the entire city. The analysis of energy consumption data in TSC produced energy use intensity values achieved 60 – 70% energy consumption reduction of around 85 – 110 kWh/m²/year, when the conventional home is 160 - 180 kWh/m²/year. TSC has achieved 100% water recycling and reuse, 100% waste diversion and clean mobility powered by solar energy. The challenges faced by the net zero energy development are design & PV integration into master plan, cleaning and operation, connectivity & power generation, distribution and optimization (Seenexus, 2017).

a) Energy Efficient Strategies

- Orientation and Facades- The villas and glazing’s in TSC are oriented northward with no openings on the south facing walls which avoid the harsh sun, maximize shading and reduce the cooling AC load.

- Thermal Insulation – In TSC, the walls, roof and windows have highly insulated U reflective properties. Comparison of achieved insulation values with local rating system have been listed in Table 2.1.

- Efficient Landscape – TSC is demarcated by a 30m wide significant buffer green belt zone. This ecological greenbelt helps in minimizing air and noise pollution. The green belt is organized in three layers; the first (outermost) act as barriers to noise and dust, the second layer offers shade for the cycle track, while the third layer with date palm trees is part of TSC’s productive landscape.

TSC has 11 biodome greenhouses with total capacity of over 3000m² area for urban farming.

Element	U-Values	Current Regulation	TSC
Roof	W/m2.K	0.30	0.20
Wall	W/m2.K	0.57	0.32
Window	W/m2.K	2.10	1.30

Table 2.1 Comparison of achieved insulation values with local rating system recommendations (Seenexus, 2017).

- Smart and Efficient Appliances – TSC has installed smart energy efficient air-conditioning systems (VRF), energy star rated kitchen appliances and LED lighting for all its residential buildings.
- Smart Water System – This system reduces water demand of buildings by 30%. Waste water recycling system and 20 organic farms are used to water plants across the city using gray and waste water of 40,000m3 (Asif, 2016).

b) Renewable Energy Systems

- Rooftop Photovoltaics and Solar Domestic Water Heaters

TSC has installed grid connected rooftop solar PV capacity of 6.4 MWp in Phase 1 equivalent to 10.2 million kWh/year on rooftops of villas and parking areas. 40,000 Trina Solar Duomax PEG5 modules are installed to produce around 24GWh per annum with CO² savings of 11,000 tons/year. The rooftop and parking PV installations are designed with tilt angle of 5° instead of the recommended 22° maintaining the building design and aesthetics but compromising performance. These durable high power yield frameless design PV panels are TrinaSolar made, with 60 and 72 cell multi crystalline module, 15.8% rated efficiency and 25-year warranty ensure no dust accumulation as shown in Figure 2.25. These PV systems align with the Executive Council Resolution No. 46/2014 (Seenexus, 2017).

Figure 2.25 Solar PVs installed in The Sustainable City (Seenexus, 2017).

2.8 Problem Statement
In the UAE, electricity demand has risen drastically in the past 10 years with 5.4 TWh increase each year which is more than 13.3% annually. This is due to the countries sharp rise in economic expansion with the population growth recorded at 6 and 11% annually. Electricity production from conventional fossil fuels such as oil and natural gas increased from 39.9 TWh in 2000 to 110 TWh in 2013 placing UAE in the 9^{th} highest electricity consumption country per capita in the world. The UAE ranks 25^{th} worldwide for CO^2 emissions with 27.14 metric tons CO^2 emissions per capita. It has the 2^{nd} position as the most pollutant countries in 2013, hence a high ecological and carbon footprint. UAE is one of the hottest and most humid cities in the world. Thus, 75% of electricity in the UAE is consumed by the built environment among which 40% is consumed for cooling and air-conditioning needs. Considering the rapid increase in energy consumption, the country's oil reserve is expected to be completely consumed in the next 80 years (Mokri, Aal & Emziane, 2013). Hence, making the energy sector in the UAE as the main source of CO^2 emission from major fossil fuel extraction and its combustions that satisfy the countries high energy demand threatening global warming and climate change.

Global and regional Interventions are urgently required for the mitigation of environmental threats and encourage clean energy generation which include new renewable energy concepts, advanced technological systems, dynamic passive and active strategies, energy generation goals targets, energy conservation strategies, investment incentives (feed in tariffs), green certificates, tax exemptions and subsidies. The main drivers to the recent focus on renewable energy resources are climate change and depleting fossil fuels which motivate the leader ship of UAE to promote energy diversification and alternative energy sources. Growing energy consumption and GHG emissions from the existing and upcoming urban dense communities and mixed use developments poses a practical challenge for the UAE. Currently, most executed measures are limited to emphasis on accomplishing net zero energy on individual building scale which may not be feasible and realistic when compared at the community scale that looks beyond the building skin and individual footprint.

The paper highlights the lack and knowledge gap for a holistic and integrated concepts, studies and reports dealing with net zero energy at community level. There is less attention to energy management at the community scale with a futuristic view on multi carrier smart micro energy grids and positive communities. Communities offer better opportunities for improved energy efficiency and cost effective onsite renewable energy generation over buildings. It then priorities innovation, development of clean net zero energy sustainable community projects and establish a strong renewable energy industry which can combat future challenges, enhance energy security and cut off CO^2 emissions. Most large scale centralized community infrastructure and integration of renewable energy sources is immature, less efficient and under developed with high initial project costs affecting its economic feasibility. Hence there is a need for an approach to net zero energy by addressing a cost-effective community energy generation system on a long-term process with continuous improvement for both new and existing communities.

Moreover, there is huge amount of untapped naturally available solar resource in the UAE which can be harnessed to eliminate the fast depleting fossil fuel consumption and greenhouse gas emissions, but the market implementation is limited due to low grid generated energy costs, lack of provisions of feed in power back in the utility grid, no tax exemptions, lack of regulations.

There is big opportunity for research in the field of net zero energy communities that pursue technical and economic development in the use of onsite renewable solar energy that can achieve an environmentally sustainable developed UAE. The base case study chosen is an ongoing emerging community in Dubai on which different scenarios will be proposed and simulated to optimize and reduce the energy demand of the community with the help of energy efficient onsite renewable energy strategies. The results of this research will support and foster further development in the UAE's vision towards sustainable communities will be delivered across the country and the world.

CHAPTER 03
METHODOLOGY

3.1 Overview

This chapter demonstrates the comprehensive studies on the various methodologies used in the field of net zero energy communities and integration photovoltaics in an urban mixed use community. The integration of photovoltaic to the built environment requires an elaborate investigation on the different research parameters such as studies on commercially available PV technology, optimum inclination angle and orientation of PV. The findings extracted from these investigations will be used as verification and validation tools to measure the accuracy and justify the results. The study will be concerned mainly on increasing the output of renewable energy generation of various PV installed in the community level. The evaluation of energy consumption, PV generation and cost savings will be explored through different configurations, system technologies and innovative solutions highlighted in the research papers.

3.2 Types of Methodology

The various methodologies with reference to the research topic and selected base case study include experimental/field studies, literature review studies, numerical studies, software simulation studies. Pros and cons of all the methodologies reviewed will assist in justifying the selection of appropriate methodology and research tools applicable to achieve the objectives of this research.

3.3 Modelling and Simulation Studies

Vermettea, Cubib & Bergersonc (2016) explored a mixed use solar community in Calgary, Canada considering the cold climate context by means of the energy generated from BIPVs installed on building envelope and reduction in buildings energy consumption. EnergyPlus simulation software is utilized to simulate the total energy consumption of the community. The overall primary energy demand and the greenhouse gas emissions are analyzed. TRNSYS simulation is carried out to investigate the various mechanical system options. The paper concluded the opportunities in the sharing and management of energy resources that assist in the higher energy performance of a mixed-use community while connected to the utility grid.

Synnefa et al. (2017) investigates the adancement and execution of a comprehensive cost effective modular system and methodology for a Net Zero Energy settlement using advanced thermal simulation techniques such as IES- VE, Energy Plus, MATlab and ENVI-met. The system developed comprises of innovative solutions for building envelope, building energy generation and for energy management at the neighborhood level. The solutions are tested in terms of energy, environment and cost performance for 4 different projects in the Europe (Cyprus, France, Italy and UK) with various building type and climate. The ZERO PLUS system constitutes several advanced state of art energy technologies such as new generation extruded polystyrene (XPS) envelope components, new solar Desiccant Evaporative Cooling HVAC concept, compact Linear Fresnel Reflector, precast BIPV glass components, thermal storage with solar collector tracking system and Integrated energy resource management. Microclimate models were simulated on ENVI-met to take advantage of passive cooling strategies along with simulation on Matlab to optimize the position of solar and wind renewable energy availability. The system was successful in achieving net zero status for the selected case studies by reducing operational energy usage by 20KWh/m² per year and generate renewable power production by 50kWh/m² per year. Hachem (2016) analyses the impact of selected design and environmental parameters of a hypothetical solar community in Alberta, Canada in terms of energy efficiency and GHG footprint using EnergyPlus and Openstudio simulation software's. The building energy performance, density, neighborhood typology, commercial sector location, street designs are the various design parameters. The balance between the overall energy consumption and rooftop PV generated power are measured to evaluate the community energy performance. Transportation and density parameters have high effect on the overall energy consumption. Results of simulation showed 75% reduction in electricity consumption and GHG emissions. This paper relates to specific location and range of design assumptions. The methodology used can serve as an efficient standard template for new sustainable communities

Hammad and Abu-Hijleh (2010) explored the influence of dynamic external louvers coupled with smart systems to achieve ideal energy savings for an office building in Abu Dhabi using IES-VE computer simulation software. For the simulation, a simple three-dimensional representative model of the building with the louvers in design phase was formed. Boundary settings such as inner walls and partitions were measured adiabatic. The analysis of the total energy performance of the exterior louvers active on the east, west and south façade were performed on four predefined dates for the four seasons in the UAE. The façade orientation, light dimming sensor position, glass shading coefficient, and slat angle of louvers were the main variables considered. Guidelines from the Lawrence Berkeley National Laboratory were followed for the louver arrangements. An energy savings result of 34.02%, 28.57% and 30.31% for the south, east and west facades, respectively was achieved by adding external louvers at different angles. The results also confirmed that major reduction in energy consumption is achieved using static louvered façade on the south side with light diming sensor associated to that of the dynamic louvers.

3.3.1 Pros and Cons of Modelling and Simulation Studies

3D modeling and simulation studies have many advantages with much advancement in recent years because of its low-cost and highly accurate results in real time scenarios. They have the flexibility to provide simulations in a controlled environment where all parameters can be individually tested, manipulated and enhanced in a limited time. Simulations can be developed and repeated several times to predict the optimum results with minimal errors by linking occupancy profiles and various weather and location data files. Flexibility in terms of scale, orientation, visual properties and building specifications are possible at all stages of simulations. Ability and knowledge of the designer using the software and requirement for an advanced dynamic software are some of its disadvantages. There are few parameters in some investigations which cannot be controlled by the software. The inherent uncertainty of the software can affect the outcome of the research (Zhai et al., 2011).

3.4 Physical Experimental/Field Studies

Sadineni, Atallah & Boehm (2012) studied the impact of the orientation roof top PV on residential electricity peak demand through field monitoring and validated by simulations. Temperature and power measurement sensors were connected to 220 case study homes to determine the energy performance for the installed PV and building orientation. The research concluded with a 38% reduction in the total annual energy consumption when compared to standard home while there was 62% reduction during peak energy demand in the 220 PV oriented homes when compared to a standard home.

Cabeza et al. (2010) and Al Homoud, Abdou & Budaiwi (2009) investigated the potential energy performance and energy savings using an experimental methodology. Cabeza et al. (2010) conducted field experiments by constructing many cubicles instrumented to assess the actual heat transmittance for the existing wall for two different climatic conditions. After deriving the final monthly energy consumptions, the results provide a comparison between various wall insulating materials per thickness, density, thermal diffusivity and conductivity. Al-Homoud et al. (2009) evaluated the annual energy consumption and thermal comfort quality for three mosques during their peak occupation period. The paper assessed the suitable thermal comfort level, energy efficiency, energy consumption for the operated HVAC system in a hot humid climate. Fifteen temperature and humidity data loggers were used for testing and recorded every five minutes.

Cuce & Riffat (2016) illustrated the thermal, lighting and optical related performance parameters for the Heat insulation solar glass (HISG) through and experimental methodology. The method used a reliable realistic retrofit application with the help of commercial PV analyser conducted via in situ and extensive laboratory tests in real time scenarios in two separate glass houses. The tools used to measure the thermal, UV and IR absorption included the standard heat flux sensors, calibrated UV meters and thermocouples. The results highlighted the better optical thermal comfort, and lighting related performance of HISG which can be integrated on the building envelope for existing and new building design and construction.

3.4.1 Pros and Cons Physical Experimental/Field Studies

The experimental methodology clearly highlights the need for testing real life mock-ups of the model under real conditions for validation purpose that needs to be performed and controlled in a laboratory or a field experiment. The equipment's used in these studies include sensors; data logging systems and thermocouples are under the direct control of the researcher which is an advantage. The advantages of progressing with an experimental/field study are the results arrived from the actual weather conditions.

The methodology requires real samples and existing buildings for its investigation, hence they need to be constructed, installed and monitored within a given time which requires permits and approvals. Moreover, considering the monitoring time frame, climate dependency, human resources requirements and high cost occurred are a limitation thus inapplicable for this study due to its complex scale. Consequently, the tools and systems required for the experimental methodology can have some errors, which affect the result accuracy. Many cases of experimental studies have been combined with other methodologies for achieving more accurate results.

3.5 Literature Review Studies

Hasan & Sumathy (2010) reviewed the performance enhancement of building integrated photovoltaic using literature review. It was discovered that an optimal design of PV/T system installation can provide 100% renewable energy and heat to the building. The study evaluates the advancement, performance, theories of various PV such as the liquid PV/T collector, air PV/T collector, ventilated PV with heat recovery, PV/concentrator. Moreover, it points to the need for more research to be undertaken to improve PV system design before implementation at design phase.

Norton et al. (2011) examined the various efficiency and economic factors of BIPV. Focus of the paper was mainly on the series of improvements on PV system components such as inverters, concentrators, thermal management systems, batteries. The paper concluded stating the charge of the BIPV system installation can be reduced by the installation of a reliable PV modules and elements which will minimize installation, operation and maintenance cost.

Taleb & Pitts (2009) examined the potential of integration and use of photovoltaics in the GCC using literature review. The paper reviews the current conditions of BIPV market, challenges from fossil fuel generated power and the possible technological developments in the future. The data used for analysis and discussion were further validated through interviews and questionnaire conducted for various construction stakeholders. The study concluded that government encouragement and support was required for a better future and achievement of set sustainable objectives and targets.

3.5.1 Pros and Cons of literature Review Studies

The literature review methodology provides a wide range of previously conducted studies, information data, parameters and range tested results that can be used for validation, comparison and justification. However, the results obtained in this method do not have a practical accurate approach especially for this topic of research; additionally, it needs to combine with other methods for better accuracy and credibility.

3.6 Numerical Method

Chen, Shen & Altermatt (2014) analysed the thermal characteristics of flat and transpired black aluminium solar facades to demonstrate the feasibility of building integrated solar technologies and its ease of application. The authors used numerical methodology with mathematical models and validated it further with the help of a physical experiment. The assessment of thermal performances under comparable operational conditions (ambient air temperature, solar radiation intensity, plate area, plenum depth, airflow rate) with respect to heat gain and losses were carried out. The flat plat produces low output air temperature and high surface temperature. The energy efficiency of the current transpired model resulted in the maximum system efficiency, system simplicity and low cost for moderate climates.

Liu, Wittchen & Heiselberg (2015) explored optimum comfort performance developed for an intelligent glazing façade using a simplified numerical model with the assistance of an experimental method. Consistent energy saving calculation and optimum comfort performance for many control strategies were developed. The numerical method developed for the intelligent glazing façade achieves reliable energy saving calculation and optimum comfort performance for various control strategies such as double glazing unit, night shutter, venetian blind using algorithms EN410, EN673, EN13363 respectively for calculating solar and thermal properties. The paper concluded with the use of intelligent building façade exhibiting 60% energy savings for Danish climate and qualifies for energy requirements building class 2020.

Elarga, Zarrella & De Carli (2016) developed a simplified mathematical model for accessing the thermal and energy performance of semitransparent PV cells fixed to an office building façade namely DIGITHON based on test reference year (TRY) and simulation by TRNSYS16.1. Parameter are associated in detail for the study i.e. façade inner layer composition, façade cavity ventilation for three cities (Venice, Abu Dhabi and Wurzburg). Increase in conversion efficiency of PV modules was achieved by cooling the cavity with the assistance of indoor temperature. The study concludes by highlighting the positive effects in the reduction of cooling loads and peak power by the integration of PV on the building which reduces the operational cost for HVAC systems. This authenticates the application façade integrated PV module in European climates and for hot arid climates with few precautions.

3.6.1 Pros and Cons of Numerical Method

The numerical method tests the relationship between multiple energy parameters using dynamic mathematical equations. They are based on many assumptions and approximations involved which raises the complexity level and impacts the accuracy of the results. Hence this method needs to be used in conjunction with other methodologies. Moreover, it is widely used for finance related and feasibility analysis studies making it inapplicable for this research.

3.7 Preferred Research Methodology

Research for the energy performance and cost savings from photovoltaic's integrated in the community level along with incorporation of passive strategies on building envelope have been best and widely performed through 3D modelling and simulation studies. Simulation software's have the advanced dynamic and flexible capabilities to manipulate, improvise and optimize parameters complexity and scale of project. Versatility, accuracy and user adaptability are other advantages. These advantages make computer simulation methodology far more higher when compared to other methods with various shortcomings. Simulation methods are best applied at early design phase and further supported by literature review, case studies and field experiments.

This study aims to quantify and bridge the energy gap of an urban mixed use residential community for achieving Net Zero Energy status by complementing the total energy consumed with renewable energy produced by the solar PVs integrated in the selected community based on UAE climate data and its building design guidelines within an efficient external controlled simulation environment. The main variables in the simulation software that affect community energy consumption are the range of occupancy pattern profiles associated to various building function, lighting system profile, electronic equipment's load profile. This study also aims to investigate the proposed integration of photovoltaics' considering the visual impact on the buildings in the community. Various add-on plugins can be configured into these simulations software's for better data output. Several simulation software's are available in the market for this purpose mentioned in the previous sections are listed and summarized below which prove computer simulations methodology are most appropriate to support the research objectives and targets.

Papers related to community, neighbourhood and urban level energy performance studies that have used advanced computer simulation software for example such as Energy Plus software that explored the energy production potential from BIPV installed in the buildings and urban level landscape are illustrated in Vermettea, Cubib & Bergersonc (2016) and Hachem (2016). Synnefa et al. (2017) optimized and combined selected innovative technologies to optimize the energy, financial and environmental performance for four case studies using IES-VE, Energy Plus, Matlab and ENVI-met simulation software's.

Other research studies focusing and describing on building envelope, PV technologies and building energy optimization using various computer simulation software's are mentioned henceforth. Hammad and Abu-Hijleh (2010) explored the energy savings potential of using dynamic external louvers in an office building in the UAE using IES-VE simulation software. Katanbafnasab and Abu-Hijleh (2013) assessed the energy impact and performance of building integrated photovoltaics and electrochromic glazing for an office building in the UAE. Elarga, Zarrella and De Carli (2016) explored the building energy dynamics and façade glazing optimization integrated with advanced PV modules using computer simulation software TRNflow. Sheikh and Gerber (2011) proved integration of a parametric design for improvement of the daylight automation and energy efficiency of the building façade using software's Rhino, Grasshopper, Galapagos and DIVA. Yasar & Kalfa (2012) conducted simulation on DesignBuilder software to investigate the impact of glazing on energy efficiency on the cooling and heating load of HVAC. Kima et al. (2011) illustrated the most cost effective sustainable active and passive strategies assisting in 30% energy reduction along with LEED and BREEAM sustainability assessment tools using IES-VE.

Moreover, Attia et al. (2009) compared and ranked ten different building performance simulation software tools used by 249 stakeholders such as engineers, architects, academia and students. Simulations were carried out on an existing building with annual electrical consumption data using current building design specification and construction guidelines for validation purpose. These comparisons were performed in three stages; firstly, Usability and Information Management (UTM), secondly Integration of Intelligent Knowledge Base (IIKB) and finally Graphical User Interface (GUI). The results highlighted IES-VE software ranking as the most sophisticated software in the market as seen in Figure 3.1 with 85% more efficient than the other software's due to its user-friendly GUI and template driven approach.

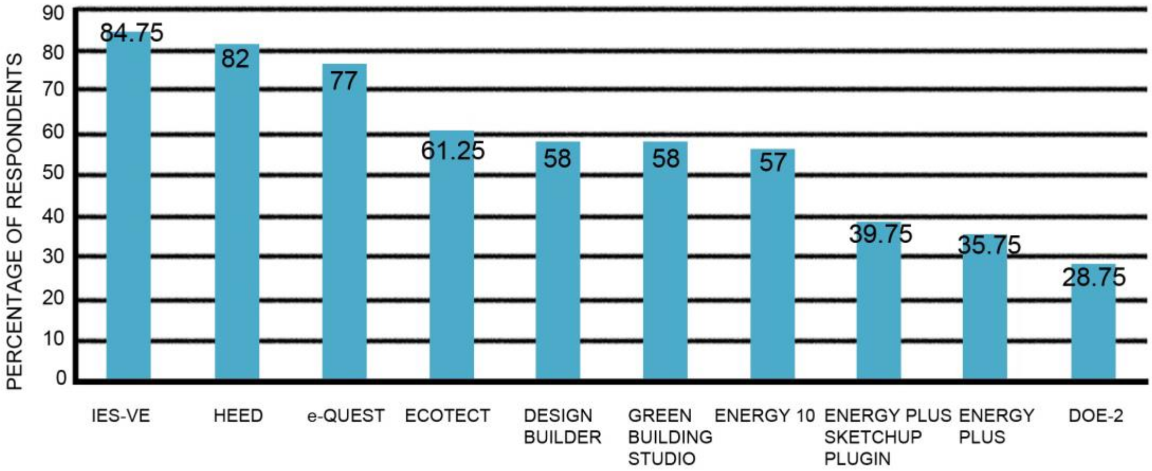


Figure 3.1 Ten simulation tools and their respective ranks (Attia et al., 2009).

3.8 Integrated Environmental Solutions – Virtual Environment (IES-VE)

IES-VE is advanced dynamic performance analytic and quantitative software used in the building construction industry which allows architects and engineers to simulate analysis, optimize energy consumption, enhance renewable energy generation and offer qualitative and quantitative accurate feedback for the built environment. The software suite is integrated with various modules for its various building energy performance analysis and investigations. It is an essential tool used in the design process which access various complex building envelope parameters and solar generation systems towards energy saving and zero carbon.

The foremost phase of the IES simulation is the ModelIT module which assists in the creation, modification and control of the building model geometry in real time. This template establishes a collaborative workflow by linking the the model details, construction details and building specifications of the building simulation model. The SunCast module allows for shading and visualization analysis using Apache thermal analysis. The results give complete calculations and graphs about its sunpath and shading impacts for any required specific day and time to access the most suitable efficient shading device system. The ApacheCalc, ApacheSim and MacroFlo calculates energy load and thermal analysis based on real weather data which help in improving energy performance of the building aspects such as solar shading, HVAC systems and natural ventilation. The FlucsPro/Radiance and Apache HVAL offer analysis lighting design and HVAC based components.

The software is relatively costly but the software provider endorses student version for reasonable costs hence in addition to all before mentioned advanced dynamic features this simulation software will be implemented for this study. Based on the current base case study, IES-VE simulation software will be utilized to analyse each parameter that impact the energy consumption and generation in a community such as:

- Community energy consumption is the total consumed electricity from the grid for space cooling, artificial lighting, equipment power and miscellaneous depending on the occupancy and building profiles of the residential villas, townhouses, schools, hospitals, mosque, clubhouse, streetlighting, infrastructure and landscape etc. Thus, It is vital to analyse and model the buildings occupancy pattern and building design specification to predict the electricity demand that needs to compensated by energy generated from PV technologies.

- Community renewable energy generation from the integration of solar photovoltaics technologies depend on various parameters such as its location, size, orientation, inclination, module technology, module efficiency, transformer, inverter efficiency and solar community street lighting. The study will examine these factors that impact PV energy generation to find the most suitable configurations.

- Increasing PV energy production by maximizing the total installed panel area in the base case community by integrating PV on building carparks, covered pathways, greenhouse PV farms, water bodies, kiosks, bus shelters, play areas. The result of this analysis will determine which are the most optimum area and location for energy generation within the community.

3.9 Validation Case

It is essential to validate the values predicted in the selected simulation software in regards to the context of the chosen community in this dissertation which is still under construction. The validation can ensure accurate building energy consumption and PV energy generation results. Since the selected building prototypes in the chosen community case study are still under construction, the author will perform simulation on a townhouse with completed construction and occupancy from another community in Dubai and compare the results for validation.

For this purpose, the available data of electrical consumption bills generated by DEWA that account for space cooling, water heating, lighting (indoor/outdoor) and electrical appliances for 12 months from the month Nov ‘16 to Oct ‘17 were collected from the house owner along with the actual building site location, layout (geometry and orientation), construction design specifications, weather conditions and occupancy schedule patterns to be utilized in the software for advanced simulation. The villa constructed conforms to the minimum energy requirements as set by the local building regulations.

The building selected for validation purpose located in Al Furjan residential development adjacent to the Discovery Garden community in Dubai, UAE. It is a 2-storey, three-bedroom townhouse with a total built-up area of 2,683 ft^2 as seen in Figure 3.1. The author performed the building simulation based on the data input parameter such as cooling loads, electrical appliances loads, lighting loads and occupancy profiles for the summer, autumn and winter seasons presented and discussed in detail in the next chapter. The cooling set point temperature is set at 24 degree Celsius as recommended by DEWA’s 24 degrees’ sustainability campaign (DEWA, 2017).

The actual electricity bills are presented in Appendix 01 were compared and verified with results from the software simulation as presented in Table 3.1. However, he results show there is a slight deviation value of 4% average annual electrical consumption. The monthly energy variation in the month of April can be justified as the family was on holiday, while the justification for the variation in the month of Nov is because of the onset of winter where people tend to switch of the HVACs and open the windows to allow for fresh cool breeze.

Figure 3.1 Base case floor plan layout and site photos (Author, 2017).

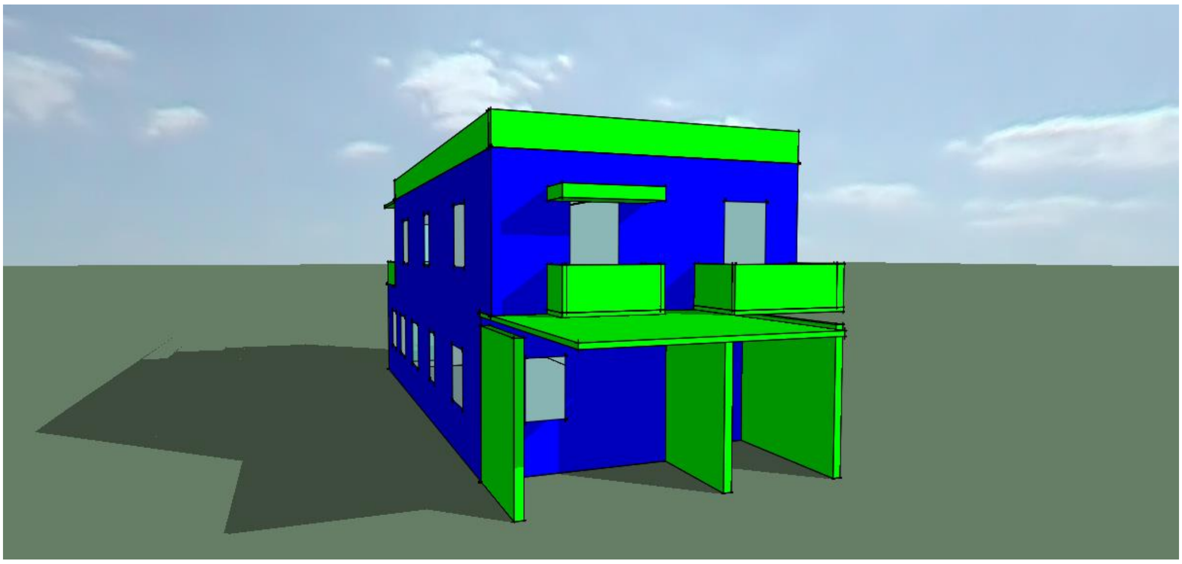


Figure 3.2 Base case 3D model created in IES-VE (by the author).

The results from the base case simulation when compared to the actual electricity bills as seen in Table 3.1 prove that the occupancy pattern and energy load profiles match hence the predictions are favorable, accurate and the selected simulation software IES-VE is validated. Lastly, since the research simulations are based on building prototypes within the mixed-use urban residential community which are under construction, the author is confident that they can be simulated over a year based on the collected energy and building data input in the validation case study which has already been built, occupied and verified above. Also, a simple economic analysis will be done which is going to rely by estimating initial cost, calculating annual savings of the electricity and using simple payback analysis.

Table 3.1: Simulated IES-VE energy results vs annual DEWA energy consumption bills (by the author)

Month	Elec Bills (MWh)	IES Model (MWh)	Variation
Jan '17	0.736	0.7402	1%
Feb '17	0.599	0.607	1%
Mar '17	0.861	0.9028	5%
Apr '17	1.521	2.0216	33%
May '17	2.511	2.5425	1%
Jun '17	2.951	3.0179	2%
Jul '17	3.891	3.9449	1%
Aug '17	4.057	3.9933	-2%
Sep '17	3.529	3.5701	1%
Oct '17	2.183	2.155	-1%
Nov '16	1.399	1.5832	13%
Dec '16	0.595	0.634	6%
TOTAL	**24.833**	**25.7077**	**4%**

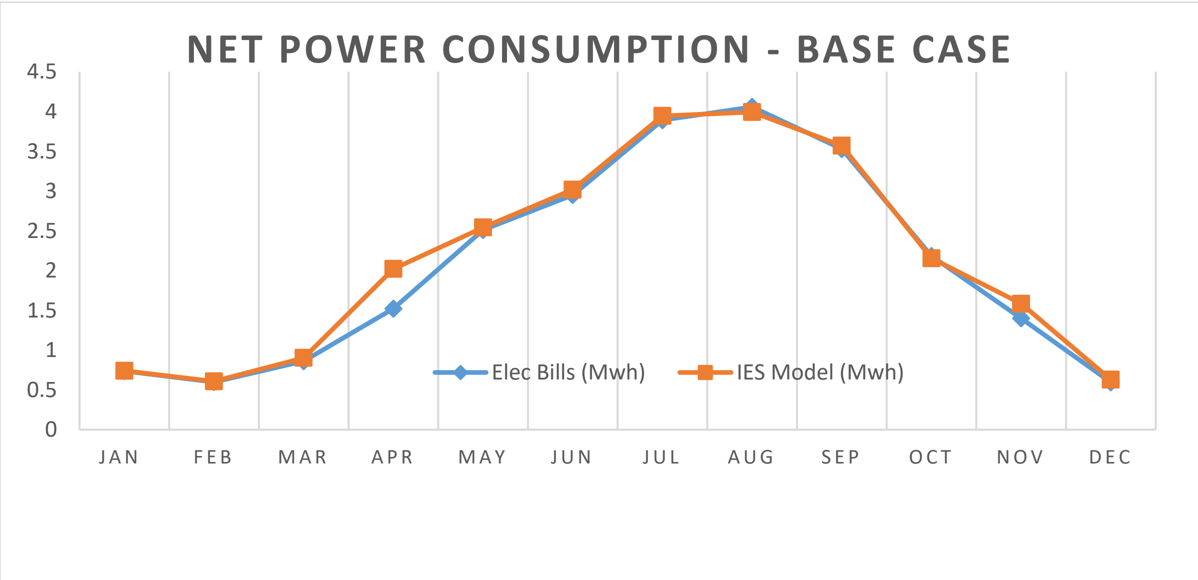


Figure 3.3: Graph presenting the IES-VE simulated energy results vs actual electricity bills (by the author).

CHAPTER 04
BASE CASE COMMUNITY & ITS ENERGY REQUIREMENTS

4.1 Overview

The chapter describes the selected base case study located in Dubai to be transformed into net zero energy community status by integrating photovoltaic technology on various built and the urban landscape elements. It explains the simulation procedure and identifies the various energy consuming components within the master community. Moreover, the total energy consumption and the optimum roof top area available for PV productivity of the community is estimated. Simulations within various scenarios based on the various parameters identified such as PV panel efficiency, inclination tilt angle, orientation, surface area and its range of technologies highlighted in the test matrix in this chapter are performed. This approach ensures a more targeted approach to achieve a high level of energy performance and efficiency for PV integrated in the community.

The chapter includes the modelling description and simulation process of the three prototype villas, their building design specification, occupancy profiles and simulation parameters that impact its energy demand. Since these buildings are currently under construction, the author will base the predicted energy consumption of base case study on the validation performed on another built villa from a different community simulated in the previous chapter using IES-VE software. Lastly, the total annual energy consumption data estimated for the remaining amenities and facilities in the selected case study community will be based on predicting of the building energy use intensity (EUI) obtained from other similar type of existing buildings in Dubai.

4.2 Case Study Description

Spanning 42 million square feet, the masterplan selected as case study located in Dubai is home to 3248 townhouses, villas and deluxe villas, public realm, and community facilities with access to over fifteen million square feet of lush greenery as seen in Figure 4.1. The strong creation of community, sense of place and richly themed landscape is well connected to the city’s major road networks. The community features a spectacularly landscaped 18 hole, par 71 championship golf course of 11 million square feet and park with skate, fitness, pond parks, sport facilities such as football, tennis, basketball, volleyball courts of 4 million square feet. Table 4.1 presents the breakup of all the buildings, community amenities and facilities provided in the masterplan such as mosques, nursery, schools, hospital, community centre, clubhouse and infrastructure such as street, golf and park lighting, STP, pumping stations, comfort stations, GSM towers and substations.

The master development located in Hebiah 3rd Dubailand consists of multiple communities referred to as clusters containing three villa prototypes categorized into townhouses, villas and deluxe villas along with neighbourhood parks and other infrastructure related utilities. The villa prototypes are designed to give the resident owners unobstructed golf and park views, shading as per the local weather context, interlacing and sustainability. The design specifications for the construction of these villas are as per the developer specification made in accordance to the Dubai Municipality guidelines. Occupancy profiles and electrical equipment loads are as per the ASHRAE standards adopted in the validated base case. The prototype dimensions and design specifications are as per the as-built and shop drawings.

Figure 4.1 Masterplan of the mixed use residential community (by the author).

Table 4.1 Energy consuming element mix of the selected master community (by the author).

S.No	Landuse	No. of Units	per Built Up Area (m²)	per Plot Area (m²)
	Residences			
1	Townhouse	1928	284.00	330.00
2	Villa	982	260.22	450
3	Deluxe Villa	538	400.73	1000
	Community Facilities			
4	Hospital	1	9016	4198.45
5	School	1	24955	36299.34
6	Community Center	1	18585	11786
7	Clubhouse	1	9277	8179.63
8	Mosque	7	1500	3834.27
	Open Spaces			

9	Golf Course			1031683.87
	Comfort Station	3		250
	Driving Range Studio	1		200
	Viewing Tower	1		20
10	Attraction Park			366775.94
	Children’s Play Area	1,15		2000, 350
	Juice Bar / Kiosks	4		20
	Beach Park Building	1		245.5
	Multipurpose Events Park	1		4750
	Lagoon Beach Pool			2500
	Skate Park			2972
	Gym + Fitness Center	1		200
	Kiosks/Juice Bar	4		13.9
	Park Toilet Blocks	3		49.4
11	Lakes	12		48108
12	Greenhouse Farm	2		25000
	Infrastructure			
13	Cluster Street Lighting	1654		
14	Golf Lighting	428		
15	STP	1		570.68
16	Pumping Station	6		457.12
18	Telecommunication	14		100
19	132 KV Substation	2		4784.22
20	Pocket Substation	134		37.6

4.3 Simulation Process

The procedure adopted to investigate the effect of the identified parameters and strategies proposed that improve the energy performance of the community to achieve net zero status are highlighted as follows:

1) Estimating the overall annual power consumption of all the buildings in the residential mixed use community by simulating the three villa prototypes and by estimating the additional loads from the various community amenities.
    - The three villa prototypes in the community are simulated based on design specification, occupancy profile and electrical appliance load data obtained from the validation case study simulated in Apache View are presented in Appendix 02.
    - While the additional loads from the various community amenities such as school, community centre, hospital, street lighting are calculated by obtaining the energy use intensity (EUI) of similar operating buildings in Dubai are presented in Appendix 02.

2) Single free standing solar panels for a standard PV technology using material specification data obtained from local PV suppliers presented in Appendix 03 is simulated in ApacheSim analysis to estimate the energy productivity, number of PV panels and the available installation square meters required in the mixed use residential community to complement the overall community grid energy consumption. Properties such as standard temperature condition (STC), module nominal efficiency, reference irradiance are collected and plugged into the simulation.
3) The photovoltaics are simulated for various energy efficiencies, orientation and inclination angle for three seasons (summer, autumn and winter) to establish the optimum configuration that can generate maximum amount of energy for the community annually.
4) Creative distribution and appropriate location in the urban landscape apart from the building footprint are assessed and selected for the installation of PVs to maximise PV generation in a manner that it does not impact visually and not a sore eye such as rooftop PVs, car parks, covered pathways, solar street lighting etc.
5) Scenarios addressing possible surplus or deficit energy based on the simulation results are analysed such as increasing the building efficiency design standards, introducing energy storage system, and energy generation from PV farms are considered.

The simulation text matrix and scenarios proposed for each case are shown in Table 4.2.

Table 4.2. Simulation Test Matrix and scenario framework (by the author).

PV Orientation	PV Inclination	PV Module Technology	Inverter / Controller Technology
N	2°	Mono Crystalline (18%)	using Standard tech
E	24°	Poly Crystalline (16%)	using MPPT tech
W	48°	Thin Film CIGS (12.6%)	using Transformerless Inverter
S			

Scenario	PV Orientation	PV Module Technology	PV Inclination	Inverter / Controller Technology
Basecase	S	Poly Crystalline (16%)	24°	Standard tech
Scenario 01 - PV Orientation	N, E, W, S	Poly Crystalline (16%)	24°	Standard tech
Scenario 02 - PV Inclination	S	Poly Crystalline (16%)	2°, 24°, 48°, Manual Tracking	Standard tech
Scenario 03 - PV Module Technology	S	Mono Crystalline (18%), Poly Crystalline (16%),Thin Film CIGS (12.6%)	24°	Standard tech

Scenario 04 - Maximum Power Point Tracking (MPPT)	S	Mono Crystalline (18%), Poly Crystalline (16%),Thin Film CIGS (12.6%)	24°	MPPT tech
Scenario 05 - Transformerless Inverters	S	Mono Crystalline (18%), Poly Crystalline (16%),Thin Film CIGS (12.6%)	24°	MPPT tech + Transformerless Inverter
Scenario 06- PV Module Efficiency	S	Kromatix 265Wp Poly (16%), Orego 335Wp Poly (17.5%), Canadian Solar 360Wp Poly (18.15%)	24°	MPPT tech + Transformerless Inverter
Scenario 07 – Community Solar Street Lighting	S	HEI Solar	2°	MPPT tech + Transformerless Inverter
Scenario 08 – Solar Car Parking Integration	S	Kromatix 265Wp Poly (16%)	2°	MPPT tech + Transformerless Inverter
Scenario 09 – Greenhouse PV Farm	S	Kromatix 265Wp Poly (16%)	2°	MPPT tech + Transformerless Inverter
Scenario 10 – Children's Play Area	S	Kromatix 265Wp Poly (16%)	2°	MPPT tech + Transformerless Inverter
Scenario 11 – Multipurpose Events Park	S	Kromatix 265Wp Poly (16%)	2°	MPPT tech + Transformerless Inverter
Scenario 12 – PV Covered Walkway	S	Kromatix 265Wp Poly (16%)	2°	MPPT tech + Transformerless Inverter

4.4 Simulation Considerations

The investigation illustrates the feasibility of photovoltaic's for energy generation in a mixed used residential community in the goal towards reduction of grid electricity demand for the whole year. It highlights the optimum PV angle, orientation, PV technology, PV installation area and locations on community buildings as well as urban landscape that maximises the production of clean energy from PV. There is no scope for passive strategy simulation as the buildings are under construction using the developer defined standard building design guideline. Moreover, the findings recorded in this paper should be treated with some prudence because of apprehensions regarding the precision of manufactures rated peak power but the physical responses of different technologies will hold true.

The annual energy consumption predictions from the software simulations of the three villa prototypes from the selected community are based on the validation case study which is built and operational further clarified with its actual electricity bills in the previous chapter. The estimated overall energy consumption for the various community amenities have very small energy consumption values of less than 4% variation highlighted in Table 4.3 derived from the EUI of similar operating buildings in Dubai. Thus, these variations will not have any significant effect on the overall energy consumption results when looked at the community level.

The EUI data for the mosque was provided by a MEP expert who worked on a similar project and scale. The EUI data for infrastructure amenities such as STP, pocket substations, 132KV substations, telecommunication was not considered as it was not available to the author, however their error in variation will not be impactful since more than 80% of the energy consumption are from villas as seen in Table 4.3. The PV integration in the community takes into consideration that these panels should be installed considering the building aesthetics and have no visual impact. The PV element integrated should appear as a part of the building and community fabric. Lastly, for any economic analysis the cost of electricity for residential and commercial in Dubai based on DEWA slab tariff is AED 0.445/KWh.

4.5 Details of Community Components

The three villa prototypes and the various community components that consume energy from the local grid located in the selected master community in Dubai are described in the below section.

Townhouse (TH-L) prototype

This prototype is the twin townhouse which has the most number of units in the community. It is a 3BHK townhouse with total built up area of 260.21 m² / 2,800.90 ft². The standard plot size is 11m wide x 30m long with occupancy of 4-member family. The spaces available in the townhouse are living room, dining room, kitchen, maids room, first floor living room and 3 bedrooms with total available roof area that can be utilized for rooftop PV panel installation is 120.69 m² / 1299 ft². The parking garage located in the front has an area of 36 m² / 387 ft² can also be proposed for PV panel installation while the backyard is designed to be a garden with a swimming pool. Figure 4.2 shows the rendered ground and first floor plans for the townhouse (TH-L) prototype.

Figure 4.2 TH-L prototype plans (by the author).

Villa (V-3) prototype
This independent villa prototype has the second highest number of units in the community. It has 5BHK with total built up area of 400.73 m² / 4,313.45 ft². The standard plot size is 18 m wide x 25 m long occupied by a family of 4. The spaces available in the townhouse are living room, dining room, kitchen, maid's room, first floor living room and 5 bedrooms with total available roof area that can be utilized for rooftop PV panel installation is 200.5 m² / 2158.1 6ft². The parking garage located in the front has an area of 36 m² / 387 ft² can also be proposed for PV panel installation while the backyard is designed to be a garden with a swimming pool. Figure 4.3 shows the rendered ground and first floor plans for the villa (V-3) prototype.

Figure 4.3 V-3 prototype rendered plans (by the author).

Deluxe Villa (VD-2) prototype
The deluxe villa prototypes are large villa units in the selected community with luxury internal finishes sold at a premium rate by the developer. It has six bedrooms with total built up area of 781.96 m² / 8,417.05 ft². The standard plot size is 25 m wide x 40 m long with occupancy of 6-member family. The spaces available in the townhouse are double living room, dining room, kitchen, maid's room, drivers room, first floor living room and 6 bedrooms with total available roof area that can be utilized for rooftop PV panel installation is 360.15 m² / 3,876.62 ft². The parking garage located in the front has an area of 48 m² / 516.67 ft² can also be proposed for PV panel installation while the large backyard is designed to be a garden with a swimming pool. Figure 4.4 shows the rendered ground and first floor plans for the villa (VD-2) prototype.

Figure 4.4 VD-2 prototype rendered plans (by the author).

Other Community Amenities & EUI

Apart from the villas, which has more than 80% of the community electricity consumption, there are other additional building loads consumed in the community such as hospital, schools, community centre, clubhouse and mosques which are also under construction. In order to estimate the approximate energy consumption for each of these building types per square meter, the average EUI of similar function building that are operational in Dubai are obtained and multiplied by the total built up area of the buildings in the current case study. Forecasting of energy use intensity (EUI) in the urban scale is vital as it assists in energy benchmarking and urban energy infrastructure planning.

However, these approximate values account for only from 2 to 3% of the overall community energy consumption as seen in Table 4.2 applied variation will have minimal impact. The monthly electricity bills data for an existing hospital with total BUA of 16,308m² are presented in Appendix 02. Similarly, the monthly energy bills for the clubhouse were obtained to derive the EUI. While the EUI for the mosque private school and community centre were obtained from reliable MEP experts working in the local construction industry. The total energy consumption for the streetlighting for all the clusters as well as the golf and park lighting are calculated by multiplying its total KWh by the average of summer and winter months which is 12 working hours.

4.6 Modelling Process

The three-villa prototype geometry are virtually modelled in IES-VE computer simulation software using the ModelIT module. The 3D models were created in ModelIT module with the help of input data such as building dimensions extracted from the As-built drawings created in AutoCAD software. This allows for high level of complexity to be integrated within a model assisted by building site location and weather data. All room space data, wall, ceiling, floor, door, windows and glazing where created and applied internally and externally. Figure 4.5 illustrate the villa prototypes modelled in IES-VE. The shading elements modelled are demarcated in green.

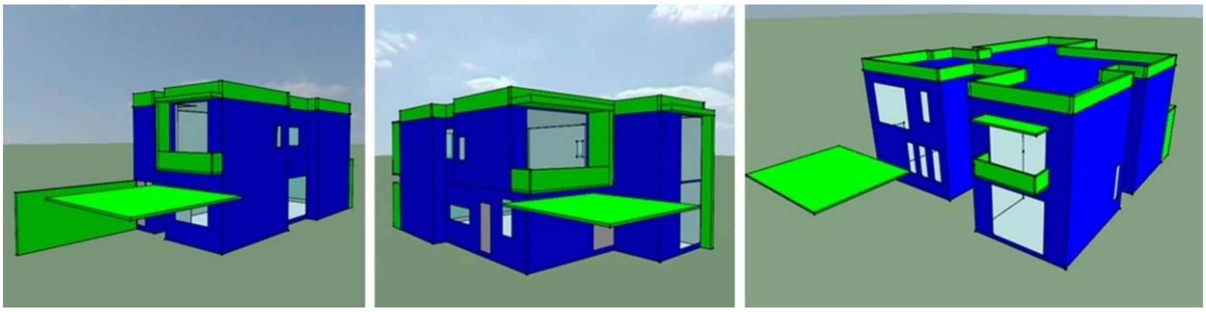


Figure 4.5 3D perspectives of three villa prototypes modeled in IES-VE
b) TH-L b) V-3 c) VD-2 (by the author).

4.7 Weather and Site Data

The IES simulation software has an interesting feature called APLocate, where in it contains weather data files for many countries in the world. The case study located in Dubai between 25.18°N - 24.36°N (latitude) and 54.54°E - 55.43°E (longitude) and at a time zone of + 4.00 hours GMT. The site is located in low rise residential neighbourhood that allow direct exposure to the sun which can increase PV power generation. Dubai lies within the subtropical region and has a hot arid climate with three climatic intervals; from Dec to March (20°C to 23°C), May to October (39°C to 45°C) and relative humidity reaching 100%. Winds prevail from the North-West direction locally known as the Shamal Winds and the wind strength varies from 5-20 knots.

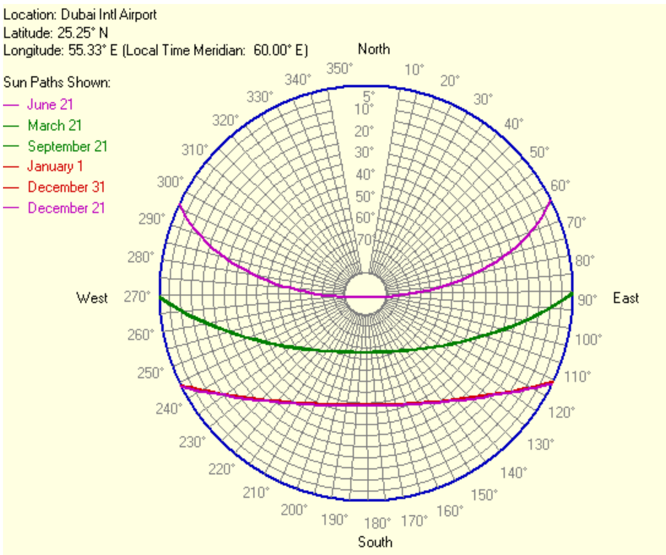


Figure 4.6 Dubai's sun path diagram (IES-VE database).

The average solar radiation for each month is 6.68 KWh/m². Figure 4.6 illustrates the sun path diagram for Dubai which highlights the importance of photovoltaic panels installed oriented towards the south expressed in degrees of azimuth and degrees of altitude. The weather data are important factors affecting the thermal conditions in a building such as the HVAC component. Figure 4.7 shows the max dry–bulb temperature, max wet-bulb temperature and min dry–bulb temperature for the complete year generated by IES-VE software.

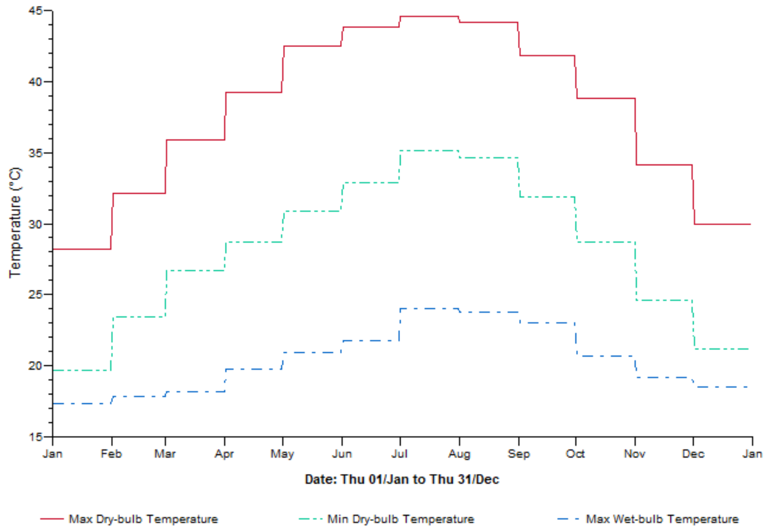


Figure 4.7 Dubai's weather data (IES-VE database).

Daylight chart in Figure 4.8 displays that during the year there is good amount of daylight in Dubai. Sky condition of Dubai can be seen from the data seen in Figure 4.9 and the regular cloud cover ranges from 0% (clear) to 25% (typically clear). The cloud cover is highest during March and minimum during June, while the cloudiest day is January 14 and clearest is June 1. Since the sky condition of Dubai is mostly clear, the variables will be tested under standard CIE Clear sky condition.

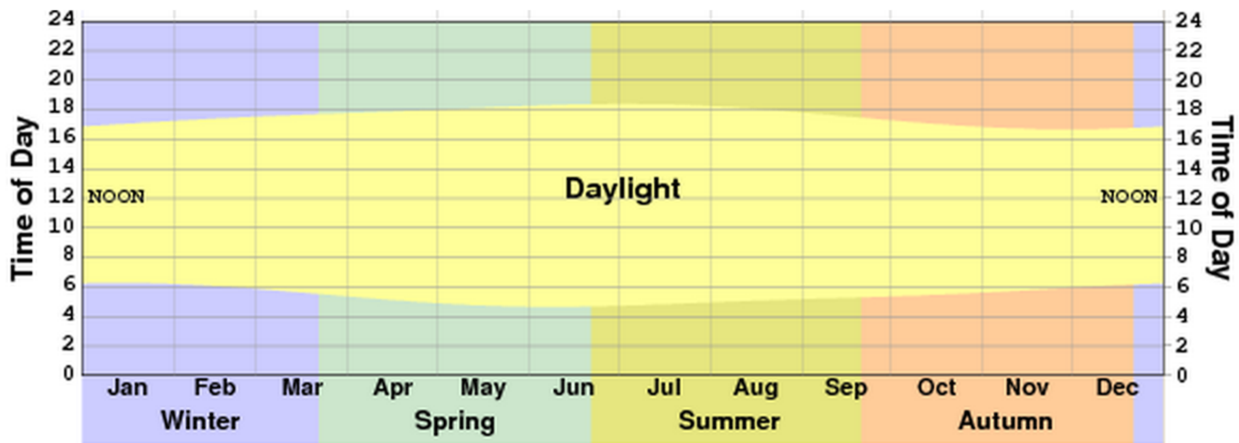
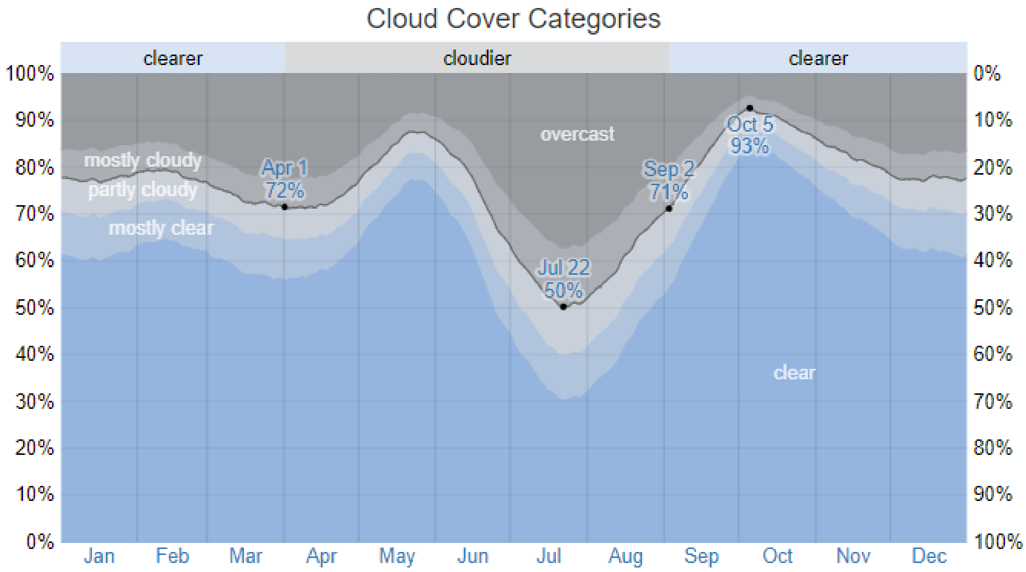


Figure 4.8 Day light Chart (World climate 2017)

From the above climatic data analysis of Dubai, it is understood that high outdoor air temperature and mostly clear cloud cover increases the solar exposure of buildings. The annual global horizontal irradiance (GHI) of the UAE reaches at 2.12 MWh/m²/y in case of harnessing energy from photovoltaic cells. While the direct normal irradiance (DNI) reaches 2.2 MWh/m²/y a relatively high potential for the UAE (Jamil, Ahmad & Jeon, 2016).



The percentage of time spent in each cloud cover band, categorized by the percentage of the sky covered by clouds: clear < 20% < mostly clear < 40% < partly cloudy < 60% < mostly cloudy < 80% < overcast.

Figure 4.9 Annual cloud cover graph (Weatherspark, 2017)

4.8 Simulation Profiles

The energy consumption of the built environment within the community is calculated based on the energy consumed from two crucial loads; the HVAC component and the occupancy profile. The impact of HVAC component is analysed based on the input data from site location and weather data featured in the IES-VE software. The occupancy variation profile is created for different types of modulating user activities regarding the daily schedules and lifestyle of the family residing in the base case study. The data collected is based on the occupancy (24-hour occupancy) or the no. of users, space cooling load, lighting load and connected plug-in load (electrical equipment's) specifying the time variation of the HVAC system supply air flow and appliance usage within the base case study.

Three essential types of user profiles for different occupancy patterns that account for the building consumption load are created based on the activities related to the family which are; daily profile, weekly profile and annual profile. These user profiles account for the working week day and the weekend day. The obtained simulation results are compared to the actual electrical consumption data of the base case for high level of validity and accuracy. The daily profile is the foundation profile, while the weekly profile which is combination of weekday and weekend profile integrating all the daily occupancy and use of HVAC system cycles. Finally, the annual profile generated from accounting the daily and weekly profile based on the season, holidays or specific time of the year with variations in the use of water heaters, electrical appliances and HVAC for space cooling.

4.8.1 Daily Profile

The daily profile was created on APpro based on the daily occupancy, lighting and HVAC operation pattern of the users in the villa. This is the actual data collected from the family in the base case study concerning their daily office work hours, outdoor workout and yoga sessions, weekend outings for shopping and dinner. All four members are out for work from 7am to 7pm as seen in Figure 4.10 which sets the occupancy and HVAC value at 0; it is set to 1 when they are back in their residence.

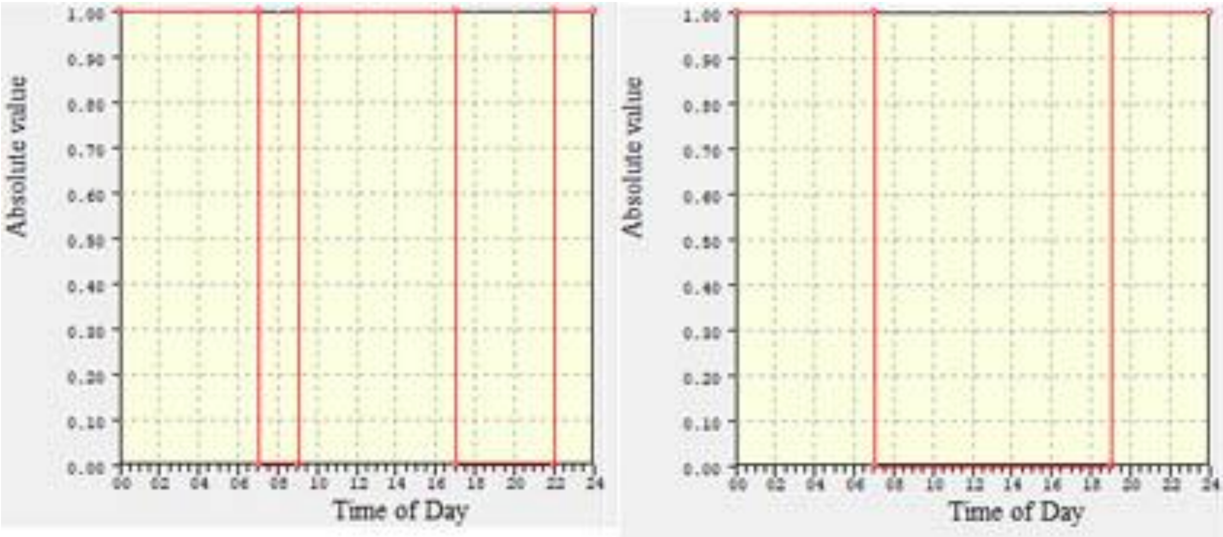
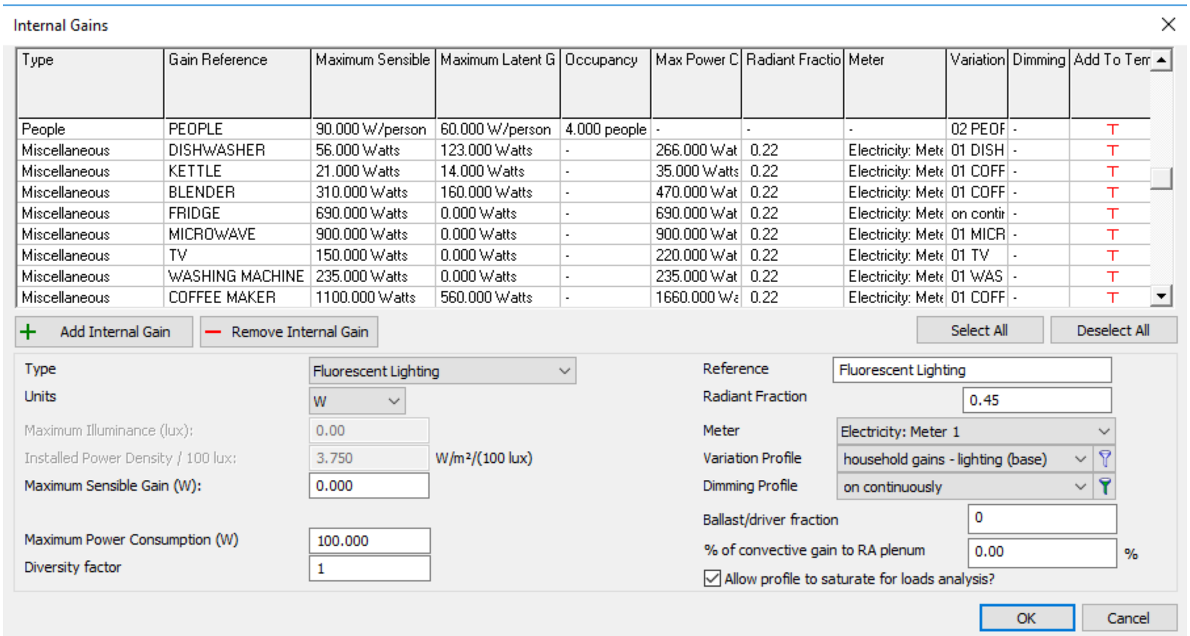


Figure 4.10 Weekend and weekday profile with the occupancy pattern of the family set up in IES (by the author).

All electrical components along with their connected load data as per ASHRAE standards are highlighted in the equipment profile as seen in Figure 4.11. This information is extracted from the actual load values mentioned on actual electrical equipment's name plate data existing in the house.


Internal Gains

Type	Gain Reference	Maximum Sensible	Maximum Latent G	Occupancy	Max Power C	Radiant Fractio	Meter	Variation	Dimming	Add To Ter
People	PEOPLE	90.000 W/person	60.000 W/person	4.000 people	-	-	-	02 PEOF	-	T
Miscellaneous	DISHWASHER	56.000 Watts	123.000 Watts	-	266.000 Wat	0.22	Electricity: Mete	01 DISH	-	T
Miscellaneous	KETTLE	21.000 Watts	14.000 Watts	-	35.000 Watts	0.22	Electricity: Mete	01 COFF	-	T
Miscellaneous	BLENDER	310.000 Watts	160.000 Watts	-	470.000 Wat	0.22	Electricity: Mete	01 COFF	-	T
Miscellaneous	FRIDGE	690.000 Watts	0.000 Watts	-	690.000 Wat	0.22	Electricity: Mete	on contir	-	T
Miscellaneous	MICROWAVE	900.000 Watts	0.000 Watts	-	900.000 Wat	0.22	Electricity: Mete	01 MICR	-	T
Miscellaneous	TV	150.000 Watts	0.000 Watts	-	220.000 Wat	0.22	Electricity: Mete	01 TV	-	T
Miscellaneous	WASHING MACHINE	235.000 Watts	0.000 Watts	-	235.000 Wat	0.22	Electricity: Mete	01 WAS	-	T
Miscellaneous	COFFEE MAKER	1100.000 Watts	560.000 Watts	-	1660.000 Wa	0.22	Electricity: Mete	01 COFF	-	T

Figure 4.11 Occupancy and electrical equipment profile for the internal gain set up in IES (by the author).

The information presented in the daily profile is vital as it highlights the peak hours, other fluctuations in the occupancy and HVAC operation therefore providing more accurate data to support the validation of the results of the simulated model.

4.8.2 Weekly Profile

Weekly profile is developed on the basic outline of the daily profile mentioned in the previous section. The profile has considered the families typical schedule for their weekdays when the family steps out to travel to their office and when they are back, also the weekends which includes gym workouts, grocery, shopping and dining (Friday and Saturday). For the remaining week, it returns to the daily business as usual weekday profile as shown in Figure 4.12.

4.8.3 Annual Profile

Annual profile is configured based on constantly repeating weekly profiles setup with variations in the summer, autumn and winter climates occupancy and HVAC pattern as seen in Figure 4.13. The profile created for the simulation of the model increases the accuracy and reliability of the results.

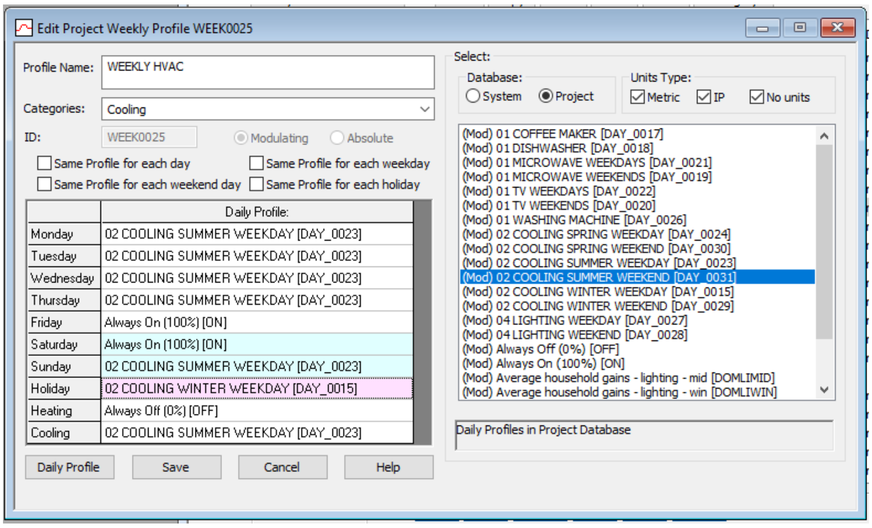


Figure 4.12 Weekly profile with the HVAC pattern for summer months set in IES (by the author).

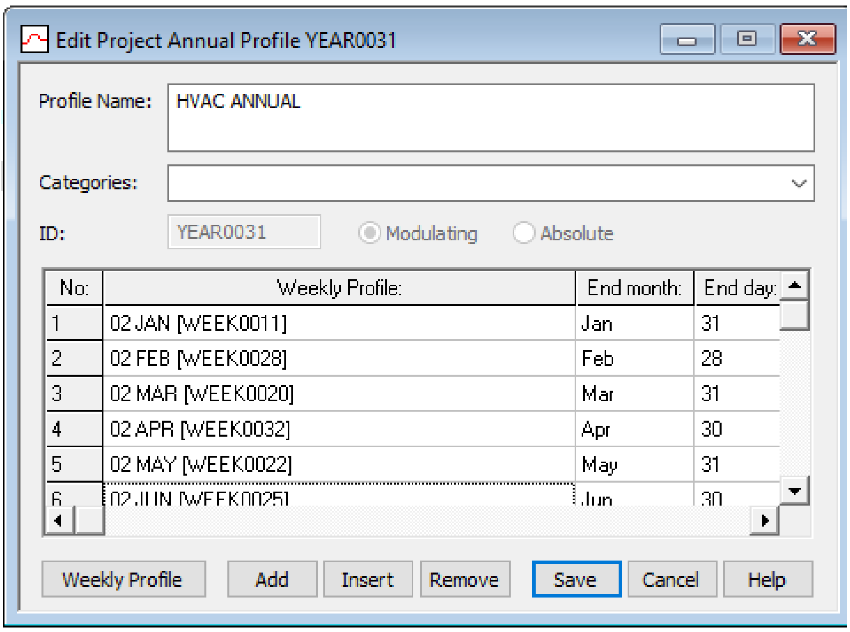


Figure 4.13 Annual profile with the HVAC inputs for each month set up in IES (by the author).

4.9 Construction Template

The simulation software can create different layers of construction materials and input their actual buildings thermophysical material properties, solar absorptivity, emissivity to be in accordance with the existing specifications of the base case villa. In the Building Template Manager feature within IES-VE, the thermal and material properties of the all the construction materials such as the floor, wall, roof, door, windows, glazing and its multiple adjacency conditions can be manually applied before performing the simulation process.

The purpose of the construction database is to assist in the selection and modification of each building attribute as per its application and to analyse their impact on the current and proposed scenarios. The base case study has construction materials conforming to minimum energy requirements as set by the Dubai Green Building Code regulations highlighted in the project construction template manager as seen in Figure 4.14 which includes specifications for the floor, wall, roof and glazing system. The material thickness and total U-value seen in the figure are in accordance with Dubai Municipality Circular number 185 issued in 11.03.2012 seen in Appendix 04.

Glazing properties are highlighted through the value of solar heat gain coefficient (SHGC) which is also known as solar energy permeability of the glazing. The database helps in highlighting the various properties that influence the energy performance of the villa hence leading to scenarios to improve and save more energy.

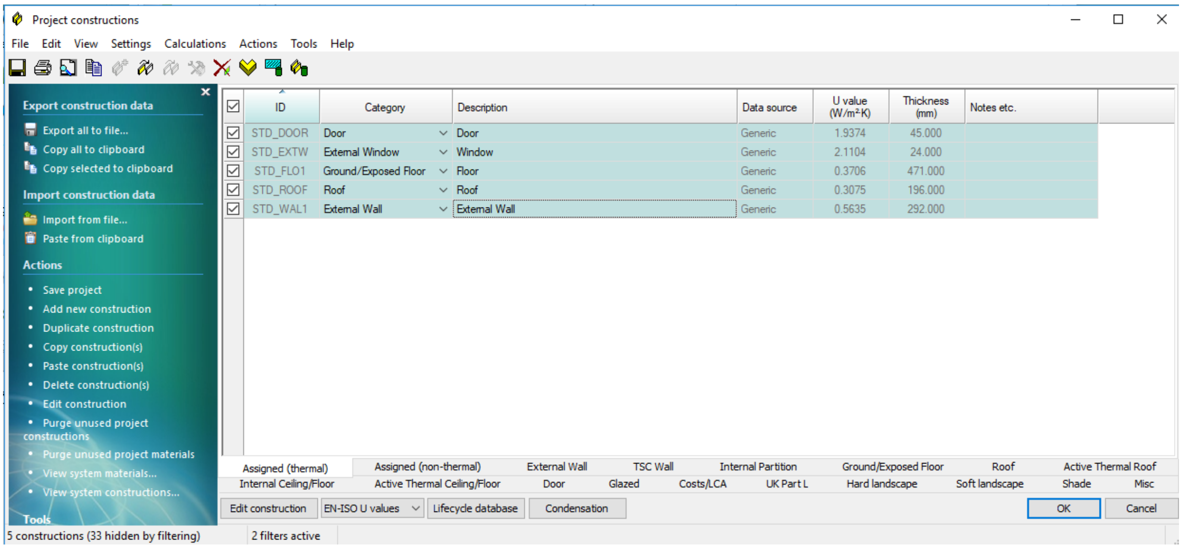


Figure 4.14 Material properties adopted in the base case villa input in IES (by the author).

4.10 Community Energy Consumption Summary

The annual overall energy consumption of the selected base case community is calculated by accounting the complete energy consumption of diverse building stock such as the energy loads of all the residential building prototype, additional loads from the various community amenities buildings and community based infrastructure as summarized in Table 4.3. This allows us to yield the highest benefits by focusing on all the vital components in the selected community and by pursuing more maximum practicable opportunities in the adoption of photovoltaic energy generation systems and energy efficient measures.

The results of the simulation show the main energy consumption component in the community are the residential villas and townhouses which consume about 83.73% i.e. about 106,006.787 MWh of total energy from the utility grid. The remaining community components consumption is minimal when compared to the villas, less than 4% each from the estimated annual total energy load which prove that they will not have any significant effect when looked at the overall community level. While Figure 4.15 illustrates the maximum energy consumption for the three villa prototypes seen in the months of July and August representing the peak energy load months due to the large estimated demand for power for space cooling in summer.

Table 4.3 Total Community Energy Consumption Summary (by the author)

S.No	**Community Components**	**ELEC CONSUMPTION (KWh)**	**EUI (Wh/m²/year)**	**ROOFTOP PV (m²)**	**% of Overall Consumption**
1	VILLAS				
a	TH-L	5,346,6717.6	106.57	232,690.32	42.23%
b	V-3	34,260,016	88.21	19,6891	27.06%
c	VD-2	18,280,054	87.56	121,730.7	14.44%
	Total Villas	**106,006,787.6**		**551,312.02**	**83.73%**
2	HOSPITAL	4,057,308.36	450	2,254	3.20%
3	SCHOOL	4,137,865.89	165.81	8,318	3.27%
4	COMMUNITY CENTER	4,330,844.00	319.67	9,293	3.42%
5	CLUBHOUSE	2,190,597.00	236.16	3,104.19	1.73%
6	MOSQUE	2,100,000	200	10,500	1.66%
7	LIGHTING	3,779,697.6			2.99%
8	INFRA SERVICES				0.00%
		126,603,100.5		**584,780.71**	

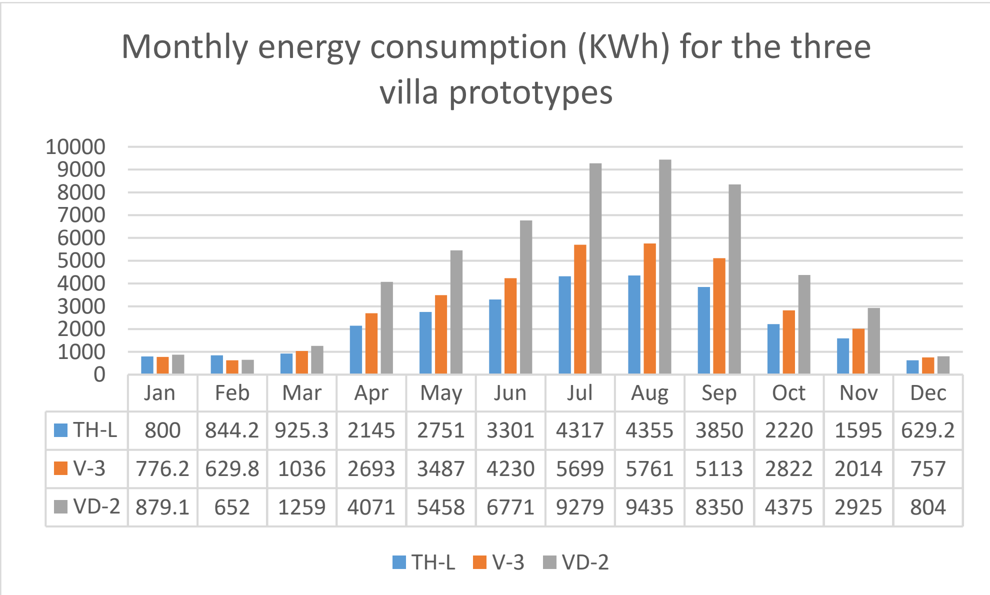


Figure 4.15 Monthly energy consumption (KWh) for the three villa prototypes (by the author).

CHAPTER 05
STRATEGIES, RESULTS & DISCUSSION

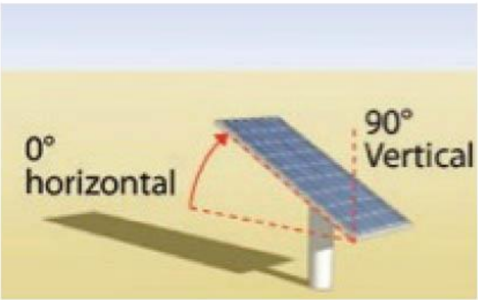
5.1 Overview

This chapter illustrates the many strategies assisted by IES-VE computer simulation software for increasing the PV energy production and PV surface area in the selected community by using series of PV configurations, integration scenarios and optimization techniques at multiple levels of sustainability outlined in the simulation test matrix in the previous chapter. Tables have been highlighted wherever required to understand the outputs of each scenarios at various scales. This has been supported with detailed calculations, simulation and specification data mentioned in the Appendices aiding in the performance and cost saving based understanding. For this purpose, the findings of each scenario will be compared with the annual community energy consumption that needs to be compensated by the total area of PV technologies available in the selected community for a carbon free clean energy production.

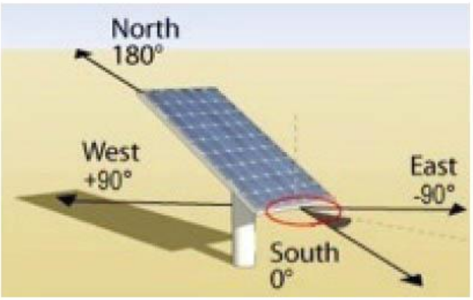
5.2 Base Case PV Panel Simulation

The results from the simulation of the base case PV test panel will help in the estimation of the correct number of square meter area of photovoltaic panels required to generate power equivalent to the annual community energy consumption for the chosen community. Initial simulations were carried out for the standard orientation and inclination tilt angle of the base case test PV panel recommended by Shams Dubai initiative mentioned in the DEWA Connection Guidelines (2015). Further to the simulation, the resulting PV panel per square meter will be considered as the baseline reference which will be compared with subsequent simulation scenarios to identify the optimum PV configuration and PV panel area that can generate maximum amount of energy for the community annually. The aim is to present the most cost effective and energy efficient method of achieving net zero energy status.

The local climate, community boundaries, building aesthetics and regulations are considered in the IES-VE simulation software. The specification and properties for the base case PV test panel such as PV panel type, size, module efficiency, temperature coefficients, nominal operating cell temp (NOCT) are presented in Appendix 03. The simulation examines the 265Wp Kromatix Traditional Poly Crystalline (60 cells) module for the base case analysis for energy generation performed under clear sky conditions. According to DEWA Connection Guidelines (2015), in Dubai the most favourable orientation (azimuth) for fixed solar cells is South (0°S) with an inclination tilt of about 24° with respect to the horizontal plane as seen in Figure 5.1.



Inclination (tilt) of a PV module



Orientation (azimuth) of a PV module

Figure 5.1 Standard PV panel inclination and orientation, Dubai DEWA Connection Guidelines (2015).

In Table 5.1, the monthly and the annual energy production simulation results from IES-VE are highlighted for the base case test PV panel namely 265 Wp traditional polycrystalline PV test panel with panel dimensions of 2000x1000mm (PV panel area = 2m²). The PV energy generation illustrated the results are the highest in summer months and lowest in winter months. Meanwhile, the per square meter energy production for the base case test PV panel of 16% module efficiency measured at standard condition is 216 KWh/m².

Table 5.1 Total energy generation of the base case test PV panel (by the author).

Date	Base Case PV Panel
Jan 01-31	-32.7
Feb 01-28	-34.4
Mar 01-31	-35.4
Apr 01-30	-36
May 01-31	-39.8
Jun 01-30	-37.6
Jul 01-31	-37.6
Aug 01-31	-38.8
Sep 01-30	-37.9
Oct 01-31	-37.9
Nov 01-30	-32.8
Dec 01-31	-30.8
Total (KWh)	***-431.6***
Summed total (**KWh/m²**)	**-216**

The results from the base case test PV panel simulation indicate that the community requires total PV panels of 586,125.47 m² to compensate the annual community energy consumption of 126,603,100.50 KWh. The summary for the test PV panel energy generation vs community consumption in Table 5.2 indicate that the community does not have enough roof area to compensate the annual community energy consumption.

Table 5.2 Summary for the base case PV energy production vs community energy consumption (by the author).

Energy	
Total Community Electricity Consumption (KWh)	126,603,100.50
Traditional PV Panel Power Generation (KWh/m²)	216
Total PV Panel required to power the Community (KWh/m²)	586,125.47
Area	
Roof Area available in the community (m²)	584,780.71
Net Roof Area (*after deducting 50% for HVAC, MEP services etc*) (m²)	292,390.35
Deficit PV Panel Area (m²)	293,735.11

Hence, in order to bridge the deficiency gap the paper proposes strategies in three categories; 1) increase PV panel energy production by optimizing the orientation, inclination angle, manual tracking, enhanced microcontrollers and inverters, 2) increase PV panel efficiency from better manufacturers, 3) increase the area of PV panel installation on the building fabric and exploring options beyond the building footprint at the community level.

5.3 Energy Production Strategies

5.3.1 Scenario 01 – PV Orientation

This scenario will examine and evaluate the most appropriate orientation that can enhance the PV energy production for the whole year considering the location and geometry of the PV array. This strategy will study the outcomes of the test PV panel orientation to the North, East, West and South orientations illustrated in Table 5.3. This is an important factor to be accounted particularly planning to install photovoltaic panels on rooftops within the community. According to Lave & Klessl (2011) and Song & Choi (2015) optimizing solar PV panels that is tuned to appropriate orientations and prevention from shading from building and trees can increase energy production benefits.

Table 5.3 Comparison of the test PV panel energy production with various orientations (by the author).

Date	North Facing Panel	East Facing Panel	West Facing Panel	**South Facing Panel**
Jan 01-31	-12	-22.7	-23.5	-32.7
Feb 01-28	-16	-25.9	-26.3	-34.4
Mar 01-31	-24.5	-30.2	-30.9	-35.4
Apr 01-30	-30.9	-33.9	-33.7	-36
May 01-31	-39.7	-39.5	-40.3	-39.8
Jun 01-30	-40.3	-38.8	-39.2	-37.6
Jul 01-31	-38.8	-38.1	-38.4	-37.6
Aug 01-31	-35.2	-36.9	-37.3	-38.8
Sep 01-30	-27.8	-33.1	-33.3	-37.9
Oct 01-31	-20.4	-29.9	-30	-37.9
Nov 01-30	-12.6	-23.6	-23.5	-32.8
Dec 01-31	-10.4	-21.2	-21.3	-30.8
Total (KWh)	*-308.4*	*-373.7*	*-377.8*	***-431.6***
Summed total (KWh/m²)	-154.2	-186.85	-188.9	**-215.8**

As seen in the table above, the energy production from the test PV panel changes with different panel orientation where the maximum energy corresponds to the array oriented to the south direction. Subsequently all PV panels in the following scenarios will be installed facing the south orientation. Moreover, this result clarifies the south facing PV panel orientation strategy for highest energy yield as highlighted by DEWA Connection Guidelines (2015).

5.3.2 Scenario 02 - PV Inclination

DEWA Connection Guidelines (2015) demonstrated that in Dubai the favourable fixed inclination tilt and azimuth angles for PV panels is about 24° with respect to the horizontal plane as illustrated in the previous scenario. This allows for an average annual irradiation of about 2000-2100 kWh/m²yr on a horizontal plane in Dubai when direct and diffused radiation is considered (Masdar, 2017).

According to solarelectricityhandbook.com (2018) the optimum tilt angles for each month to achieve the optimum performance for the PV panels are highlighted in Figure 5.2. Three different inclination angles for each season have been selected to evaluate the energy performances that consider the peak load for each season. The fixed inclination tilt angle for winter, spring and summer will be 48°, 25° and 2° from the horizontal respectively while the azimuth will be maintained as 180°.

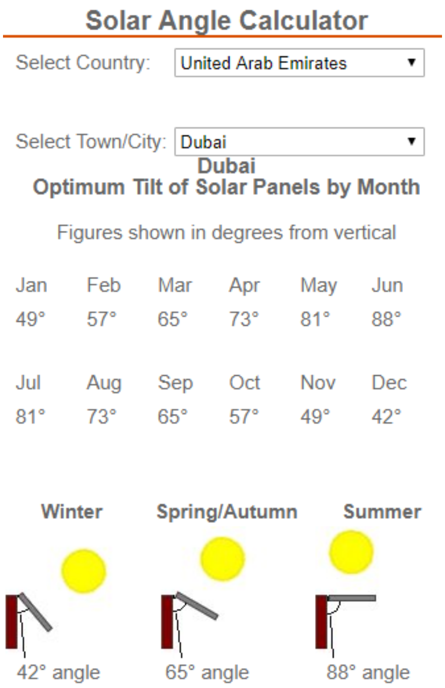


Figure 5.2 Monthly and seasonal optimum tilt of solar panels in Dubai (solarelectricityhandbook.com, 2018).

However, small variations around these values do not impact the energy production. Varying the tilt from 2° to 40° will account for around 5% variation by maintaining the south orientation. Since the inclination angle 24° and 25° are in close range, the inclination angle 25° will not be simulated. Hence, the IES-VE simulations for the selected three-respective seasonal inclination angles have been highlighted in Table 5.4 to access the optimum inclination angle for the annual PV energy production.

Table 5.4 Comparison of the PV power generation for three seasonal inclination angles (by the author).

Date	2°	24°	48°	Manual Tracking
Jan 01-31	-25.3	-32.7	-35.7	-35.7
Feb 01-28	-28.4	-34.4	-35.8	-35.8
Mar 01-31	-32.4	-35.4	-33.4	-33.4
Apr 01-30	-36.2	-36	-30.9	-36.2
May 01-31	-42.7	-39.8	-30.7	-42.7

Jun 01-30	-41.6	-37.6	-27.5	-41.6
Jul 01-31	-40.9	-37.6	-28.6	-40.9
Aug 01-31	-40	-38.8	-31.9	-40
Sep 01-30	-35.9	-37.9	-34.5	-35.9
Oct 01-31	-32.7	-37.9	-38	-38
Nov 01-30	-25.6	-32.8	-35.4	-35.4
Dec 01-31	-23.2	-30.8	-34.1	-34.1
Total (KWh)	*-404.9*	*-431.6*	*-396.5*	*-449.7*
Summed total (KWh/m²)	-202.45	**-215.8**	-198.25	**-224.85**

The results of the simulation show the PV energy generation for the spring/autumn months for fixed inclination angle (24°) have the highest energy performance of 216 KWh/m². Moreover, the simulation of these angles also highlights the potential of manual tracking of the test PV panel that can further maximize the energy production by 4 %. Hence, by changing the PV inclination angle manually twice a year, the total annual power production of the test PV panel increases from 216 KWh/m² to 225 KWh/m² specifically maximising PV energy production during all seasons.

However, the changing of the PV inclination angle manually or by using a tracking device is not recommended because its costs outweigh the benefits. Introduction of complex moving parts further increase maintenance and operations costs. NREL (2010) conducted a study comparing fixed tilted and single axis tracking PV arrays demonstrating a 200% increase in operations and maintenance costs with a payback period of more than 9 years. Thus, the most optimum PV fixed inclination angles for annual energy generation for the selected base case community is 24°. Consequently, all next simulations with rooftop PV installation will adopt the optimized 24° inclination fixed tilt angle.

5.3.3 Scenario 03 - PV Module Technology

The data presented in this strategy are of three commercially available PV cell technologies namely monocrystalline, polycrystalline and thin film technologies described earlier in the literature review section compared between their performance and cost per production. DEWA Connection Guidelines (2015) describe how mono and polycrystalline achieve the maximum energy efficiency when compared to thin film technologies which require more surface area to produce the same power than their crystalline counterparts. MESIA (2014) explain how monocrystalline panels are most space efficient but costly when compared to the less expensive polycrystalline panels because of their higher energy output for a given area. However, in the Middle East, polycrystalline panels are more popular as they have lower conversion efficiency loss under high temperature. Moreover, AlAjmi et al. (2016) described how the monocrystalline panels showed comparable payback period to the polycrystalline panels with 15% higher energy production which makes monocrystalline panels ideal when the project surface area is limited.

However, thin film technologies offer a better choice when initial cost is a major constraint with various benefits such as indirect light performance, resistance to module soiling, high temperature performance and adaptability. Although this technology is much cheaper, the total panel area required to cover the community building energy consumption by these panels will be much larger because of its low module efficiency level. In Table 5.5 the comparison of energy generation outputs and cost benefit analysis for the three PV technologies for each month have been highlighted. The manufacturer data sheets have been presented in Appendix 03.

Table 5.5 Comparison of the three PV technologies energy generation and their costs benefits (by the author).

Date	265Wp Poly Crystalline	275Wp Mono Crystalline	133Wp Thin Film CIGS
Jan 01-31	-32.7	-36.9	-15.1
Feb 01-28	-34.4	-38.8	-15.9
Mar 01-31	-35.4	-39.9	-16.4
Apr 01-30	-36	-40.6	-16.7
May 01-31	-39.8	-44.9	-18.5
Jun 01-30	-37.6	-42.4	-17.5
Jul 01-31	-37.6	-42.5	-17.5
Aug 01-31	-38.8	-43.8	-18.1
Sep 01-30	-37.9	-42.8	-17.7
Oct 01-31	-37.9	-42.8	-17.7
Nov 01-30	-32.8	-37	-15.2
Dec 01-31	-30.8	-34.7	-14.3
Total (KWh)	***-431.6***	***-487.1***	***-200.6***
Summed total (KWh/m²)	**-215.8**	**-243.55**	**-100.3**
AED/KWh	2.21	2.48	2.25

The simulation results demonstrate the total annual production for the mono crystalline has the highest PV energy generation of 244 KWh/m² and polycrystalline panels at 216 KWh/m². Despite the 13% increase in energy production, the polycrystalline technology will be the most economical solution as they have the cheapest cost per production for each panel with many opportunities for integration of PVs at the urban landscape community scale. Thus, the most appropriate cost effective PV technology for the selected base case community is polycrystalline PV technology.

5.3.4 Scenario 04 – Maximum Power Point Tracking (MPPT)

Peng & Lu (2013) explained how external weather conditions such as solar irradiation exposure, temperature, humidity, dust and breezes all influence the performances of a PV system. Moreover, Obi & Bass (2016) describe the inherent function nature of PVs because of the decrease in energy generation when the sun goes down. Due to this nature PV systems are not able to contribute to the grid when demand for power increase after sunset. Incorporation of this strategy provides an ideal option in increasing the output power of the selected grid connected PV system during low irradiance and high unpredictability.

Maximum Power Point Tracking (MPPT) is a technique used to operate the fixed operation point (MPP) of the PV cell continuously when the ambient temperature and solar radiation changes thus improving the PV system efficiency. These trackers consist of DC-DC converters with varying duty cycles and pulse with generator ensuring delivery of the most power from a PV system (Dounis et al., 2013).

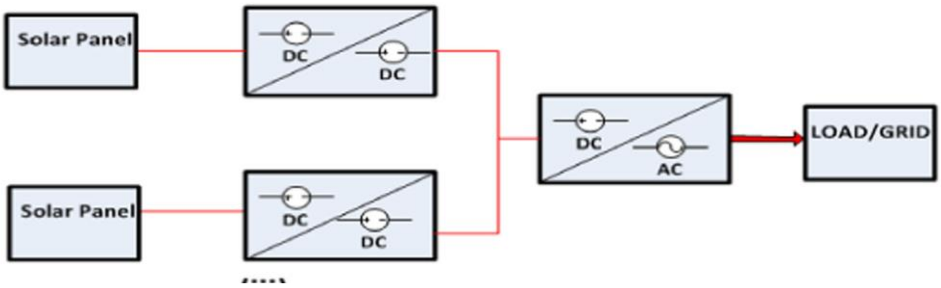


Figure 5.3 Distributed MPPT schematics (Obi & Bass, 2016).

In Figure 5.3 the schematic of the distributed MPPT controllers is illustrated which are inexpensive and improves the PV energy production by 25% when compared to systems without MPPT controller (Swiegers & Enslin, 1998). Similarly, Poshtkouhi et al. (2010) observed a 26% increase in power generation after the deployment of local MPPT controller for each solar panel instead of using a centralized string MPPT controller. While, Koutroulis et al. (2016) demonstrated 15% higher power output using a simple MPPT method controlled by a micro-controller powered by the output from the PV array.

Table 5.6 Comparison of the three PV technologies after integrating MPPT (by the author).

Date	**265Wp Poly Crystalline**	**275Wp Mono Crystalline**	**133Wp Thin Film CIGS**
Jan 01-31	-32.7	-36.9	-15.1
Feb 01-28	-34.4	-38.8	-15.9
Mar 01-31	-35.4	-39.9	-16.4
Apr 01-30	-36	-40.6	-16.7
May 01-31	-39.8	-44.9	-18.5
Jun 01-30	-37.6	-42.4	-17.5
Jul 01-31	-37.6	-42.5	-17.5
Aug 01-31	-38.8	-43.8	-18.1
Sep 01-30	-37.9	-42.8	-17.7
Oct 01-31	-37.9	-42.8	-17.7
Nov 01-30	-32.8	-37	-15.2
Dec 01-31	-30.8	-34.7	-14.3
Total (KWh)	*-431.6*	*-487.1*	*-200.6*
Summed total (KWh/m²)	**-215.8**	**-243.55**	**-100.3**
20% increase by MPPT	*-43.16*	*-48.71*	*-20.06*
Summed total (KWh/m²) + MPPT	**-258.96**	**-292.26**	**-120.36**

The comparison between the three PV cell technologies after integrating MPPT illustrates the total annual PV production from the mono crystalline panel as the highest PV energy generation of 292 KWh/m². However, the ideal choice in this scenario would be the polycrystalline technology with power generation of 259 KWh/m² because of the lower cost per production as highlighted in the previous scenario.

5.3.5 Scenario 05 – Transformerless Inverters

Obi & Ross (2016) investigates the need of an inverter which converts the DC power from the output of PV panel in AC power for use by end utility customers. Transformers are added in many inverters to provide galvanic isolation between DC and AC components. This addition provides safety and prevents damage to sensitive electronic devices. It also acts as filter and remove unwanted high frequency signals and noise produced by the inverter.

Moreover, removing the transformer in the inverter decreases the complexity, reduces the inverters size and weight, decreases the overall inverter cost and improves the system efficiency (lowers the power loss). The advantages of transformer less inverters outweigh their costs from economic and operational cost. Gonzalez et al. (2008) and Gu et al. (2013) provide evidence of transformerless inverters available in the market with efficiencies between 96% and 98%. The world's largest inverter manufacturer SMA Solar Technology has commercially available grid connected transformerless inverters with efficiencies of 98.7%. Kerkes et al. (2011) investigated three types of grid connected transformerless inverters designs and achieved additional overall PV system efficiency of 1 to 2%. However, according to Lopez et al. (2007) this technology could possibly introduce additional leakage ground currents increasing electromagnetic emissions leading to lesser power quality of the inverter. Many researches has been devoted to remove or bring the leakage current to tolerable minimum for grid connected PV systems, due to the benefits of this strategy.

Table 5.7 Comparison of the three PV technologies incorporating MPPT and transformerless inverters (by the author).

Date	265Wp Poly Crystalline	275Wp Mono Crystalline	133Wp Thin Film CIGS
Jan 01-31	-32.7	-36.9	-15.1
Feb 01-28	-34.4	-38.8	-15.9
Mar 01-31	-35.4	-39.9	-16.4
Apr 01-30	-36	-40.6	-16.7
May 01-31	-39.8	-44.9	-18.5
Jun 01-30	-37.6	-42.4	-17.5
Jul 01-31	-37.6	-42.5	-17.5
Aug 01-31	-38.8	-43.8	-18.1
Sep 01-30	-37.9	-42.8	-17.7
Oct 01-31	-37.9	-42.8	-17.7
Nov 01-30	-32.8	-37	-15.2
Dec 01-31	-30.8	-34.7	-14.3
Total (KWh)	*-431.6*	*-487.1*	*-200.6*
Summed total (KWh/m²)	**-215.80**	**-243.55**	**-100.30**
20% increase by MPPT	*-43.16*	*-48.71*	*-20.06*
Summed total (KWh/m²) + MPPT	**-258.96**	**-292.26**	**-120.36**
1% increase by TI	*-2.59*	*-2.92*	*-1.20*
Summed total (KWh/m²) + MPPT+TI	**-261.55**	**-295.18**	**-121.56**

In this scenario, three PV technologies combined with MPPT and transformerless inverters have been compared and analysed in Table 5.7 illustrating the production for the monocrystalline panel as highest total annual PV energy generation of 295.2 KWh/m². However, the most cost effective panel selection will be the polycrystalline technology with power generation of 262 KWh/m².

Therefore, the results from the strategies with reference to the increase in PV energy production indicate that the community now requires total PV panels of 483,217.94 m² to compensate the annual community energy consumption of 126,603,100.50 KWh. The summary illustrated in Table 5.8 shows that there still is a deficit PV panel area of 190,827.59m², however there was 21.3% overall increase in PV power generation when compared to the traditional PV energy production.

Table 5.8 Summary for the selected polycrystalline energy production, community energy consumption and available PV panel area (by the author).

Energy	
Total Community Electricity Consumption (KWh)	126,603,100.50
Selected PV Panel Power Generation (KWh/m²)	262.00
Total PV Panel required to power the Community (KWh/m²)	**483,217.94**
Area	
Roof Area available in the community (m²)	584,780.71
Net Roof Area (after deducting 50% for HVAC, MEP services etc) (m²)	**292,390.35**
Deficit PV Panel Area (m²)	**190,827.58**

5.4 Energy Efficiency Strategies

5.4.1 Scenario 06 – PV Module Efficiency

This scenario will simulate three polycrystalline technologies with various module efficiencies from different manufacturers presented in the manufacturer data sheet in Appendix 03. The results illustrated in Table 5.9 will analyze which polycrystalline technology will achieve the highest production of energy.

Table 5.9 Comparison of the three polycrystalline technologies with various energy efficiencies from different manufacturers (by the author).

Date	Kromatix 265Wp Poly 16%	Orego 335Wp Poly 17.5%	Canadian Solar 360Wp Poly 18.15%
Jan 01-31	-32.7	-35.8	-37.2
Feb 01-28	-34.4	-37.7	-39.1
Mar 01-31	-35.4	-38.8	-40.2
Apr 01-30	-36	-39.5	-40.9
May 01-31	-39.8	-43.7	-45.3
Jun 01-30	-37.6	-41.3	-42.8
Jul 01-31	-37.6	-41.3	-42.8
Aug 01-31	-38.8	-42.6	-44.1
Sep 01-30	-37.9	-41.6	-43.2
Oct 01-31	-37.9	-41.6	-43.2
Nov 01-30	-32.8	-36	-37.3

Dec 01-31	-30.8	-33.8	-35
Total (KWh)	*-431.6*	*-473.6*	*-491.2*
Summed total (KWh/m²)	**-215.8**	**-236.8**	**-245.6**
20% increase by MPPT	*-43.16*	*-47.36*	*-49.12*
Summed total (KWh/m²) + MPPT	**-258.96**	**-284.16**	**-294.72**
1% increase by TI	*-2.59*	*-28.42*	*-29.47*
Summed total (KWh/m²) + MPPT+TI	**-261.55**	**-312.58**	**-324.19**
AED/KWh	***-2.21***	***-2.83***	***-3.08***

The comparison between the three polycrystalline technologies illustrate the total annual PV power generated by the Canadian Solar 360Wp Poly Crystalline panel with 18.15% module efficiency has the highest PV energy generation of 324.19KWh/m² which is 24% higher than the Kromatix 265Wp Poly with 16% module efficiency. However, Canadian Solar 360Wp is 39% costlier than the Kromatix 265Wp, the additional cost per production (AED/KWh) for the higher efficiency polycrystalline modules in this case is not feasible solution considering the payback period. Therefore, in this scenario the Kromatix 265Wp polycrystalline technology with 16% module efficiency offer a better choice when compared with other panel manufacturers. However, it is important to note that the PV technologies with higher efficiencies may become a better choice over panels with lower efficiencies as it reduce the amount of panels required successively decreasing the structural installation that support the panels hence adding to the overall cost savings.

Additional benefits of integrating PV panels on rooftops were noticed though passive panel shading. Kotak et al. (2014) illustrated the passive benefits of rooftop solar panels shading in India which minimized solar gain and enhanced the thermal comfort which resulted in reduction of cooling load consumption by 75%. But when comparison of similar simulations performed in the London scenario showed lesser energy savings because of the greater solar intensity received in India which is located in the sun solar belt.

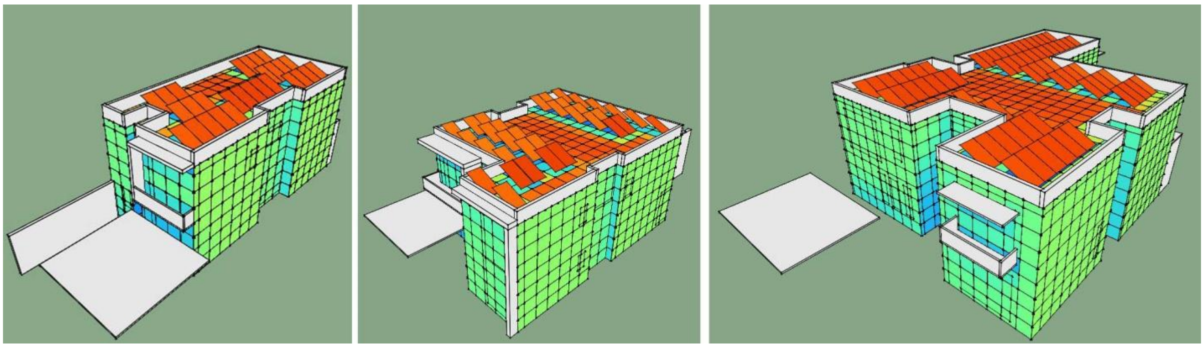


Figure 5.4 Rooftop PV panel distributions on top of the three villa prototypes (by the author).

Energy simulations for the three villa prototypes integrated with rooftop photovoltaic panels is performed to analyse the impact on the building energy consumption. Preliminary analysis of the villa prototype rooftops show maximum 50% of the roof can only be utilized for solar PV panel installations as illustrated in Figure 5.4 as the roof area is already occupied by the building HVAC and MEP service systems as well as space allowed for the PV maintenance work and to avoid shading effects from the building parapet.

The energy reduction from the three villa prototypes has positively reduced their respective energy loads by 1%. This value will be applied to the remaining community buildings with similar roof conditions to calculate the reduced total community energy consumption. Accordingly, the annual energy consumption for the community is reduced by 1,228,234.03 KWh that is cost savings of 552,705.31 AED per year considering the current DEWA energy tariff rates.

However, even after increasing the PV energy production by integrating various technologies, increasing PV energy efficiency and additional savings from passive PV panel shading we still have a gap as illustrated in Table 5.10. The deficit of PV panel area of 186,139.67 m² needs to be bridged by venturing beyond the building footprint like making common areas specifically by using street lighting more energy efficient and by increasing the area of PV in the urban landscape areas.

Table 5.10 Summary for the polycrystalline energy production, reduced community energy consumption due to panel shading (by the author).

Energy	
Total Community Electricity Consumption (kWh)	125,374,866.4
Selected PV Panel Power Generation (KWh/m²)	262
Total PV Panel required to power the Community (kWh/m²)	**478,530.02**
Area	
Roof Area available in the community (m²)	584,780.71
Net Roof Area (after deducting 50% for HVAC, MEP services etc) (m²)	**292,390.36**
Deficit PV Panel Area (m²)	**186,139.67**

5.5 Area Optimization Strategies

5.5.1 Scenario 07 – Community Solar Street Lighting

In this scenario, the application of solar energy in the community street lighting to realize an energy positive off grid street lighting is examined. The proposed intelligent energy efficient system minimizes the energy consumption and the operating costs of the community lighting system by applying energy efficient LED luminaries coupled with photovoltaic panels as seen in Figure 5.5.

As illustrated in Appendix 03, the community lighting which consists of infrastructure street lighting, golf and park lighting accounting for 3% of the overall annual community energy consumption. However, it is not practical to replace the golf and park lighting with solar street lighting as it is scarcely lit at night unlike the community street lighting in addition they are proposed to be integrated with automated motion occupancy sensors beneficial in reducing electrical light demand.

Figure 5.5 Energy efficient LED luminaires coupled with photovoltaic panels (HEI, 2018).

Therefore, it is ideal to only replace the community street lights in the community (24%) by energy efficient standalone LED luminaires coupled with photovoltaic panels presented in the manufacturer data sheet in Appendix 03 resulting in energy savings of 895,320 KWh per year meaning a saving of 402,894 AED per year at today's DEWA rate. Although the initial investment of community LED solar street lighting is high because of equipment and rechargeable battery costs, the substantial yearly costs savings in its operation and maintenance in addition to sustainable source of clean energy outweigh its costs.

Table 5.11 Summary for the PV energy production, reduced community energy consumption due to community street lighting (by the author).

Energy	
Total Community Electricity Consumption (kWh)	124,479,546.40
Selected PV Panel Power Generation (KWh/m²)	262.00
Total PV Panel required to power the Community (kWh/m²)	**475,112.77**
Area	
Roof Area available in the community (m²)	58,4780.71
Net Roof Area (after deducting 50% for HVAC, MEP services etc) (m²)	**292,390.36**
Deficit PV Panel Area (m²)	**182,722.42**

5.5.2 Scenario 08 – Solar Car Parking Integration

This scenario investigates the potential of integrating photovoltaic's at 2° inclination angle on each of the individual shaded car parks of the residential buildings and the designated surface parking lots for the various community buildings such as the hospitals, school, community centre, clubhouse and the mosques within the base case community as seen in Figure 5.6. Solar PV panel integrated car parks have proved to be a cost effective and efficient power generation energy system strategy as previously illustrated in the case studies of The Sustainable City, Dubai and DEWA Headquarters, Dubai described in the literature review.

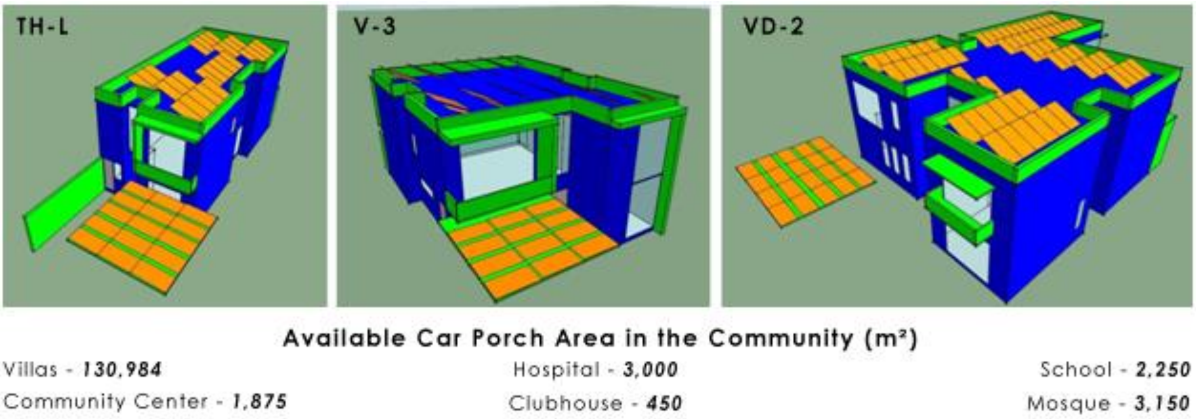


Figure 5.6 Villa car park PV panel distributions and other available designated surface parking summary (by the author).

These solar car parks will be able to cater car park to community residents and visitors as well as supply renewable power generated to the plug-in hybrid electric vehicles (PHEV) and the electric golf buggy for free. Table 5.12 illustrates the total available additional Solar Car Parking of 141,709 m² in the base case community that can be utilized for solar capture. The proposed strategy has enhanced the PV area coverage by additional 48% with deficit PV panel area of 41,013.42 m². Additionally, it is important to note the photovoltaic PV panels on building facades are not considered as the vertical surfaces do not receive enough solar irradiation thus less effective in Dubai.

Table 5.12 Summary for the PV energy production vs community energy consumption with additional solar car park integration (by the author).

Energy	
Total Community Electricity Consumption (kWh)	124,479,546.43
Selected PV Panel Power Generation (KWh/m²)	262.00
Total PV Panel required to power the Community (kWh/m²)	**475,112.77**
Area	
Net Roof Area (after deducting 50% for HVAC, MEP services etc) (m²)	292,390.36
Additional Solar Car Parking Integration (m²)	141,709.00
Total PV Area (m²)	**434,099.36**
Deficit PV Panel Area (m²)	41,013.42

5.5.3 Scenario 09 – Greenhouse PV Farm

Currently the community has two urban greenhouse farm with a total capacity of 25,000 m², one for the golf community and the other for park community essentially providing for urban farming that produce as many organic fruits and vegetables along with grey water recycling. Kannan & Vakeesan (2016) describes the benefits of urban greenhouse PV farm which allows selective capturing of light wavelength and temperature control suitable for agricultural purposes as seen in Figure 5.7.

Figure 5.7 PV panels integrated in a horticultural greenhouse (Polysolar, 2015).

The proposed installation provides a dual strategy for providing carbon free energy production and organic farming that can contribute to the whole community. However, there must be dedicated agreement with DEWA for how this generated energy can be shared and transmitted within the community. Hence a total PV area of 25,000 m² applicable to install 12,500 panels of Kromatix 265Wp polycrystalline technology with 16% module efficiency recorded in the manufacturer data sheet in Appendix 03. Thus, in Table 5.13 the additional PV installation on the two greenhouse farms has highlighted an increase of 6% PV area coverage and the reduction of the deficit PV panel area to 16,013.42 m².

Table 5.13 Summary for the PV energy production vs community energy consumption with additional greenhouse PV farm (by the author).

Energy	
Total Community Electricity Consumption (kWh)	124,479,546.43
Selected PV Panel Power Generation (KWh/m²)	262.00
Total PV Panel required to power the Community (kWh/m²)	**475,112.77**
Area	
Net Roof Area (after deducting 50% for HVAC, MEP services etc) (m²)	292,390.36
Solar Car Parking Integration (m²)	141,709.00
Greenhouse PV Farm (m²)	25,000.00
Total PV Area (m²)	**459,099.36**
Deficit PV Panel Area (m²)	16,013.42

5.5.4 Scenario 10 – Children's Play Area

Within the 4million square feet Attraction Park in the community contains large outdoor children's play area of 2000 m² and community children play area/tot lots of 350 m² dedicated in fifteen community clusters. The play area is fully exposed to the sun which adversely impacts the children particularly in summer. Hence to mitigate the impact, a central non air condition site structure providing shade coverage as seen in Figure 5.8 is proposed to cover the children's play area. The proposed shaded structure is applicable to be installed with Kromatix 265Wp polycrystalline technology that covers a total area of 7250m².

Figure 5.8 PV panel grid installations in the children's play area (by the author).

Moreover, it is important to highlight the educational aspects in this strategy as the visibility of the PV technology for the playing children make them recognize and aware of the need for these systems in the aid for sustainability. Table 5.14 has highlighted the reduction of the deficit PV panel area to 8,763.42m² assisted by the additional 2% increase in PV systems integrated in the children's play area.

Table 5.14 Summary for the PV energy production, community energy consumption with PV systems integrated children's play area (by the author).

Energy	
Total Community Electricity Consumption (kWh)	124,479,546.43
Selected PV Panel Power Generation (KWh/m²)	262.00
Total PV Panel required to power the Community (kWh/m²)	475,112.77
Area	
Net Roof Area (after deducting 50% for HVAC, MEP services etc) (m²)	292,390.36
Solar Car Parking Integration (m²)	141,709.00
Greenhouse PV Farm (m²)	25,000.00
Children's Play Area (m²)	7,250.00
Total PV Area (m²)	466,349.36
Deficit PV Panel Area (m²)	8,763.42

5.5.5 Scenario 11 – Multipurpose Events Park

The attraction park also contains a multipurpose events park of 5750 m² available for hosting community events and entertainment shows. Currently the area is exposed to the sun that can cause discomfort for the community residents especially during summer months. Introduction of large tensile shaded structures as seen in Figure 5.9

is proposed to provide shaded cover and enhances the overall aesthetics of the community park.

Figure 5.9 PV integrated shaded structure in the multipurpose events park area (by the author).

As illustrated in the previous strategy, the increase in visibility of these PV integrated technologies invoke a sense of sustainable responsibility and hence creating awareness and a psychological impact to the community residents. In Table 5.15, the PV installation on the multipurpose events park has highlighted the reduction of the deficit PV panel area to 3,013.42 m², indicating a nearly net zero energy community status.

Table 5.15 Summary for the PV energy production, community energy consumption with PV integrated multipurpose events park (by the author).

Energy	
Total Community Electricity Consumption (kWh)	124,479,546.43
Selected PV Panel Power Generation (KWh/m²)	262.00
Total PV Panel required to power the Community (kWh/m²)	475,112.77
Area	
Net Roof Area (after deducting 50% for HVAC, MEP services etc) (m²)	292,390.36
Solar Car Parking Integration (m²)	141,709.00
Greenhouse PV Farm (m²)	25,000.00
Children’s Play Area (m²)	7,250.00
Multipurpose Events Park (m²)	5,750.00

Total PV Area (m²)	472,099.36
Deficit PV Panel Area (m²)	3,013.42

5.5.6 Scenario 12 - PV Covered Walkway

The community encompasses an urban lifestyle retail strip which combines shopping and entertainment with restaurants from with total length of 1.5 km. In order to create an aesthetic comfortable shopping and leisure experience for the visitors and community residents as well as shade from the sun, covered semi-transparent PV integrated walkways as seen in Figure 5.10 are proposed.

Figure 5.10 PV integrated covered walkways at the 1.5km retail strip (by the author).

Considering the covered walkway width of 2.5m, a total PV coverage of 3750m² integrated with 1875 panels of Kromatix 265Wp polycrystalline technology can be installed for carbon free energy generation. Finally, a surplus of PV panel area of 736.58m² has been highlighted in Table 5.16 by integrating PV technologies on five urban landscape strategies.

Table 5.16 Summary for the PV energy production, community energy consumption with PV covered walkways (by the author).

Energy	
Total Community Electricity Consumption (kWh)	124,479,546.43
Selected PV Panel Power Generation (KWh/m²)	262
Total PV Panel required to power the Community (kWh/m²)	475,112.77
Area	
Net Roof Area (after deducting 50% for HVAC, MEP services etc) (m²)	292,390.36
Solar Car Parking Integration (m²)	141709
Greenhouse PV Farm (m²)	25000
Children's Play Area (m²)	7250
Multipurpose Events Park (m²)	5750
PV Covered Walkway (m²)	3750
Total PV Area (m²)	475,849.36
Surplus PV Panel Area (m²)	736.58

in view of the fact that there is a surplus of PV panel area achieved as seen in the above table there is no requirement to go ahead with further PV integration strategies on the urban landscape. This surplus PV area will help in covering for any potential increase of community energy consumption or reduction in PV productivity due to accumulation of dust. Moreover, it is essential to highlight the potential technologies for integration of PV systems in the urban landscape such as PV integrated bus shelters and floating solar photovoltaic platforms as seen in Figure 5.11.

Figure 5.11 PV integrated Bus Shelters and floating solar photovoltaic platforms (by the author).

5.6 Simple Payback Analysis

In order to justify the investment of the proposed integration of photovoltaic's into the chosen community it is vital to perform a simple payback analysis comparing its economics with the electricity purchased from consumption from the DEWA utility grid. The simple payback period is calculated considering the chosen Kromatix 265Wp polycrystalline technology costs 3600 AED per KWp (477 AED per panel) which has annual productivity of 262 KWh/m² and the cost of electricity for residential and commercial in Dubai based on DEWA slab tariff is AED 0.445/KWh. Table 5.17 illustrates a simple payback period of 4 years which from an economical perspective prove to be a worthwhile investment.

Table 5.17 Calculation for Simple Payback Period (by the author).

Total Cost of Panels	475,112.77 x 477	226,628,792.5
Total Annual Production (KWh)	475,112.77 x 262	124,479,546.4
Annual Value of Energy saved (AED)	124,479,546.42 x 0.45	56,015,795.89
Simple Payback Period	226,628,792.53 / 56,015,795.89	4.0

CHAPTER 06
CONCLUSION

6.1 Overview

Accelerated global economic and population growth are the main influencing factors that has led to the increase of electricity consumption. In addition, the release greenhouse gas (GHG) emissions from energy resources such as the fast depleting fossil fuels whose prices are rising globally. Therefore, the key challenge is to lessen the consumption of fossil fuels which decreases the production of greenhouse gases such as CO_2 and CH_4 using renewable energy technologies to provide clean carbon free energy that can combat future energy security challenges.

Considering the UAEs progresses towards sustainability, the concept of Net Zero Energy Communities has become very vital to the UAEs national agenda as it aligns with the key priorities of the country of driving innovation and sustainability. The UAE plans to install more solar capacity through distributed rooftop photovoltaic considering abundant regional solar irradiation and drop in global PV prices. This research is a stepping stone to the achievement of a net positive built environment and decarbonized global economy, where economic growth and environment degradation are decoupled.

The literature study helps in identifying the objectives of the research and describes several studies which discuss the definitions, targets and benefits of NZEC's along with the role of solar technologies in the reduction of the overall community energy consumption. The dissertation investigates the feasibility of achieving NZEC status for a selected community in the Dubai by adopting photovoltaic panels integrated in its built environment and urban landscape.

Further the paper adapts the simulation methodology to evaluate the impact of cost effective applications of several photovoltaic technologies with various changing parameters, to increase the PV energy production and maximising PV surface area against the base case. Finally, the optimum configurations of using solar renewable energy sources to achieve a net zero energy community along with its economical viabilities for the local context was presented. These results offer various scenarios and potential solutions that support the present development and enhance future studies in regards to net zero energy communities in Dubai.

6.2 Conclusion

This research studied the application of various photovoltaic technologies in an urban mixed use community in Dubai for compensating the total community energy consumption from the utility grid. The first stage of this study was the IES-VE simulation of the base case test photovoltaic panel power productivity per m² (216 KWh/m²) which helped in assessing how much PV area (586,125.47 m²) is required to compensate the annual community energy consumption (126,603,100.5 KWh). However, the practical roof area (292,390.35 m²) available in the community after deducting area for HVAC and MEP services highlights deficiency in rooftop PV panel area of 293,735.11 m².

Therefore the dissertation proposes various scenarios for the incorporation of photovoltaic's to bridge the deficiency in three categories; firstly by increasing PV panel energy production by optimizing the PV orientation, inclination angle, manual tracking, better microcontrollers and inverters, secondly by increasing PV panel efficiency from better manufacturers, lastly by increasing the area of PV panel installation on the building level and exploring options beyond the building footprint at the community level.

The first scenario which simulated the four PV orientations showed highest energy production among the south facing PV panels. The second scenario examined three fixed inclination tilt angles (48°, 25° and 2°) for three seasons (winter, spring and summer) in which 25° fixed inclination tilt angle achieved maximum energy production. Although it was found that the manual tracking of the test PV panel twice a year increased the energy production by 4% but not recommended due to high maintenance and operation costs.

Meanwhile, the next scenario examined three different PV module technologies. Amongst the three technologies, the best PV module technology from an economic point of view is polycrystalline; it is to be noted that a 13% increase in energy production was recorded in the costlier monocrystalline module technology. The power output from the thin film technologies showed the least amount of energy production and requires more area to achieve the similar energy production rate when compared to crystalline counterparts.

The next two scenarios evaluated the impact of enhanced inverter and controller technologies in the increase of PV energy production. Upgrading the standard technology to a cost effective MPPT device resulted in an increased energy production in the polycrystalline module by 20%. Meanwhile, the addition of transformerless inverters increased the overall power output of polycrystalline by 1% bringing the total energy production of the test PV panel to 262 KWh/m² (21.3% increase from base case).

In addition, polycrystalline technologies with higher energy efficiencies from different manufacturers were analyzed. The simulations illustrated the energy generated by the Canadian Solar 360Wp Polyrystalline panel with 18.15% module efficiency generated 24% more than the base case Kromatix 265Wp Poly with 16% module efficiency. Nonetheless the Canadian Solar 360Wp Polyrystalline panel is not a cost-effective solution due to its high cost per production AED/KWh rate.

Moreover, additional benefits of integrating PV panels on rooftops were noticed though passive panel shading which minimized the solar gain and reduced the overall community energy consumption by 1% hence bringing the total community energy consumption to 125,374,866.40 KWh. Based on the energy production per m² for the selected polycrystalline PV technology (262 KWh/m²) the rooftop PV panel area deficiency reduced by 186,139.67 m².

On the account of the lack of enough rooftop area for PV installation to compensate for the total community energy consumption, various scenarios for increasing the area of PV installation on the building envelope and options beyond the building footprint at the community level were explored. In this scenario, for aesthetic reasons the PV angles were changed to be 2° inclination tilt angle. Besides, the Integration of community solar street lighting decreased the overall energy consumption to 124,479,546.4 KWh. Finally, the deficit PV panel area of 182,722.42 m² was accumulated from combination of additional PV panel installation on solar car parking integration (141,709 m^2), greenhouse PV farm (25,000 m^2), children's play area (7,250.00 m^2), multipurpose events park (5,750 m^2) and PV covered walkway (3,750 m^2).

Ultimately, there was a surplus of 736.58 m^2 of PV area achieved which can assist in compensating for any potential increase in the community energy consumption or reduction in PV productivity due to accumulation of dust, sand and other deterring factors. Therefore, it is concluded that based on the results of following series of optimized strategies using different PV technologies it is possible and feasible to convert an existing urban mixed use community to a Net Zero Energy Community in Dubai. Economic analysis illustrates an overall payback period of 4 years which is found to be very reasonable, however the next section will discuss ways to further reduce the overall PV system installation investment and promote the concept of NZEC's in UAE.

6.3 Recommendation and Future Research

Since the villas and community buildings in the selected community are near completion or under construction there was no scope of evaluating the passive strategies. Thus, in the future studies the impact of cost effective passive strategies such as insulation, glazing, orientation need to be implemented first before the integration of photovoltaic' which can provide as a design alternative and dual strategy from developers and architects.

Within the community, the construction of golf course was completed hence there was no scope to replace the golf course lights by efficient solar lighting with enhanced energy performance and cost savings which could further reduce the total community energy consumption and the community carbon footprint.

Upgrading the community by integration of smart technologies such as Internet of Thing (IOT) and intelligent building management systems, beneficial in the reduction of the overall community energy consumption as well as reduce the investment of photovoltaic's in the community eventually paving the way for the development of future smart cities.

The occupants in the urban mixed use communities directly impact energy performance. Community awareness and education through an open communication framework are critical to achieve the reduction of energy consumption. Concept of net zero goes beyond buildings and infrastructure to become lifestyle of the all the users in the community and particularly attractive as saving energy equals saving money.

There is lack of data and research related to a comprehensive design guideline for using renewable technologies integrated in the built environment at a community/neighborhood scale. Only through such studies, a systematic community design guideline integrating these renewable technologies can be recognized.

Strategies supported by policy frameworks apart from feed in tariffs (FiTs) and net metering need to be pursued by the Dubai government such as opportunities for energy storage, energy exchange, rooftop tendering, equipment subsidies, smart micro grid at the neighborhood scale to further the reduce peak energy demand, diversify energy supply and propel these renewable technologies reach their full potential.

Government authorities should adopt policies to mandate the optimal use of photovoltaic technologies like Dubai's existing requirement for solar hot water systems on new villas. They should support developers with financial incentives to retrofit existing buildings with photovoltaic technologies. They can provide economic incentives to manufacturers and users of environmental friendly products. Exemption of Value Added Tax's and government funding will further facilitate the penetration of photovoltaic systems to architects and developers for their future projects.

In the end, this research will serve as model and can be extended for the design and analysis of other existing residential mixed use communities and future net zero energy communities in the Dubai and UAE. This will provide more opportunities for the government, policy makers, market stakeholders; private developers work together to reduce energy consumption and achieve the set target towards Dubai Clean Energy Strategy 2050.

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APPENDICES

APPENDIX 01 – DEWA Electricity bills of a Townhouse at Al Furjan, Dubai.

GOVERNMENT OF DUBAI

هيئة كهرباء ومياه دبي
Dubai Electricity & Water Authority

Page 2 of 3

Green Bill
100010283051

Issue Date: 31/01/2017
Month: January 2017
Period: 28/12/2016 to 27/01/2017

Account Number
2020704560

Electricity

Kilowatt Hours(kWh)
736

Meter number: 825762T
Current reading: 69355
Previous reading: 68619

Carbon Footprint

Kg CO2e
368

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
- above 2,000
- upto 2,000
- upto 1,250
- upto 500

Learn how to conserve and save the environment.

View Conservation Tips

Electricity	Consumption	Rate	AED
	736 kWh	0.230 AED	169.28
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	736 kWh	0.065 AED	47.84

Meter service charge	6.00

NOTE
Consumption = (Current reading - Previous reading)

Electricity total	223.12

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For Generations to Come

Customer Care **04 601 9999**
dewa.ae/social dewa.gov.ae dewa.ae/smart

GOVERNMENT OF DUBAI

هيئة كهرباء ومياه دبي
Dubai Electricity & Water Authority

Page 2 of 3

Green Bill
100096691246

Issue Date: 30/03/2017
Month: March 2017
Period: 27/02/2017 to 27/03/2017

Account Number
2020704560

Electricity

Kilowatt Hours(kWh)
861

Meter number: 825762T
Current reading: 70775
Previous reading: 69914

Carbon Footprint

Kg CO2e
431

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
- above 2,000
- upto 2,000
- upto 1,250
- upto 500

Learn how to conserve and save the environment.

View Conservation Tips

Electricity	Consumption	Rate	AED
	861 kWh	0.230 AED	198.03
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	861 kWh	0.065 AED	55.97

Meter service charge	6.00

NOTE
Consumption = (Current reading - Previous reading)

Electricity total	260.00

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For Generations to Come

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dewa.ae/social dewa.gov.ae dewa.ae/smart

GOVERNMENT OF DUBAI

هيئة كهرباء ومياه دبي
Dubai Electricity & Water Authority

Page 2 of 3

Green Bill
100096691246

Issue Date: 30/03/2017
Month: March 2017
Period: 27/02/2017 to 27/03/2017

Account Number
2020704560

Electricity

Kilowatt Hours(kWh)
861

Meter number: 825762T
Current reading: 70775
Previous reading: 69914

Carbon Footprint

Kg CO2e
431

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
- above 2,000
- upto 2,000
- upto 1,250
- upto 500

Learn how to conserve and save the environment.

View Conservation Tips

Electricity	Consumption	Rate	AED
	861 kWh	0.230 AED	198.03
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	861 kWh	0.065 AED	55.97

Meter service charge	6.00

NOTE
Consumption = (Current reading - Previous reading)

Electricity total	260.00

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Green Bill
100243164473

Issue Date: 30/04/2017
Month: April 2017
Period: 28/03/2017 to 26/04/2017

Account Number
2020704560

Electricity

Kilowatt Hours(kWh)
1,521

Meter number: 825762T
Current reading: 72296
Previous reading: 70775

Carbon Footprint

Kg CO2e
846

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
- above 2,000
- upto 2,000
- upto 1,250
- upto 500

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View Conservation Tips

Electricity	Consumption	Rate	AED
	1,521 kWh	0.230 AED	349.83
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	1,521 kWh	0.065 AED	98.86

Meter service charge	6.00

NOTE
Consumption = (Current reading - Previous reading)

Electricity total	454.69

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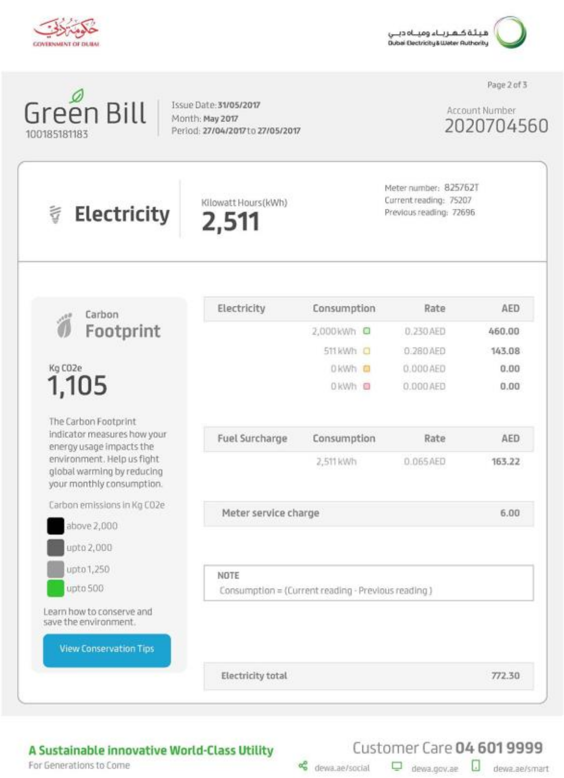

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Green Bill
100185181183

Issue Date: 31/05/2017
Month: May 2017
Period: 27/04/2017 to 27/05/2017

Account Number
2020704560

Electricity
Kilowatt Hours(kWh)
2,511

Meter number: 825762T
Current reading: 75207
Previous reading: 72696

Carbon Footprint
Kg CO2e
1,105

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
above 2,000
upto 2,000
upto 1,250
upto 500

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View Conservation Tips

Electricity	Consumption	Rate	AED
	2,000 kWh	0.230 AED	460.00
	511 kWh	0.280 AED	143.08
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	2,511 kWh	0.065 AED	163.22

Meter service charge 6.00

NOTE
Consumption = (Current reading - Previous reading)

Electricity total 772.30

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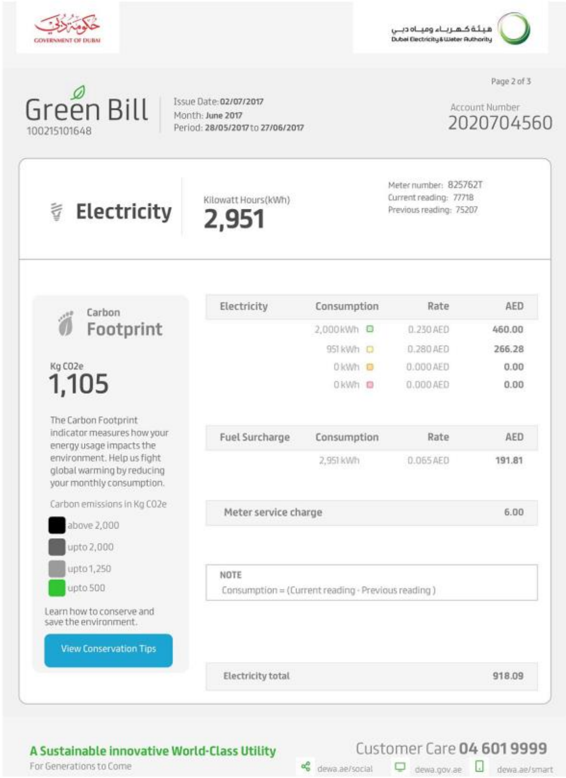

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Green Bill
100215101648

Issue Date: 02/07/2017
Month: June 2017
Period: 28/05/2017 to 27/06/2017

Account Number
2020704560

Electricity
Kilowatt Hours(kWh)
2,951

Meter number: 825762T
Current reading: 77718
Previous reading: 75207

Carbon Footprint
Kg CO2e
1,105

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
above 2,000
upto 2,000
upto 1,250
upto 500

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View Conservation Tips

Electricity	Consumption	Rate	AED
	2,000 kWh	0.230 AED	460.00
	951 kWh	0.280 AED	266.28
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	2,951 kWh	0.065 AED	191.81

Meter service charge 6.00

NOTE
Consumption = (Current reading - Previous reading)

Electricity total 918.09

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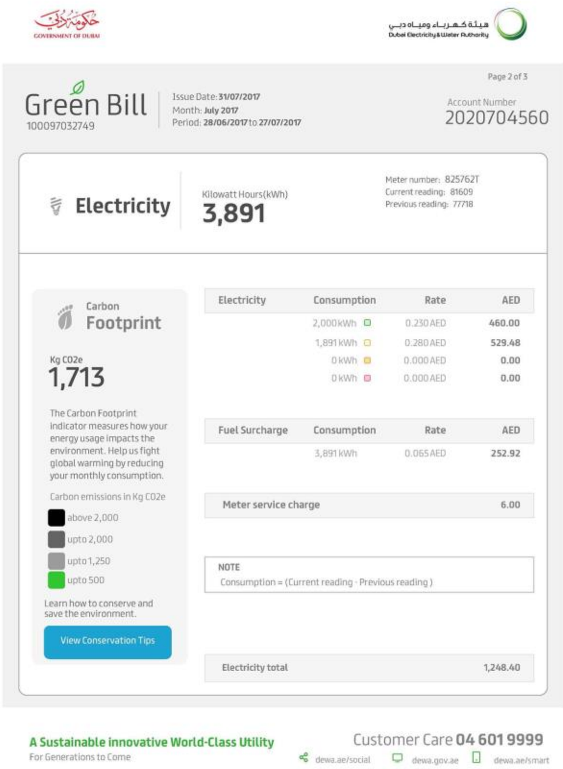

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Green Bill
100097032749

Issue Date: 31/07/2017
Month: July 2017
Period: 28/06/2017 to 27/07/2017

Account Number
2020704560

Electricity
Kilowatt Hours(kWh)
3,891

Meter number: 825762T
Current reading: 81609
Previous reading: 77718

Carbon Footprint
Kg CO2e
1,713

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
above 2,000
upto 2,000
upto 1,250
upto 500

Learn how to conserve and save the environment.

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Electricity	Consumption	Rate	AED
	2,000 kWh	0.230 AED	460.00
	1,891 kWh	0.280 AED	529.48
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	3,891 kWh	0.065 AED	252.92

Meter service charge 6.00

NOTE
Consumption = (Current reading - Previous reading)

Electricity total 1,248.40

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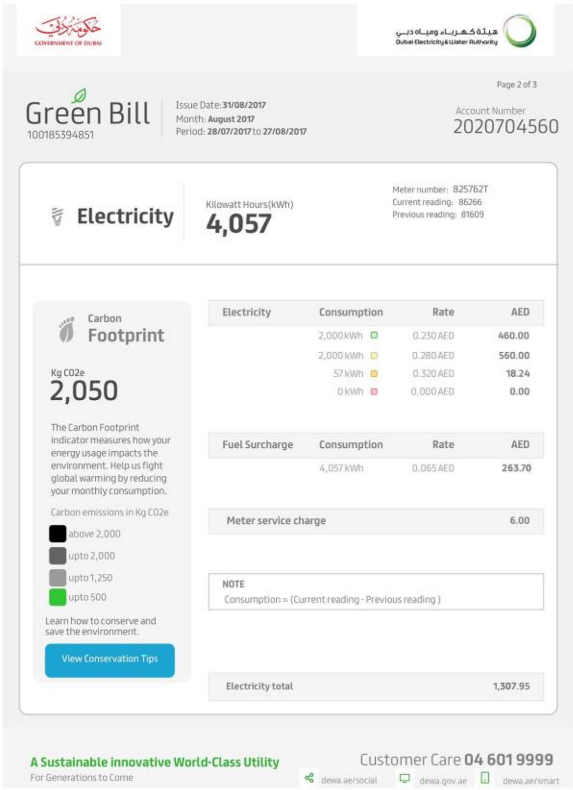

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Green Bill
100185394851

Issue Date: 31/08/2017
Month: August 2017
Period: 28/07/2017 to 27/08/2017

Account Number
2020704560

Electricity
Kilowatt Hours(kWh)
4,057

Meter number: 825762T
Current reading: 86266
Previous reading: 81609

Carbon Footprint
Kg CO2e
2,050

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
above 2,000
upto 2,000
upto 1,250
upto 500

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Electricity	Consumption	Rate	AED
	2,000 kWh	0.230 AED	460.00
	2,000 kWh	0.280 AED	560.00
	57 kWh	0.320 AED	18.24
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	4,057 kWh	0.065 AED	263.70

Meter service charge 6.00

NOTE
Consumption = (Current reading - Previous reading)

Electricity total 1,307.95

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Green Bill
100126755544

Issue Date: **30/09/2017**
Month: **September 2017**
Period: **28/08/2017** to **26/09/2017**

Account Number
2020704560

Electricity

Kilowatt Hours(kWh)
3,529

Meter number: 825762T
Current reading: 90025
Previous reading: 86266

Carbon **Footprint**

Kg CO2e
1,654

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
- above 2,000
- upto 2,000
- upto 1,250
- upto 500

Learn how to conserve and save the environment.

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Electricity	Consumption	Rate	AED
	2,000 kWh	0.230 AED	460.00
	1,529 kWh	0.280 AED	428.12
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	3,529 kWh	0.065 AED	229.34

Meter service charge	6.00

NOTE
Consumption = (Current reading - Previous reading)

Electricity total	1,123.46

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Green Bill
100126841319

Issue Date: **31/10/2017**
Month: **October 2017**
Period: **27/09/2017** to **26/10/2017**

Account Number
2020704560

Electricity

Kilowatt Hours(kWh)
2,183

Meter number: 825762T
Current reading: 92208
Previous reading: 90025

Carbon **Footprint**

Kg CO2e
961

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
- above 2,000
- upto 2,000
- upto 1,250
- upto 500

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View Conservation Tips

Electricity	Consumption	Rate	AED
	2,000 kWh	0.230 AED	460.00
	183 kWh	0.280 AED	51.24
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	2,183 kWh	0.065 AED	141.90

Meter service charge	6.00

NOTE
Consumption = (Current reading - Previous reading)

Electricity total	659.14

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Green Bill
100037106712

Issue Date: **29/11/2016**
Month: **November 2016**
Period: **27/10/2016** to **26/11/2016**

Account Number
2020704560

Electricity

Kilowatt Hours(kWh)
1,399

Meter number: 825762T
Current reading: 68044
Previous reading: 66445

Carbon **Footprint**

Kg CO2e
704

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
- above 2,000
- upto 2,000
- upto 1,250
- upto 500

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Electricity	Consumption	Rate	AED
	1,399 kWh	0.230 AED	321.77
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	1,399 kWh	0.065 AED	90.93

Meter service charge	6.00

NOTE
Consumption = (Current reading - Previous reading)

Electricity total	418.71

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Green Bill
100126053035

Issue Date: **31/12/2016**
Month: **December 2016**
Period: **27/11/2016** to **27/12/2016**

Account Number
2020704560

Electricity

Kilowatt Hours(kWh)
595

Meter number: 825762T
Current reading: 68619
Previous reading: 68044

Carbon **Footprint**

Kg CO2e
288

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
- above 2,000
- upto 2,000
- upto 1,250
- upto 500

Learn how to conserve and save the environment.

View Conservation Tips

Electricity	Consumption	Rate	AED
	595 kWh	0.230 AED	136.85
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	595 kWh	0.065 AED	38.67

Meter service charge	6.00

NOTE
Consumption = (Current reading - Previous reading)

Electricity total	181.52

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APPENDIX 02a - Annual Energy Consumption (KWh) per villa prototype simulated on IES-VE software:

1. Townhouse (TH-L) prototype

TH-L	**m²**	**ft²**		
Ground Floor Area	116.50	1,254.05	**W per m²**	106.57
First Floor Area	123.96	1,334.31	No. of Townhouses	1,928
Total Building Area	240.47	2,588.37	IES Electricity per villa (KWh)	27,731.70
Terrace Area	19.75	212.59	Total Electricity (KWh)	53,466,717.6
Total Built Up Area	260.22	2,800.95		
Garage Area	36.00	387.50		
Roof Area	120.69	1,299.10	Total PV Car Park Area TH-L (m²)	69,408
PV Area	156.69	1,686.60	Total PV Area TH-L (m²)	232,690.32

Date	**TH-L Total Energy (KWh)**
Jan	800
Feb	844.2
Mar	925.3
Apr	2144.7
May	2750.9
Jun	3301.4
Jul	4316.6
Aug	4354.9
Sep	3849.5
Oct	2220.3
Nov	1594.7
Dec	757.0
Total	**27,731.7**

Villa (V-3) prototype

V-3	**m²**	**ft²**		
Ground Floor Area	170.21	1,832.14	**W per m²**	87.06
First Floor Area	183.30	1,973.04	No. of Villas	982
Total Building Area	353.51	3,805.18	IES Electricity per villa (KWh)	34,888
Terrace Area	47.22	508.27	Total Electricity (KWh)	34,260,016
Total Built Up Area	400.73	4,313.45		
Garage Area	36.00	387.50		
Roof Area	200.5	2,158.16	Total PV Car Park Area V-3 (m²)	35,352
PV Area	**236.50**	**2,545.66**	Total PV Area V-3 (m²)	232,243

Date	**V-3 Total Energy (KWh)**
Jan	776.2
Feb	629.8
Mar	1035.5
Apr	2692.6
May	3487.3
Jun	4230.4
Jul	5698.8
Aug	5760.6
Sep	5112.6
Oct	2821.9
Nov	1885.9
Dec	757
Total	**34,888.6**

Deluxe Villa (VD-2) prototype

VD-2	**m^2**	**ft^2**		
Ground Floor Area	368.81	3,969.87	**W per m^2**	69.16
First Floor Area	346.37	3,728.33	No. of Deluxe Villas	538
Total Building Area	715.18	7,698.20	IES Electricity per villa (KWh)	54,083
Terrace Area	66.78	718.81	Total Electricity (KWh)	18,280,054
Total Built Up Area	781.96	8,417.01		
Garage Area	48.00	516.67		
Roof Area	360.15	3,876.62	Total PV Car Park Area VD-2 (m^2)	16,224
PV Area	**408.15**	**4,393.29**	Total PV Area VD-2 (m^2)	137,954.7

Date	**VD-2 Total Energy (KWh)**
Jan	879.1
Feb	652
Mar	1258.5
Apr	4071.4
May	5457.7
Jun	6771
Jul	9278.9
Aug	9435
Sep	8350.1
Oct	4374.8
Nov	2750.5
Dec	804
Total	**54,083**

b) Annual Energy Consumption (KWh) per community amenities estimated using Energy Use Intensity (EUI)

2. Hospital

EXISTING PRIVATE HOSPITAL			PROPOSED HOSPITAL @ Master Plan		
(B+G+3+R)	**m²**	**ft²**	(B+G+4)	**m²**	**ft²**
Total Built Up Area	16,308	175,537.84	BUA	9,016	97,047.41
Total Electricity (KWh)	7,338,796		Total Predicted Electricity (KWh)	**4,057,308.36**	
EUI (Wh/m²/year)	450.01				
Jan	437,018				
Feb	448,249				
Mar	499,404				
Apr	537,381				
May	684,029				
Jun	763,929				
Jul	800,470				
Aug	756,138				
Sep	740,569				
Oct	635,309				
Nov	572,485				
Dec	463,815				
			Total PV Car Park Area **(m²)**	3000	(200 slots)
Roof Area	5,436 m²		**Total PV Roof Area (m²)**	2,254	

3. School

EXISTING PRIVATE SCHOOL			PROPOSED SCHOOL @ Master Plan		
(G+2+R)	**m²**	**ft²**	(G+3+R)		
Total Built Up Area	4,901	52,753.92	BUA	24,955	268,613.37
Total Electricity (KWh)	812,650		Total Predicted Electricity (KWh)	**4,137,865.89**	
EUI (Wh/m²/year)	165.81				
Jan	52,618				
Feb	52,293				
Mar	56,840				
Apr	57,165				
May	79,576				
Jun	83,798				
Jul	51,968				
Aug	77,302				
Sep	89,645				
Oct	82,499				
Nov	73,730				
Dec	55,216				
			Total PV Car Park Area **(m²)**	2,250	(150 slots)
Roof Area	4,500 m²		**Total PV Roof Area (m²)**	8,318	

4. Community Centre

EXISTING COMMUNITY CENTER		PROPOSED COMMUNITY CENTER @ Master Plan		
via Email	**KWh**	(B+G+2+R)	**m²**	**ft²**
Centre 01	385	BUA	13,548	145,829.45
Centre 02	233	Total Predicted Electricity (KWh)	**4,330,844.00**	
Centre 03	341			
		Total PV Car Park Area **(m²)**	1,875	(125 slots)
Average EUI (Wh/m²/year)	319.67	**Total PV Roof Area (m²)**	9,292.5	

5. Club House

EXISTING CLUB HOUSE		
B+G+2+R	**m²**	**ft²**
Total Built Up Area	9,277	99,857.22
Total Electricity (KWh)	21,90,597	
EUI (Wh/m²/year)	236.13	
Jan	152,880	
Feb	153,471	
Mar	155,736	
Apr	158,642	
May	169,421	
Jun	208,975	
Jul	224,589	
Aug	258,762	
Sep	153,289	
Oct	137,472	
Nov	252,240	
Dec	165,120	
Total PV Car Park Area (m²)	450	(30 slots)
Total PV Roof Area (m²)	3,104.19 m²	

6. Mosque

EXISTING MOSQUE			PROPOSED MOSQUE x 7 No.s	
G+1	**m²**	**ft²**	**m²**	**ft²**
Total Built Up Area	1,500	16,145.865	10,500	113,021.055
Total Electricity (KWh)	300,000		210,0000	
EUI (Wh/m²/year)	200.00			
			Total PV Car Park Area (m²)	3,150
PV Area (m²)	1,500		**Total PV Roof Area (m²)**	10,500

c) Annual Energy Consumption (KWh) per infrastructure amenities estimated using Energy Use Intensity (EUI)

7. Cluster Street Lighting

INFRASTRUCTURE STREET LIGHTING					
Type	**No.s**	**Watts**	**KWh**	**x 12 hours**	
SL1 10m, 2 Fixtures	12	100	2.4	28.8	
SL2 14m, 2 Fixtures	60	250	30	360	
SL3 10m, 1 Fixtures	nil	150	0	0	
SL4 10m, 1 Fixtures	53	250	13.25	159	
SL5 14m, 3 Fixtures	nil	250	0	0	
SL6 14m, 1 Fixtures	26	250	6.5	78	
SL7 10m, 2 Fixtures	nil	250	0	0	
SL8 10m, 1 Fixtures	nil	250	0	0	
SL9 8m, 1 Fixtures	1455	100	145.5	1,746	
SL10 10m, 1 Fixtures	48	100	9.6	115.2	
SL11 10m, 2 Fixtures	nil	2x150w	0		
Total Lights	1654			2,487	per day
				74,610	per month
				895,320	**per year**

8. Golf Street Lighting

LANDSCAPE LIGHTING GOLF					
Type	**No.s**	**KWh**	**Total**	**x 12 hours**	
LSG-1500-2, 15.24m, 2 Fixtures	82	1.56	127.92	1,535.04	
LSG-1500-4, 18.29m, 4 Fixtures	24	1.56	37.44	449.28	
LSG-1500-3, 15.24m, 3 Fixtures	96	1.56	149.76	1,797.12	
LSG-1500-3, 18.29m, 3 Fixtures	135	1.56	210.6	2,527.2	
LSG-1500-2, 18.29m, 2 Fixtures	58	1.56	90.48	1,085.76	
LSG-1500-6, 18.29m, 6 Fixtures	18	1.56	28.08	336.96	
LSG-1500-8, 21.34m, 8 Fixtures	8	1.56	12.48	149.76	
LSG-1500-7, 21.34m, 7 Fixtures	7	1.56	10.92	131.04	
Total Lights	428			8,012.16	per day
				240,364.8	per month
				2,884,377.6	**per year**

APPENDIX 03 – PV Technology Data Sheets

a) Kromatix PV manufacturer data sheet

KROMATIX™ DATA SHEET

Models	Traditional Modules - 60 cells		Kromatix™ Thin film	Kromatix™ Framed	Kromatix™ GG
	Mono Crystalline	Poly Crystalline	CIGS	Mono Crystalline	Mono Crystalline
Article no.			0802.3021 (Grey)	0802.3021 (Grey)	0802.3021 (Grey)
			0802.3022 (Light grey)	0802.3022 (Light grey)	0802.3022 (Light grey)
			0802.3024 (blue)	0802.3024 (blue)	0802.3024 (blue)
			0802.3025 (yellow green)	0802.3025 (yellow green)	0802.3025 (yellow green)
			0802.3026 (green)	0802.3026 (green)	0802.3026 (green)
			0802.3027 (bronze)	0802.3027 (bronze)	0802.3027 (bronze)
			0802.3028 (gold)	0802.3028 (gold)	0802.3028 (gold)
			0802.3029 (Terracota)	0802.3029 (Terracota)	0802.3029 (Terracota)
Backsheet colour	Black or White	Black or White	Black glass	Black sheet	Black glass
Cell color	Black	Dark Blue	Black	Dark Blue	Dark Blue
Electrical STC *					
Nominal power Pmpp	**260-275 Wp**	**250 - 265 Wp**	**120 - 133 Wp (Depending on color)**	**230 - 250 Wp (Depending on color)**	**230 - 250 Wp (Depending on color)**
Nominal voltage Umpp	30.59 V	30.3 V	42.4 V	31.9 V	30.0 V
Nominal current Impp	8.5 A	8.20 A	2.95 A	7.56 A	8.10 A
Open circuit voltage Uoc	38.3 V	38 V	58.0 V	38.9 V	37.6 V
Short circuit current Isc	9.3 A	8.8 A	3.35 A	8.11 A	8.51 A
General data	* Standard Test Conditions: irradiance 1000 W/m2, cell temperature 25 °C, AM 1.5	* Standard Test Conditions: irradiance 1000 W/m2, cell temperature 25 °C, AM 1.5	* Standard Test Conditions: irradiance 1000 W/m2, cell temperature 25 °C, AM 1.5	* Standard Test Conditions: irradiance 1000 W/m2, cell temperature 25 °C, AM 1.5	* Standard Test Conditions: irradiance 1000 W/m2, cell temperature 25 °C, AM 1.5
	STC measurement tolerances: ± 3% (Pmpp); ± 10% (Isc, Voc, Impp, Umpp)	STC measurement tolerances: ± 3% (Pmpp); ± 10% (Isc, Voc, Impp, Umpp)	STC measurement tolerances: ± 3% (Pmpp); ± 10% (Isc, Voc, Impp, Umpp)	STC measurement tolerances: ± 3% (Pmpp); ± 10% (Isc, Voc, Impp, Umpp)	STC measurement tolerances: ± 3% (Pmpp); ± 10% (Isc, Voc, Impp, Umpp)
Power tolerance	0/+5 W	0/+5 W	-	0/+5 W	0/+5 W
Cell type	156*156 mm	156*156 mm	CIGS	156 x 156 mm	156 x 156 mm
Cell matrix	6 strings with 10 cells (60 cells)	6 strings with 10 cells (60 cells)	-	6 strings with 10 cells (60 cells)	6 strings with 10 cells (60 cells)
Bypass diodes	3 pcs	3 pcs	-	3 pcs. (less power loss in case of partial shading)	3 pcs. (less power loss in case of partial shading)
Cell efficiency level	18--20.3 %	18.2%~18.3%	17.90%	18.80%	18.20%
Module efficiency level	**18 %**	**16%**	**12.6%**	**14.6% -16%**	**14.1% - 16%**
Temperature coefficient	Uoc -0.41 % / °C , Isc 0.053 % / °C	Uoc - 0.35 %/ °C, Isc + 0.05 %/ °C,	Uoc -170 mV/ °C, Isc 0 mA/ °C,	Uoc - 0.30 %/ °C, Isc + 0.004 %/ °C,	Uoc - 0.32 %/ °C, Isc + 0.05 %/ °C,
	Pmpp -0.41 % / °C	Pmpp - 0.43 %/ °C	Pmpp - 0.39 %/ °C	Pmpp - 0.45 %/ °C	Pmpp - 0.43 %/ °C
Nominal operating cell temp. (NOCT)	45 °C (±2 °C)	46 °C (± 2 °C)	40 °C (± 2 °C)	45 °C (± 2 °C)	46 °C (± 2 °C)
Operating temperature range	- 40 ... + 85 °C	- 40 ... + 85 °C	- 40 ... + 85 °C	- 40 ... + 85 °C	- 40 ... + 85 °C
Max. system voltage	1000 V	1000 V	1000 V	1000 V	1000 V
Max. reverse current	-	-	5.0 A	20 A	-
String fuse	15 A	15 A	-	16 A	15 A
Dimensions	1652 x 986 mm	1652 x 986 mm	664 x 1587 mm	1000 x 1640 mm	986 x 1652 mm
Weight	18-20 Kg	20 kg	17 Kg	18kg	19 kg
Mechanical data					
Laminate structure	Glass-Glass	Glass-Glass	Glass-Glass	Glass-foil	Glass-Glass
Frame	frameless	frameless	frameless	Black anodized aluminium	frameless
Front glass	2mm + 2mm	2mm + 2mm	3.2 mm Kromatix™ colored solar glass, tempered / mat surface	3.2 mm Kromatix™ colored solar glass, tempered / mat surface	3.2 mm Kromatix™ colored solar glass, tempered / mat surface
Encapsulation material	POE	POE	PVB	EVA with lowest yellowness index	EVA with lowest yellowness index
Back foil	2 mm glass	2 mm glass	3.2 mm glass	Three-layer build-up (Polyester / PET / Tedlar) with lowest water vapour permeability	2 mm glass
Junction box	LSB00070, LSC-01 or MC4 connector type	LSB00070, LSC-01 or MC4 connector type	IP65, LC4 connector type	MC: PV-JB/WL-V, MC4 connector type	LSB00070, LSC-01 or MC4 connector type
Certificates					
Wind suction / Snow pressure	2400 N/m^2 / 5400 N/m^2	2400 N/m^2 / 5400 N/m^2	Up to 8000 N/m^2, IEC/EN 61215 2nd Ed	Up to 8000 N/m^2, IEC/EN 61215 2nd Ed.	2400 N/m^2 / 5400 N/m^2
Information on fire protection	Top layer is made of heat-resistant glass, component is considered to be non-combustible material	Top layer is made of heat-resistant glass, component is considered to be non-combustible material	Top layer is made of heat-resistant glass, component is considered to be non-combustible material	Top layer is made of heat-resistant glass, component is considered to be non-combustible material	Top layer is made of heat-resistant glass, component is considered to be non-combustible material
Warranty	10 years product warranty, 25 years linear performance warranty	10 years product warranty, 30 years linear performance warranty	10 years product warranty, 25 years linear performance warranty	10 years product warranty, 25 years linear performance warranty	10 years product warranty, 30 years linear performance warranty
Premium quality	Ion implanters and selective emitter cells, No PID (potential induced degradation),	Ion implanters and selective emitter cells, No PID (potential induced degradation),	Top layer is made of heat-resistant glass, component is considered to be non-combustible material	Ion implanters and selective emitter cells, No PID (potential induced degradation), Unmet low-light performance, Full traceability of all raw materials	Ion implanters and selective emitter cells, No PID (potential induced degradation), Unmet low-light performance, Full traceability of all raw materials

Note: The installation instructions must be followed. For more information installation and operating manuals can be requested.
All the values mentioned are as per STC (Standard Testing Conditions) and can vary with project conditions .

b) Orego PV manufacturer data sheet

MG-H6-P315-335

POLYCRYSTALLINE SOLAR MODULE

SUPERIOR YIELD
High power output thanks to advanced 6-busbar technology and outstanding performance under real-life conditions (available with double current sorting).

LOW LEVELIZED COST OF ELECTRICITY
Higher yield per surface area and lower BOS costs and higher power classes and an efficiency rate of up to 17.5%.

INNOVATIVE ALL-WEATHER TECHNOLOGY
Optimal yields,whatever the weather with excellent low-light and temperature behaviour.

EXTREME WEATHER RATING
High-tech aluminium alloy frame,certified for high snow (5400 Pa) and wind loads (2400 Pa)

MAXIMUM COST REDUCTIONS
Lower logistics costs due to higer module capacity per box.

A RELIABLE INVESTMENT
Inclusive 10-year product warranty and 25-year linear performance warranty.

The ideal solution for:
Rooftop arrays on residential buildings
Ground-mounted solar power plants
Rooftop arrays on commercial / industrial buildings

OREGOSOLAR

MECHANICAL SPECIFICATION

Dimensions	1960mm x 991mm x 35mm (LxWxH)
Weight	22.5kg±5%
Front Glass	3.2mm, thermally pre-stressed glass with anti-reflection technology
Frame	Anodized aluminum profile
Back Cover	Multi-layer composite sheet
Cells	6 x 12 polycrystalline solar cells
Junction box	Protection class IP ≥67, with bypass diodes
Cable	Length 1200mm, 1x4mm²
Connector	Intermateable connector with H4, MC4

MECHANICAL SPECIFICATION

POWER CLASS			315	320	325	330	335
MINIMUM PERFORMANCE AT STANDARD TEST CONDITIONS, STC[1](POWER TOLERANCE +5W / -0W)							
Power at MPP	P_{MPP}	[w]	315	320	325	330	335
Short Circuit Current	I_{SC}	[A]	9.11	9.15	9.20	9.30	9.40
Open Circuit Voltage	V_{OC}	[V]	45.7	45.8	46.0	46.1	46.3
Current at MPP	I_{MPP}	[A]	8.50	8.61	8.67	8.76	8.87
Voltage at MPP	V_{MPP}	[V]	37.1	37.2	37.5	37.7	37.8

Standard Test Conditions [STC]: irradiance 1,000 W/m², AM1.5G, module temperature 25℃.Measuring uncertainty of power is within ±3%.

PREFORMANCE WARRANTY

The power output shall not be less than 97.5% of the nominal power output stated in the product data sheet in the first year of the product's life cycle.
The loss of power output shall not exceed 0.7% per year thereafter, ending with 82% in the 25th year.

All data within measurement tolerances.

TEMPERATURE COEFFICIENTS

Temperature Coefficient of I_{SC}	α	[%/k]	+0.05	Temperature Coefficient of VOC	β	[%/k]	-0.31
Temperature Coefficient of P_{MPP}	γ	[%/k]	-0.40	Normal Operating Cell Temperature	NOCT	[℃]	45±3

PROPERTIES FOR SYSTEM DESIGN

Maximum System Voltage	V_{SYS}	[V]	1000	Safety Class	Ⅱ
Maximum Reverse Current	I_R	[A]	20	Fire Rating	C
Wind/Snow Load (Test-load in accordance with IEC 61215)		[Pa]	2400/5400	Permitted Module Temperature On Continuous Duty	-40℃ up to +85℃

QUALIFICATIONS AND CERTIFICATES

IEC 61215, IEC 61730, Conformity to CE, TUV, CQC, ISO9001, Application Class A

Specifications subject to technical changes Morego Solar

Nanjing Moge New Energy Co.,Ltd.
ADD: Building 2, No. 605, Zhushan Road,Jiangning,Nanjing,Jiangsu,China TEL: +86(0)25 5213 9610 WEB: www.moge-solar.com

OREGOSOLAR

c) Canadian Solar PV manufacturer data sheet

NEW

CanadianSolar

KuMax

SUPER HIGH EFFICIENCY POLY^GEN 4^ MODULE CS3U-345|350|355|360P (1000 V / 1500 V)

With Canadian Solar's industry leading poly-PERC cell technology and the innovative LIC (Low Internal Current) module technology, we are now able to offer our global customers high power poly modules up to 360 W.

The KuPower poly modules with a dimension of 2000 × 992 mm, close to our 72 cell MaxPower modules, have the following unique features:

- **Higher** power classes for equivalent module sizes
- **High** module efficiency up to 18.15 %
- **LOW** hot spot temperature risk
- **LOW** temperature coefficient (Pmax): -0.38 % / °C
- **LOW** NMOT (Nominal Module Operating Temperature): 43 ± 2 °C

More power output thanks to low NMOT: 43 ± 2 °C

Low power loss in cell connection

Safer: lower hot spot temperature

Heavy snow load up to 5400 Pa, wind load up to 2400 Pa

Low BoS cost with 1500 V_{oc} system voltage

25 years linear power output warranty

10 years product warranty on materials and workmanship

PRODUCT CERTIFICATES*

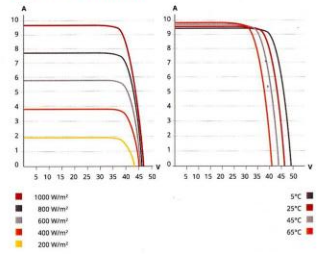
IEC 61215 / IEC 61730: 2005 & 2016: VDE / CE

UL 1703: CSA

* Please contact your local Canadian Solar sales representative for the specific product certificates applicable in your market.

ENGINEERING DRAWING (mm)

CS3U-355P / I-V CURVES



ELECTRICAL DATA | STC*

CS3U	345P	350P	355P	360P
Nominal Max. Power (Pmax)	345 W	350 W	355 W	360 W
Opt. Operating Voltage (Vmp)	39.0 V	39.2 V	39.4 V	39.6 V
Opt. Operating Current (Imp)	8.86 A	8.94 A	9.02 A	9.10 A
Open Circuit Voltage (Voc)	46.4 V	46.6 V	46.8 V	47.0 V
Short Circuit Current (Isc)	9.43 A	9.51 A	9.59 A	9.67 A
Module Efficiency	17.39%	17.64%	17.89%	18.15%
Operating Temperature	-40°C ~ +85°C			
Max. System Voltage	1000 V (IEC / UL) or 1500 V (IEC / UL)			
Module Fire Performance	TYPE 1 (UL 1703) or CLASS C (IEC 61730)			
Max. Series Fuse Rating	30 A			
Application Classification	Class A			
Power Tolerance	0 ~ + 5 W			

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m², spectrum AM 1.5 and cell temperature of 25°C.

ELECTRICAL DATA | NMOT*

CS3U	345P	350P	355P	360P
Nominal Max. Power (Pmax)	255 W	259 W	262 W	266 W
Opt. Operating Voltage (Vmp)	35.6 V	35.8 V	36.0 V	36.1 V
Opt. Operating Current (Imp)	7.17 A	7.24 A	7.29 A	7.37 A
Open Circuit Voltage (Voc)	43.3 V	43.5 V	43.7 V	43.9 V
Short Circuit Current (Isc)	7.61 A	7.68 A	7.74 A	7.80 A

* Under Nominal Module Operating Temperature (NMOT), irradiance of 800 W/m², spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s.

MECHANICAL DATA

Specification	Data
Cell Type	Poly-crystalline, 156.75 × 78.38 mm
Cell Arrangement	144 [2 × (12 × 6)]
Dimensions	2000 × 992 × 40 mm (78.7 × 39.1 × 1.57 in)
Weight	22.6 kg (49.8 lbs)
Front Cover	3.2 mm tempered glass
Frame	Anodized aluminium alloy, crossbar enhanced
J-Box	IP68, 3 diodes
Cable	4.0 mm² (IEC), 12 AWG (UL)
Cable Length	1250 mm (49.2 in), 1670 mm (65.7 in) is optional for single tracking system with leap-frog connection
Connector	T4 series
Per Pallet	27 pieces
Per Container (40' HQ)	594 pieces

TEMPERATURE CHARACTERISTICS

Specification	Data
Temperature Coefficient (Pmax)	-0.38 % / °C
Temperature Coefficient (Voc)	-0.29 % / °C
Temperature Coefficient (Isc)	0.05 % / °C
Nominal Module Operating Temperature	43±2 °C

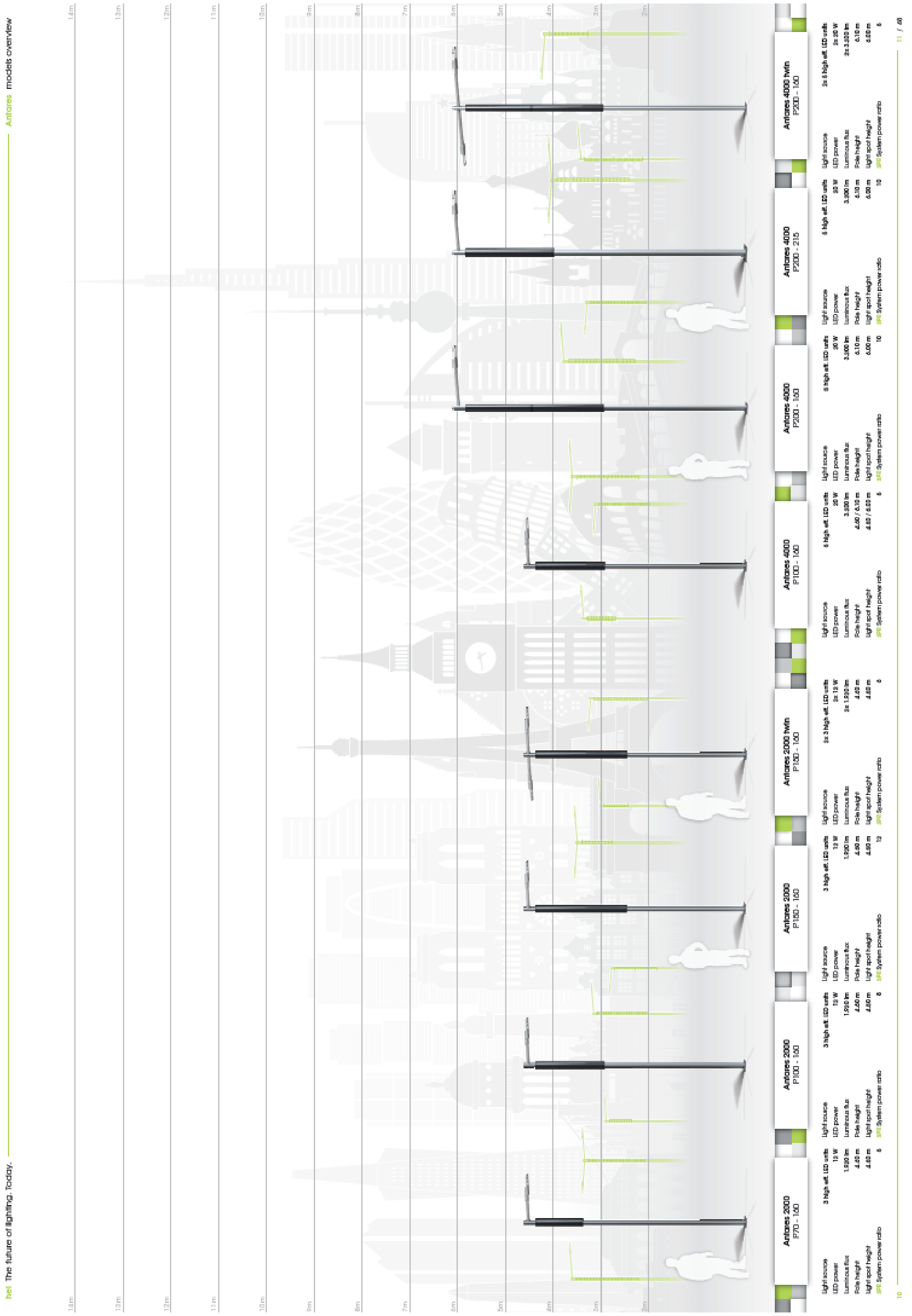
PARTNER SECTION

The aforesaid datasheet only provides the general information on Canadian Solar products and, due to the on-going innovation and improvement, please always contact your local Canadian Solar sales representative for the updated information on specifications, key features and certification requirements of Canadian Solar products in your region.

Please be kindly advised that PV modules should be handled and installed by qualified people who have professional skills and please carefully read the safety and installation instructions before using our PV modules.

545 Speedvale Avenue West, Guelph, Ontario N1K 1E6, Canada, www.canadiansolar.com, support@canadiansolar.com

d) HEI Solar Street Lighting Catalogue



Antares 4000 twin P200 - 215	
Light source	2x 6 high eff. LED units
LED power	2x 20 W
Luminous flux	2x 3,200 lm
Pole height	6.10 m
Light spot height	6.00 m
SPR System power ratio	5

Antares 8000 P200 - 160	
Light source	10 high eff. LED units
LED power	40 W
Luminous flux	6,400 lm
Pole height	6.10 / 8.10 m
Light spot height	6.00 / 8.00 m
SPR System power ratio	5

Antares 8000 P200 - 215	
Light source	10 high eff. LED units
LED power	40 W
Luminous flux	6,400 lm
Pole height	6.10 / 8.10 / 10.10 / 12.10 m
Light spot height	6.00 / 8.00 / 10.00 / 12.00 m
SPR System power ratio	5

Antares 8000 twin P400 - 215	
Light source	2x 10 high eff. LED units
LED power	2x 40 W
Luminous flux	2x 6,400 lm
Pole height	8.10 / 10.10 / 12.10 m
Light spot height	8.00 / 10.00 / 12.00 m
SPR System power ratio	5

Antares 16000 P400 - 215	
Light source	20 high eff. LED units
LED power	80 W
Luminous flux	12,800 lm
Pole height	10.10 / 12.10 / 14.10 m
Light spot height	10.00 / 12.00 / 14.00 m
SPR System power ratio	5

Antares 16000 twin P800 - 215	
Light source	2x 20 high eff. LED units
LED power	2x 80 W
Luminous flux	2x 12,800 lm
Pole height	10.10 / 12.10 / 14.10 m
Light spot height	10.00 / 12.00 / 14.00 m
SPR System power ratio	5

APPENDIX 04a – Dubai Municipality Circulars 183

حكومة دبي
GOVERNMENT OF DUBAI

بلدية دبي
DUBAI MUNICIPALITY

Ref: 812/02/02/1/1116293

06/12/2011

تعميم إلى جميع المكاتب الاستشارية وشركات المقاولات العاملة في إمارة دبي

رقم (183)

بشأن "استخدام نظام السخانات الشمسية لتوفير المياه الساخنة في المباني بإمارة دبي"

تنفيذا لقرار صاحب السمو الشيخ محمد بن راشد آل مكتوم نائب رئيس الدولة رئيس مجلس الوزراء حاكم دبي بالبدء بتطبيق معايير "المباني الخضراء" على كافة المباني والمنشآت في إمارة دبي والحفاظ على الموارد الطبيعية والعناصر البيئية في الإمارة و إلى التعميم رقم 161 الصادر بتاريخ 2008/4/3 بشأن تطبيق معايير المباني الخضراء في إمارة دبي،وإلى القرار الإداري رقم (344) لسنة 2011 بشأن اعتماد وتطبيق لائحة شروط ومواصفات المباني الخضراء في إمارة دبي ، فإن بلدية دبي تهيب بجميع المكاتب الاستشارية و شركات المقاولات العاملة بإمارة دبي العمل على استخدام نظام السخانات الشمسية لتوفير المياه الساخنة في الفيلات السكنية ومساكن العمال وكذلك في المباني والفنادق والشقق الفندقية والمراكز التجارية والأماكن العامة والمنشآت التعليمية والصناعية حيثما أمكن وطبقا للتالي :

- أن تكون وفقاً للمعايير والمواصفات الفنية المرفقة بهذا التعميم.
- أن يقوم الاستشاري المشرف على المشروع بعمل حسابات التصميم لنظام السخانات الشمسية مع تقديم مخططات توضح أماكن وسعة السخانات الشمسية من خلال المخططات الميكانيكية المقدمة للترخيص.
- أن يكون نظام السخانات الشمسية حاصل على شهادة اعتماد من مختبر دبي المركزي مع الاحتفاظ بنسخة من شهادات المطابقة في موقع العمل.
- أن يكون نظام السخانات الشمسية مزود بنظام تسخين كهربائي احتياطي يعمل في حال عدم توفر الطاقة الشمسية اللازمة
- أن يوفر النظام الشمسي المستخدم على الأقل 75% من الاحتياجات الكلية من المياه الساخنة في المبنى.
- في حال وجود أحواض للسباحة يجب توفير نظام تسخين مياه خاص بها بسعة لا تقل عن 50% من السعة الكلية المطلوبة لتسخين هذه الأحواض.
- أن يتم التركيب والتشغيل والصيانة لنظام التسخين الشمسي من قبل شركة مسجلة ومرخصة في دائرة التنمية الاقتصادية ومعتمدة من بلدية دبي.
- يجب تنظيف المعدات وصيانتها بشكل دوري لضمان استمرارية التشغيل بكفاءة .

علماً بأنه سيتم البدء اعتبارا من تاريخ 2012/3/4 بالتدقيق علي هذه المعايير لجميع المخططات الجديدة المقدمة لقسم تراخيص المباني بغرض الترخيص .

آملين من الجميع الالتزام بما جاء في هذا التعميم لما فيه المصلحة العامة

المهندس/ خالد محمد صالح

مدير إدارة المباني

DUBAI MUNICIPALITY

ملاحظة للإطلاع على كافة التعاميم الصادرة من إدارة المباني يرجى الرجوع إلى موقع البلدية على الإنترنت – www.dm.gov.ae أعمالك / مباني / قانون البناء / لائحة شروط ومواصفات البناء

رؤيتنا : بناء مدينة متميزة تتوفر فيها رفاهية العيش ومقومات النجاح.

Our Vision : To create an excellent city that provides the essence of success and comfort of living.

ص.ب. 67 P.O. Box، دبي، إ.ع.م ، Dubai, UAE هاتف : Tel: +9714 221 5555، فاكس : Fax: +9714 224 6666 ، تلكس: 45688 بلدية إم Telex: 45688 Baladya EM
E-mail : info@dm.gov.ae / Website : www.dm.gov.ae

b) Dubai Municipality Circulars 185

حكومة دبي
GOVERNMENT OF DUBAI

بلدية دبي
DUBAI MUNICIPALITY

Ref: 812/02/02/1/1203511

11/03/2012

تعميم إلى جميع المكاتب الاستشارية وشركات المقاولات العاملة في إمارة دبي

رقم (185)

بشأن اعتماد وتطبيق شروط ومواصفات المباني الخضراء في إمارة دبي

حرصاً على المصلحة العامة وفي إطار تحقيق أهداف خطة دبي الإستراتيجية والجهود التي تبذلها بلدية دبي في الحفاظ على البيئة والمحافظة على الموارد الطبيعية والارتقاء بدبي إلى مدينة مستدامة وإشارة إلى القرار الإداري رقم (344) لسنة 2011 م الصادر بتاريخ 2011/11/27 بشأن اعتماد وتطبيق لائحة شروط ومواصفات المباني الخضراء في إمارة دبي والتي تتناول المحاور الخمسة التالية :

1- التصميم وبيئة المباني
2- حيوية المباني والراحة الإنسانية (صحة المباني)
3- كفاءة استخدام الطاقة
4- كفاءة استخدام المياه
5- كفاءة استخدام المواد وإدارة النفايات

فقد تقرر تطبيق لائحة شروط ومواصفات المباني الخضراء إلزاميا في مشاريع المباني والمنشآت العائدة للجهات الحكومية في إمارة دبي واختياريا في المباني والمنشآت العائدة للقطاع الخاص لمدة ثلاث سنوات تبدأ من تاريخ 2011/1/1 م على أن يتم تقييمها بعد انقضاء تلك المدة.

وبناءً عليه يرجى من جميع المكاتب الاستشارية وشركات المقاولات العاملة في إمارة دبي مراعاة ما يلي:

1- الحصول على نسخة من لائحة شروط ومواصفات المباني الخضراء والدليل الإرشادي للائحة من أي مركز خدمة عملاء تابع لبلدية دبي أو من خلال الموقع الإلكتروني على الرابط التالي :
www. dm .gov.ae
2- الالتزام بحضور المحاضرات وورش العمل التي تعقدها إدارة المباني والجهات المعنية والخاصة بلائحة شروط ومواصفات المباني الخضراء والتي يتم الإعلان عنها من خلال الموقع الإلكتروني لبلدية دبي ونظام تراخيص ورقابة المباني الإلكتروني.
3- الالتزام باستخدام المواد المطابقة لمعايير المباني الخضراء والمعتمدة من بلدية دبي والتي يمكن الإطلاع عليها من خلال الموقع الإلكتروني لبلدية دبي
4- تم تخصيص بريد الكتروني خاص لتواصلكم معنا فيما يخص اقتراحاتكم أو ملاحظاتكم على لائحة وشروط المباني الخضراء وهو : greenbuilding@dm.gov.ae

آملين من الجميع الالتزام بما جاء في هذا التعميم لما فيه المصلحة العامة.

المهندس / خالد محمد صالح
مدير إدارة المباني

بلدية دبي
DUBAI MUNICIPALITY

ملاحظة: للإطلاع على كافة التعاميم الصادرة من إدارة المباني يرجى الرجوع إلى موقع البلدية على الانترنت www.dm.gov.ae أعمالك / مباني / قانون البناء / لائحة شروط ومواصفات البناء

رؤيتنا: بناء مدينة متميزة تتوفر فيها رفاهية العيش ومقومات النجاح.
Our Vision : To create an excellent city that provides the essence of success and comfort of living.

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